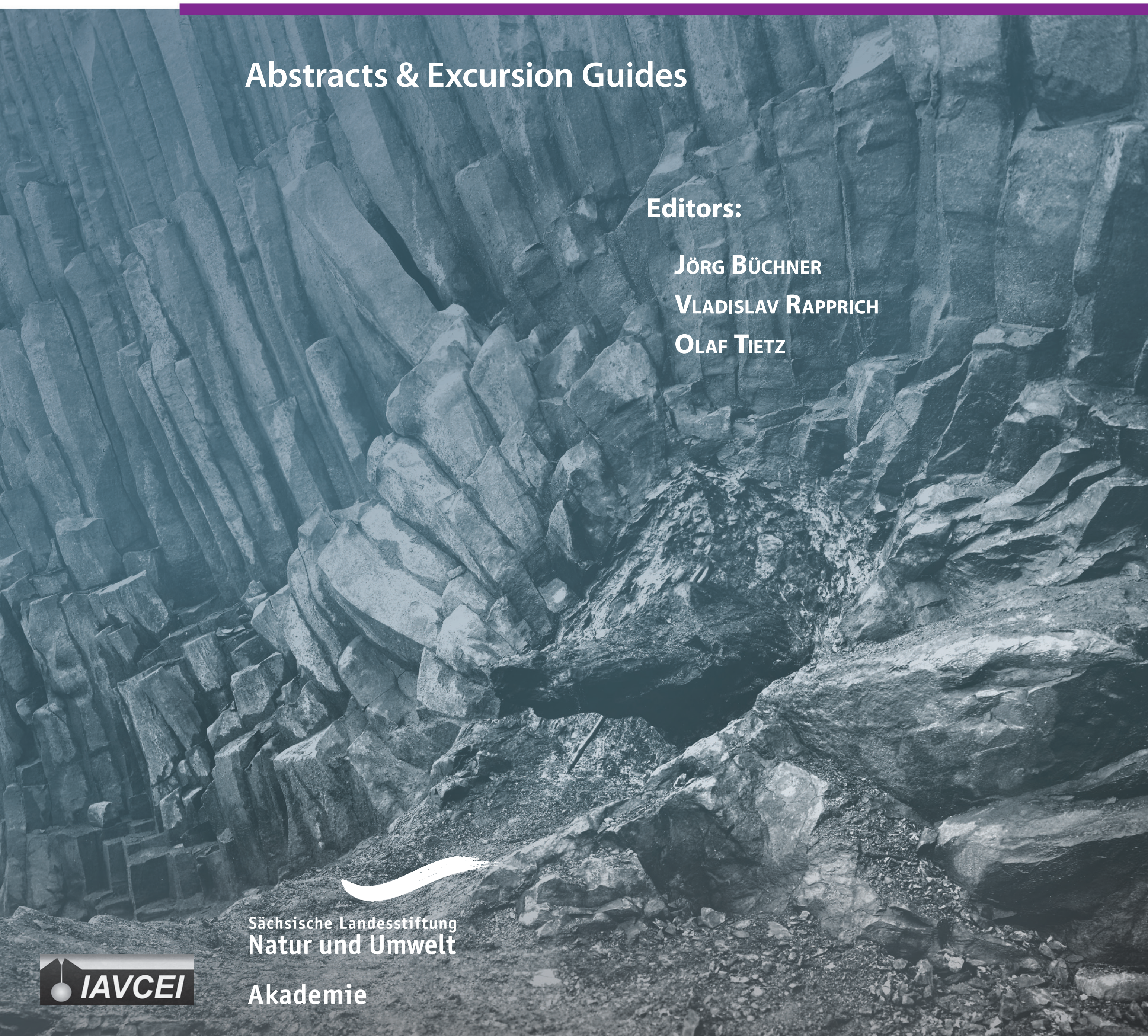
SENCKENBERG
scientific conference

Basalt 2013

Cenozoic Magmatism in Central Europe

24th to 28th April 2013, Görlitz / Germany



Abstracts & Excursion Guides

Editors:

Jörg Büchner
Vladislav Rapprich
Olaf Tietz

Sächsische Landesstiftung Natur und Umwelt
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IAVCEI

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Czech Geological Survey Prague &
Senckenberg Museum of Natural History Görlitz

Organized by:

Senckenberg Museum of Natural History Görlitz

Co-organized by:

International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI)
Academy of the Saxon Regional Conservation Foundation (LANU Academy)

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EDITORIAL

The volume in your hands is the book of abstracts and excursion guides for the international scientific conference "Basalt 2013 – Cenozoic Magmatism in Central Europe" being held in Görlitz, Germany from 24th to 28th April 2013. The Organizer of this meeting is the Senckenberg Museum of Natural History Görlitz (SMNG) under the leadership of the geological section of the museum together with the International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI) and the Academy of the Saxon Regional Conservation Foundation (LANU Academy).

This conference is not incorporated into an established series. Nevertheless, in the past some meetings or workshops in Czech Republic and Poland existed with a similar aim. These were:

1. (Prague) 1991 (CZ):
   Symposium on Central European Alkaline volcanic rocks
2. Liblice 1998 (CZ):
   Final session of IGCP 369, Subproject 2a "Magmatism and rift basin evolution: Peritethyan region"
3. Teplá near Třebenice – Ústí nad Labem – Mariánske Lázně 2002 (CZ):
   HIBSCH 2002 Symposium
4. Czocha Castle 2004 (PL):
   International workshop "BASALTS 2004".

The Görlitz conference "Basalt 2013" could be the starting event for such a conference series. The excellent response, with 130 active conference contributions from 24 countries, is reflective of the scientific importance as well as the interest of scientists from Europe and the rest of the world in this topic.

The Conference "Basalt 2013" has, as its main focus, Cenozoic magmatism in Central Europe, dealing with multifarious aspects of igneous systems. One major aim of the conference is the communication between scientists with differing approaches to Cenozoic magmatism. For this reason the conference does not include parallel lectures. The conference agenda will cover the process- and material-oriented aspects of intra-plate magmatism in Central Europe and adjacent areas from Spain to the Ukraine and from the Balkans and Italy to Great Britain. All disciplines of geo-sciences, ranging from geology and physical volcanology to petrology, mineralogy, geochemistry and geophysics, are here employed. The conference programme is subdivided into three plus one major features:

1. Mantle: physical, mineralogical and chemical characteristics of the upper mantle beneath Central Europe;
2. Ascent zone: physical, chemical, mineralogical and textural composition of the lithosphere and its interaction with ascending magmas and fluids as well as the development of the fluids themselves;
3. Surface: volcanism, eruption styles, crystallisation, alteration, growth and decease of volcano edifices, as well as aspects of the impact of volcanoes on society;
4. In honour of Prof. K.H. Scheumann (1881-1964) special attention is to be devoted to the 100th anniversary of his polzenite definition. On this occasion, the Scheumann session includes contributions on the subject of melilitic rocks in general as well as new views of the type localities in Northern Bohemia.

The differing views on igneous systems will be reflected in all sessions. In the three days of the conference sessions, contributions will be made from across the spectrum of the geo-sciences, including oral and poster presentations. The conference will be preceded by, and followed by, accompanied field trips. The pre-conference field trip leads to the Osečná complex in Northern Bohemia (FT. 1) with its polzenite dykes, as described and defined by Scheumann. The post-conference field trips comprise visits to localities in the Lusatian Volcanic Field: firstly an outcrop of a xenolith-bearing nephelinite lava flow in Poland (FT. 2); secondly, six outcrops with newly investigated volcanic remnants in the German part of the Lusatian Volcanic Field (FT. 3).

This volume contains the guides of these three field trips along with the scientific abstracts of all the contributions to the conference. In total, 130 abstracts are published here, including those from the twelve invited speakers who will give keynote speeches or review talks. The extraordinarily high number of talk invitations is due to the wide range of research approaches in the area of igneous systems. Therefore keynote speeches will literally play a key role at the conference. In this way we hope successfully to manage communication between the different disciplines. The contributions are divided into 67 talk abstracts and 63 poster abstracts.

Here we would like to express our gratitude to all the members of the Scientific Committee and the team of the Senckenberg Museum of Natural History Görlitz, for the long-lasting, fruitful discussions and the excellent organization of the conference which has been the result of hard, cooperative and constructive work. Furthermore, we would like to thank all the participants, sponsors and supporters that have enabled the exciting and important idea of the "Basalt 2013 Conference" to come to fruition.

Yours sincerely,

the editors

Dipl.-Geol. Jörg Büchner	**Dr. Vladislav Rapprich**	**Dr. Olaf Tietz**
Organizing committee	Scientific committee	Organizing committee

Görlitz and Prague, April 2013

PREFACE

We welcome all the participants of the Basalt 2013 meeting on behalf of the International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI). IAVCEI is one of the supporting scientific organisations and co-organizer standing behind the Basalt 2013 Conference emphasizing the importance of focused thematic, field-related workshop-style meetings with regional aspects. The IAVCEI's Commission on Monogenetic Volcanism (CMV) specifically welcomes the Basalt 2013 meeting as another landmark in the ever growing research activity on monogenetic volcanic fields in many parts of the globe. The CMV's (to join please visit: https://vhub.org/groups/iavcei_cmv) main goal is to provide a forum for researchers to define and understand the phenomenon of small volume magmatic systems and their surface expression as volcano fields.

The term monogenetic as applied to volcanic systems carries with it the concept of eruptions of batches of magma within short timescales. Monogenetic volcanism is commonly expressed as clusters of individual volcanoes forming fields of small-volume volcanoes which are a consequence of dispersed plumbing systems feeding discrete batches of magma to the Earth's surface. Beyond this relatively simple concept there is a wide range of temporal, spatial and compositional variables that can be explored from time to time through focused workshop-style meetings such as the Basalt 2013 Conference.

The aim of the CMV is to take a leading role in facilitating, coordinating and focusing research and research outputs with regard to monogenetic volcanism and to assist researchers in developing a refined and unified model of this type of volcanism. In this respect the CMV envisaged the Basalt 2013 Conference as another very important opportunity to bring together experts working on monogenetic volcanoes. The scientific meeting will be a particularly important event as many of the first descriptions and characterisation of intra-plate basaltic volcanism, commonly monogenetic and small-volume, were made in Central Europe. These facts make the Basalt 2013 Conference a unique event providing an opportunity for the participants to revisit sites where the first recognition and ensuing discussions were initiated on columnar jointing, peperite or diatreme formation. The Basalt 2013 Conference also intends to provide an avenue to discuss current development in our understanding on monogenetic volcanism and this is reflected well in the comprehensive scientific program. Basic scientific questions, such as the monogenetic nature of these commonly small-volume, small magma output volcanoes are currently frontline research subjects showing growing evidence which could develop into a more suitable and united model for the formation of these volcanoes from an interdisciplinary perspective. The IAVCEI Commission on Monogenetic Volcanism serves a mediating and facilitating role in this scientific process as well as providing an interface in order to disseminate the fragmented research effort so that it may be possible to be viewed in a broader perspective. Hence the CMV's support of the Basalt 2013 Conference. The scientific meeting focuses primarily on Cenozoic magmatism in Central Europe from a global perspective dealing with multidisciplinary aspects of its igneous systems. The main aim of the Basalt 2013 Conference is to provide a communication-platform between scientists with different scientific approaches to Cenozoic magmatism in Central Europe and its analogues worldwide. The Conference will clearly emphasizes the process-oriented and material aspects of magmatism from the geophysical to the geochemical and volcanological point of view, highlighting the source to surface concept of melt segregation and volcano formation in intra-plate settings. All disciplines of geosciences are to be represented in this workshop- and field visit- driven conference. The topical meeting is a synergetic conference encouraging the scientific information exchange between the widespread geo-science divisions. In that manner "Basalt 2013" is an innovative contribution to the research on European Cenozoic Volcanoes looked at from a global perspective and should be established in future as regular series of conferences to that topic. The Conference is officially labelled as an activity of the IAVCEI Commission on Mongoenetic Volcanism. Maars, tuff rings and scoria cones are the most common manifestation of monogenetic volcanism in any geotectonic and environmental setting including the various intracontinental regions in Central Europe. The volcanic eruptive products of small-volume intracontinental volcanoes are generally the result of short-lived eruptions that frequently reflect the role of the specific ratios of external (eruptive environment) versus internal (magmatic) factors acting on rising magma when it approaches the Earth's surface. Maars, tuff rings and scoria cones are end-member types of volcanoes of small-volume intracontinental volcanism. Comparison of these volcanoes in the past decades has produced an ever-growing dataset to identify and distinguish various internal versus external factors forcing the various eruption styles of such short-lived small-volume monogenetic volcanoes. The final manifestation of monogenetic volcanism (e.g. maars, tuff rings or scoria cones) strongly reflects the relative roles of the internal and external parameters. The Basalt 2013 Conference will take the participants to a region in Central Europe where such researches have had a long tradition and their results can be applied to other volcanic fields on Earth.

The Basalt 2013 Conference fits perfectly with this natural research progress tendency and serves as an important step towards the understanding of small-volume intracontinental volcanism in general. I hope all the participants enjoy the opportunity of a clash of ideas, to share views and exchange research directions over basaltic intracontinental volcanism.

Kind regards,

Dr. Károly Németh

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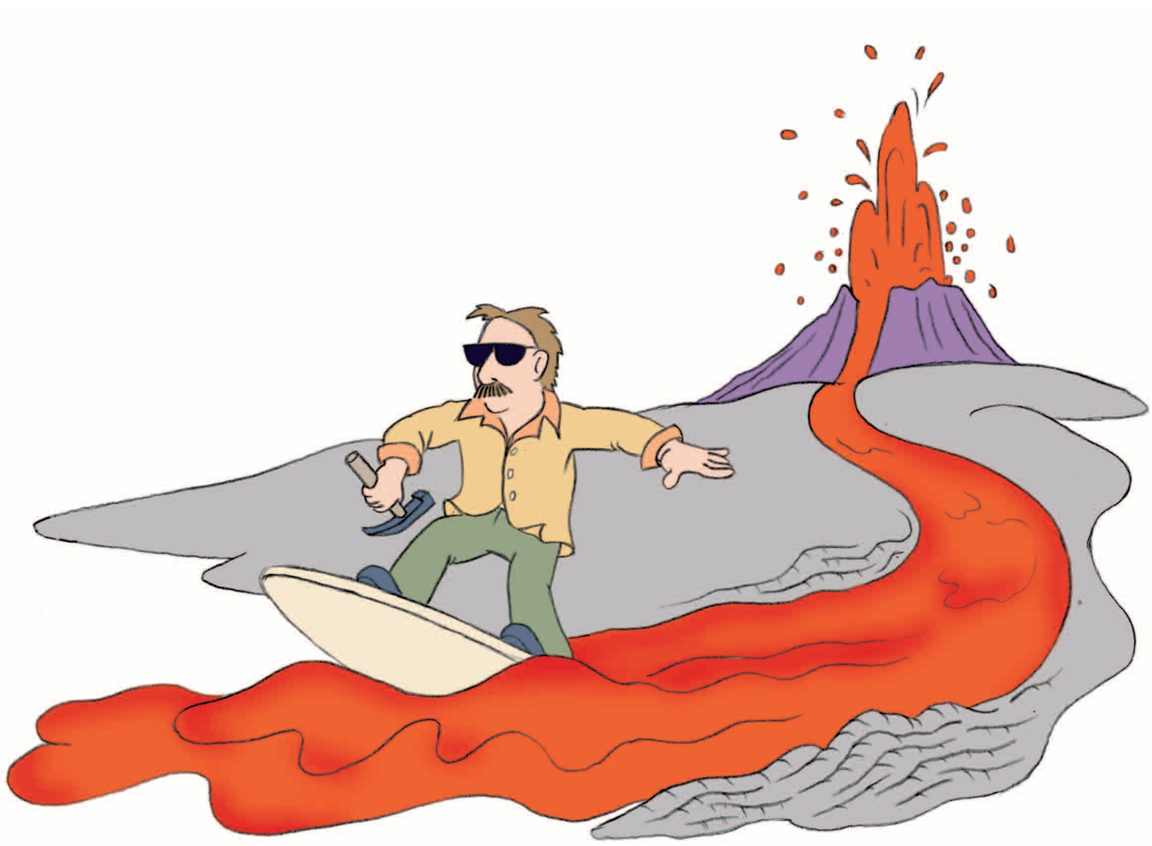
April 2013, Jeddah, Kingdom of Saudi Arabia



Session 1 – Mantle

The Upper Mantle beneath Central Europe – physical, mineralogical and chemical characteristics

(Talks and Posters)

1

What is the lithosphere-asthenosphere boundary? – a quest for information: the LABPAX project

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The lithosphere-asthenosphere boundary (LAB) is the most extensive and active plate boundary in the Earth. It is inextricably linked to the properties of the underlying low velocity zone, which is of key importance to the architecture of continental and oceanic lithosphere and to the dynamics of plate tectonics. However, the LAB beneath the continents is relatively cryptic compared to other first-order structural subdivisions of Earth. Some aspects of the boundary are attributable to changes in physical properties along the geotherm, but new results suggest the possible influence of small amounts of melt, variations in hydration of nominally anhydrous minerals, grain size or, last but not least, in lattice preferred orientations. Though we face different physical definitions of the LAB in dependence on methods used to map the boundary, a general understanding and consensus on “WHAT is the LAB” is still missing.

General conlusion from recent studies is that while a lithosphere-asthenosphere boundary is seen by most disciplines in Earth Sciences, the definition, depth and what the boundary means from the structural, rheological, physical and/or chemical point of view are highly debated. There seem to be several “boundaries”, namely the LAB-S (seismological), the LAB-M (mechanical), the LAB-T (thermal), the LAB-C (chemical) and the LAB-E (electromagnetic), all called by the colleagues from the particular fields in Earth Science “LAB” which differ in depth and thickness. Questions, whether the ‘discontionuities’ are discrete, or, more likely represent a transitional layer are debated broadly. But it is generally accepted that almost certainly the LAB definitions will not “define” at all the same object, phenomenon or feature!

It is evident that only a multi-disciplinary approach, bringing together all disciplines from Earth Sciences will help us to shed light on the above questions and to better understand and communicate between the different fields in Earth Sciences, what the lithosphere-asthenosphere boundary is all about, what it’s origin is and what role it has played and still plays in the evolution of our planet. So, the ILP task force “LABPAX” has been suggested and granted by ILP in the end of 2010.

In this contribution we present the state-of-art of the LABPAX project and highlight some new results as well as discuss the differences between inferences from the different disciplines.

A shear-wave velocity model of the European upper mantle from automated inversion of seismic shear and surface waveforms

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Broadband waveforms recorded at stations in Europe and surrounding regions were inverted for shear-wave velocity of the European upper mantle. For events between 1995 and 2007 seismograms were collected from all permanent stations for which data are available via the data centers ORFEUS, GEOFON, ReNaSs and IRIS. In addition, we incorporated data from temporary experiments, including SVEKALAPKO, TOR, Eifel Plume, EGELADOS and other projects. Automated Multimode Inversion of surface and S-wave forms was applied to extract structural information from the seismograms, in the form of linear equations with uncorrelated uncertainties. Successful waveform fits for about 70,000 seismograms yielded over 300,000 independent linear equations that were solved together for a three-dimensional tomographic model.

Resolution of the imaging is particularly high in the mantle lithosphere and asthenosphere and main features of the lithosphere-asthenosphere system in Europe have been identified. The highest velocities in the mantle lithosphere of the East European Craton are found at about 150 km depth. There are no indications for a large scale deep cratonic root below about 330 km depth. Lateral variations within the cratonic mantle lithosphere are resolved by our model as well. The locations of diamond bearing kimberlites correlate with reduced S-wave velocities in the cratonic mantle lithosphere. This anomaly is present in regions of both Proterozoic and Archean crust, pointing to an alteration of the mantle lithosphere after the formation of the craton. Strong lateral changes in S-wave velocity are found at the western margin of the East European Craton that hint to erosion of cratonic mantle lithosphere beneath the Scandes by hot asthenosphere. The mantle lithosphere beneath Western Europe and between the Tornquist-Teyissere Zone and the Elbe Line shows moderately high velocities and is of an intermediate character, between cratonic lithosphere and the thin lithosphere of central Europe. In central Europe, Caledonian and Variscian sutures are not associated with strong lateral changes in the lithosphere-asthenosphere system. Cenozoic anorogenic intraplate volcanism in central Europe and the Circum Mediterranean is found in regions of shallow asthenosphere and close to sharp gradients in the depth of the lithosphere-asthenosphere boundary. Indications for low-velocity anomalies extending vertically from shallow upper mantle down to the transition zone are found beneath the Massive Central, in the Middle East beneath Sinai and the Dead Sea, beneath the Canary Islands as well as Iceland.

Seismic imaging the lithosphere-asthenosphere system beneath the Bohemian Massif to better understand the structural setting of the Cenozoic volcanism

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Over the last two decades a strong effort has been devoted to the study the lithosphere-asthenosphere structure of the Bohemian Massif. Imaging and mapping its inherited structure is necessary to better understand the geodynamic/magmatic processes related to the widespread Cenozoic volcanism. Occurrences of the Cenozoic volcanism are spatially related to recent geodynamic activity (e.g., earthquake swarms, CO2 degassing) in the Bohemian Massif.

Passive seismology became the most important tool to study upper mantle structures, including methods such as regional teleseismic travel-time tomography, Ps and Sp receiver functions and body-wave anisotropy. Mapping the most distinct, but still enigmatic discontinuity in the upper mantle – the lithosphere-asthenosphere boundary (LAB) – contributes significantly to better understanding the past volcanic processes in the Variscan massifs. The results show that the structure of the deep lithosphere, particularly to the boundaries of mantle lithospheric domains control recent geodynamic phenomena in the crust and at the surface.

In this contribution we will summarize the results obtained from data collected during a series of passive seismic experiments covering large areas of the Cenozoic volcanic fields along the northern rim of the Bohemian Massif (e.g., BOHEMA-I and -II). We present detailed relief maps of the Moho and LAB beneath the Bohemian Massif using different methods and we compare different structural features of the Western Bohemia/Vogtland area, the Elbe Fault Zone and the Jeseniky Mts. The upper mantle seismic velocity images do not prove the existence of a potential mantle plume beneath the western part of the Eger Rift, as proposed by the similarity with the French Massif Central and the Eifel in the baby-plume concept (Granet et al 1995, Ritter et al. 2001). The plumes were postulated as sources of magmatic material and related phenomena.

We want to stimulate discussion on how the seismological (geophysical) findings can be combined with petrological/geodynamic models to improve our understanding and imaging of complex processes related to Cenozoic volcanism from the deep source up to the surface.

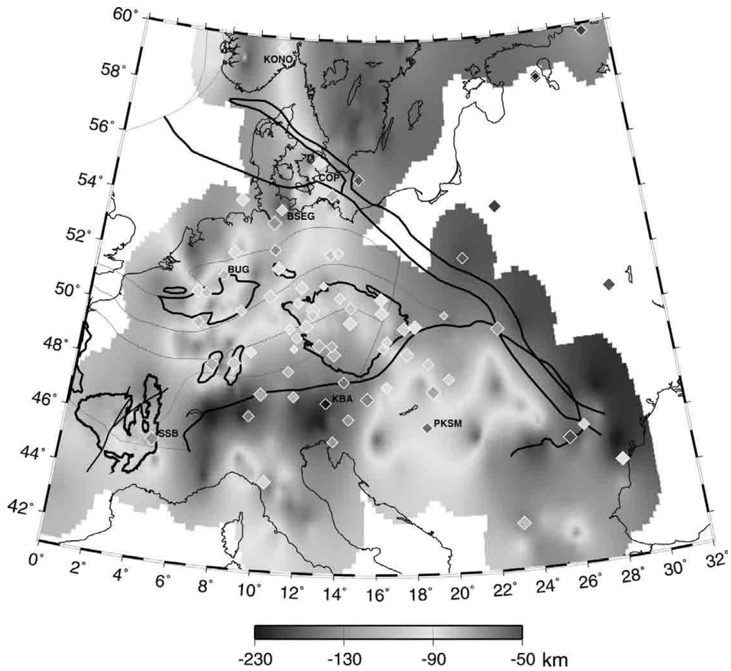

Fig. 1. Comparison of the LAB depths derived from the P-residual study (Plomerová & Babuška 2010) and from the Sp receiver functions (diamonds) after Geissler et al. (2010).

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1

Rejuvenated Variscan boundaries of mantle lithosphere domains as major paths of Cenozoic volcanism

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Teleseismic data recorded at dense networks of temporary and permanent seismic stations were analyzed to investigate large-scale fabric of the lithosphere–asthenosphere system of the French Massif Central (MC) and of the Bohemian Massif (BM). The inferences from seismic anisotropy image both massifs as a mosaic of microplates preserving a fossil olivine fabric in the mantle lithosphere, formed before their Variscan assembly.

Three major lithosphere domains with different seismic anisotropy are distinguished in the MC (Babuška et al 2002). The suture between the western and eastern MC parallels the major crustal boundary, the late Variscan Sillon Houiller transfer fault in the south and the Tauve-Aigueperse fault in the north, with an offset of 10–20 km to the east (Fig. 1, lower left). The offset of the crustal and mantle parts of the same suture indicates that the rigid upper crust might be detached from the mantle lithosphere. We suggest that the mantle suture, hidden beneath an allochthonous crust, was reactivated during the Cenozoic extension of the weakened and thinned lithosphere in the south of the eastern MC and predestined a space for the major volcanism (Mont Dore, Cantal). The rigid northern domain, characterized by a thicker lithosphere with a well-preserved mantle fabric, reacted to the extension predominantly by rifting (e.g., Limagne and Roanne Grabens).

Five mantle domains (microplates) modeled in the BM (Plomerová et al. 2012, Babuška & Plomerová 2013) can be associated with the Saxothuringian Zone (ST), Teplá–Barrandian Block (TB), Moldanubian Zone (MD), Moravian and Silesian parts of the MS Zone (above two different parts of the Brunovistulian (BV) mantle lithosphere). However, the TB mantle lithosphere does not continue east of the Elbe zone, where most authors assume the TB crust. Instead, our observations indicate a south-eastward continuation of the ST mantle lithosphere beneath the Cretaceous basin. Boundaries of the mantle domains witnessed either Variscan oceanic subductions followed by an underthrusting of the continental lithosphere, or they predestined future strike-slip faults of lithospheric dimensions. Major occurrences of the high-pressure/ultra high-pressure (HP–UHP) rocks follow the ENE and NNE oriented sutures and boundaries of the mantle–lithosphere domains. The collisional mantle boundaries, blurred by tectonometamorphic processes in easily deformed overlying crust, probably served as major exhumation channels of the HP–UHP rocks.

Unlike the widely distributed HP–UHP rocks exhumed during the Variscan orogeny, the Late Cretaceous and Cenozoic volcanic products within the BM follow only the broader rim of the ST mantle lithosphere along the Ohře (Eger) rift and along the Labe-Odra fault system. We suggest that the 3D geometry of boundaries of the mantle domains might be decisive whether a boundary could be rejuvenated by younger tectonic processes or not. While the TB/MD and MD/BV mantle boundaries are inclined and well 'welded' during the Variscan orogeny, the ST/TB mantle boundary is steep and obviously easier to be 'reopened' by later stresses. It is possible that such model may have worked in the northern BM, localizing the so-called 'intraplate' Cenozoic volcanism mainly along the southern rim of the ST mantle lithosphere (top part of Fig. 1).

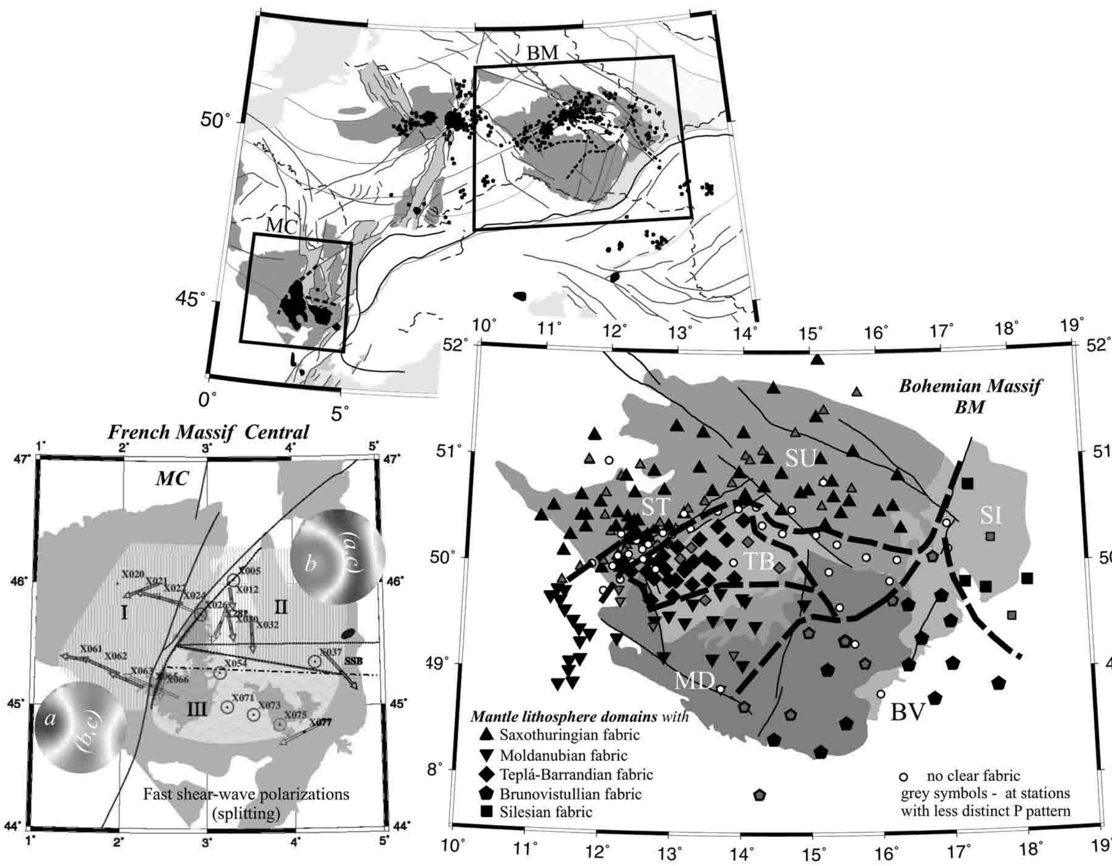

Fig. 1. Mantle lithosphere of the Bohemian Massif (BM, lower right) and of the French Massif Central (MC, lower left), modeled from seismic anisotropy, can be divided into five and three domains (microplates), respectively. Note that in the MC (upper and lower left), major occurrences of the Cenozoic volcanism concentrate near the junction of the three domains and near the boundary between domains II and III, while in the BM (upper and lower right) the Cenozoic volcanism is mainly located along the southern rim of the Saxothuringian domain (ST) comprising also the Sudetes (SU).

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1

Scientific delirium vs. scientific dogma in basalt petrogenesis

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In ancient Greek the "lyra" was the track left by a plough (the "lystron"). To go out of (or jump) the "lyra" was considered a sort of lapse of reason, a raving or, more properly, a delirium. In doing Science, it should be easy to distinguish delirium (i.e., proposing unconstrained or unnatural hypotheses and models) from dogma (i.e., the basic rules governing the systems). Strictly speaking, scientific theories can be falsified, in contrast with dogmas (assumptions) which do not need to be verified. In reality, the distinction between delirium and dogma is not easy, particularly in the Earth Sciences.

The thermal state and chemical composition of Earth's mantle are not yet well known. Not only are the detailed structure and distribution of the chemical and mineralogical heterogeneities unknown in detail, but also the gross features are at best cloudy. Basic and intuitively simple concepts such as geotherm, mantle adiabat, potential temperature, lithosphere, asthenosphere and others probably need to be re-thought. The message given by an igneous rock allowing one to infer the characteristics of its mantle source or the tectonic setting of formation is not yet fully understood and may not be understandable at all. There is much chemical and geophysical evidence arguing for disequilibrium at different depths in the Earth's mantle, diminishing the importance of classical thermodynamic approaches. The problem of the scales at which the processes develop must similarly be taken into consideration. As a consequence, the basic assumption that there is chemical equilibrium in the upper mantle also needs re-thinking.

In this framework the more logical scientific hypotheses have been defined as delirium, while other "untouchable" hypotheses (dogma), such as the alleged presence of mantle plumes rooted in the core-mantle boundary layer, survive as zombies. A few didactic concepts will be presented to show how distant we probably are from true understanding of the Earth's mantle dynamics.

Trace element and Nd-Hf isotope geochemistry of Cenozoic volcanic rocks from the Lausitz, Eastern Germany

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Intraplate magmatism is widespread in Europe and major activity was during Eocene to Miocene times. The dominant rock types are alkaline SiO_2 undersaturated volcanic rocks, e.g. alkalibasalts, basanites, nephelinites, ankaratrites, melilitites and more differentiated types such as tephriphonolites, phonolites and trachytes (see review paper by Lustrino & Wilson 2007, and references therein). The geochemical characteristics of European volcanic rocks are similar to those of alkaline magmas erupted in intra-plate tectonic settings worldwide, with a distinct anorogenic geochemical signature (Lustrino & Wilson 2007).

Major volcanic centres in Europe are, from SW to NE, the Betic Cordillera in Spain, the Massif Central in France, the Eifel, Westerwald and Vogelsberg provinces in Germany and the Bohemian Massif in the Czech Republic, Poland and Eastern Germany (Lustrino & Wilson 2007). Within Germany, the Lausitz in Saxony is part of the Bohemian massif. Oligocene to Miocene magmatism in this region is related to the opening of the Eger rift and marks the NE continuation of the main graben.

Here we present major- and trace element along with Nd-Hf isotope data of a series of mostly primitive volcanic rocks (basanites, alkalibasalts and two tholeiites) taken from 10 different locations in the Lausitz region in order to constrain their mantle source composition and petrogenesis (asthenospheric versus lithospheric origin, melt-lithosphere interactions, crustal assimilation and fractional crystallisation).

All samples, except the two tholeiites, have been dated in Freiberg by the $^{40}Ar/^{39}Ar$ method and yielded Oligocene ages ranging from 26.5±2.1 to 32.8±0.5 Ma (Büchner et al. 2013). Field relationships suggest a similar or slightly older age for the two tholeiites. The MgO contents of the lavas range from 7.6 to 13.7 wt% with Ni concentrations between 76 and 308 ppm and Cr concentrations ranging from 185 to 588 ppm, indicating olivine and clinopyroxene fractionation for some of the samples. The Ni and Cr contents of the most primitive lavas indicate that they likely represent primary magmas. Rare-earth element concentrations of the basanites and alkalibasalts are 100 to 300 times chondritic for the LREE and about 5 to 10 times chondritic for the HREE. Chondrite-normalized La/Yb ratios range from 17 to 36. LREE concentrations of the two tholeiites are nearly an order of magnitude lower and chondrite-normalized La/Yb ratios are 6.6 and 6.7, respectively. Chondrite-normalized Gd/Yb ratios are 2.7 - 4.1 for the basanites and alkalibasalts and 2.2 and 2.3 for the tholeiites, suggesting the presence of garnet in the melt source region of both rock types. High Ba concentrations (546 - 977 ppm) and relatively low K/La ratios (68 - 215) in basanites and alkalibasalts suggest the presence of residual amphibole in their mantle source.

Present-day Nd and Hf isotope compositions are relatively uniform within basanites and alkalibasalts and range from $^{143}Nd/^{144}Nd$ = 0.512830 – 0.512890 (ε_{Nd} = +3.7 to +4.9) and $^{176}Hf/^{177}Hf$ = 0.282921 – 0.282989 (ε_{Hf} = +5.3 to +7.7), respectively. In a diagram ε_{Hf} vs. ε_{Nd}, the basanites and alkalibasalts plot slightly below the mantle array but fall into the range defined by other continental basalts from Central Germany (e.g., Rhön, Eifel, Vogelsberg; Jung et al. 2011; Pfänder et al. 2012). Nd and Hf isotope compositions of the tholeiites are less radiogenic (ε_{Nd} = +2.8 and +3.8, ε_{Hf} = -1.5 and +0.4) and reflect assimilation of pre-existing crustal material, which is also evident from lower Ce/Pb (<19 vs. >27) and Nb/U (<37 vs. >42) ratios in tholeiites than in basanites and alkalibasalts.

The data presented here indicate that the investigated alkaline basalts were derived from a recently enriched mantle source with a time-integrated depletion of incompatible trace elements. Melting modelling suggests the presence of garnet in the sources of basanites and alkalibasalts as well as tholeiites (assuming melting degrees between 5 and 10%

and non-modal batch melting). Low K/La ratios along with high Ba contents also suggest that residual amphibole played a role during magma genesis, placing the melt source region likely to the asthenosphere-lithosphere boundary. Significant crustal assimilation can be ruled out for the basanites and alkalibasalts, but is evident in the tholeiites from low initial ε_{Hf} values. This suggests a relatively fast magma ascent and eruption for the alkaline basalts, and possibly melt pooling associated with assimilation and fractional crystallisation for the tholeiites.

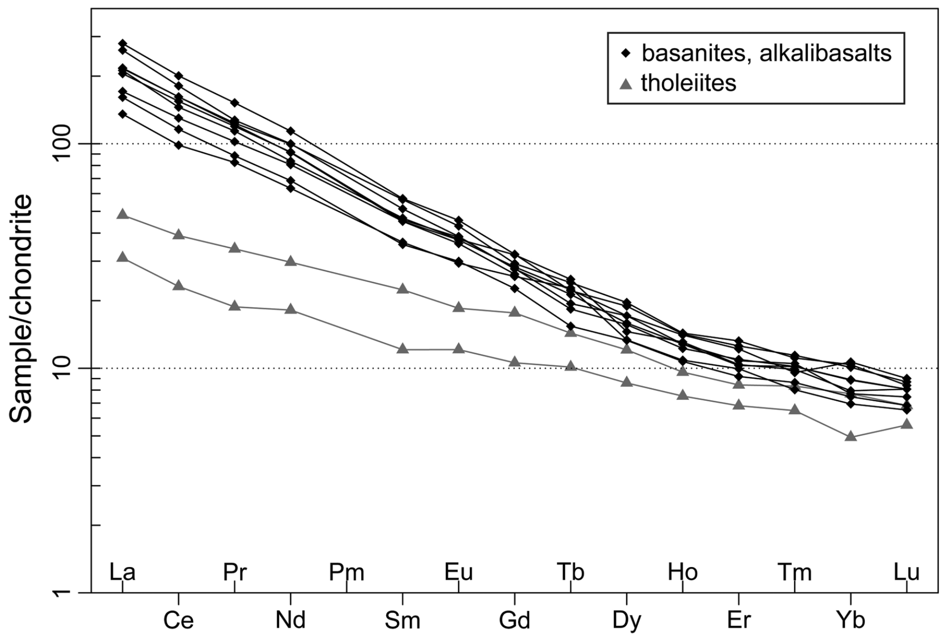

Fig. 1. Chondrite normalized rare earth element concentrations in the investigated samples.

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Origin of the magmas in the Late Miocene to Quaternary Nógrád-Selmec monogenetic alkali basalt volcanic field, southern-central Slovakia

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The Neogene alkali basaltic volcanism of the Nógrád-Selmec (Novohrad-Stiavnica) area has a wide temporal range from the oldest (8 - 6.4 Ma) to the youngest (0.1-0.22 Ma) formations. Up to now the last basaltic eruption of the Carpathian-Pannonian Region took place in this area, when the Putikov Vŕšok volcano was formed at 100 ka. The volcanism can be divided into 7 stages (Konečný et al. 2002). In our studies, we focused on the basalts of the oldest and youngest volcanic stages. Apart from the classic bulk rocks compositional investigations, we performed a detailed textural and mineral chemical study of each rock. The first liquidus phases of the alkali basalts (Cr-spinel and olivine) could give important information about parental melts and their genesis and source rock characteristics.

The studied rocks are mostly tephrites-basanites, in addition to trachybasalts and phonotephrites. Most of the rocks are olivine phyric, however some basalts contain considerable amount of clinopyroxene and in two cases kaersutite crystals too. Cr-spinel inclusions usually are very common in olivines. Most of them are primitive, only spinels from the youngest formations are clearly evolved. The most primitive ones show a very wide compositional range from Cr-rich to Cr-poor and Al-rich crystals. They could be divided into two groups, a chromium rich (cr# 16-50) and into a very aluminous, practically Cr-free (cr# 0.7-10) group. Latter ones could be found only in the older basalts (3.4 - 8 Ma).

Spinels have also a wide range on the magmatectonic diagram of Kamenetsky et al. (2001), they overlap the spinel compositional field of the Western-Pannonian Basin and Perşani Mts. basalts spanning from the OIB through MORB field. They show a more complex feature if we plot them with their host olivines mg#. In the case of three localities they show only horizontal (olivine) fractionation trends – it is compatible with their olivine phyric texture. Samples from the other three localities have a notable clinopyroxene content and thus a diagonal, pyroxene fractionation trend on this spinel cr# vs. olivine mg# diagram (after Arai 1994). Besides that the spinels of this region cover a very wide compositional range from fertile to more depleted mantle sources; besides spinels of Sőreg, Selmec and Dobogó have a wide compositional range in themselves. The extraordinary Al-rich crystals are clearly separated from the majority.

The most basalts were formed under similar redox conditions, whilst Selmec basalts were formed from a little bit reductive melt. Rocks from Putikov Vŕšok are special because the "Put 1" vesicular lava rock sample fits into the main trend, however sample Brehy (massive lava rock) shows a more oxidative state. Olivines from "Put 2" scoria sample are highly oxidized, but this was related to eruptional processes.

Based on trace elements the alkali basalts of Nógrád-Selmec area were formed with a very little degree melting of spinel lherzolite. The mantle potential temperature of the eastern volcanoes of the area is like average, 1200-1300 ºC, in contrast the western ones have higher than 1400 ºC, a little bit elevated temperature.

The products of the long lasting volcanism of this area could be divided both temporally and spatially into two groups. Basalts of the western part (Selmec-Putikov area) were formed at higher temperature from spinel lherzolite, whereas the eastern Nógrád area basalts were derived at average mantle temperatures from similar mantle source. The older basalts from both Selmec and Nógrád were formed at least from two different melts, suggested by the occurrence of Al-rich spinel inclusions in olivines. The spinels indicate a heterogeneous mantle source beneath the area, the fertility of the mantle source do not so clearly follow the age of the basalts, however except for the younger basalts of Bulgárom area, the younger ones were derived from a more depleted peridotite as the older basalts.

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Petrologic constraints on melting conditions in the Strait of Sicily Rift Zone

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The Strait of Sicily Rift Zone (SSRZ) is a northwest-southeast trending transtensional rift situated in the Mediterranean Sea between Sicily and north Africa. The SSRZ consists of three basins: the Pantelleria Trough, the Linosa Basin, and the Malta Trough. Volcanoes are situated in or adjacent to all except the Malta Trough, and include two islands (Pantelleria and Linosa) and several seamounts. The thickness of the crust throughout the region is 25-35 km, but thins to 16-18 km in the basins of the SSRZ. The Pantelleria Trough is characterized by high average heat flow values and a strong positive Bourger anomaly, which suggest assthenospheric upwelling to ~60 km and the presence of abundant basaltic material at depth.

Mafic lavas ranging in composition from alkaine and transitional basalt to hawaiite (~45-50 wt% SiO_2) comprise the dominant volume of eruptive products in the SSRZ; evolved rocks (trachyte and pantellerite) and common only on Pantelleria, where they crop out over ~94% of the island's surface. Mafic lavas on Pantelleria are also the most evolved with Mg# ≤ 58, Ni ≤ 98 ppm, and Cr ≤ 183 ppm; more primitive mafic lavas can be found forming the seamounts (Mg# ≤ 67, Ni ≤ 280 ppm, and Cr ≤ 391 ppm) and cropping out on the island of Linosa (Mg# ≤ 71, Ni ≤ 409 ppm, and Cr ≤ 674 ppm). There are two distinct mafic series on Pantelleria: a generally older (>50 ka) High Ti-P series ("Paleo-Pantelleria"), characterized by $TiO_2 > 3.0$, $P_2O_5 > 0.9$, and high REE ratios; and a generally younger (<50 ka) Low Ti-P series ("Neo-Pantelleria"), characterized by $TiO_2 < 3.0$, $P_2O_5 < 0.75$, and low REE ratios. Linosa mafic lavas are more similar to the Neo-Pantelleria series, whereas Seamounts may be more similar to either series.

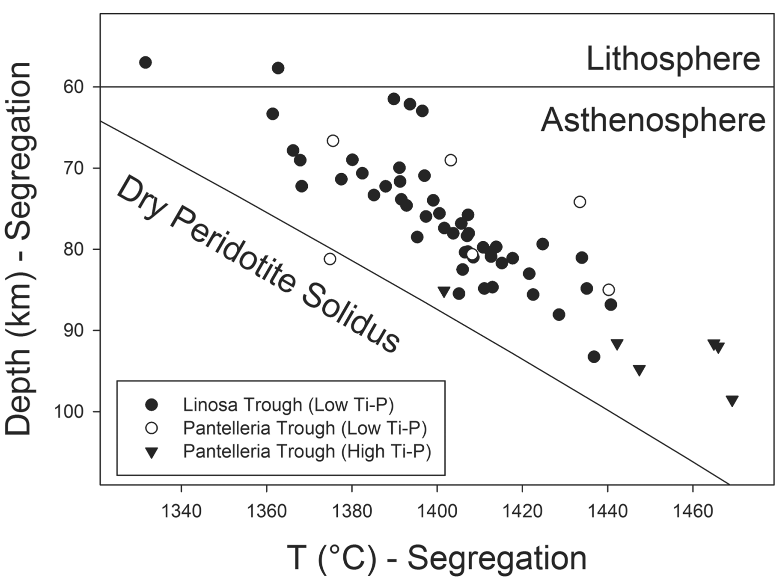

Fig. 1. Calculated temperatures of segregation plotted versus pressures of segregations for primitive magmas from the Linosa and Pantelleria Troughs. Dry Peridotite Solidus from Hirschmann (2000).

To constrain the melting conditions in the SSRZ we have attempted to estimate the ancestral magma compositions for the most primitive basalts (MgO > 7.0 and Mg# > 0.55) following Hertzberg and O'Hara (2002), Leeman et al. (2005, 2009), and Lee et al. (2009) by which equilibrium olivine is incrementally added to basalt until the calculated ancestral basalt has a Mg# shown experimentally to have been in equilibrium with mantle peridotite. From this composition, the temperature and pressure of magmatic segregation may be calculate following Lee et al. (2009). For the purposes of our investigation, we assumed $Fe^{3+}/\Sigma Fe = 0.1$, with K_D for MgO-FeO between olivine and melt calculated following Hertzberg and O'Hara (2002). From our pressure estimates, we inferred depths of segregation assuming a 17 km thick crust with an average crustal density of 2.69 g/cm^3 and an average mantle density of 3.20 g/cm^3. Results are presented in Figure 1. Both magma series are found to have originated from asthenospheric spinel lherzolite, but High Ti-P magmas are the result of partial melting at greater depths (92.2 ± 4.4 km), near the spinel-garnet transition zone, whereas Low Ti-P magams are the result of partial melting at shallower depths (76.1 ± 7.8 km), nearer the lithosphere-ashtenosphere boundary.

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New geochemical constraints on mafic volcanism in the French Massif Central from Sr-Nd-Hf-Pb isotope analyses

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The abundance of Tertiary and Quaternary mafic volcanic rocks in the French Massif Central provides the opportunity to study the origin and evolution of the mantle source(s) for some of the largest intraplate volcanic provinces in central Europe. Pioneering geochemical studies on these rocks from the Massif Central have focused on magmatic mantle sources beneath the western section (Chauvel & Jahn 1981, Downes 1984, Wilson & Downes 1990) and the coexistence of silica undersaturated and saturated magmatic series within the entire volcanic area (Briot et al. 1991, Downes 1984). Recent studies on lava hosted peridotitic mantle xenoliths point towards contrasting northern and southern mantle domains beneath the area (Lenoir et al. 2000, Downes et al. 2003). In order to geochemically characterize the magmatic mantle source(s) and the relationship between the primitive melts from different areas within the French Massif Central, a large suite of fresh and mostly olivine-bearing mafic volcanic rocks was sampled.

The majority of samples consist of alkaline basalts and basanites showing no signs of significant differentiation as revealed by their major element distributions: (40 – 46 wt. % SiO_2, 6 – 13 wt. % MgO, 4.5 – 7.5 wt. % total K_2O+Na_2O). Trace element patterns are remarkably uniform for samples from all volcanic provinces and display enrichments in incompatible over compatible elements (e.g., $(Sr/Y)_N$ of 5 – 13 and $(La/Yb)_N$ of 11 – 24, $_N$ = primitive-mantle normalized using McDonough and Sun 1995). Marked positive Nb and Ta anomalies are in agreement with previous constraints that invoke one or more mantle plumes as the origin for the volcanism (e.g., Wilson & Downes 1990). Additionally, combined Sr-Nd-Hf isotopic data for mafic samples from the East volcanic provinces (Deves, Velay, Coirons) reveal isotopic values similar to those of HIMU (Hofmann 1997), in marked contrast to samples from the Western volcanic provinces (Aubrac, Cantal, Mont-Dore, Chaine des Puys, Chaine de la Sioule) that show isotopic signatures more similar to that of enriched mantle (EM-I or EM-II component) (e.g., East: $^{87}Sr/^{86}Sr$ = 0.7030 - 0.7032, ε Nd=4.7 - 5.3 and ε Hf=7 - 8.5; West: $^{87}Sr/^{86}Sr$= 0.7033 - 0.7036, ε Nd= 3 - 4.3 and ε Hf= 4 - 6.5).

This altogether testifies to the existence of a ca. 100 km-scale heterogeneity within the magmatic sources of the West and East Massif Central volcanism. Supplemental Pb isotope data will contribute to further constrain the East-West sub-continental mantle domains and to reconstruct the origin and distribution of the HIMU component of the Massif Central basaltic lavas, a component which is characteristic for the entire European Asthenospheric Reservoir (EAR) (Wörner et al. 1986, Kolb et al. 2012).

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Compositional variations of magmas in volcanic fields of the Central European Cenozoic Igneous Province reflect the topography of the lithosphere-asthenosphere-boundary

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Several intraplate volcanic fields between the Eifel (Germany) and Silesia (Poland) form the northern E – W oriented zone of the Central European Cenozoic Igneous Province (CECIP). The mafic magmas show systematic regional trends in geochemistry and mineralogy that require variations in the pT conditions during melt formation in the upper mantle. From the Eifel to NW Bohemia the magmas exhibit increasing Si-saturation and decreasing (La/Yb) N ratios approaching the volcanic field of the Vogelsberg from both sides. The chemical variations correlate with (1) decreasing depths of melt segregation indicated by increasing melt proportions from the spinel instead of garnet lherzolite mantle and/or (2) increasing degrees of partial melting. Geochemical and mineralogical data correlate with the decreasing depth of the lithosphere-asthenosphere boundary (LAB) from > 100 to about 60 km towards the Vogelsberg, which marks the northern extension of the Rhine Graben. The characteristics can be explained by (1) assuming this topography to be older than the magmatism and due to Cenozoic rifting, being followed by (2) buckling of the European lithosphere induced by the alpine deformation front.

Within the Bohemian Massif towards Silesia the chemical variations indicate an additional overprint by two lithosphere penetrating NNW-running tectonic structures paralleling the Tornquist-Teisseyre-Lineament, the Elbe zone as well as the zone of earthquake swarms crossing the Cheb Basin. Approaching these structures from both sides the necessary amount of partial mantle melting decreases as well as the volumes of erupted magma, an observation similar to oceanic fracture zones. This may be explained by the cooling effect of these tectonic elements on the melting zone at the LAB or by metasomatically induced linear lithospheric mantle heterogeneities.

We propose a genetic model where the rifting induced LAB topography of Central Europe determines the composition of the younger basaltoid magmas that erupted within the Cenozoic intraplate volcanic fields.

1

Insights into Cenozoic alkaline basalts from SW Poland: high mantle potential temperatures as an evidence for local thermal anomalies ("finger plume"?)

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Cenozoic lava flows and necks belonging to the Central European Volcanic Province are widespread in Lower Silesia in SW Poland. They occur in the NE part of the Variscan Bohemian Massif (Sudetes and Fore-Sudetic Block). Part of the lavas occurs at the NE prolongation of the Ohře (Eger) Rift into Poland (westernmost part of Lower Silesia), whereas those situated in the central and eastern parts of Lower Silesia are distant from the Rift. Samples from 22 outcrops show that, besides one site consisting of basaltic trachyandesites, the majority of the lavas are nephelinites and basanites. According to Birkenmajer et al. (2007), the Cenozoic volcanic activity in the area culminated in three periods: I from 31 to 25 Ma, from 23 to 18 Ma and the youngest volcanic activity was 4.5 Ma ago.

The basanites have higher MgO contents than the nephelinites. Their 100mg# ranges from 62 to 71 and from 54 to 63, respectively. The most striking feature of the studied lavas is the relatively low concentration of the total alkalis that range from 6.3 to 3.5 wt. %. The Ba/Ce in nephelinites and basanites ranges from 4.5 to 6.5 and is consistent with the mean OIB ratio of 4.5 +/-1.5, which is slightly higher that the Primitive Mantle ratio of 3.9 and considerably different from the MORB ratio (Ba/Ce=1.1). Radiogenic Sr, Nd, Hf isotopic ratios for nephelinites and basanites range between HIMU and DMM (Ladenberger 2006).

The calculated melt segregation temperatures for basanites from the north-eastern prolongation of the Ohře/Eger Rift range between 1550 and 1580 °C, whereas the calculations for basanites from the Kaczawa Block (located in the western part of Lower Silesia, but outside the Ohře Rift) vary from 1550-1560 °C (Herzberg & Asimow 2008). These segregation temperatures for basanites corresponds mantle potential temperatures around 1480 °C, which are higher than the mantle ambient temperature estimated to be 1400 °C. Pressure estimates for the segregated melts are 3 GPa, which correspond depths of approximately 100 km (Scarrow & Cox 1995).

The nephelinites could not be modelled using the same approach. Their chemical characteristics show that the source has been affected by CO_2 metasomatism. The estimated amount of CO_2 that affected the source is not higher than 0.5 % (Dasgupta et al. 2007). Basanites and nephelinites as can be inferred from the radiogenic isotopes and the incompatible elements are of asthenospheric origin. In addition, the $(La/Nd)_N$ ratio in nephelinites is higher (1.7) than in basanites (1.3) suggesting that the nephelinites have been generated in the asthenosphere after lower degree of partial melting than the basanites. Probably due to the increasing solubility of CO_2 with depth, the nephelinites could have been generated at higher depths.

The estimated high temperatures at low pressures (~100 km) point to a thermal anomaly underneath the studied area, which coincides with the postulated low-velocity material underneath Europe (Hoernle et al. 1995). This could be attributed to local small "finger-like" plume activity suggested to exist beneath Europe by Granet et al. (1995). A partial melting caused by the presence of fluids could be excluded as LILEs are not enriched in the lavas (Ba/Ce ratios are similar to the Primitive Mantle ratio). However not everywhere in Europe the alkaline basalts are related to plumes. For example Ali and Ntaflos, 2011 have shown that in Styrian Basin, Austria, the mantle potential temperature is below 1400 °C and that lithospheric attenuation is responsible for the generation of the alkaline basalts. It is therefore evident that thermal anomalies are not widespread everywhere underneath Europe but there are small low-velocity bodies causing the alkaline volcanism (Granet et al. 1995). This could be valid at least for SW Poland.

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1

Mantle formation – ancient and modern

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Studies of the petrology and composition of Earth's upper mantle depend heavily on observations made on ultramafic xenoliths brought to the planet's surface by volcanic activity. Xenoliths entrained in young volcanoes provide a snapshot of the present-day mantle, whereas those from older eruptions can also reveal part of the history of the lithospheric mantle. Pieces of mantle that have been emplaced into the continental crust at different times in the tectonic history of the Earth also provide a great deal of information about the upper mantle in Mesozoic and early Tertiary times (e.g. Lherz, Ronda and Beni Bousera, Ivrea zone massifs), and in particular provide field relationships that can rarely be examined in xenoliths (Downes 2001). From studies of mantle xenoliths erupted by intraplate oceanic volcanoes, together with dredge samples of in situ oceanic lithosphere, and studies of ophiolite complexes in various parts of the world, we can determine that the oceanic mantle lithosphere generally differs from the sub-continental mantle lithosphere in the degree of depletion and lack of metasomatism (Simon et al. 2008). Previous studies of xenoliths within ocean island volcanoes have tended to emphasise the rare but more metasomatised varieties, rather than the more abundant depleted lithologies.

Garnet peridotite xenoliths in kimberlites yield Re-Os ages that suggest that the lithosphere beneath cratonic continetal crust has existed since early Archean times. However even the oldest known kimberlites or alkaline rocks containing mantle xenoliths are themselves relatively young (ca. 1.2 Ga). The continental mantle beneath ancient cratons differs from that beneath younger continental regions in being significantly more depleted (Griffin et al. 2009). Once again, studies of mantle peridotites in kimberlites have tended to concentrate on those samples that contain abundant (and easily analysable) garnet and clinopyroxene, to the detriment of more strongly depleted samples that lack these phases. Griffin et al. (2009) suggest that much of the garnet and clinopyroxene in these xenoliths is due to refertilisation of the mantle, rather than being resitic after partial melting. Older massifs, such as the Jormua ophiolite in Finland and parts of the Archean in Greenland, provide some data for Archean and early Proterozoic lithospheric mantle, but are highly altered and tectonised.

However there is no easy way to investigate the very early history of the Earth's mantle, because the dynamic processes that have affected our planet have erased all evidence of the Hadean mantle lithosphere. An alternative method of investigation is via ultramafic meteorites, which are in effect mantle xenoliths from asteroidal bodies. The most abundant group of ultramafic meteorites is the ureilite group, which have many commonalities with Earth's mantle. They are composed of olivine and pyroxene, together with carbon polymorphs (diamond, graphite), sulphides and metals. Although, due to wide differences in oxygen isotope compositions, ureilites cannot be directly related to Earth, nevertheless both Earth and the ureilite parent asteroid share some common characteristics. Studies of ureilite meteorites show that their parent body underwent differentiation into a mantle and core. However, unlike Earth and other terrestrial planets, the parent body never reached a "magma ocean stage". Instead it experienced a catastrophic impact disruption and some of the features observed in ureilite meteorites indicate the shock effects of this immense impact. Gravitational re-accretion re-formed the asteroid as a "rubble-pile" body at an early stage of planetary differentiation (Downes et al. 2008), essentially fossilizing the remaining 4.56 Ga old mantle material.

The mantle of the ureilite parent asteroid shows depletion in LREE in all its silicate minerals, indicating removal of a basalt component, although no basaltic meteorites have yet been associated with the ureilites. Perhaps basalt magmas were vented into space by fire-fountaining and lost, rather than forming a primary basaltic crust. Nevertheless, some rare basaltic melt droplets and melt inclusions were retained within the re-accreted rubble-pile asteroid. Studies of ureilite meteorites suggest that the parent body was richer in both carbon and iron than the material which formed Earth. Thus the ureilite parent body is an analogue of early Hadean terrestrial planetary processes, but represents accretion in a different part of the Solar System than the Earth.

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Light elements in mantle minerals – what we are talking about

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The concentration of light elements (Z < 10) in mantle minerals plays a pivotal role in our understanding of several key processes of mantle petrology. Beside the "global leader" oxygen all the other elements are defined as "mantle-incompatible" or "birds of paradise". These light elements have been recognized to be present in several chemical states and mineralogical forms:

- Gaseous and fluid inclusions
- Single minerals like diamond, graphite, moissanite, …
- Thin films on mineral surfaces and cracks of mostly unknown composition and structure
- Solid solutions in the crystal lattice and on interstitial places.

Of all the above named possibilities solid solutions are the most immobile and inert ones. Therefore we can use the 'pure' mantle minerals as indicators conserving information about:

- Prolonged, slow processes like intragrain-diffusion
- Deformation history and mechanisms
- Thermal history.

Microanalytical methods as well as imaging and mapping techniques need to be used necessarily to visualize and characterize internal growth and alteration features of the studied minerals. Unfortunately the electron microprobe, the petrologist's workhorse fails to analyze the elements of interest in the low concentrations typical for mantle minerals. Non-standard analytical tools like SIMS (secondary ion mass spectrometry), PIGE (Particle Induced Gamma-ray Emission), NRA (Nuclear reaction Analysis) or proton-proton scattering analysis will be presented and compared to spectroscopic methods like FTIR (Fourier transform spectroscopy) or Raman spectroscopy. Typical detection limits, precision and reproducibility as well sample preparation requirements are described. Specific problems like missing reference materials may weight our knowledge about the elemental budget of elements like H, B, Be or F in single mantle reservoirs considerably. Striking examples for carbon and fluorine are shown.

Lithium isotope evidence for pervasive metasomatism of subcontinental lithospheric mantle in peridotitic xenoliths from the Upper Palatinate, Germany

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Peridotitic xenoliths enclosed in volcanic rocks are an important source of information about chemical composition of subcontinental lithospheric mantle. Although these rocks may carry key information about pristine isotope signatures of their source mantle, it is vital to deconvolve possible imprint of fluid/melt interactions in mantle that could impose severe modification to the original elemental/isotope composition. As an integral part of the Central European Volcanic Province (CEVP), the Eger Graben represents its easternmost part and associated volcanic occurrences frequently host xenoliths of lherzolite, harzburgite and dunite. In this study, we focused on western continuation of the Eger Graben at Zinst, Hirschentanz and Teichelberg localities (NE Bavaria) with numerous exposures of mantle xenoliths. The xenoliths show signs of complex metasomatic history by alkaline and/or carbonatitic melts.

We have employed stable isotope systematics of lithium (Li) in order to (i) unravel the original Li isotope signature of subcontinental lithospheric mantle, (ii) provide evidence of pervasive metasomatism and its effect on Li isotopes, and (iii) detect whether differences in primary and secondary mineral assemblages may impart changes to Li isotope fractionation. No clear general relation between petrography and modal composition and Li contents is apparent, but significant differences exist for Zinst and Hirschentanz/Teichelberg xenoliths, respectively. The Zinst peridotites are enriched in Li (1.4–5.3 ppm) and show more variable and negative δ^7Li values from +1.3 to –9.7‰ compared to Hirschentanz/Teichelberg xenoliths with 1.3–2.7 ppm Li and δ^7Li values between +2.5 and –2.5‰. It is apparent from our Li isotope data, that all of the xenoliths underwent metasomatic overprint either at mantle conditions or after their emplacement. A highly negative δ^7Li_{WR} (down to –9.7‰) is a prominent feature of samples with significantly elevated Li contents whereas the highest Li content of the whole suite (5.3 ppm) was found for a xenolith with secondary melt pockets with carbonate suggestive of alkaline-carbonatitic metasomatic overprint. The latter sample does not differ greatly from the other samples in its Li isotope systematics, however. This is consistent with Na-carbonatite signature which is usually distinguished by extreme Li enrichments compared to Ca- and Si-carbonatites (Halama et al. 2008). The overall light Li isotope signature in all xenoliths, paralleled by Li contents that are elevated over primitive mantle values (e.g. Magna et al. 2006, Jeffcoate et al. 2007), are similar to findings of Su et al. (2012) who argue for either Na-carbonatite metasomatism or low- δ^7Li mantle reservoir with significant contribution of eclogitic fragments. It is important to note that eclogites with extremely light Li isotope compositions (–8.3‰) exist in the region (Magna et al. 2004) but the extent to which they might participate in melting and/or metasomatism of NE Bavaria xenoliths suite remains to be further investigated. Apparently, diffusive isotope fractionation can be avoided despite we analyzed only whole-rock samples. The dominant proportion of olivine coupled with slow Li diffusion in olivine compared to clinopyroxene renders this kinetic mechanism an unlikely explanation for low δ^7Li signature found in our studied xenoliths. It is important to stress that a δ^7Li vs. MgO dichotomy exists between Zinst and Hirschentanz/Teichelberg (Fig. 1). Modest degrees of melting and/or crystallization do not impart resolved Li isotope fractionation (Tomascak et al. 1999) and, therefore, calculated degrees of melting (<18%; Ackerman et al., in prep.) cannot alter the Li isotope compositions. From the presence of garnet pseudomorphs and associated melt domain in some Zinst xenoliths (Špaček et al. 2012), it may be deduced that these samples were more fragile and thus, more prone to fluid/melt-induced metasomatic overprint. This may be evidenced by extremely light Li isotope signature in Zinst xenoliths. In either case, a metasomatic overprint of the whole NE Bavaria suite strongly modified a δ^7Li composition of the subcontinental lithospheric mantle in this area.

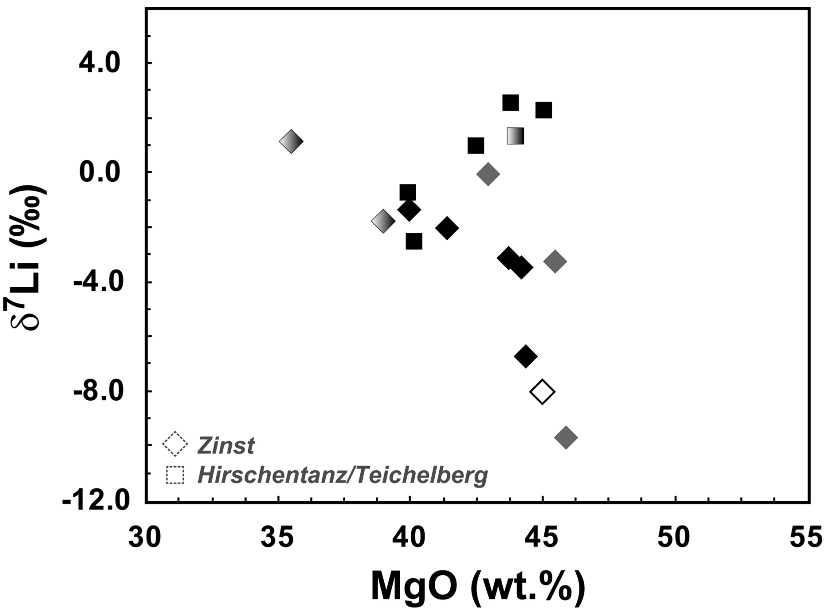

Fig. 1. Lithium isotope composition vs. MgO contents in Zinst (diamonds) and Hirschentanz/Teichelberg peridotite xenoliths. Black – lherzolites; grey – harzburgites; open –dunite/wehrlite; pattern – carbonate-bearing lherzolites. Two anti-correlated patterns suggest two distinct modes of metasomatism: the most depleted Zinst peridotites have δ^7Li less affected by metasomatic overprint whereas the opposite systematics is observed for Hirschentanz/ Teichelberg. Carbonate-bearing xenoliths do not have uniform Li systematics.

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Lithospheric mantle beneath Central Europe: Lithology beyond standard?

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The lithospheric mantle occurring beneath the Variscan Bohemian Massif in Central Europe has been sampled by numerous lavas belonging to the Cenozoic Central European Volcanic Province. The volcanism was intense in the western, north-western (Ohře Rift and Erzgebirge) and north-eastern (Lower Silesia) parts of the Bohemian Massif. The K-Ar datings of Birkenmajer et al. (2004) show that volcanic activity culminated in Oligocene-Miocene (33 – 18 Ma), and most of the xenoliths from the area represent mantle sampled at this time; the late ca. 5 My episode supplied xenoliths in Kozákov (Ackerman et al. 2007) and Lutynia (Matusiak-Małek et al. 2010). Recent studies (Puziewicz et al. 2011 and references therein) show that the lithospheric mantle is mostly harzburgitic, and was subjected to various kinds of metasomatic events. Christensen et al. (2001) proposed the model of stratified lithospheric mantle beneath Kozákov (east of the Ohře Rift), based on calculated temperatures of mantle xenoliths, assumed geotherm at 5 My and seismic data. In this model the uppermost 10 km of lithospheric mantle is more magnesian and colder than those situated beneath. Puziewicz et al. (2012) proposed steeper geotherm at 5 My for area located outside the Ohře Rift, basing on heat flow measurements and modelling of heat budget in the crust-mantle column.

The large-scale structure of lithospheric mantle beneath Central Europe is under debate. The Bohemian Massif is the Variscan assembly of fragments of lithospheric plates. Seismic studies (e. g. Babuška & Plomerová 2006) suggest that the lithospheric mantle preserved the individual seismic features of assembled plates. However, strong geological evidence shows delamination of the roots of European Variscan Orogen at the late stages of its development, and replacement of the delaminated lithospheric mantle by new upwelled asthenospheric material (e.g. Ziegler & Dézes 2005). This model excludes the possibility of preservation of pre-orogenic lithospheric plate roots.

Puziewicz et al. (2011) suggested that the lithospheric mantle beneath the Ohře Rift was rejuvenated at the time of Cenozoic volcanism, whereas the remnants of older lithologies are preserved in areas located outside the Rift. Our data from Lower Silesia and Lusatia (op. cit. and unpublished results) show that in some sites two populations of mantle peridotites occur, characterized by different major element composition of olivine and pyroxenes. Population "A" (minimal temperatures close to 800 ºC or no equilibrium between cpx and opx) contains olivine $Fo_{90.5-92.0}$, whereas the population "B" (equilibration temperatures close to 1000 ºC or slightly above) contains olivine $Fo_{87.5-90.0}$. The study of population "B" shows that it originated due to "Fe-metasomatism" of more magnesian peridotites by silicate melts moving pervasively through lithospheric mantle and that metasomatism was coeval with Cenozoic volcanism (Puziewicz et al. 2011). The peridotites belonging to population "A" were supposedly the protolith of those of the population "B". Part of the population "A" peridotites contain the clinopyroxene of mg# 94 – 95, typical for low-temperatures of equilibration. In some sites (e.g. Krzeniów) the trace element patterns show that decreasing mg# of clinopyroxene in population "A" peridotites is due to gradual replacement of primary lower-temperature mineral assemblage by the later higher-temperature one. This suggests that the variation of mineral chemistry is due to chromatographic effect and not due to vertical variation in lithospheric mantle temperatures.

The data on Central European lithospheric mantle are insufficient, sometimes excluding each other and allowing various interpretations of history of the same lithologies. We suggest that the lithospheric mantle has a mosaic structure, and consists of the mantle roots of plates assembled during Variscan orogeny which escaped late-Variscan delamination, intermingled with upwelled and "lithospherized" asthenospheric mantle. It was further reworked during Cenozoic volcanism, and some of its parts were rejuvenated thermally and compositionally, whereas the other preserved the relics of older lithologies.

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Garnet breakdown in basanite-hosted peridotite xenoliths from southern Eger Rift (Zinst, Bavaria)

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Reaction coronae around garnet are commonly found in garnetiferous mafic and ultramafic rocks of the upper mantle and lower crustal origin. The importance of these features lies in the fact that they record retrograde metamorphism and carry information on pressure-temperature paths or exhumation rates of the host rocks, bearing serious implications for their tectonic evolution.

While garnet peridotite is the most common member of xenolith suites in kimberlites, it is generally very rare in alkali basalts and typically absent in most occurences of basalts worldwide. Taking into account the generally accepted assumption that garnet peridotite is a source rock for basaltic magmas, this fact probably reflects some important changes in the style of magma transport taking place close to the garnet/spinel peridotite transition. It is therefore desirable to understand the interactions between garnet peridotite and basaltic melt, since these can play an important role in chamber formation and thus control the transport of magma to shallower levels in the lithosphere. Both local advective heating and introduction of reactive fluids from the rising melts very likely destabilise the mineral assemblage in garnet peridotite. The rapidly exhumed and cooled xenoliths of garnet peridotites can bear numerous fingerprints of such late transformation processes in the sub-volcanic mantle, allowing for backward reconstruction of the physico-chemical conditions at which they occurred.

Recently, we found rare xenoliths in Oligocene basanite from Zinst (Bavaria, Germany) containing zoned mineral clusters with fine-grained symplectites, representing former garnet and its reaction coronae. The chemical and textural evidence clearly shows a multiphase breakdown of garnet which was not completed before the entrainment of xenoliths into basanites. These complex „pseudomorphs“ record the processes taking place in the upper mantle prior to eruption and allow the study of the interaction between garnet peridotite and melts/fluids both prior to entrainment of the xenoliths and during their ascent. Based on microstructures, crystallographic fabric, major and trace element mineral chemistry, four distinct concentric zones were defined in various types of pseudomorphs:

1. coarse grained ($\leq$ 1 mm) aggregate of orthopyroxene+clinopyroxene+spinel with a granular structure,
2. fine- to medium-grained (order of 10–100 μm) orthopyroxene+spinel symplectite,
3. fine grained (10–300 μm), radially fibrous orthopyroxene+spinel symplectite with ultrafine-grained (0.5–5μm) interstitial anorthite, and,
4. ultrafine-grained ($\leq$ 1 μm) orthopyroxene+spinel+anorthite symplectite with an internal domain sub-structure.

Pseudomorphs dominated by Zone III are most typical, while Zone IV is rarely developed. Similarly, Zone I is missing in some samples. Pristine (non-metasomatised) parts of Zones III and IV have bulk compositions of pyrope-rich garnet ($Prp_{72}Alm_{15}Grs_{13}$). Radially arranged veinlets with ternary feldspar-dominated fill, spread from Zone III/IV boundary outward. All zones exhibit perfect inter-sample correlation and document the discontinuous evolution of peridotite under changing conditions with successively increasing rates of garnet breakdown. Based on thermometry and microstructural relations, a sequence of three pre- and syn-volcanic events is discerned:

1. Early reaction Grt + Ol → Opx + Cpx + Spl (reaction 1) related to regional heating in the uppermost mantle and possible small-scale lithospheric extension, both likely taking place in the early stages of Tertiary rifting. Partial re-equilibration of the rocks in the spinel peridotite stability field at 1040–1080°C. Inclusions of clinopyroxene, olivine and spinel, rarely found within Zones III and IV, lack any significant reaction rims, suggesting that the progress of reaction 1 was controlled by presence of fluids.

2. Largely isochemical, fluid-mediated breakdown of garnet to kelyphitic rim of Zones II+III (Grt → Opx + Spl + An; reaction 2) in a short period of heating by ~100-250°C. Melting and progressive crystallization of Opx+Spl symplectite and interstitial anorthite is indicated by mineral habits and geometrical relations. The subsequent partial metasomatism by Na-rich, K-poor, carbonate-bearing melts/fluids suggests that this phase of garnet breakdown occured largely prior to the formation of xenolith and its entrainment in basanite magma.
3. Rapid isochemical breakdown of rare garnet relics into Opx+Spl+An microsymplectite (same as reaction 2) leading to local swelling and opening of radial veinlets which introduced alkali-rich melts of largely external origin. Metasomatic reaction in the external parts of the symplectites resulted in local formation of Ol+Pl intergrowths at the expense of Opx. This phase of garnet breakdown is compatible with rapid decompression of basanite-hosted xenolith, immediately preceding the eruption in Oligocene.

The well developed and clearly separated symplectite zones indicating the isochemical breakdown of garnet are uncommon to garnet peridotites worldwide and they have only been reported from olivine-free rocks. The absence of chemical reaction between garnet and olivine or pyroxene on symplectite formation in samples from Zinst is explained by an extremely short time span between the formation of the kelyphite, Na-carbonate metasomatism and the final garnet breakdown on the basanite eruption, allowing for rapid quenching of the multiple advancing reaction fronts.

Chemical and physical properties of central European lithospheric mantle from the Moho to a depth of 83 km: evidence from Kozákov spinel peridotite xenoliths

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Spinel lherzolite xenoliths are abundant in basanite lavas (4-6 Ma) of Kozákov volcano, which is located in the Czech Republic along the Lusatian (Lužice) fault system at the eastern end of the Eger (Ohře) graben. These xenoliths reveal a layered structure of the lithospheric mantle, which is accompanied by a decreasing depletion of incompatible major elements in lherzolite with depth and a metasomatic enrichment in LREE and HFSE in depleted lherzolite (Christensen et al. 2001, Ackerman et al. 2007). We have investigated additional lherzolite xenoliths from Kozákov to provide a continuous view of the lithospheric mantle beneath the Moho at 32 km to a depth of 83 km, which is not far above the lithosphere-asthenosphere boundary at 90 km.

The lherzolite xenoliths exhibit two general types of texture: a medium-grained (1-3 mm) equigranular texture with discrete, intergranular spinel, and a coarse-grained protogranular (i.e., porphyroclastic) texture (3-6 mm) with opx+cpx+spl symplectite after garnet (Fig. 1). Xenolith extraction depths were determined by combining the average temperature estimate from three, two-pyroxene geothermo- meters with a geotherm for Kozákov at 5 Ma, the time of eruption. The two textural types are distributed in three separate layers at depth: 1) an Upper Equigranular Layer (UEL) between 32 km (670 ºC) and 47 km (860 ºC); 2) a Protogranular Layer (PL) between 47 km and 71 km (1075 ºC); and 3) a Lower Equigranular Layer (LEL) between 71 km and 83 km (1160 ºC) (Fig. 1). The apparent slight overlap of the layer boundaries reflects the uncertainty in depth estimates of ±1 km.

The different chemical compositions of the layers are reflected in their mineral compositions (Fig. 1). The UEL is the most depleted, with a mean Mg#(ol) of 91.5, mean Cr#(opx) of 11.9, and mean Na_2O content (cpx) of 0.5 wt.%. Depletion diminishes with depth in the PL, with Mg#(ol) decreasing from 91.5 to 90.2, Cr#(opx) decreasing from 8.9 to 6.2, and Na_2O content (cpx) increasing from 0.8 to 1.2 wt.%. Although mineral compositions in the LEL are variable, their mean values are comparable to those in the overlying PL, i.e. Mg#(ol), 90.7; Cr#(opx), 8.5; and Na_2O content (cpx), 1.1 wt.%.

Xenolith olivine fabrics, measured by U-stage (Christensen et al., 2001) and EBSD (this study), display orthorhombic symmetry (point maxima for [100], [010], and [001]) or axial symmetry ([100] point maxima; [010] and [001] girdles), the distributions of which are independent of depth. In contrast, fabric strengths and seismic anisotropies are strongly depth dependent; M-values are 0.12-0.25 in the UEL and 0.05-0.11 in the LEL, and AVp decreases over the profile from 8-14% to 3%, and AVs, from 5-9% to 3% (Fig. 1).

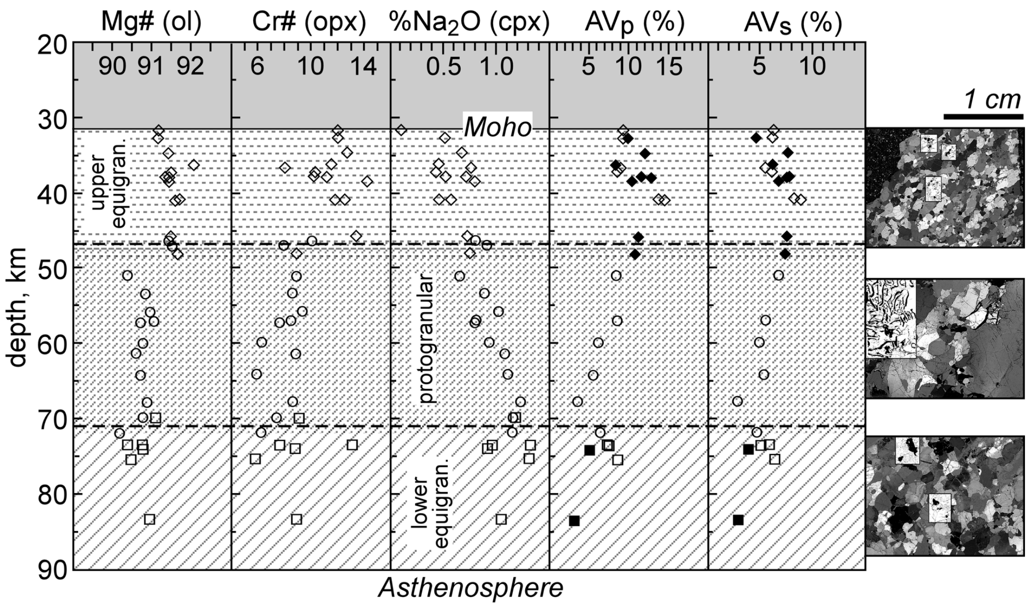

Fig. 1. Variation in mineral compositions, seismic anisotropies, and textures with depth. Symbols: diamonds, UEL; circles, PL; squares, LEL. For AVp and AVs: open symbols, U-stage; filled symbols, EBSD. Photomicrographs, crossed polarizers; insets, plane polarized light.

Comparison of xenolith anisotropies (maximum Vp and Vs parallel to foliation) with geophysical measurements of Pn anisotropy and SKS shear wave splitting in the region indicate that foliation is steeply dipping in the PL and LEL. This has been attributed to an inheritance from the Variscan collision of Saxothuringia, Bohemia, and Moldanubia, when garnet peridotite (PL) and spinel peridotite (LEL) were tectonically juxtaposed by subvertical shear (Christensen et al. 2001, Babuška & Plomerová 2006). In contrast, the subhorizontal foliation and strong fabrics observed in the UEL are hypothesized to have formed during Neogene extensional shearing and heating related to development of the Eger (Ohře) graben. Weakening of olivine fabrics with depth in the PL and LEL may be due to annealing during the same Neogene deformation event.

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The fluid and melt metasomatism of lithospheric mantle beneath SW Poland: the Krzeniów basanite case

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Mafic rock of Central European Volcanic Province (CEVP) are abundant in Sudetes Mts. and Fore-Sudetic Block (SW Poland). A volcanic plug occurring nearby Krzeniów village (North Sudetic Depression) is formed of Miocene (ca. 19 Ma, Birkenmajer et al. 2007) basanite. It encloses scarce peridotite (spinel harzburgite and spinel dunite) xenoliths, which are usually up to 4 cm in diameter.

The peridotites display protogranular to porphyroclastic texture. Clinopyroxene is present in small amounts (£ 4.5 vol. %) only in some of the xenoliths. The contents of forsterite in olivine defines two groups of peridotites: A – $Fo_{90.4\text{-}91.7}$ and B – $Fo_{88.2–89.8}$. The group A orthopyroxene is more magnesian (mg# 0.913-0.921) than that of group B (mg# 0.899-0.920).

The variations in clinopyroxene major and trace element composition defines subgroups A1 and A2 in the group A peridotites; the subgroup A3 comprises the clinopyroxene-free xenoliths. The A1 clinopyroxene is characterized by various Rare Earth Elements (REE) contents and "spoon-shaped" REE patterns (Fig. 1a). The most REE poor clinopyroxene is highly magnesian (mg# 0.936-0.945) and impoverished in aluminium (Al 0.065 atoms per formula unit, a pfu in the following, corresponding to 1.450 wt % Al_2O_3). It is relatively poor in Na (0.016 a pfu) and rich in Ca (0.935 a pfu). The A1 clinopyroxene, if contains more REE's, is also rich in magnesium (mg# 0.924-0.936), but the Al and Na contents are elevated in comparison to REE-poor clinopyroxene (0.086-0.112 and 0.037-0.069 a pfu, respectively). The Ca content is 0.854-0.909 a pfu. All the A1 xenoliths contain low- Al orthopyroxene (0.055-0.090 a pfu). The REE poor clinopyroxene equilibrated its composition at 760 ºC (Brey & Köhler 1990 opx-cpx thermometer), whereas that REE-enriched at 910 ºC. The A2 clinopyroxene displays continuous enrichment in REE from Heavy Rare Earth Elements (HREE) to Nd (Fig.1b). It is less magnesian than A1 clinopyroxene (mg# 0.918-0.924) and richer in Al and Na (0.148-0.158 and 0.079-0.098 a pfu, respectively). The Ca content is relatively low (0.800-0.824 a pfu). The Al content in A2 orthopyroxene is 0.102 a pfu while in A3 orthopyroxene it varies from 0.021 to 0.095 a pfu. The A2 xenoliths record equilibrium between opx and cpx at 1030 ºC.

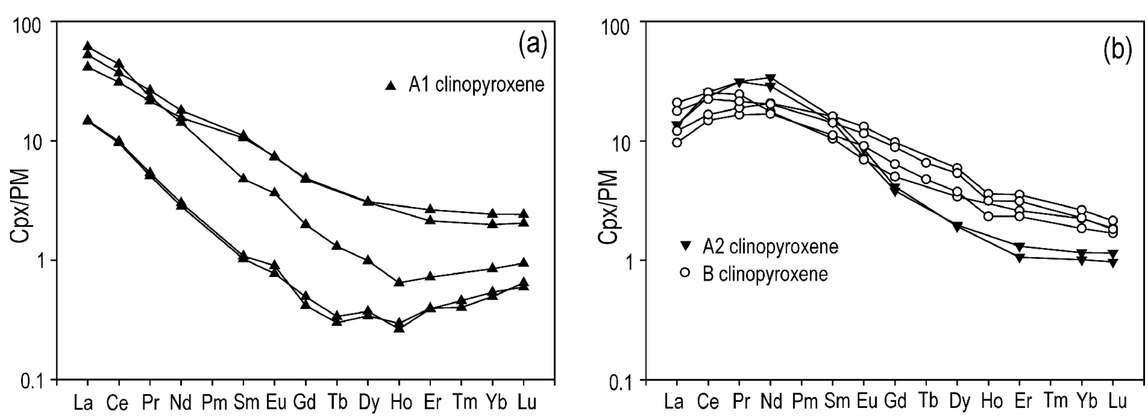

Fig. 1. Primitive mantle normalized REE patterns of A1 clinopyroxene (a) and A2 and B (b) clinopyroxene.

Major element composition of group B clinopyroxene is variable (mg# 0.903-0.924, Al 0.074 to 0.095, Na 0.057-0.075, Ca 0.843-0.88 1a pfu), but REE composition remains constant and mimics that of group A2 (Fig.1b). Orthopyroxene contains 0.035-0.074 atoms of Al pfu. The temperatures of opx-cpx equilibration are highly variable (850 – 970 ºC) due to varying compositions of the minerals.

The REE patterns in group A1 change gradually from the REE poor and spoon-shaped to REE richer and more flattened (Fig. 1a). Concomitantly, the Ca content decreases and those of Al and Na of increase. The REE and trace elements content of the REE poor A1 clinopyroxene suggest that they were shaped by reaction with the fluid. The REE patterns of A2 clinopyroxene are similar at MREE and HREE to those of the most REE rich A1 patterns, but inflected at LREE. The inflection is typical for clinopyroxene which equilibrated its REE contents with silicate melt. The A2 clinopyroxene is less magnesian and is significantly enriched in Al and Na and impoverished in Ca relative to the A1 one. This suggests that the A1 REE enriched and A2 clinopyroxenes were affected to a different degree by silicate melt metasomatism. Thus, the REE poor A1 clinopyroxenes probably represent compositions of the peridotites in the Krzeniów mantle section before silicate melt infiltration. The group B clinopyroxene is similar to the A2 one, but its major element composition is more variable and the forsterite content in olivine is lower than that in A group, suggesting that it was affected by silicate melt metasomatism ("Fe metasomatism"). This kind of metasomatism seems to be common in the lithospheric mantle beneath Lower Silesia.

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Petrology and geochemistry of mantle xenoliths from České Středohoří Mts. and Lusatia, Bohemian Massif

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Cenozoic anorogenic volcanism of alkaline character forms several centers throughout Europe. In western and central Europe, volcanic activity is associated with development of the European Cenozoic Rift System (ECRIS) forming Western and Central European Volcanic Province (CEVP). The NE-SW trending Ohře/Eger rift system in the Bohemian Massif represents the easternmost part of the rift system within CEVP. Volcanic rocks from Ohře/Eger rift system contain abundant mantle xenoliths, but only a few localities were studied in detail – Kozákov in NE Bohemia, Ksieginki in SW Poland and Mýtina in W Bohemia and these record mantle depletion by partial melting and subsequent metasomatism by basaltic melts (Ackerman et al. 2007, Geissler et al. 2007, Puziewicz et al. 2011).

We studied spinel-bearing peridotite mantle xenoliths from central (České Středohoří Mts. - ***Dobkovičky, Kuzov, Prackovice***) and eastern (***Brtníky***) parts of the Ohře/Eger rift to provide more details on mantle composition beneath the rift. The xenoliths from ***Dobkovičky*** have predominantly composition of harzburgite (~ 72 vol. % olivine, ~ 22 vol. % orthopyroxene, < 5 vol. % clinopyroxene, 1 vol. % spinel) and coarse-grained texture with common signs of host lava infiltration and hydrothermal alteration. The ***Kuzov*** lherzolites (55-65 vol. % olivine, > 20 vol. % orthopyroxene, ~ 8 vol. % clinopyroxene, 1 vol. % spinel) have equigranular texture, while the ***Prackovice*** lherzolites (~70 vol. % olivine, > 18 vol. % orthopyroxene, > 8 vol. % clinopyroxene, 1-2 vol. % spinel) exhibit partially serpentinized coarse-grained texture. The lherzolite xenoliths (> 55 vol. % olivine, ~ 25 vol. % orthopyroxene, ~ 15 vol. % clinopyroxene, < 5 vol. % spinel) from ***Brtníky*** have porphyroclastic texture with large clinopyroxene and orthopyroxene grains. Spinel forms symplectites with pyroxenes or rarely also Al-rich rounded inclusions on silicate grain boundaries.

Olivine has magnesian composition for all studied localities with variable # Mg ranging from 89.8 to 91.6, CaO contents of 0.01-0.14 wt. % and NiO contents between 0.36 and 0.42 wt. %. Orthopyroxene exhibit # Mg in the range between 90.9 and 92.4 and variable Al_2O_3 contents of 0.78-2.47 wt. % with the lowest average values for Prackovice (0.78 wt. %) and the most variable for Dobkovičky (1.00-2.40 wt. %). Clinopyroxene has similar #Mg of 91.0-95.1 and variable Al_2O_3 and Cr_2O_3 contents (0.32-3.47 wt. % and 0.14-3.32 wt. %, respectively). Spinel composition show a narrow interval in #Mg ranging from 67.4 to 74.8, but very large differences in #Cr from 29.2 to 81.4. The #Mg and #Cr values are well positively correlated.

The equilibrium temperatures were calculated using several geothermometers obtaining the best reliable results with two-pyroxene geothermometer. Calculated temperatures varied from 850 to 1062 °C for xenoliths from the České Středohoří Mts. localities and between 869 and 940 °C for xenoliths from Brtníky.

The mineral composition and whole-rock geochemical analyses show a highly refractory character of the studied mantle xenoliths. Trace element contents are highly variable and show depleted nature of mantle peridotite in case of compatible elements, but strong enrichment in incompatible elements. Comparing to primitive upper mantle, all xenoliths are variably enriched in Rb, LREE (La_N/Yb_N = 5.9-66.5), but depleted in Th, MREE and distinctly in HREE (Figure 1). These geochemical patterns suggest that upper mantle underwent variable partial melting degrees during melt extraction and subsequent metasomatism most likely by basaltic melt.

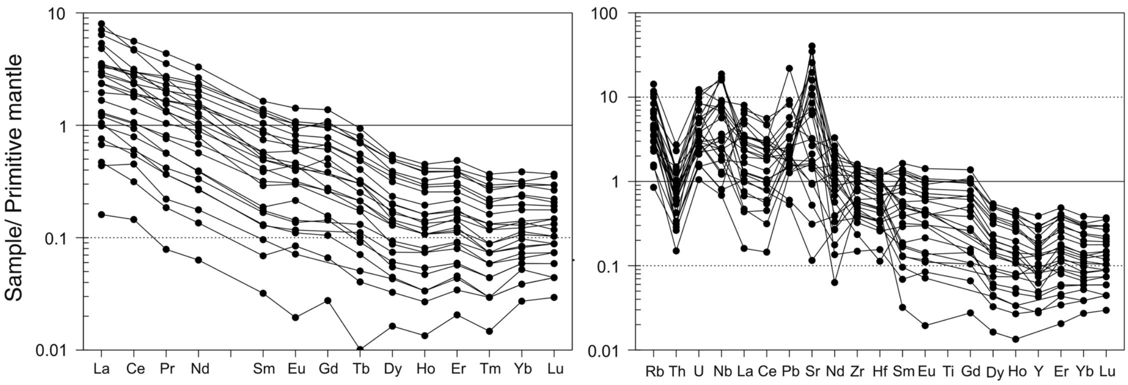

Fig. 1. Rare earth element (REE) and trace element distributions for the studied mantle xenoliths normalized to primitive mantle (McDonough & Sun 1995).

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Major element whole rock and mineral chemistry of Southern Patagonian Mantle Xenoliths

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The Pali Aike Volcanic Field (PAVF) situated in the back-arc tectonic setting of southern Patagonia is one of the two Patagonian localities where garnet and spinel peridotites are brought to the surface by alkaline basalts. The other locality is Prahuaniyeu in northern Patagonia (Bjerg et al. 2009). The xenoliths from the PAVF were collected at Salsa, El Ruido and Potrok Aike mare and the majority of the studied samples comprise spinel- and spinel-garnet-lherzolites, followed by spinel- and spinel-garnet harzburgites. A single dunite was found in El Ruido maar. Textures are protogranular to protogranular-equigranular with some samples slightly foliated. None of the studied xenoliths contain hydrous phases such as phlogopite and/or amphibole but few contain secondary interstitial clinopyroxenes (Cpx) and melt pockets. Some Garnet (Gt) show Olivine (Ol), Cpx or Spinel (Sp) inclusions suggesting that the garnet grew at the expense of Sp and pyroxenes according to the reaction Sp + Opx + Cpx → Ol + Gt. Kelyphitic rims resemble the reverse breakdown reaction Gt + Ol → Sp + Opx + Cpx resulting from decompression, where Gt becomes unstable and re-equilibrates during its rise to the surface. This is observed in all of the Sp-Gt-peridotites examined. Kelyphitic rims consist of fine grained Ol, Opx and aluminous Sp $^{+}$/- glass and their thickness varies from 50 to 500 µm. In most Sp-Gt-peridotite samples the kelyphitic rim shows an outer zone, where mineral phases can be identified and a very fine grained inner zone, where phases are undistinguishable. Some Gt have been entirely consumed and only kelyphitic rims are left around the still existing Sp-inclusions. Sp-inclusions in Gt and kelyphitic rims are round to wormlike, while matrix-Sp occurs as inclusion in Ol or Px as well as interstitial. In most samples, Opx show exsolution lamellae of Cpx ($^{+}$/- Sp) and vice versa indicating subsolidus cooling. Some Cpx show spongy rims suggesting either decompression or reaction with infiltrating melt.

Whole rock Al_2O_3 and CaO contents range from 0.625 to 3.543 wt% and 0.242 to 2.897 wt%, respectively. The variation diagrams of CaO and Al_2O_3 versus MgO exhibit a linear correlation that could be interpreted as residuals after extraction of melts with different degrees of partial melting from a common mantle source (Fig.1). The sample ELRU-10 deviates strongly from this trend suggesting a cumulate nature. Sample ELRU-2 is enriched in CaO suggesting either inhomogeneous distribution of Cpx or carbonatitic metasomatism.

The olivine forsterite contents for lherzolites, harzburgites and dunite vary between $Fo_{89.51}$ – $Fo_{90.91}$, $Fo_{91.1}$ – $Fo_{92.04}$ and $Fo_{91,67}$, respectively. However, one El Ruido Sp-harzburgite and one Gt-harzburgite have lower Fo-contents ($Fo_{88.88}$ -$Fo_{89.11)}$ indicating either a cumulate nature of the xenoliths or a change of chemical composition of the rocks due to reaction with infiltrating melts. With exception of the two El Ruido harzburgites that are slightly enriched in NiO, the NiO contents of Ol range from 0.36 to 0.45 wt% for all 3 rock types. Primary Cpx are mainly Cr-diopsides with mean compositions $En_{47-50}Fs_{4-5}Wo_{48-45}$ in lherzolites, $En_{49-53}Fs_{6-5}Wo_{44-41}$ in harzburgites, and $En_{47}Fs_{3}Wo_{50}$ in the El Ruido dunite. Cpx Al_2O_3 and Cr_2O_3 contents in all rock types vary from 2.061 to 6.105 wt% and 0.774 to 1.952 wt%, respectively. Opx compositions are in the range $En_{88-91}Fs_{10-7}Wo_{1.5-1.2}$ with magnesium number (mg#, Mg/(Mg+Fe)) varying between 89.44 and 92.05. Primary Sp show variable chromium numbers (cr#, Cr/(Cr+Al)^{x}100) from 16.6 in lherzolites to 50.3 in dunite. Gt is Cr-rich pyrope with Cr_2O_3 between 1 and 1.5 wt%.

Fractional melting calculations using cr# in Sp for Sp-peridotites yield melting rates of 18% for Salsa Sp-harzburgite. El Ruido Sp-lherzolites and Sp-harzburgites show melting rates of 6 – 12 % and 14 – 18 %, respectively. Calculated results for Potrok Aike Sp-lherzolites yield 6 – 13 % fractional melting. (Hellebrand et al. 2001)

Equilibrium T estimates are calculated based on compositions of coexisting Cpx-Opx and pressure estimates were established using Al in Opx coexisting with Gt (Brey & Köhler 1990). The calculations yield equilibration temperatures in the range of 975 to 1140°C for Salsa samples with pressures from 18 to 21 kbar. El Ruido peridotites equilibrated in the range of 950 to 1175°C and pressures of 18.7 to 19.7 kbar for Gt-peridotites. One sample of the El Ruido suite stands out with an equilibration temperature of 750°C, which indicates subsolidus cooling. Potrok Aike samples yield equilibration temperatures of 950 to 1000°C with pressures of ~20 kbar. Sp inclusions in Gt indicate initial P-T conditions within the Sp-stability field and subsequent passing through the Gt-stability field.

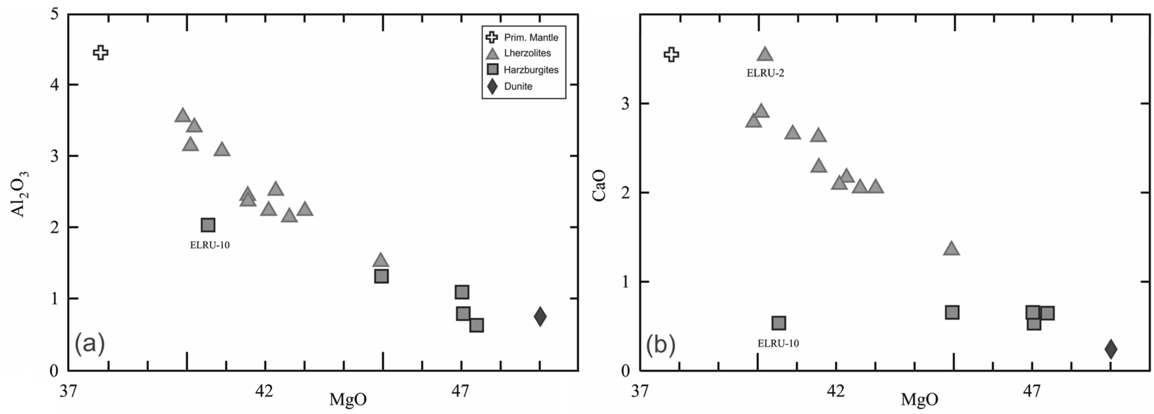

Fig. 1. Variation of whole rock Al_2O_3 and CaO vs. MgO for PAVF xenoliths, Primitive Mantle composition from McDonough & Sun (1995).

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Later chromitites from ophiolites of Albania

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The geology of Albania is characterized by the presence of ophiolitic formation, known as Mirdita Zone, which is distinguished by important chromite-bearing mineralization.

This formation is among the most representative examples of an old oceanic lithosphere that is well exposed and undisturbed by Alpine deformation, followed by its situation on the Korabi - Pelagonian platform.

Mirdita ophiolite formation has been divided into two belts, related to the Moho Transition Zone (MTZ). While MTZ eastern belt is represented by massive dunite, deformed by asthenospheric conditions, the western belt consists of plagioclasic peridotites, lherzolites and wehrlites of intensive lithospheric deformation, related to oceanic detachment in the level of tectonic Moho (Meshi et al. 2005).

This ophiolitic formation is widely known for deposits of large chromite reserves as well as a very large number of its occurrences, but it differs significantly from the structural features of ore bodies, of chromite textural features, and chemical composition of chromite itself (Çina 2010 2012).

Most and largest chromite deposits are related to mantle hartzburgites, near the contact with massive dunites of MTZ of eastern belt. Chromite mineralization, related to massive dunites, seems to have more limited significance.

According to structural classification, are evidenced chromite ore bodies, concordant, subconcordant and discordant, regarding to foliation of wall rocks (Meshi et al. 1996).

Regarding to structures of plastic deformation, chromite ore bodies in mantle hartzburgites belong to concordant and subconcordant types, which are considered to be of early and middle age, while the discordants are of later age. Concordant and subconcordant deposits are large, with folded platy, or tubular shapes of ore bodies, composed by Cr-rich chromite type. On the contrary, discordant deposits are smaller, frequently as chromite occurrences, as lenticular, veined and schliere shapes of ore bodies, while chromite belongs to Al-rich type, accompanied mainly by PGE amount.

As a result of structural and mineralogical investigations there have been evidenced the cases that undeformed chromite ore bodies are discordant to foliation of surrounding peridotites, that are considerated as later ones. Similarly, in some cases, textural features of mutual relationships among chromitite-bearing minerals, testify for a chromite formation after orthopyroxene or olivine, as the distinct brecciated texture.

Chromite occurrance of Ajazaj of Al-rich type (Cr#65.7 and Mg# 65.80) is situated at the same "stratigraphic" level with Bulqiza deposit, composed by Cr–rich type (Cr# 78.8 and Mg# 68.7) (Çina, 2010). The ore body of this occurrance, that have dike-like shape, is discordant to foliation of surrounding hartzburgites.

In chromite deposit of Qafe Lame, occur two ore bodies of different structural types, concordant composed by Cr-rich type and discordant of Al-rich type. (Cr# 73.5; Mg# 65.3 and Cr# 63.1; Mg# 40.5 respectively), accompanied by 700ppb PGE.

A particular chromite deposit, of vein body, Maja Hudres, consists of chromitite, matrix of which is Cr-amphibole, while chromite belongs to Al-rich type (Cr# 70.1; Mg# 70.8).

In Tropoja – Hasi ultramaphic massif, North – Eastern Albania, occur several discordant chromitite ore bodies, veined and schliere shaped, composed by Al-rich chromite type or Fe-rich type PGE-bearing. Such is Bregu i Bibes deposit, where chromite schlieren are situated within pyroxenite veins. The chromite grains are distinguished by large crystal euhedral structures and by presence of many PGM inclusions mainly of Pt-Fe alloys, while chromite itself more than usual, is ferrous. (Cr# 79.3 and Mg# 39.3). PGE content is high, 2000 to 10000 ppb.

At a particular nodular chromite deposit, the earliest one composed by chromite of Cr-rich type is intersected by gabro veins containing euhedral chromite crystals of a later generation of Al-rich type. (Cr# 77.1; Mg# 39.7 and Cr# 60.4; Mg# 43.0, respectively).

In the passage ultramaphic-cumulate gabbro, occur a "chromite" with a very particular composition, as chromite – magnetite of Fe-Ti chromite or Cr-Ti magnetite variety.

Conclusions:

In the ophiolites of Albania, exceptio besides the chromites of concordant and subconcordant ore bodies, composed by chromite of Cr-rich type, related to mantle hartzburgites, there are present also discordant ore bodies, of undeformed veined and lenticular shape composed by large euhedral chromite of Al-rich type, associated with PGM and inclusions of postmagmatic minerals, belonging to later stage formation.

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Preliminary data on mantle xenoliths from Steinberg (Upper Lusatia, SE Germany)

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The Steinberg quarry is located about 2 km to the west of Ostritz village, ca 15 km to the south of Görlitz in Lusatian part of Saxony (Germany). The basanite occurring in the quarry contains in some places numerous peridotite xenoliths of size not exceeding 8 cm.

Four kinds of peridotite occur in xenoliths from Steinberg. The peridotite I has a protogranular texture with up to 6 mm (typically 2-3 mm) olivine grains exhibiting kink bands. Peridotite consists of olivine (91.0 – 91.4 % Fo, 0.39 – 0.46 wt. % NiO), orthopyroxene (mg# 0.92, Al 0.08 – 0.11 atoms per formula unit, a pfu in the following) and subordinate clinopyroxene (mg# 0.93 – 0.94). Spinel occurs as (1) large grains up to 2 mm, mostly associated with clinopyroxene ($Al_{1.10}Cr_{0.80}Mg_{0.69}Fe_{0.39}O_4$, cr# = 0.41 – 0.43), (2) small rounded through elongated to needle intergrowths in clinopyroxene ($Al_{1.20}Mg_{0.87}Cr_{0.59}Fe_{0.31}Ni_{0.01}O_4$, cr# 0.33 – 0.40), (3) grains with altered rims, located in host basalt infiltrated glass pools (centre: $Al_{1.33}Mg_{0.74}Cr_{0.58}Fe_{0.33}Ni_{0.01}O_4$, cr# 0.30 – 0.31, rim: $Al_{1.13}Cr_{0.83}Mg_{0.72}Fe_{0.30}O_4$, cr# 0.42). Clinopyroxene is characterized by low aluminium (0.06 – 0.12 a pfu) and sodium (0.02 – 0.04 a pfu) and high calcium (0.89 – 0.94 a pfu) contents.

The peridotite II is texturally similar to the first one, but the grains are intensely fissured. It consists of olivine (88.9 – 91.0 % Fo, 0.38 – 0.46 wt.% NiO), clinopyroxene (mg# 0.92) and orthopyroxene (mg# 0.89 – 0.92, Al 0.05 – 0.18 a pfu). Clinopyroxene is characterized by higher aluminium (0.11 – 0.19 a pfu) and lower calcium (0.78 – 0.83 a pfu) contents than that occurring in peridotite I. Olivine contains abundant, elongated inclusion trails. Spinel occurs as thin (< 1 μm) needles or small intergrowths in orthopyroxene ($Al_{0.87}Cr_{0.83}Mg_{0.66}Fe_{0.58}Ti_{0.04}Mn_{0.01}Ni_{0.01}O_4$, cr# 0.49) or as few tens of microns grains associated with clinopyroxene ($Al_{1.45}Mg_{0.81}Cr_{0.43}Fe_{0.29}Na_{0.01}Ni_{0.01}O_4$, cr# 0.23).

The peridotite III is composed of olivine (83.45 – 90.87 % Fo, 0.24 – 0.46 wt. % NiO), orthopyroxene (mg# 0.90 – 0.91, Al 0.09 – 0.11 a pfu) clinopyroxene and spinel (cr# 0.48). Grain size varies typically from 0.7 and 4 mm, with scarce grains up to 8 mm. Clinopyroxene occurs as (1) interstitial, mostly spongy aggregates (Al 0.05 – 0.07, Ca 0.82 – 0.84, Na 0.05, mg# 0.91), (2) interstitial, massive aggregates (mg# 0.85 – 0.89, Al 0.17 – 0.22, Ca 0.73 – 0.89, Na 0.04 – 0.05), (3) large (up to 200 μm) grains (mg# 0.87, Al 0.18, Ca 0.78, Na 0.06) surrounded by aluminous rims (mg# 0.79, Al 0.40, Ca 0.92, Na 0.05) The rock has locally cumulate texture with olivine and clinopyroxene (3) grains embedded in glass/feldspar ($Or_{59}Ab_{37}An_4$) intercumulus.

The last kind of peridotite – peridotite IV – contains ferruginous olivine (72.7 – 77.5 % Fo, 0.02 – 0.11 wt. %NiO), orthopyroxene (mg# 0.76 – 0.77, Al 0.15 – 0.20 a pfu), clinopyroxene (mg# 0.77 – 0.85) and alkali feldspar + plagioclase (An_{31-75}) forming the few hundred micrometres aggregates containing rare olivine (77.0 % Fo) and iron sulfide. The texture is similar to that of peridotite III, but with no grains exceeding 4 mm. The olivine in aggregates is enriched in Ca (ca. 1500 – 2200 ppm) relative to that forming large grains (Ca content below detection limit of microprobe, settled at ca 200 ppm). The rock contains also 500 μm aggregates built of (1) vermicular intergrowths of spinel in clinopyroxene and (2) symplectitic aggregates of elongated spinel ($Al_{1.92}Mg_{0.65}Fe_{0.42}O_4$) embedded in groundmass consisting of ca 10 μm grains of alkali feldspar ($Or_{31-42}Ab_{56-65}An_{2-5}$), olivine (75.0 – 76.1 % Fo, 0.02 – 0.05 wt % NiO) and orthopyroxene (mg# 0.77).

The mineral assemblage and major element composition of peridotites I and II correspond to the harzburgites occurring in other sites in Lower Silesia and considered to be a common rock in lithospheric mantle beneath NE part of the Bohemian Massif. Almost constant chemical composition of minerals suggests that they are in chemical equilibrium. The peridotite I is protogranular and contains no evidence of melt metasomatism related to pre-volcanic period. The temperatures of its equilibration (after the exsolution of spinel from clinopyroxene) are ca. 850 – 880 ºC (Brey & Köhler 1990, opx-cpx). The temperatures of equilibration of grains of ortho- and clinopyroxene in peridotite II are vary between 1080 – 1115 ºC, whereas the exsolution of clinopyroxene from orthopyroxene happened at temperatures 980 – 990 ºC. The forsterite and nickel content in olivine occurring in peridotites III and IV are typical for lower crustal cumulates. The cumulative origin of those kinds of peridotites is also supported by remnants of cumulate texture.

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Preliminary data on mantle xenoliths from the Pilchowice basanite (SW Poland)

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The Cenozoic basanite from Pilchowice (SW Poland) is one of the numerous Cenozoic alkaline lava occurrences in SW Poland, which form the NE part of the Central European Volcanic Province. The basanite occurs in the Intra-Sudetic Fault, the major Variscan geological border in the NE Bohemian Massif. The rock, known for abundant rhönite (Ladenberger et al. 2006 and references therein) contains numerous, usually small (<10 cm) peridotitic mantle xenoliths.

The protogranular texture (olivine up to 8 mm, common kink bands) of peridotites is obliterated by intense fissuring and fragmentation of the grains. The rocks contain crystallized melt pockets filled with olivine, clinopyroxene and plagioclase. The primary mineral assemblage consists of olivine, orthopyroxene and clinopyroxene and sparse spinel. Clinopyroxene occurs only in the part of the studied samples. The olivine is rich in forsterite (Fo 90.2 – 91.5) and contains 0.35 – 0.45 wt. % NiO. Clinopyroxene-free harzburgite contains Al poor orthopyroxene (mg# 0.92, 0.02 – 0.03 atoms of Al per formula unit, pfu in the following) and Cr –rich spinel (cr# 0.8). The clinopyroxene-bearing peridotites contain Al poor orthopyroxene (mg# 0.92, 0.04 atoms of Al pfu) and mildly Al impoverished clinopyroxene (mg# 0.92, 0.09 atoms Al pfu). The temperatures of equilibration (Brey & Köhler 1990) recorded in ortho- and clinopyroxene pairs are close to 900 °C. One of the peridotites contains clinopyroxene with abundant spongy rims. The orthopyroxene occurring in this rock is Al-rich (mg# 0.92, 0.12 atoms Al pfu) and the primary(non-spongy) clinopyroxene is Al-enriched (mg# 0.92, 0.17 atoms of Al pfu). Major element mineral composition in these rocks suggests that they preserved depleted chemical characteristics, which has been little changed by later metasomatic events, excepting the sample containing spongy clinopyroxene. One of the studied peridotite xenoliths contains low-forsterite olivine (Fo 83.00 – 86.50), relatively rich in nickel (NiO 0.28 – 0.42). This suggests its cumulative origin in upper lithospheric mantle or lower crust.

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1.P

Lithospheric structure beneath the Lusatian and Silesian Volcanic Fields – constraints from teleseismic receiver functions

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Between 2006 and 2008 more than 150 temporary broadband and short-period seismic stations from various institutions in Europe and the USA were installed along a 1100 km long and approximately 300 km wide array spanning from Bavaria/Germany in the southwest to Lithuania in the northeast. This huge seismic network was dedicated to the study of the Tornquist-Teisseyre Zone (TTZ) as part of the Transeuropean Suture Zone (TESZ). It is one of the most prominent suture zones in Europe separating the young Palaeozoic platform from the much older Precambrian East European craton.

Since the main axis of the network is situated close to the Cenozoic Eger Rift and crosses the Odra Volcano-Tectonic Zone the data will also shed light into the lithospheric structure below the Lusation and Silesian volcanic fields. These areas were not yet covered previously by any passive seismological experiment. The new data extend our knowledge gained from the BOHEMA-I and BOHEMA-II experiments in the western and northeastern parts of the Bohemian Massif.

In this contribution we present results from teleseismic receiver functions. This passive seismological method is suitable to map seismic discontinuities as the Moho and lithosphere-asthenosphere boundary by means of converted seismic waves. The knowledge about the deep lithospheric structure will help to understand the geodynamic setting of the northeastern-most branch of the European Cenozoic Rift System. We will discuss similarities and differences in comparison to the volcanic fields in Western Bohemia, along the Elbe Fault Zone and in the Jeseniky Mountains.

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Diopside megacrysts from the Cenozoic Ostrzyca Proboszczowicka basanite (SW Poland)

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The Ostrzyca Proboszczowicka basanite (Lower Silesia) is one of over 300 hundred outcrops of Cenozoic alkaline volcanic rocks forming the north-eastern part of Central European Volcanic Province in SW Poland. The basanite forms conic hill (now nature reserve) located close to Złotoryja and is known for few centimetre (typically 1.5 – 3 cm) clinopyroxene megacrysts. The megacrysts are anhedral fragments of broken crystals of larger size, is some singular euhedral faces are preserved. They are black in hand specimen and emerald-green or rarely yellow in thick (100 µm) section. The sector-zoning is common; locally the sectors show internal zoning. The megacrysts contain abundant, euhedral, large apatite crystals up to 7 mm in length or scarce, euhedral yellow 5 mm diopside crystals of older generation. The margins of megacrysts are covered by reaction fringe (typically 1 - 2 mm).

The megacrysts have the composition of iron-rich diopside (mg# = 0.61 – 0.68; Fig. 1), contain significant sodium (0.09 – 0.12 atoms per formula unit, a pfu in the following), are Cr-free and poor in Ti. Aluminium content varies from 0.13 to 0.27 a pfu (Fig. 1), and that of Ca is 0.89 – 0.92 a pfu. The composition of sectors differs, some are enriched in Al (0.17 – 0.27 a pfu) and Ti (0,04 - 0,05), whereas others contain 0.13 – 0.15 atoms of Al pfu. The fringe contains 0.23 – 0.39 atoms of Al pfu, is more calcic (0.92 – 0.96 a pfu) and more titaniferous (up to 0.12 atoms of Ti pfu). The clinopyroxene crystals occurring in the basanite groundmass have the composition of subsilicic diopside (Si down to 1.6, Ca up to 1.1 atoms pfu; Al: 0.21 – 0.48, Cr: 0.00 – 0.02, Ti: 0.05 – 0.14, atoms pfu, cf. Fig. 1).

The textural relationships (large broken crystals with intergrowths of euhedral apatite and older generation diopside) suggest that the megacrysts are fragments of very coarse-grained cumulate. Major element composition suggests that the megacrysts formed at significant depth (lower crust? upper mantle?). Trace-element study is necessary to find if the megacrysts have originated by crystal settling from host basanite magma or have crystallized from melt of another composition.

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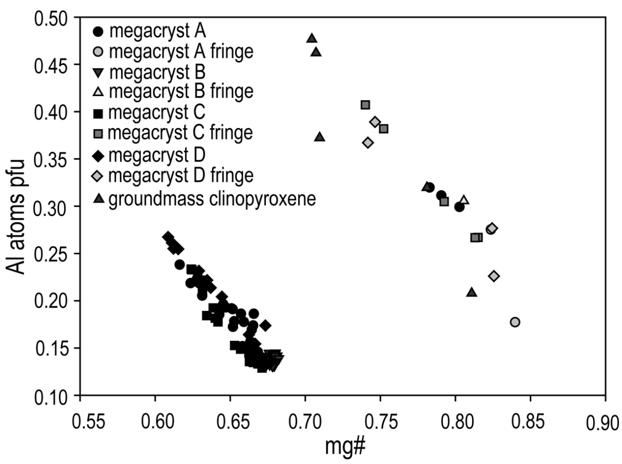

Fig. 1. Mg# vs. Al in megacrysts of clinopyroxene and groundmass crystals from the Ostrzyca Proboszczowicka basanite.

Cretaceous intra-continental basalt volcanism on north-east Ellesmere Island, Canadian High Arctic

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Widespread early Cretaceous to Cenomanian continental tholeiitic flood-basalt volcanism of the High Arctic Large Igneous Province (HALIP) is documented by lava flows, sills and dykes on Svalbard, Franz Josef Land, the Canadian Arctic Archipelago, the De Long Islands and likely also the Alpha Ridge. It is probably related to plume activity which preceded/accompanied the opening of the Amerasian Basin of Arctic Ocean. Flood-basalt volcanism was followed by Late Cretaceous alkaline, rift-related igneous activity in the Canadian High Arctic (Ellesmere Island) and North Greenland.

In the Canadian Arctic, a first peak of tholeiitic flood-basalt volcanism occurred during the Aptian (c. 125 to 112 Ma) and is documented by basalt flows within the Isachsen Formation of the Sverdrup Basin on Axel Heiberg Island and western Ellesmere Island. During a second peak in the late Albian to early Cenomanian, around 100 Ma, the up to 800 m thick volcanic Strand Fiord Formation on Axel Heiberg Island, as well as up to 45 m thick flows within the Hassel Formation on NE Ellesmere Island and on northern Amund Ringnes Island were formed (Embry & Osadetz 1988, Osadetz & Moore 1988). Both volcanic events were accompanied by the emplacement of dykes and sills, which are exposed over almost the whole extent of the Sverdrup Basin and its northern rim (e.g. Buchan & Ernst 2006).

Four areas of basalt outcrops on NE Ellesmere Island were sampled for petrographical, geochemical and geochronological studies. The outcrops are exposed over a length of c. 100 km in the vicinity of the NE-SW trending Lake Hazen Fault Zone at a marginal position of the Sverdrup Basin. The post-mid Cretaceous Lake Hazen faults superimpose older Paleozoic thrust faults (Piepjohn et al. 2007). The basalts are mainly fine-grained, aphyritic, intergranular to subophitic or intersertal and consist of plagioclase, clinopyroxene, olivine, glass, accessory opaque minerals (Fe oxides) and apatite. $^{40}Ar/^{39}Ar$ whole-rock dating indicates a formation age of c. 98 Ma for all outcrop areas consistent with the stratigraphic age of the Hassel Formation.

While the basalts of the Isachsen and Strand Fiord formations are geochemically very similar, despite the difference in their formation age of about 20 Ma (Estrada & Henjes-Kunst 2004), the basalts of NE Ellesmere Island show higher concentrations mainly of total Fe_2O_3 (14.0 – 16.9 wt%), TiO_2 (3.0 – 3.8 wt%), K_2O (0.8 – 1.5 wt%), P_2O_5 (1.2 – 0.3 wt%), Ba (360–990 ppm), Sr (494–537 ppm), as well as steeper C1-normalized REE patterns (La_N=119–152, Lu_N=14–16) with positive Eu anomalies. The basalts of NE Ellesmere Island can be divided geochemically into two groups, a western group occurring north and northeast of Lake Hazen (between Cuesta Creek and Mesa Creek as well as east of the Turnabout Glacier tongue) and an eastern group occurring south of Piper Pass and between Eugene and South Wood glaciers. The western group with mg# values of 33–35 is stronger enriched in K_2O, P_2O_5, Ba, Rb, and LREE with a distinct positive Eu anomaly, whereas the eastern group with mg# values of 39–46 is characterized by higher CaO, V, and Zr concentrations and shows only a very small positive Eu anomaly. A fractional crystallization relation of the two groups is not likely. According to their REE pattern, melts of both groups were generated in the garnet-peridotite stability field, with only slightly smaller degrees of partial melting for the western group. However, values of $\varepsilon_{Nd}(t)$ of 1.3, $^{87}Sr/^{86}Sr(t)$ of 0.707, and t_{DM} of 1.08 Ga for the western group and $\varepsilon_{Nd}(t)$ of 4.5–4.9, $^{87}Sr/^{86}Sr(t)$ of 0.704, and t_{DM} of 0.47–0.51 Ga for the eastern group, resp., indicate origin of the basaltic melts from two different mantle sources. The $\varepsilon_{Nd}(t)$ values of the basalts from NE Ellesmere Island may represent end-members of the Isachsen and Strand Fiord formation basalts, but the $^{87}Sr/^{86}Sr(t)$ ratios of the latter are higher. The Sr and Nd isotope ratios of the eastern group are consistent with an OIB-like mantle source and are very similar to those of the alkaline Hansen Point volcanics from northwest Ellesmere Island, which also show a small positive Eu anomaly (unpublished BGR data). The melts of the western group were probably formed by mixing of melts from the same OIB-like mantle source with melts from a more enriched source, probably from metasomatized subcontinental lithospheric mantle or deeper crust. Elevated Eu, Ba, K, and P contents point to melting of feldspar, phlogopite, and apatite rich materials.

The two groups of basalts of NE Ellesmere Island can be interpreted as erosion relicts of two distinct large flow units. Their eruption was likely tectonically controlled by pre-existing faults and was related to intense crustal extension during a new phase of the opening of the Amerasian Basin of the Arctic Ocean probably accompanied by the formation of the Alpha Ridge that was interpreted as a hot-spot track of a mantle plume (e.g. Forsyth et al. 1986).

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1.P

Low temperature fertile mantle xenoliths from Sikhote-Alin, Far East Russia

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The Pacific margin of East and NE Asia is part of the circum-Pacific orogenic system and could be considered as a tectonic collage of nappes, displaced terrenes, accreted island arcs and accretionary complexes (Sokolovov et al. 1997). This tectonic environment is the consequence of the convergence between the Palaeo-Pacific plate and the eastern Eurasian continent. The Pacific-margin orogenic system could be divided into three main units; the Koryak-Kamachatka fold belt, the Sikhote-Alin fold belt and the Okhotsk volcanic belt. The broadly defined Sikhote-Alin fold belt here refers to a nearly N–S belt extending north from the southern shoreline of the Okhotsk Sea south to the northern margin of the Japan Sea.

The study area comprises Mantle xenoliths from Tuttochi, a locality close to Khabarovsk, Sikhote-Alin. The xenoliths are spinel peridotites, their sizes vary from 3 to 8 cm in diameter and they are exceptional fresh. The majority of the samples are coarse grained with protogranular texture. However a number of xenoliths have transitional textures from relatively coarse grained protogranular to fine grained equigranular textures. Hydrous phases such as phlogopite and/or amphibole were not found so far. The most striking feature is the fact that part of the xenoliths show heavy infiltration of melts. These melts circulate intergranular and react with the neighbor minerals creating veinlets with variable thickness that consists of glass and new forming minerals. Especially, their interaction with orthopyroxene results often to its almost entirely consumption, indicating that the invaded melt was silica undersaturated but rich in alkalies.

According to their modal composition the xenoliths are fetile spinel lherzolites as also can be inferred from the compositions of the constituent minerals. Olivine is forsteritic with Fo varying from 89.3 to 90.1 and the average NiO content is 0.37 wt%. The mg# of othopyroxene and clinopyroxene vary from 0.895-0.904 and 0.904-0.915, respectively and the spinel is Al_2O_3-rich with an average of cr# = 0.100.

According to the REE abundances in cpx the spinel peridotites could be divided into three groups; group 1 has chondrite normalized REE with s concave upwards pattern. The LREE depletion expressed by the La/SmN ratio is medium to strong and varies from 0.11 to 0.53. The group 2 does not show any enrichment or depletion in LREE (La/Sm_N=0.64-1.05) and the group 3 shows an enrichment in LREE (La/Sm_N=1.85). While the chondrite normalized LREE abundances in cpx demonstrate variable enrichments and depletions, the HREE do not show significant differences among the three groups. Their overall Dy/Yb_N ratios vary from 1.05-1.16.

In the primitive mantle normalized incompatible trace elements clinopyroxens show moderate negative Ti anomaly in respect to their neighbor elements. Same behavior has been observed for Zr.

The lithospheric mantle underneath Tuttochi, Sikhote-Alin is a fertile spinel lherzolith., which experienced low degrees of partial melting. Model calculation have shown that the lithospheric mantle in this area, according to model calculations, has experienced 1-5 % batch melting (Fig. 1) Also the calculated equilibrium temperatures (Brey & Koehler 1990) for the xenoliths at 1.5 GPa are relative low and range from 780° to 940°C.

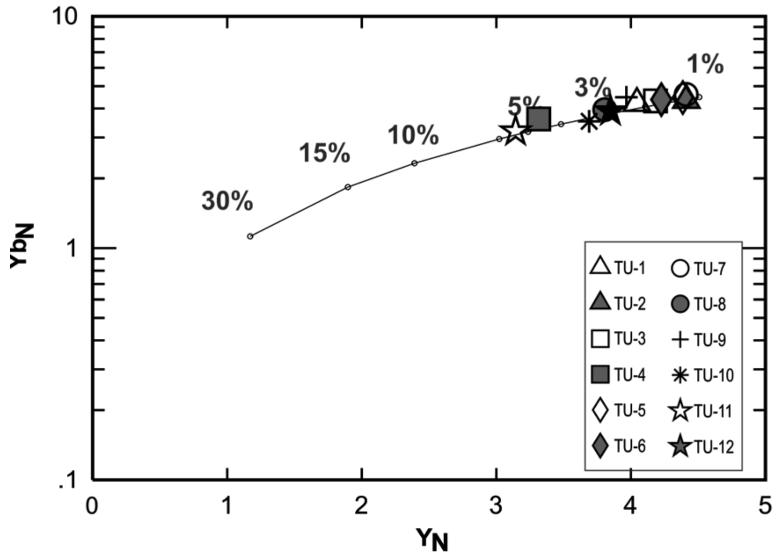

Fig. 1. Predicted batch melting model trend with primitive mantle normalized Y and Yb (Norman, 1998). The Tuttochi data fit the trend very well showing that clinopyroxenes are residues after 1-5 % batch melting. Normalization values after McDonough & Sun (1995).

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1.P

Trace element and Sr-Nd isotopic characteristics of basalts from the Elmadağ Volcanic Complex, Turkey

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The Elmadağ volcanic complex (EVC) to the South of Ankara forms one of the largest volcanic province in the Central Anatolia of Turkey. The EVC comprises a medium- to high-K calc-alkaline volcanic suite ranging in composition from basalt through andesite to dacite and rhyolite. The published K-Ar age data show that volcanic activity occurred during the Miocene (ca. 19-16 Ma.) in the area. All the basalts are nepheline-normative (up to 8 %) and have relatively low Mg-numbers (0.49-0.62), and Cr (100-250 ppm) and Ni (60-160 ppm) contents, suggesting that they are not primary magmas, but have been modified since leaving their mantle source. N-MORB-normalized trace element patterns of the most primitive basalt samples display strong enrichments in LILE (Rb, Ba, K, Sr), Th, U, La, and negative Nb-Ta anomalies, all typical of calc-alkaline orogenic lavas (Figure 1). They display LREE-enriched (La_N/Yb_N: ~10-30), but relatively flat, unfractionated HREE (Gd_N/Yb_N: ~2.0) patterns, with no Eu anomaly. $^{87}Sr/^{86}Sr$ ratios and εNd values of the basalts range from 0.704183 to 0.705435, and 0.14 to 3.49, respectively, and resemble the isotopic reservoir of Bulk Silicate Earth (Figure 2).

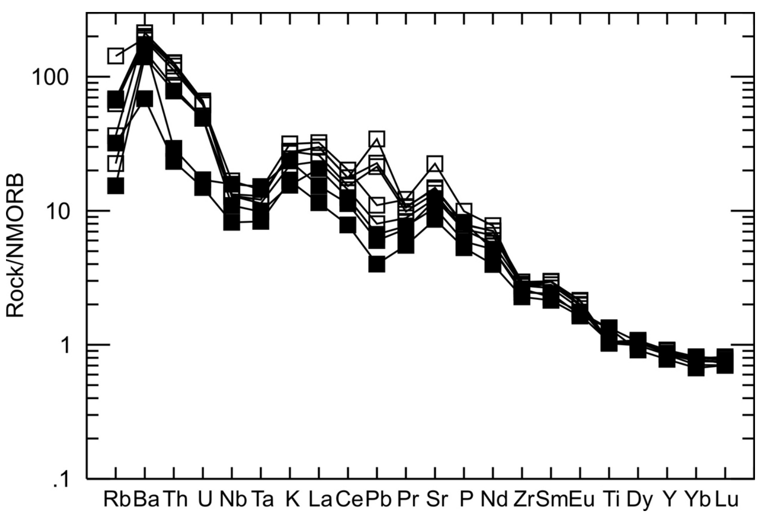

Fig. 1. N-MORB (Sun & McDonough 1989)-normalized incompatible trace element patterns of the basalts.

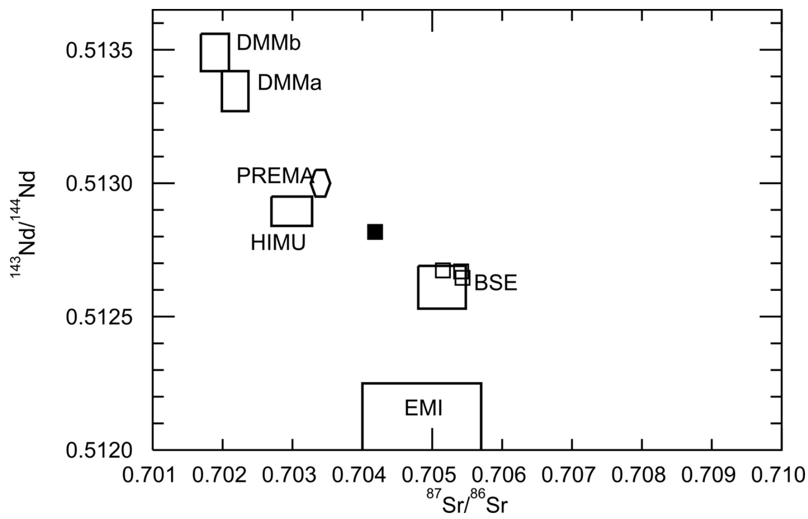

Fig. 2. Sr-Nd isotope correlation diagram of the basalts (Zindler & Hart 1986).

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1.P

Ultrabasic-basic evolution of primary mantle magma by evidence of physicochemical experiments

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Liquidus phase relations for the upper-mantle systems, peridotite-eclogite olivine Ol – clinopyroxene Cpx – coesite Cs – corundum Crn at 4 GPa (Litvin 1991) and peridotite-basalt forsterite Fo – diopside Di – anortite An – quartz Qtz at 3 GPa (Milholland & Presnal 1998), were experimentally determined. In both cases, an extensive divariant field garnet Grt + clinopyroxene Cpx + liquid L (formation of bimineral eclogite) was found. For the complex peridotite-eclogite system, periclase Per, orthopyroxene Opx, kyanite Ky and coesite Cs phases were involved in addition to Grt and Cpx. Correspondingly, spinel Spl, orthopyroxene Opx, corundum Crn, kyanite Ky and quartz Qtz were added to in case of the peridotite-basalt system. The complex melting relations are of particular interest for untangling the physicochemical links between the primary mantle peridotite and all the varieties of eclogitic and basaltic rocks. In this case, physicochemical mechanisms of ultrabasic-basic evolution of the primary mantle magma evolution have assumed a key significance for formation of both eclogites and basalts.

Direct petrogenetic relations and continuous transitions between peridotites and eclogites are known by petrochemical trends. Earlier (Litvin 1991) it was experimentally found that formation of primary ultrabasic magma in garnet peridotite system Ol – Opx – Cpx - Grt is under control of quasi-invariant peritectics Ol+Opx+Cpx+Gr+L. The peridotite peritectics is directly bounded up with eclogite peritectics Cs+Opx+Cpx+Gr+L by univariant curve Opx+Cpx+Grt+L. But, the univariant curve has a temperature maximum in the piercing point on the boundary plane Opx-Cpx-Grt between the tetrahedral composition simplexes of peridotitic and SiO_2-saturated eclogitic systems. The maximum represents a thermal eclogitic barrier (O'Hara 1968) that is insuperable obstacle for ultrabasic-basic differentiation under as equilibrium so fractional magma evolution.

Another univariant curve Ol+Cpx+Grt+L links the peridotite peritectics Ol+Opx+Cpx+Grt+L with the eutectics of rarely occurring olivine eclogites in temperature-lowering way without a thermal maximum.That is of interest in view of the fact that Ol can disappear in reaction with jadite Jd components while Grt, Opx and Na-Mg-silicate are formed above 4.5 GPa (Gasparik & Litvin 1997). Fractional crystallization of primary komatiitic magma is accompanied by increasing concentration of jadeite component at residual melts. Experimental study of the model system Fo – Di – Jd at 7 GPa demonstrates a reaction point Ol+Jd-Cpx=Grt+L (Butvina & Litvin, 2010) over liquidus of peridotite-eclogite system. The reaction point is effective in Ol elimination along the univariant curve Ol+Cpx+Grt+L mentioned above. The reaction brings figurative points of the residual melts compositions to the Cpx-Grt join that is a commonplace for all the peridotite and eclogite systems (simplexes). This mechanism called as "peridotite-to-eclogite tunnel" makes the round the thermal eclogitic barrier and, correspondingly, paves the way for continuous fractional crystallization of ultrabasic-basic magmas with transfer in formation from Ol-bearing peridotite to Cs-bearing eclogite rocks. The mechanism is demonstrated by melting phase diagram of the multicomponent Grt-peridotite (Per) – eclogite (Ecl) system for conditions of fractional crystallization (derived from the experimental phase diagram of the Per – Ecl system of equilibrium image). Similar mechanism may be also workable for the basalt rocks origin.

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1.P

Testing validity of geochemical mantle domains mixing theory (EM, DM, HIMU-FOZO) for the metasomatized, Cenozoic, lava-driven lithospheric mantle rocks from the Złotoryja Volcanic Field (SW Poland)

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Mantle xenoliths are one of the best sources of information on the upper mantle (Pearson et al. 2003). During the Cenozoic magmatic activity in Europe, several hypotheses on the potential regions of partial-melting of the upper mantle material were proposed (Lustrino and Wilson 2007). For the Polish part of the Central European Volcanic Province (CEVP), three-component mixing theory (EM, DM, HIMU-FOZO) was postulated (Ladenberger et al. 2006). These three geochemical components were linked to three different regions in the upper mantle: lithospheric mantle, asthenospheric mantle and the boundary between these two (Ladenberger et al. 2006). This contribution focuses on examination of the lava-driven xenoliths as an independent source of information that allows testing the three-component mixing theory.

Rock samples from seven outcrops were investigated: Wołek Hill (WH), Muchowskie Hills (MW), Owczarek (O), Czartowska Skała (CzS), Wilcza Mountain (WG), Kozia Mountain (KG) and Jeziorna (J). The outcrops are located about 100 km SW of Wrocław and belong to the Złotoryja Volcanic Field (part of CEVP) which lies on both parts of the Sudetic Marginal Fault. This study focuses on the area located in the SW part of the field beetwen Złotoryja, Jawor and Świerzawa. The Cenozoic volcanic rocks cross-cut country rocks of different age and lithology.

Over 600 xenoliths were collected: peridotite xenoliths (66%), pyroxenite xenoliths (5%), ultramafic cumulates (5%), crustal xenoliths (20%) and megacrysts (4%).

The peridotite xenoliths are mainly harzburgites, although dunites and wehrlites also occur. The harzburgite xenoliths exhibit strong variability in orthopyroxene (Opx) content varying from 10 to 35%. Six mineral generations were identified for the peridotite xenoliths. The first generation accounts for about 63% area of the samples and is represented by typical rock-forming minerals: olivine (Ol; Fo~89-95), Opx (Enstatite; mg# 90-92) and rare clinopyroxene (Cpx; Diopside, mg# 94-95%). Around 16.5% of the studied minerals - Ol (Fo~82-89), Cpx (Diopside or Diopside enriched in Ca; mg# 86-93 rare crystals rims display decreasing mg# to 75%), Amphibole (Amph, Pargasite, mg# 86-90%) - are related to mantle metasomatism processes, both: cryptic and modal (Nowak et. al 2013). The rest of the identified minerals (ca. 20.5%) occur within the pockets (also with Amph), or as ingrowths with other phases. They also originate from the xenolith – host-rock interactions or are related to secondary post-volcanic processes e.g. or weathering.

The pyroxenite xenoliths belong to clinopyroxenites and Ol-bearing clinopyroxenites; only one sample (WG4-4) could be described as Amph-bearing clinopyroxenite. The studied ultramafic cumulates can be divided into two groups: extremely Ol-rich (mainly dunites) and Cpx enriched (wehrlites). Olivines inside the cumulates show decreasing Mg content (Fo 75-80%) compared to peridotitic xenoliths. Three types of megacrysts (Amph, Fsp, Cpx) were collected, but only Amph megacryst (Pargasites; mg# 71-76%) were studied in detail.

The obtained data gives a picture of rather depleted lithospheric mantle (80%), locally enriched due to cryptic (15%) or modal metasomatism (5%). REE-patterns in Cpx and Amph as well as their $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ ratios suggest strong relationship to the Cenozoic lavas. The Amph megacrysts together with pyroxenite xenoliths and ultramafic cumulates are good evidence for influence of additional magmas on the lithospheric mantle (Puziewicz et. al 2011). These magmas can be linked with HIMU-FOZO component and are probably of asthenospheric origin, although no mantle-plume activity was required for the production of such magmas. The time period for the enrichment of the lithospheric mantle took place between Eocene (ca. 45 Ma) and Miocene (ca. 20 Ma). Currently there is not enough evidence for such a process being related to older geological events (e.g the Variscan Orogeny). Locally enriched lithospheric mantle (EM), during the last stages of the volcanic activity (younger than 20 Ma), was partially melted and these small portions of lithospheric melt affected the chemical and isotopic composition of the last-stage magmas.

Based on the examination of the mantle xenoliths we can say that the three-component mixing theory is very possible for the studied area. Nevertheless, time and duration of such mixing is very important factor, which should be taken under consideration.

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1.P

Structure of mantle column beneath Bartoy volcanoes (South-East Khamar-Daban, Transbaikal) and the factors of it's evolution

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Group of 6 Pleistocene volcanoes (Ashchepkov et al. 2003) contain various set of mantle inclusions, megacrysts and cumulates which are most variable in Bolshoy volcano. Peridotite deep seated inclusion from Bartoy volcanoes (Ashchepkov 1991, Ionov & Kramm 1992) reveal a number of petrographic and textural varieties (Ashchepkov 1991, Ionov et al. 1992). Peridotites regular range of T and P create a sequence 1) deformed Fe - lherzolites, 2) Phl porhyroclastic, 3) Amph –Phl, 4) Dry protogranular, 5)Amph equigranular and 6) dry and fine grained. and Fe-rich poikilitic (Ashchepkov 1991).

The sequence of the megacrysts which represent the walls of the feeder in pre - eruption stage is starting from HT dark green websterites then appear black Cpx- Gar varieties evolved to Phl –CPx intergrowths and Cpx -Ilm. T (Nimis, Taylor, 2000) <1000°C here Cpx low in TiO_2. Intermediated trend located in the T°C-Fe sub parallel to lherzolitic are correspondent to the fractionation of the hydrous alkali basalt melt which leave the abundant veins in peridotitic wall rocks.

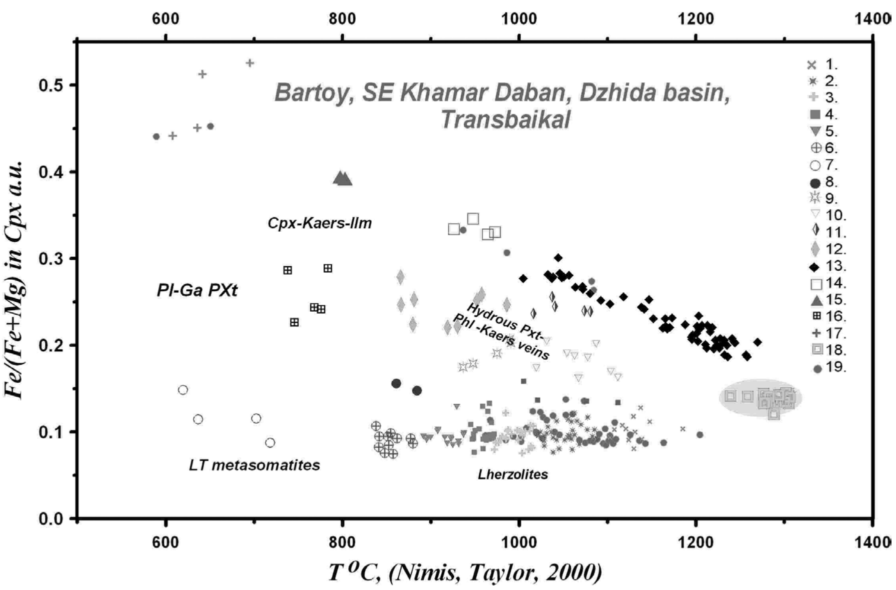

Fig. 1. Fe- dry HT lherzolites; 2. Phl lherzolites; 3. Amph – Phl lherzolite; 4. Amph – Phl peridotites Fe- rich; 5. Amphybole lherzolites; 6.low T dry lherzolites;7. poikilitic Fe- lherzolites; ; 8. . Hybridic LT pyroxenites; 9. Kaers-Phl veins; 10. Phl veins; 11.Contact zones of black CPx veins with Phl veins. 12. Contact zones of black CPx veins with Kaers; 13.Black CPx megacrystals; 14 LT Gar pyroxenites with Pl; 15. Kaersutite- Sanidine veins; 16. Cpx Kaers-Ilm veins; 17. low-P cumulates with Pl; 18. dark green HT pyroxenites. 19. Cpx from the road quarry.

Trace elements for the cumulative and megacrystalline rocks show the rounded patterns with humps, the fluctuations in LILE and HFSE which are determined by the co – precipitated phases. The green series show now humps in TRE related to the garnet in meting source and are depleted in HFSE.

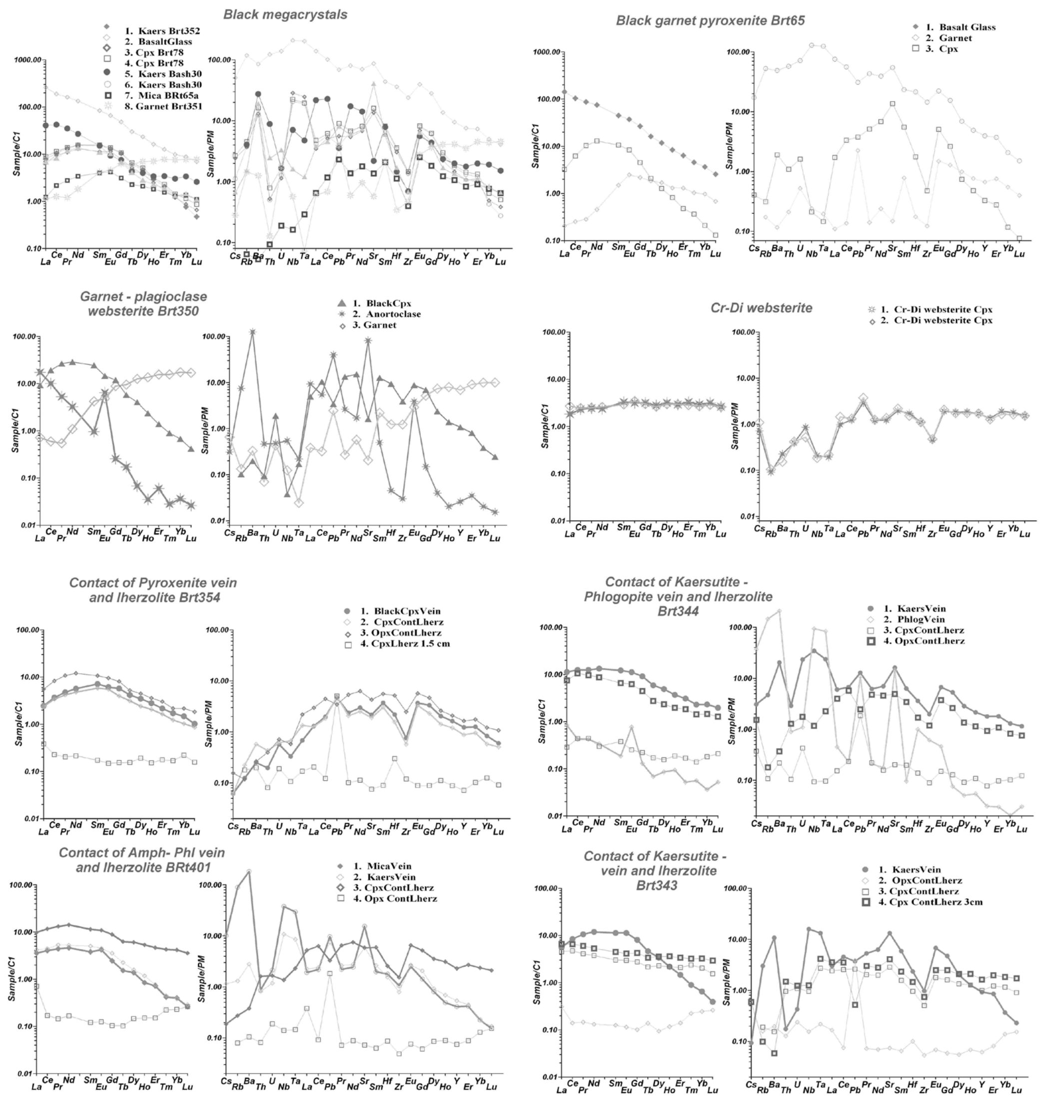

Fig. 2. REE patterns and TRE spider diagrams of various pyroxenites megacryst and cumulates from Bartoy volcanoes.

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1.P

Mantle xenoliths from Primorie (Russian Far East)

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Mantle lherzolite xenoliths abundant Cenozoic alkali basalts in Primorie show general similarities in compositions close to fertile Primitive mantle. Variations of mineral chemistry for > 600 determined by xenoliths and TRE in IGM Novosibirsk but rather similar bulk rock compositions.

In NE Sovgavan plateau xenolths (Esin et al. 1992) in Miocene - Pliocene basalt plateau (Tuttocha) are slightly more depleted then in post erosion valley flows (Sunku and Kamku rivers) and Mount Kurgan scoria cones where amphiboles, Phl are occurred in lherzolites and hybrid websterites. In Southern Sikhote Alin in Shkotkov plateau Fe- lherzolites with amphiboles and mica dominate in base lavas. The Pliocene Pogelbanochny containing huge xenoliths (to 1 m) (Scheka 1981) and jewel as xenocrysts (Vysotsky, Barkar 2006). The xenolith in the SW Sikhote Alin Lesozovoskaya, Medvezhy, Podgelbanochny volc. contain Phl and rare kelyphites after garnets and. The Cr-diopsides in Tuttocha basalts are more (Na, Al, Ti) depleted and variable in compositions. In Kamky basalt flow the Fe-rich trend is found similar for CPx in Sunku flow and Mount Kurgan (Esin et al. 1992). In the Nelma and Shkotov palateu Cr-Di are more variable in compositions. In Mesozoic Anyui basalts slightly depleted xenoliths with zircons and kaersutites were regenerated by hydrous melts.

Most of the PT estimates for Cpx from Primorie basaltic xenoliths (Ashchepkov et al. 2011) trace 90 mw/m^2 SEAG geotherms starting from 18kbar. General tendency in that in the first and last stages of developing of lava plateau in scoria cones and post erosion lavas the PT gradients are steeper than for xenoliths from lava plateaus.

TRE were determined for 30 Cpx and some Cr spinels by LAM ICP in Analytic centre of IGM SB RAS. Cpx from Kamku river show nearly flat or inclined (La/Yb_n ~2.5) and depressions in Ta, Nb and less in Zr. Similar patterns show Cpx from volc, Medvezhy showing higher fluctuations in LREE 0.1>La/Yb_n >1 rich patters and depressions in HFSE. The Cpx from Tuttocha lava plateau show small depletion in LREE correspondent to 1-2 melting in Sp facie but one with humped LREE probably refer to interaction with basalt melt. Mount Kurgan CPx show slightly humped in MREE convex patterns some of them show LREE Zr, Hf, Nb, Ta depleted patterns common for subduction related mantle melts but other reveal . Another one show La/Yb>1 correspondent to presence of small amount of Gar and flattened incompatible part of TRE spectrum. The Cpx from Koppy reveal common REE slightly depleted LREE pattern and deeper Zr, Ta. minima. Podgelbanochny Cpx (Ionov et al. 1995) show stronger inclination referring to 2-5 % of Gar in melting source and progressively depleted incompatible part as well as minima in Pb and smaller in Zr.

The Cr spinels from Tuttocha show depleted LREE or U shaped patterns with peaks in Pb, N , U. But for Cr- Sp from Medvezhy the REE inclination is positive, the Pb dip is higher, and small Y depletion exists. Supported by Grant RBRF 05-11-00060a.

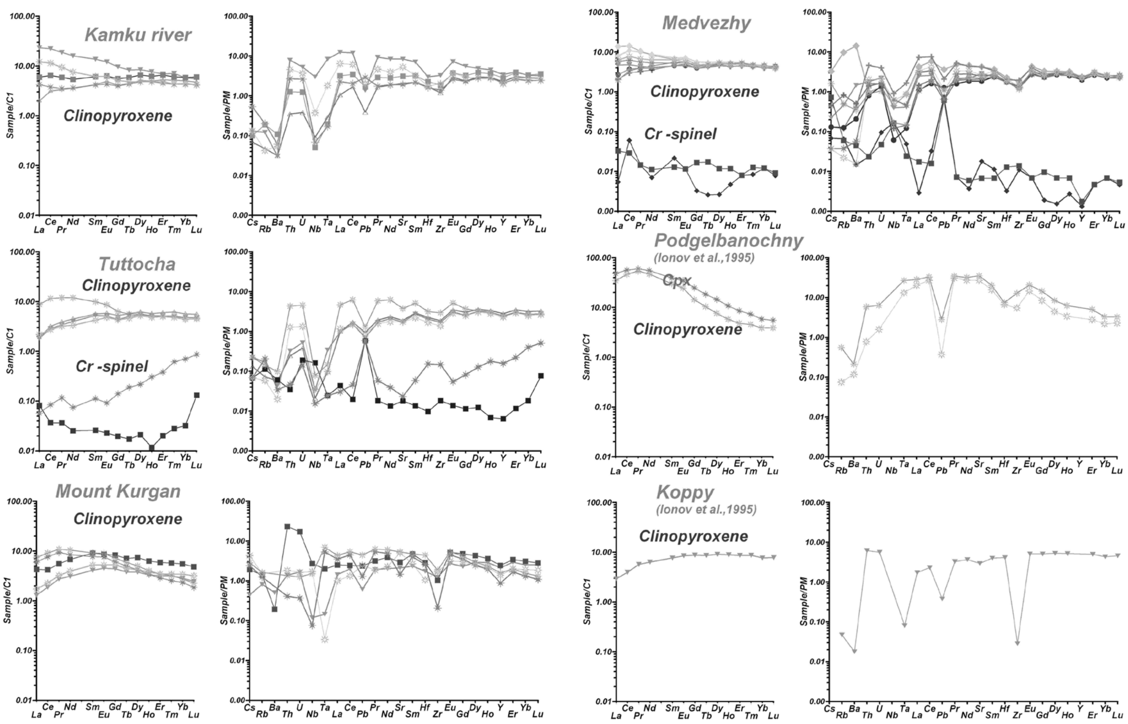

Fig.2. REE patterns and TRE spider diagrams of Cr diopsides and Cr-spinels from xenoliths in Cenozoic basalts from Primorie.

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Session 2 – Ascent zone

Session 2a

Tectonic & age control on magmatism

(Talks and Posters)

Session 2b

Documents of magma ascent, storage and melt evolution:
fluids, seismology, phenocrysts & petrology

(Talks and Posters)

Insight into the Geochronology of Cenozoic alkaline basaltic volcanic activity in Lower Silesia (SW Poland) and adjacent areas

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The present review is an attempt to correlate radiometric ages of alkaline magmatic rocks of the Lower Silesia Basaltic Field (LSBF) on the basic of more than 100 K/Ar age determinations, carried out in ATOMKI, Debrecen, Hungary.

In Lower Silesia (SW Poland) Cenozoic alkaline rocks, mostly basanites ankaratrite, nephelinites and olivine basalts occur at relatively small cluster of eruptive centers. They represent the eastern part of the more than 700 km – long Central European intraplate Volcanic Province (CEVP), extending from the Eifel in the west through Germany & Czech Republic.

The volcanic activity started in the western part of the chain, during the Late Cretaceous, however the main phase along the whole chain took place since the Eocene to Late Miocene. The youngest Quaternary rocks occur only in West & East Eifel, Bohemian and in northern Moravia (Lippolt 1982, Gradstein et al. 2004).

This volcanic belt consists of large individual volcanic fields (e.g. Vogelsberg etc.) and small separate volcanic eruptions in the form of volcanic pipes, necks, scoria cones, microlaccolith and lava flows, respectively.

During the last decade systematic K-Ar age determinations on basaltic volcanic sequences in LSBF combined with additional field and paleomagnetic studies, have led to stratigraphic revision and recognition of three distinct volcanic episodes:

a. Eocene-Oligocene, (34.0–26.0 Ma)
b. Lower- Miocene, (22.0–18.0 Ma)
c. Pliocene-Pleistocene, (5.5–1.0 Ma), respectively (Birkenmajer & Pécskay 2002, Birkenmajer et al. 2002, 2004, 2007).

Palaeomagnetic investigations indicate the existence of a volcanic episode of reversed polarity close to the Early/Late Oligocene boundary (“Odra Event”) and another one of normal polarity during the Late Oligocene (“Gracze Event”, Birkenmajer et al. 2011).

Newly obtained radiometric and paleomagnetic data confirm, that three different Late Cenozoic volcanic phases exist along the Moravia-Silesia border (NE Bohemia Massif), (Cajz et al. 2012).

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Geochemistry of Na-alkalic Tertiary volcanics in Lower Silesia, Poland; a geodynamic analysis

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The present article is a review of geochemistry of Lower Silezia Tertiary Na-alkalic volcanics (LSTv) that represents the eastern part of European Cenozoic rift system (ECRIS). It is based on 50 analyzed samples for major and trace elements and dated using K/Ar method. The magmas were generated in three main intervals corresponding to Oligocene (31.9-23.4 Ma), Early Miocene (22.3-18.54 Ma) and to the limit between Late Miocene-Pliocene (4.56-5.46 Ma). The volcanic rocks are erosional remnants of volcanic feeding system (plugs, necks and sills) and associated lava flows. The shallow intrusive rocks shows a larger crystallized groundmass then lava flows and a variable proportions of phenocrysts represented mainly by clinopyroxenes, olivine and nepheline and/or plagioclase. The rocks are variably unsaturated and are classified in TAS diagram as basanites and alkali basalts. A few clearly differentiated samples were observed: one basaltic trachyandesite (BP-47a) and a trachyte (BP-56a), both generated in Oligocene. Most of the Oligocene lavas are basanites showing higher MgO (>10%) as compared with Lower Miocene ones that are dominantly represented by the alkali basalts. The primitive mantle normalized incompatible element pattern of most primitive rocks show prominent trough of K, and less of Rb and Th. Assuming that the trace element concentrations of the LSTv rocks are close to primitive and the unfractionated melts were in equilibrium with their mantle sources, a geochemical modeling was done in order to get the degree of melting and composition of the mantle source. Key trace elements (MREE, HREE and Y) were used as sensitive to the presence of residual spinel or garnet. Most of the Oligocene basanites were generated at a lower degree of melting (2-4%) as compared with the Early Miocene or Late Miocene/Pliocene lavas (4-8%). The mantle source looks heterogeneous and requires melting of variable amount of both garnet and spinel peridotites that are hypothetical initially situated at the base of the lithosphere. The Early Oligocene magmas showing the lowest degree of partial melting are the result of these melting processes. The further Early Miocene and Late Miocene/Pliocene, dominantly alkali basaltic melts were generated at higher melting degrees and shallower average melting depths, that is more easily explained by fertility heterogeneities in the source, suggesting lithospheric thinning and associated upwelling of the asthenosphere.

The Na-alkalic magmatism situated at the margins of Africa–Eurasia convergence is a direct result of various cycles of collision and it was associated to the formation of continental rifts and tensional tectonics that mainly cross-cut older Variscan sutures. Partial melting was likely induced by adiabatic decompression at the base of the lithosphere and further by asthenosphere uplift and melting. Initiation of the magmatism and resulted uplift of the asthenosphere–lithosphere boundary may have been influenced also by the ductile lower crust resulted after the subduction of lower-continental-crust during Alpine cycle. Similar scenarios were revealed recently to the north of the Alpine collision area in the Central European Volcanic Province (e.g. Jung et al. 2012, Kolb et al 2012, Ulrych et al. 2011), but also to the south, at the northern margin of the Africa (e.g. Lustrino et al. 2012).

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On the northern termination of the Eger (Ohře) Graben

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It is traditionally maintained that the Eger (Ohře) Graben (Kopecky 1978), a prominent neotectonic feature of the Bohemian Massif, terminates at the major Upper Elbe (Labe) Fault Zone (Adamovič & Coubal 1999, Suhr 1999, Ulrych et al. 1999). Some authors, however, extend it into the Zittau Trough or even significantly further to the north (e.g. Kasiński 1991) or to the northeast and east after having crossed the Lusatian "Overthrust" fault (Vaněčková et al. 1993).

The difficulties in tracing the morphotectonic boundaries of the Eger Graben stem from the lack of easily recognizable graben-bounding scarps in the topography as well as from historical/political reasons.

The delimitation of the graben boundaries reported here is based on the distribution of exposures of the pre-Cenozoic rocks and on the geometry of Tertiary basaltic bodies known from geophysical investigations or drilling. The morphology of the sub-Quaternary and sub-Cenozoic surfaces was also analysed, making use of thousands of boreholes and geoelectric soundings, carried out mainly in the Polish segment of the graben.

The northern part of the graben can poorly be seen in the topography due to a minor amount of uplift of the graben shoulders. The latter are also obscured by glaciofluvial sediments, 20-40 m thick, resting on their top. In the west, exposures of Palaeozoic rocks extend up to the faults being a continuation of those of the Erzgebirge/Ohře Mts and of Děčín (Fig. 1). In the east, on the Izera-Karkonosze Horst a broad valley of probably tectonic origin seems to be an extension of the Stráž Fault, which further to the SW represents the SE border of the graben. To the north, the eastern graben margin is defined by the Leśna Horst, uplifted with respect to that of Platerówka, downthrown inside the graben. To the west of the Kwisa Fault, exposures of basaltoid rocks form distinct trains of hills oriented NNE-SSW. In the North-Sudetic Basin, the Eger Graben floor is built up of Permo-Mesozoic rocks.

The Eger Graben extends thus well beyond the Lusatian "Overthrust" fault, crossing the Main Lusatian Fault and reaching as far as the Warta-Osiecznica Fault Zone and the Sudetic Boundary Fault. Two distinct volcanic centers - of Varnsdorf and Opolno-Frydland are located within the graben, whose northern part comprises second-order grabens of Zittau, Bersdorf, Radomierzyce, Siekierczyn and Węgliniec, separated one from another by horsts or tectonic steps.

The northern part of the Eger Graben was formed at the same time as its main, central part. The oldest traces of volcanism date back to the Eocene. In the late Eocene kaolinitized granitic and gneissic bedrock became covered by lacustrine sediments. The main phase of volcanic activity took place between the Oligocene and Middle Miocene (Alibert et al. 1987, Cajz et al. 2007, Birkenmajer et al. 2011). In the early and middle Miocene thick brown coal measures were formed. In the late Miocene, the graben and its shoulders became uplifted. The Działoszyn Horst splitted the Zittau-Bersdorf-Radomierzyce Trough into two minor grabens. The Izera-Karkonosze Horst underwent intense uplift in the Pliocene, while in the middle Pliocene the Działoszyn Horst continued its uplift, as evidenced by fluvial sediments in the southern part of the horst that were elevated by at least 8 m, whereas terrace alluvia of the Weichselian glacial stage were faulted.

In this way the Eger Graben cuts across the Lusatian-Izera-Karkonosze Block and dies out in the North-Sudetic Basin. The width of the graben attains 30 km and its total length, measured from its SSW termination to Węgliniec in the NE, exceeds 220 km.

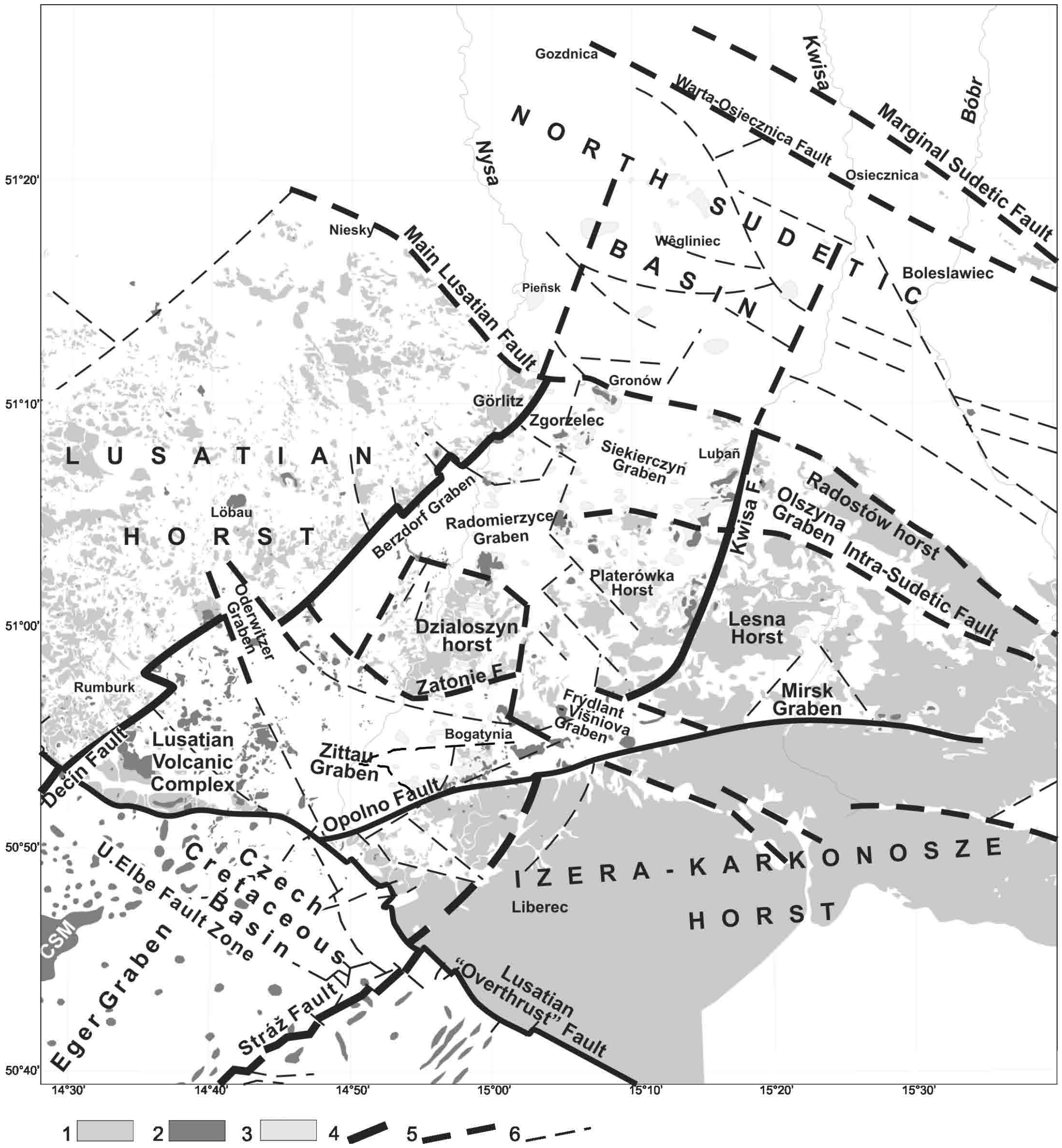

Fig. 1. The northern part of the Eger (Ohře) Graben on uncovered map (without Permian, Mesozoic and Neogene): 1. Palaeozoic, mostly metamorphic and igneous rocks , 2. Paleogene-Neogene basaltoid volcanics, 3. volcanics rocks as above, under younger cover, 4. boundary faults of the Eger (Ohře) Graben, 5. main faults, 6. other faults.

2a

The Lusatian Volcanic Field – link between the Ohře Rift and the Eastern European Volcanoes

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The so called Lusatian Volcanic Field (LVF, fig. 1) is part of the Central European Volcanic Province (CEVP) and connects the volcanoes of the České středohoří Mts. (CS) in the Czech Republic as the westernmost volcanic region along the Ohře Rift with those located in the east in Lower Silesia (LS) in Poland. The LVF is characterized by bimodal volcanism ranging in composition from nephelinites to phonolithes (trachytes). In previous literature, it was often included in the North Bohemian volcanic areas or distinguished as a volcano-complex (e.g. Pfeiffer & Suhr 2008). However, the distinguished volcanic charactersistics of this zone and the well-defined Elbe zone that separates this volcanic field from others justifying its stand alone right to be defined as a separate volcanic field formally named as Lusatian Volcanic Field.

The age of the Cenozoic volcanic rocks ranges from about 35 to 26 Ma. Additional single volcanic "events" are dated with about 22 and 65 Ma. No age clustering regarding rock types or geographical location is detectable. Volcanism was associated with tectonic movements and basin development. Thus the main distribution of volcanic rocks can be found in the surrounding of the Cenozoic coal basins and their main faults. Away from these localities only small occurrences appear.

The basaltic rocks preserved mostly as small remnants of necks, plugs, lava lakes, or maars or dissected parts of formerly extensive lava flows (e.g. Lorenz et al. 2003, Büchner and Tietz 2012). Phonolithic and trachytic rocks formed mostly small monogenetic domes or cryptodomes (Tietz et al. 2011). Normally, the superficially deposited volcanic constructs have already been eroded. However, pyroclastic rocks are commonly preserved in "sheltered" positions like in sedimentary basins or under thick lava flows. Primary bedding and structure has survived strong chemical weathering.

The greatest variety of volcanic rocks can be observed in the southern part of the LVF whereas in the northern part mostly SiO_2 under-saturated volcanic rocks occur. In general the volcanic rocks in the Lusatian Volcanic Field represent an alkaline trend typical for intra-continental suites.

The neighbouring volcanic areas are characterized in more (CS) or less (LS) variable lithologies and other ages.

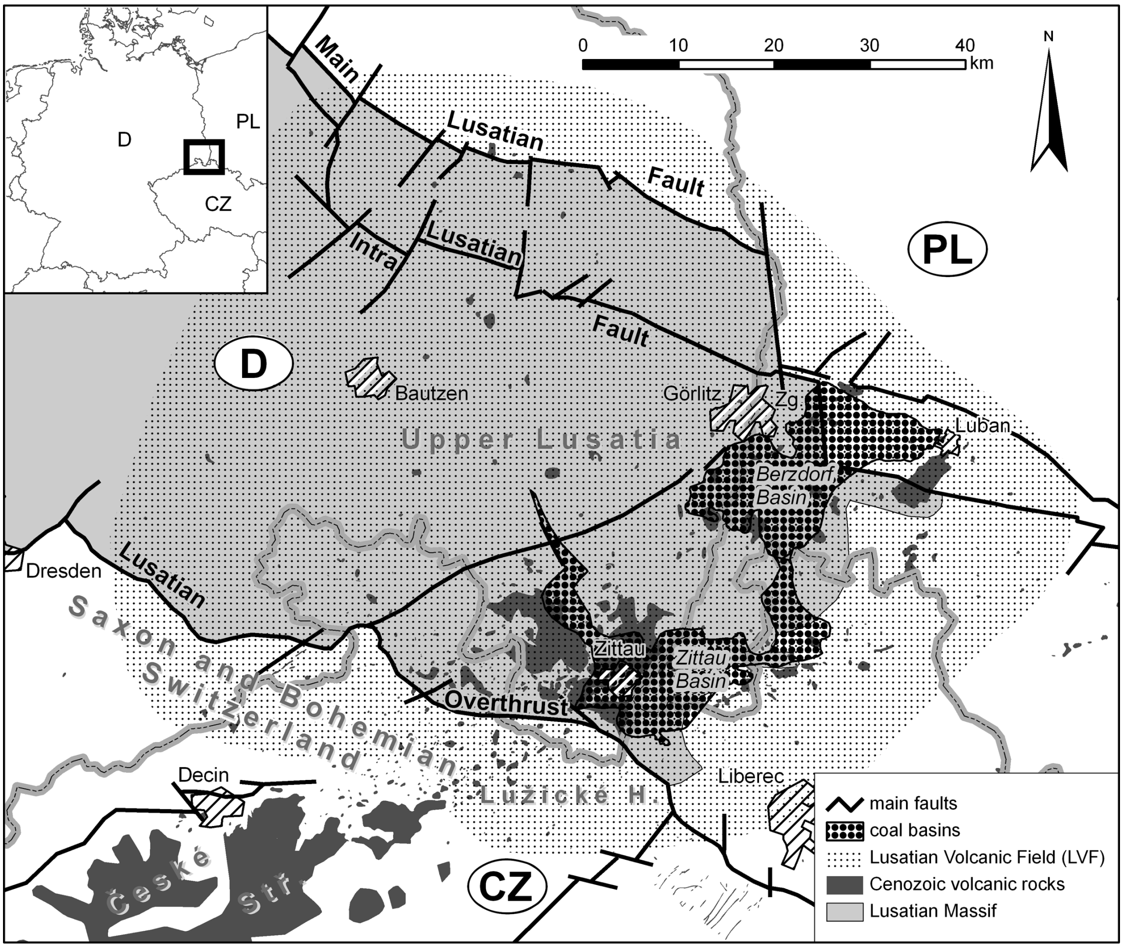

Fig. 1. Map of the Lusatian Volcanic Field with the main geological units.

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2a

Origin and geodynamic relationships of the Late Miocene-Quaternary alkaline basalt volcanism in the Pannonian Basin, eastern-central Europe

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Formation and evolution of the Pannonian Basin has been accompanied by a variety of volcanic activities during the last 20 Myr. Among them, the origin of the Late Miocene to Quaternary alkaline basaltic volcanism is still unresolved. The basaltic volcanism resulted in clustered, low- to medium-fluxed monogenetic volcanic fields as well as single volcanic events in different parts of this region.

The alkaline basaltic volcanism was taking place during the post-rift thermal subsidence and the tectonic inversion phases of the Pannonian basin from 11.5 to 0.1 Ma. In the Stiavnica-Nógrád-Gömör and the Bakony-Balaton Upland volcanic fields, the volcanism was relatively long-lived (7-0.4 Ma and 7.9-2.6 Ma, respectively), involving distinct active phases and several 100's ka long quiescence periods. In the Styrian Basin only one active phase can be detected from 4.9 to 1.9 Ma, whereas the youngest volcanic field (Persány) in the southeastern part of this region is characterized by two active volcanic stages (1.2-1.4 Ma and 0.5-0.6 Ma) so far. Two areas can be considered as still potentially active (Stiavnica-Nógrád-Gömör and Persány) and further volcanic events at the southern Hungarian Plain also cannot be excluded.

The basaltic volcanic fields in the Pannonian basin show a remarkable spatial distribution. They are situated mostly at the west-northwestern periphery of the Pannonian basin and not in the region which underwent significant thinning and thus characterized by thin lithosphere. This peripheral area is underlain by a lithosphere/asthenosphere boundary with a steep gradient (from 110 to 70 km depths). In contrast, the Persány volcanic field is found just the opposite parts of this region, close to the Vrancea seismically active area.

The composition of the basaltic rocks is in a wide range from nephelinites to trachybasalts, however, no subalkaline types exist. Large compositional variety can be often found even within the volcanic fields. In single monogenetic volcanoes, however, we have not found significant change in the composition of the erupted magmas so far.

The chemical composition of the mafic rocks indicates that melt generation could have occurred mostly in the sublithospheric mantle, within the garnet-peridotite stability zone, i.e. > 60-80 km depth by 1-4% of melting. Partial melting at such depths could take place only if the potential temperature of the upper mantle is higher than the average (i.e. upwelling plume) or there are materials with lower solidus than the peridotite. This could be either peridotite with hydrous phases (amphibole or phlogopite) or existence of pyroxenite/eclogite. Indeed, trace element patterns of many basalts show a negative K-anomaly, which could be consistent with low-degree melting of an amphibole- or phlogopite-bearing garnet-peridote. However, this geochemical feature could be explained also by the fingerprint of the source region, i.e. melting of inherently K-depleted rocks. Pyroxenites and eclogites representing dehydrated oceanic crustal material could be reasonable candidates for this. The negative correlation between the $^{143}Nd/^{144}Nd$ isotope ratio and the degree of negative K-anomaly (K/K*) within individual basalt volcanic fields may indicate the latter scenario and melting of heterogeneous mantle source regions. The sublithospheric mantle beneath the Pannonian basin could be heterogeneous on a relatively small-scale (possibly in a scale of 100-1000 m), where the erupted magmas represent often a mixture of mafic melts occasionally coming from very different mantle source domains (e.g., pyroxenitic/eclogitic and peridotitic sources). Involvement of pyroxenitic material could be implied by the relatively low CaO contents of the basalts as well as the olivine compositions.

Additional implications for a small-scale heterogeneous mantle source come from a detailed study of the chemistry of spinels. Spinels are among the first phases to crystallize from basaltic magma and their compositions strongly depend on the magma- and source compositions. They are fairly common as inclusions enclosed by olivine phenocrysts in basalts of each volcanic field. Selecting only those spinels, which occur in forsteritic olivine and are not undergone in differentiation process, we can found a remarkable compositional variation. The spinel compositions are in the range from typical OIB to MORB spinel characteristics even within single volcanic fields. This could suggest melting of variously enriched mantle material. Remarkably, we found strong compositional variation of spinels even in single samples that could be explained by amalgamation of mafic magma batches from different source regions.

The reason of melt generation following well the main extensional phase of the Pannonian basin has been still a subject of debate. The lack of broad topographic updoming, a high velocity body in the mantle transitional zone, the sporadic distribution of the mafic volcanic fields and the fairly low magma production rate are all inconsistent with an upwelling mantle plume. This is corroborated by the obtained mantle potential temperature data from the most primitive mafic rocks that do not exceed the normal mantle temperature range (mostly less than 1400 ^{o}C). Instead, the spatial distribution of the basaltic volcanic fields could have significance. The magma generation occurred mostly at the western and northwestern peripheral areas of the Pannonian basin that are underlain by a lithosphere/asthenosphere boundary with a steep gradient. We suggest that the Pannonian basin could act as a thin-spot providing suction in the sublithospheric mantle and generating mantle flow from below the thick lithospheric roots. This mantle flow would have a near-vertical component along the steep lithosphere/asthenosphere boundary that could lead to decompression melting in the strongly heterogeneous upper mantle. On the other hand, a different scenario is necessary for the mafic magmas at the southeastern part of this region. The single basaltic eruption event at Lucaret could be related to the differential crustal movements (it occurs at the boundary of subsiding and uplifting blocks) in the present tectonic inversion phase, whereas the formation of the youngest volcanic field in the Persány area could be due to a combined result of a major reorganization in the sublithospheric mantle and stretching of the lithosphere as a cold, dense material is descending beneath the Vrancea zone. Since this is a still ongoing process, further volcanic eruptions might be still expected here.

2a

New Findings on Gas Migration and Active Tectonics in the East Eifel Volcanic Field

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In the Eifel volcanic field gas analyses (carbon dioxide, helium, radon, hydrogen sulphide and methane) of mofettes and mineral springs were performed in several campaigns during the period 2008 to 2012. Additionally soil gas samples were collected by pounding a stainless steel probe (with a sacrificial tip) to the desired depth of 1.0 m into the unsaturated zone of selected locations. Based on the analyses results specific distribution patterns can be identified, which allow conclusions to be drawn to tectonic and magmatic activities.

In the East Eifel volcanic field, the recent gas anomalies are connected to tectonic faults which are part of the postvariscan shear system and to normal faults which are formed in the direction of the main stress direction. The most clear appearence are 105° trending strike-slip faults, which are staggered in equidistant intervals of several kilometers. This system continues to the North into the Ruhr Carboniferous, where it has been recognized due to the extensive underground coal mining first (Loos et al. 1999). Our recent research on analyses of tectonics in quarries, quartz/ore-dykes, mapping of minerals springs and gas analyses, has revealed a 105° trending strike-slip fault („Laacher See Strike-slip Fault“) cutting the South of Laacher See. At present, the „Laacher See Strike-slip Fault“ can be tracked from Holzmühlheim in the West, Spessart, Wehrer Kessel, Laacher See, Plaidt to Bad Ems in the South-East. In the tectonic depression of Neuwied Basin, near Plaidt, the „Laacher See Strike-slip Fault“ is intersected by the NW-SE-trending Ochtendung Fault. Along this fault system, an area of intensive micro-seismicity and a new seimically active zone with local magnitudes up to 4 has developed over the last 40 years (Hinzen 2003). In the last decade, a second new seismically active zone developed in the Bad Ems region with local magnitudes up to 4.4 (BNS 2012).

Our results of gas analyses show a split of the East Eifel volcanic field into two parts. Helium (He) anomalies with concentrations excceding up to seven-fold the atmospheric standard of 5.220 ppb (Holland & Emmerson 1987) are evident in the northern and in the northwestern part of Laacher See, whereas Helium anomalies with concentrations up to 70-fold of the atmospheric standard are evident southeast of Laacher See, indicating a large-scale anisotropy in the tectonic depression of Neuwied Basin. East of Laacher See, Radon anomalies up to 130 Bq/l are found. H_2S anomalies are evident northeast of Laacher See. The highest gas anomalies are evident in the mofette field (500 m length) in the river Lahn in Bad Ems: Helium anaomalies with concentrations excceding up to 150-fold the atmospheric standard, Radon anomalies up to 500 Bq/l and H_2S anomalies up to 18 ppm were found.

The mofette field in the river Lahn is prolonging the Laacher See Fault. The position of this mofette field seems to be far away from the East Eifel volcanic field with a distance of appox. 30 km to an assumed center in the East Eifel volcanic field South-East of Laacher See. But the Quaternary volcano Rodderberg near Bonn and the youngest Eifel volcano, the Ulmener Maar (it is not clearified yet whether this Maar is part of the West Eifel or East Eifel volcanic field) show the same distance to the assumed center. It is also striking to see, that all three loactions lie on a circle with equal distance to each other. Together with the assumed center they form sectors with an angle of 120 degrees.

Strikingly high He values within the new seismically active zone near Plaidt can be associated with tectonic movements along the „Laacher See Strike-slip Fault“ which lead to the formation of secondary faults. But tectonics as the only cause for the high He values is called into question. In the East Eifel, movement rates of active tectonic faults are approx. 1 mm/year. Block rotation in combination with uplift could have provided the voids for the magma chambers of the Wehrer Kessel and the Laacher See Caldera. Our research findings suggest that due to the slow movement rates of active tectonic faults, an estimated 18 km³ magma chamber within the brittle fracture section of the earth's crust beneath the Laacher See (Bogaard & Schmincke 1984) cannot be confirmed yet. The Laacher See caldera has a volume of 0.5 km³ with regard to the pre-eruptive surface (Viereck & v.d. Bogaard 1986). A volume compensation of an ascending magma of approx. 6 km³ which could have prevented a further subsidence of the magma chamber seems to be an unrealistic assumption. An order of magnitude smaller magma chamber of 1 km³ stretched over a longer vertical crustal section could help to better match the given tectonic movement rates.

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Understanding $^{40}Ar/^{39}Ar$ age variations in basalt lavas: A combined geochemical, petrographic and X-ray computed tomographic study

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The $^{40}Ar/^{39}Ar$ technique is the main radiometric dating tool applicable to basaltic igneous rocks. It relies upon the assumption that the rapid cooling rates of lavas should be sufficient to close the $^{40}Ar/^{39}Ar$ system uniformly, preventing any loss or gain of argon from the lava during cooling. This age should therefore be independent of where in the lava the samples are collected, but in practice age variations of more than 10% have been found within individual lavas. Understanding the causes of the age variability is crucial if $^{40}Ar/^{39}Ar$ data are to be accurately interpreted.

There are 3 hypotheses that can explain intra-flow age variations:

1. The $^{40}Ar/^{39}Ar$ age variations are caused by variations in the geochemical composition of the groundmass. Laboratory experience has shown a correlation between groundmass $^{40}Ar/^{39}Ar$ plateau-age and the weight % K_2O of the groundmass.
2. The $^{40}Ar/^{39}Ar$ age variations are caused by alteration of groundmass by post-emplacement low-temperature meteoric fluids, which can introduce or remove potassium. The effects of this would be more pronounced in near-surface, field outcrop samples.
3. The $^{40}Ar/^{39}Ar$ age variations are caused by the migration of post-emplacement high-temperature fluids through basaltic lavas. These fluids can also introduce or remove potassium but can also cause degassing of argon from the basalt.

We have performed a suite of analyses on 5 variably vesicular Palaeogene basaltic lava flows, in order to investigate the causes of poor age reproducibility. Our sampling strategy was to collect at intervals throughout each of the lavas to test for the processes responsible for the observed age variations in basalt lavas. 20 groundmass $^{40}Ar/^{39}Ar$ plateau-ages from two of the flows range from 35 Ma to 55 Ma. Both flows show a similar magnitude of age variation and have a similar distribution of ages with percentage height above lava base.

Groundmass x-ray fluorescence analysis and electron microprobe chemical element mapping have been used to produce a detailed understanding of sample geochemistry, allowing us to identify regions where potassium and calcium are concentrated, and assess the role of geochemical and mineralogical variability in the observed age variations. This is important for correctly calculating the $^{40}Ar/^{39}Ar$ plateau ages. The groundmass geochemistry shows that these flows have been variably altered since lava emplacement; therefore any link between the geochemistry and the age must reflect the effects of a post-emplacement alteration process.

The $^{40}Ar/^{39}Ar$ technique relies on the assumption that the system remains closed, an assumption that fails if the migration of fluid through the basalt causes the addition or removal of argon and/or potassium. The ability to accurately model both chemical and heat transfer during fluid migration through a basalt would allow a step-change in our understanding of post-emplacement effects on the $^{40}Ar/^{39}Ar$ dating system. To determine the degree to which age variability is controlled by the movement of these low-temperature (near-surface) meteoric fluids, or high-temperature (burial or hydrothermal) fluids, we are comparing variably weathered samples, collected from field outcrops and onshore boreholes. The first order pathways for fluid flow though most basalts are interconnected vesicles. The vesicles were imaged in 3D using x-ray computed tomography, allowing the non-destructive imaging of the size, shape and interconnectivity of the vesicles to be quantified. In our samples the vesicles are generally partially or fully filled with various species of precipitated minerals. Identification of these varying vesicle fills by x-ray diffraction analysis will allow the construction of a relative time-temperature chronology. Initial CT results suggest that our samples contain a high proportion of interconnected vesicles and element mapping of the vesicle fills indicates the presence of significant potassium within the vesicle fills, indicating the migration of post-emplacement potassium-bearing fluids.

Our study is the first to combine geochemistry, petrography, $^{40}Ar/^{39}Ar$ dating, field observations and x-ray computed tomography to investigate the causes of poor age reproducibility within individual basalt lava flows. While we use a case study from the Faroe Island Basalt Group, our results are important for understanding $^{40}Ar/^{39}Ar$ ages from any basaltic system. We will present preliminary models of the age modification processes and place our findings in context for the interpretation of $^{40}Ar/^{39}Ar$ ages from any basaltic sample.

Basalt dyke swarm patterning in extensional rift systems: insight from scaled analogue modeling

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Physical scaled analogue modeling is a well-established technique (Hubbert 1937, Koyi 1997) employed for studies of a wide range of geological processes in reasonably short time scales and small scales in the laboratory. This technique is for example frequently used for modeling of faults evolution in brittle crust in oblique, orthogonal or offset rift-like structures (e.g. McClay & White 1995, Corti et al. 2003). In contrast, our study will focus on the development of basaltic magma intrusions, which propagate in part along major faults in such rift systems. The major aim of our study is the understanding of the different factors influencing the dyke swarm pattern propagation in extensional rift systems and the role of these factors on the distribution of vents generated by such dyke swarms at the surface (Mazzarini & Isola 2010). These factors comprise the geometry and kinematics of the rift systems (different degree of oblique extension), the volume, overpressure and geometry of the underlying magmatic reservoir and the role of stress and pre-existing fractures on dyke propagation (e.g. Valentine & Gregg 2008). Since the distribution of monogenetic volcanoes are believed to be a result of the mechanical layering and stress conditions in the crust (Zhang & Lutz 1989) suitably approached by quantitative analysis - e.g. 2-point azimuth technique (Cebria et al. 2012), we plan to correlate the results of our experiments with the rift geometries and monogenetic volcano distributions in active or extinct rift systems on both Earth and Mars.

Sandbox setup:

The apparatus (Fig. 1) consists of two boxes (100x100x40cm) facing each other with opened frontal side and move apart (or against each other) along rails being pulled by a computer controlled step-motor (see Fig. 1). The angle of oblique extension (or convergence) in the middle part of the apparatus is adjustable. A rubber plate is fixed to the edges of opened sides of both boxes to provide the homogeneous deformation of the bottom part of the experimental rift system allowing oblique extensional (or compressional) deformation. The magma intrusion in layered crust (visualized by colored sand) at the bottom and middle part of the deformation zone will be provided by injection of molten parafine-wax from a preheated cylindrical container by a computer-controlled step motor driven piston. Fine-grained dry quartz sand is used as the analogue for the upper crust. A circular hole is pre-cut into the rubber plate between two boxes to allow injection of the analogue magma into the sand. In the first series of experiments, the analogue magma will be injected at first from a point source – 2.5 cm wide cylindrical conduit. The next step of the analogue modeling approach will be to create a horizontal intrusion elongated along the axis of the future rift that would represent the extensive melt bearing regions underlying the natural rifts that produce numerous dykes bringing magma to the surface.

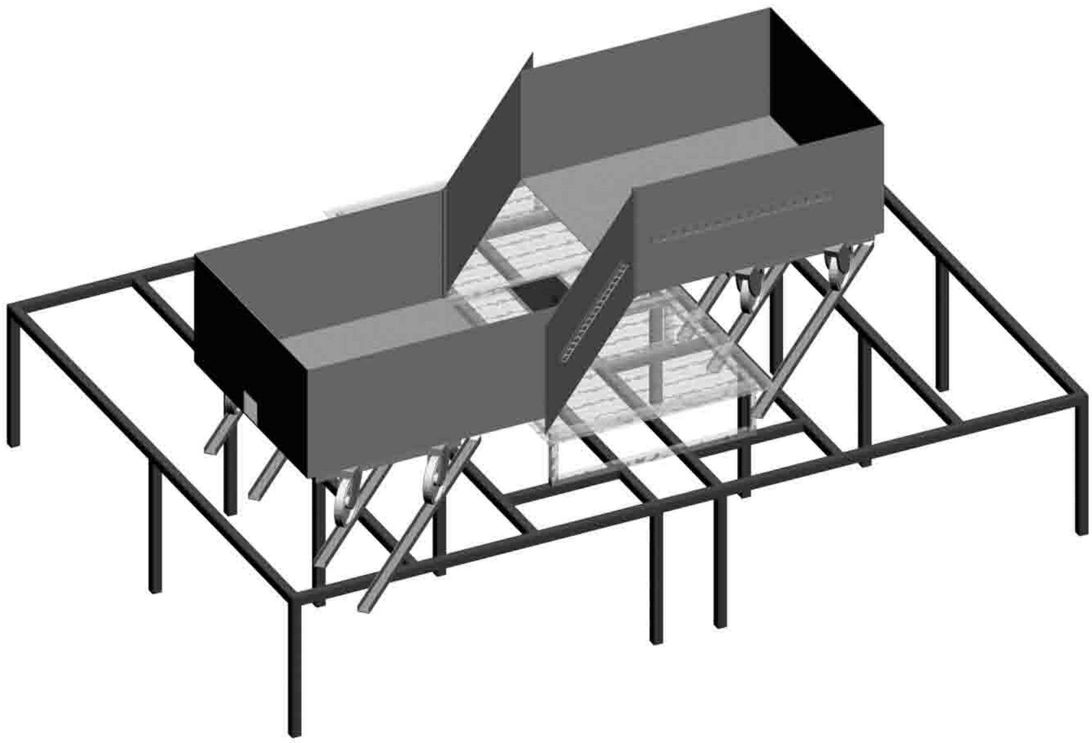

Fig. 1. Sketch of experimental sandbox which is used for simulation of dyke swarm pattern development during normal-oblique extensional rift systems. Parafine wax and sand are used as analogue materials for basaltic magma and upper crust, respectively.

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2a

Intraplate basaltic magmatism of the British Isles during the late Palaeozoic

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After a long magmatic quiescence following Caledonian subduction, subaerial intraplate magmatism commenced in the early Carboniferous (~ 354 Ma) over a large area of the British Isles in response to regional extension. Whilst subordinate in England, much of Ireland, the Isle of Man and Scotland north of the Highland Boundary Fault, eruptions commencing in the Tournaisian and climaxing in the Visean were substantial in south and central Scotland and in SW Ireland (Limerick volcanics). Subsequent basaltic magmatism persisted in Scotland to the late Permian. Despite presenting an essential continuum, the magmatism is broadly divisible into a) that in the Mississippian and b) that in the Pennsylvanian and Permian.

In Scotland, the Mississippian magmatism principally comprised mildly alkaline ('transitional') olivine basalts, basaltic hawaiites and hawaiites erupted from small central-vent and/or fissure volcanoes. These gave rise to lavas sequences from ~500 to 1000 m thick in the Scottish Midland Valley and the Limerick district of SW Ireland. Magma residence in crustal chambers gave rise to silicic differentiates (trachytes, quartz trachytes, phonolites and (rare) rhyolites). Early-stage evolution of the most primitive magmas involved fractional crystallisation of olivine, clinopyroxene and spinel. Compositions of the two latter indicate crystallisation at pressures up to 11.5 Kb. No erupted melts had >10 wt% MgO.

Transition from Mississippian to Pennsylvanian times saw a change to more silica-poor magmatism, mainly basanitic. These younger magmas were more primitive than their Mississippian antecedents and included phenocryst-enriched lavas with up to 20 wt% MgO. The most primitive melts attaining shallow crustal levels are represented by olivine mela-nephelinitic dykes in Orkney with >12 wt% MgO. The small-volume Pennsylvanian/Permian eruptions are considered to be products of smaller melt fractions in the mantle than those of the Mississippian and Permian. The absence of significant amounts of differentiates (*i.e.* <3 wt% MgO) contrasts sharply the Mississippian magmatism. High ascent rates are suggested by their contents of mantle and lower crustal xenoliths.

Primitive mantle-normalised plots show the Pennsylvanian-Permian magmas to have had significantly higher incompatible element contents than the Mississippian magmas. The latter are inferred to represent <3% asthenospheric partial melts with minor contributions from lithospheric mantle. The Pennsylvanian/Permian magmas are regarded as having arisen from still smaller melt fractions. Low Y contents of all the Carbo-Permian basalts signify that garnet remained as a residual phase during melting. It is concluded that all came from a heterogeneous source, with melting taking place across the sp – gt lherzolite transition. Trace element and Nd and Sr isotopic compositions all fall within OIB-fields.

The sequence of mildly to strongly alkalic magmas was interrupted in latest-stage Carboniferous times (~300 Ma) by a brief interlude of tholeiitic magmatism. This, which appears to have had no extrusive representatives, formed an extensive dyke swarm (approximately E-W trending) across northern England and south-central Scotland. The whole swarm is ~200 km broad, with dykes of up to 50m width. Contemporaneous quartz dolerite sill complexes were produced in northern England and the Scottish Midland Valley. The high Fe-Ti composition of these tholeiites, together with their higher Zr/Nb ratios, reflects larger-scale melting of a more depleted mantle source. Whilst genesis of the Carboniferous-Permian alkaline magmas is inferred to be unrelated to mantle plumes, a plume origin for the tholeiitic magmas cannot be excluded.

The late-Palaeozoic British/Irish province is of interest in being either the earliest, or one of the earliest, examples of transitional to alkali basaltic magmatism with OIB-type trace element and incompatible element characteristics, in a continental intra-plate environment. The majority of such provinces (e.g. the Central European, East African Rift, Basin and Range and Cameron Line provinces) are Cainozoic. Mesozoic examples are scarcer and Palaeozoic instances are distinctly rare. This non-uniformitarian behaviour is inferentially related to the thermal evolution of the planet. Furthermore, the late Palaeozoic volcanism in the British Isles may also provide the oldest instance of mantle xenoliths being hosted by basaltic magmas (as opposed e.g. to kimberlitic and ultra-mafic lamprophyric magmas).

Leucitites and leucitites within and around the Mediterranean

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Leucitites represent a very rare group of volcanic rock cropping out in different continental tectonic settings but never on oceanic plates. According to IUGS, leucitites are defined on the basis of the modal mineral abundance only, whereas whole-rock chemical analyses cannot be used, because their composition spreads over the foidite field in the TAS classification scheme, towards more silica-rich and/or alkali-poorer types (e.g., tephrites, phonolitic tephrites, tephritic phonolites). Leucitites must contain at least 10% modal leucite, leucite must be the most abundant foid, and the feldspars/foids modal ratio needs to be lower than 0.1. Typical mafic minerals can be anhydrous (commonly Ca-Mg-Fe clinopyroxene, olivine, Fe-Ti oxides, melilite, nepheline) or volatile-bearing (biotite, amphibole, sodalite, calcite).

Rocks classified as leucitites occur in few localities within and around the Mediterranean area: Central Spain (Calatrava), Western Germany (West Eifel), Czech Republic (Doupovské hory Mts.), Southern Hungary (Bàr), Central Italy (Ernici Mts., Vico and Alban Hills), Southern Kosovo (Devaje-Visoča), Western Turkey (Balçikhisar-Afyon) and NW Iran (East of Urmieh Lake, Ahar). Apart these few localities, other leucite- (or analcime-) bearing compositions occur in several other districts like Central France (French Massif Central area), central Sardinia (Montiferro), peninsular Italy (Roman magmatic province), Aeolian Islands, Northern Morocco (Gourougou and neighbouring districts), Czech Republic (Eger Graben) and central Serbia. Volcanic rocks found in association with leucitites range from ultrabasic, strongly silica-undersaturated, typically MgO- and CaO-rich types (carbonatites, silicatic-carbonatitic hybrids, melilitites, nephelinites, basanites) to intermediate, silica-saturated to silica-oversaturated (shoshonites, lamproites, tephri-phonolites) and more evolved types (trachytes, latites, phonolites), some of which reach peralkaline compositions.

Circum-Mediterranean leucitites range in age from Early Miocene (~22 Ma; Devaje) to Late Pleistocene (~0.3 Ma; Alban Hills) with no age clusters. Their volume is very low in absolute terms and in relative proportion compared with the bulk of the local volcanic activities. Magmatic styles are mostly explosive, i.e., strombolian (Spain and Italy) to phreatomagmatic (Spain, Germany, Turkey), but also effusive (lava flows and small domes; Hungary, Spain, Germany, Turkey Italy). The explosion propellant has been inferred to be very shallow (groundwater), intermediate (decarbonatation of marine limestone host rocks) or very deep (instability of mantle carbonatitic melt).

Petrographically the investigated leucitites are moderately porphyritic, with phenocrysts of leucite (Italy, Kosovo and Iran), olivine and clinopyroxene (Spain and Germany), hornblende (Iran) and biotite (Spain, Germany, Italy, Iran), set in a groundmass with the same phases plus melilite (Spain-Germany), rare feldspars (Italy-Iran) and nepheline (Spain-Germany).

From a geodynamic and a structural geological point of view the circum-Mediterranean leucitites can be grouped into two main types: 1) leucitites emplaced away from active or recent subduction zones, as volcanic districts of Calatrava, Eifel and Doupovské hory Mts. (hereafter named "anorogenic"); and 2) leucitites emplaced along active subduction settings or along ancient sutures (here defined "orogenic"), like those from Bàr (Pannonian back-arc basin formation close to Carpathians fold-and-thrust belt), Ernici Mts., Vico and Alban Hills (Tyrrhenian back-arc basin close to the Apennine fold-and-thrust belt), Devaje (emplaced in a post-collisional setting, following the Dinaride collapse), Balçikhisar-Afyon (associated with post-collisional extension in between the Menderes and the Kırşehir massifs) and those East of Urmieh Lake in NW Iran (in a suture zone in between the Arabian and the Eurasian plates).

Anorogenic leucitites are characterized by higher TiO_2 (1.9-3.6 wt%), Fe_2O_3tot (9.7-13.6 wt%), MgO (8.5-19.3 wt%), but lower Al_2O_3 (8.5-14.3 wt%), K_2O (0.5-4.3 wt%) and K_2O/Na_2O ratios (0.1-1.9) compared with orogenic leucitites. Compared with orogenic types, the anorogenic leucitites have lower Rb (13-303 vs. 96-670 ppm), Th (all but two samples 6-41 vs. 14-106 ppm), Pb (all but three samples 6-34 vs. 28-211 ppm), Ba/Nb (6-19 vs 42-193), La/Nb (0.7-1.2 vs. 1.1-9.5), Zr/Nb (1.5-6.5 vs. 4.9-29.8), Th/Ta (1-12 vs. 8-108) higher Nb (54-172 vs. 4-60 ppm), Ta (3.4-9.9 vs. 06-3.4 ppm), Nb/U (all but two samples 19-51 vs. 1-17), Ta/Yb (2.2-4.5 vs. 0.2-1.7) and Nb/Nb* (0.7-3.0 vs. 0.04-0.6).

This survey evidences the following important features: 1) rocks classified as leucitites are emplaced in different tectonic settings; 2) not all the leucitites are ultrapotassic rocks, according the Foley et al. (1987) criteria, due to their MgO <3% and/or K_2O/Na_2O <2; 3) some rocks classified as leucitites are instead leucite-bearing basanites, tephrites, tephriphonolites-K trachybasalts; 4) some rocks classified as basanites-tephrites should rather be defined leucitites because of the absence or paucity of feldspars; 5) leucitites are not confined in the foidite field of TAS diagram only, but spread over more silica-richer composition; 6) leucitites may be associated with silica-oversaturated rocks (e.g. lamproites); 7) rocks classified as leucitites emplaced in the foreland of subduction zones or in intraplate settings are not leucitites. These can be easily distinguished from true leucitites, emplaced above active or recent subduction zones or along ancient sutures, on the basis of several major and trace element constraints; 8) Melilite-bearing leucitites should be rather classified among the melilite rock group; 9) Rocks classified in different terms (e.g., leucite-basanite, tephrite, leucitite, leucite-nephelinite, phonotephrite, lamproite) generally have roughly the same incompatible element content, therefore can be related to similar petrogenetic processes, independently from the given rock name.

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2a

The intrusive substructure of the Deccan Traps volcanic province

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Continental flood basalts (CFBs) represent fissure eruptions on a grand scale. Deeply eroded CFB provinces expose extensive dyke-sill networks as well as larger intrusions (such as lopoliths). Dense mafic dyke swarms may represent the magma-filled fissures through which the lavas poured out, as well as later intrusions, and these provide valuable data on the tectonics of CFB eruptions.

The ~65 MY old Deccan CFB of India has a present-day areal extent of ~500,000 km^2 and an original extent estimated at three times this size. The flood basalt pile is dominantly tholeiitic and up to 2 km thick in the Western Ghats (Sahyadri) escarpment parallel to the western Indian rifted margin. It formed in a relatively short time interval (debated to be <1 MY to a few MY). The Deccan has been extensively studied in terms of geochemistry, palaeomagnetism, and volcanic stratigraphy, and recent work has addressed the question of the feeder dykes of the extensive lava flows. The Deccan province has three major zones where mafic (dolerite-basalt) dyke swarms attain profuse development. Many individual dykes several tens of kilometers long are found, and the longest en echelon dyke known is 79 km in length (Ray et al. 2007). Following field and petrographic studies, probable feeder dykes of several well-studied lava packages have been identified based on geochemical comparisons (using major and trace elements and Sr-Nd-Pb isotopes) and in some cases magnetic polarity. It is known from these studies that several of the large Deccan lava flows covered distances of several hundred kilometers after eruption (e.g., Bondre et al. 2006, Sheth et al. 2009, Vanderkluysen et al. 2011).

Sills are much rarer in the Deccan province, and only two or three important examples are known from the pre-Deccan sedimentary basins. A probable Deccan saucer-shaped sill has also been noted from the Gondwana Basin in central India (Sheth et al. 2009). This rarity of sills and abundance of dykes reflect generally extensional conditions. Basanite-melanephelinite intrusions and a maar-diatreme, in Mesozoic sandstone in the Kachchh region (northwestern Deccan), have been identified as the plumbing system of a monogenetic volcanic field (Kshirsagar et al. 2011). Dykes are rare here.

The largest Deccan intrusion is that forming Mount Girnar in the Saurashtra region of the northwestern Deccan. This is a major gabbroic intrusion, dioritic-monzonitic in its upper parts, and has domed up the overlying lava flows as a laccolith. Many tholeiitic and alkalic (e.g., lamprophyre) dykes occur around and inside it, and a large ring dyke of granophyre and silicic porphyry encircles it.

Intrusions in the Deccan Traps dominate the western Indian rifted margin and the northwestern Deccan region (e.g., Sheth et al. 2011, Zellmer et al. 2012). These intrusions are of great petrological interest owing to their great compositional diversity compared to the Deccan lava flows, and even within individual intrusive complexes. These intrusions cover the entire spectrum of igneous rock compositions, including gabbros (Girnar, Chogat-Chamardi, Mundwara), diorite and monzonite (Girnar), alkali gabbros and syenites (e.g., Mundwara), basanites and melanephelinites (Kachchh), trachytes (e.g., Mumbai), granophyres (e.g., Barda, Chogat-Chamardi), rhyolite and pitchstone (e.g., Rajpipla, Rajula), lamprophyres (several of the above), as well as carbonatites (e.g., the Amba Dongar diatreme hosting a commercial fluorspar deposit).

The Deccan CFB lava pile hides the basement rocks over a vast region, and mantle and crustal xenolith localities are few. All known Deccan basement xenoliths are within dykes (Ray et al. 2008).

Any study of the Deccan CFB province is incomplete without its intrusive phase. Recent and ongoing studies of the intrusive substructure of the Deccan Traps have provided, and will continue to provide, exciting insights into the physical and compositional-petrogenetic evolution of this great volcanic province.

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Firiza basalts - the final stage of the Neogene calc-alkaline volcanic activity from Gutâi Volcanic Zone, Eastern Carpathians, Romania

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The Gutâi Volcanic Zone (GVZ) belongs to the Neogene-Quaternary volcanic chain of the Eastern Carpathians built up during the complex Miocene subduction processes developed in the Carpathian-Pannonian region. The volcanic system of GVZ develops on the north-western part of the Romanian territory. The calc-alkaline intermediate volcanic rocks of Sarmatian-Pannonian age (13.4-7.0 Ma, Pécskay et al. 2006) are predominant. Underneath, lies the older, Badenian calc-alkaline, felsic volcanic rocks. The medium-K pyroxene andesites are the prevalent volcanic rocks (Kovacs & Fülöp 2003). Subvolcanic and shallow-level intravolcanic intrusions occurred contemporaneously with the paroxysm of the GVZ intermediate calc-alkaline volcanism. A mafic intrusive complex occurs in the central part of GVZ along a NE-SW oriented alignment crossing the Firiza Valley (Fig.1). This intrusive complex consists of small intrusions (50 to 200 m length and 20 to 80 m width) of basalts crosscuting the entire succession of the intermediate volcanism, radiometrically dated between 8.1-7.0 Ma (Edelstein et al. 1993). The Firiza mafic intrusive complex/ Firiza basalts comprises of fine porphyritic to aphyric pyroxene basalts with the phenocrysts/groundmass ratio of 20-25/75-80 and an intergranular groundmass texture. Plagioclase (An_{65-81}) commonly occurs as microphenocrysts; clinopyroxene (Al-titanium diopside and Al-augite) is the predominant mineral phase of the rock (mainly as glomeroporphyric clusters) and orthopyroxene, magnetite and ilmenite are subordinate. It is worth to mention the presence of some large amphibole phenocrysts (Ti-magnesiohastingsite) with clinopyroxene crystals as inclusions and of the quartz crystals often with clinopyroxene coronas, as outstanding features.

The Firiza mafic intrusive rocks are high Al basalts (49.7-51.7 SiO_2, 15.2-19.1 Al_2O_3) with typical calc-alkaline and medium- to high-K character (according to AFM and K_2O-SiO_2 diagrams). The trace elements geochemistry constrains typical subduction-related zone signatures: strong LILE and LREE enrichment and HFSE depletion which suggest source enrichment and crustal contamination as main petrogenetic processes, similar to the intermediate calc-alkaline volcanic rocks from GVZ. The Firiza basalts exhibit similar geochemical signatures with the calc-alkaline basalts from other volcanic arcs (i.e. Călimani Mts. from Eastern Carpathians, Aeolian arc) but higher LILE and LREE enrichment than other uncontaminated basalts from the arc-type volcanic zones (i.e. Cascades). The lead isotope study shows strong crustal contamination of the Firiza basalts parental magma as shown by the whole suite of intermediate calc-alkaline volcanic rocks from GVZ. The mafic parental magma was stored and crystallized at as much as 16-20 km based on Al-in-hornblende and amphibole-plagioclase barometers. Besides the AFC processes, a slight mixing with a more differentiated magma (constrained by the presence of the quartz crystals with clinopyroxene coronas) was involved in the generation of the Firiza basalts.

The Firiza basalts represent the final stage of the calc-alkaline volcanism in GVZ. Mafic final stages also occur in other volcanic areas of the Carpathian-Pannonian region such as Central Slovakia, Tokay Mts. and Apuseni Mts. (Pécskay et al. 2006). Among these mafic stages, the Firiza basalts appear as the unique calc-alkaline high Al basalts of intrusive origin. Except for the mafic stage described in Apuseni Mts., which is similar in age with the Firiza basalts, all the other mafic stages are older. A further study of these mafic final stages of the calc-alkaline volcanism from the Carpathian-Pannonian region could get to a better understanding of their significance from the petrogenetic perspective.

Fig. 1. Distribution of the Firiza basalts in the Gutâi Volcanic Zone (GVZ).

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2a

Early Eocene basaltic ashes ('cement stones') in north-eastern Germany

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Rifting processes between Greenland and NW Europe during the Palaeocene-Eocene led to the opening of the North Atlantic Ocean. Tectonism was accompanied by intense volcanic activities in the area of today's Iceland. This is mainly documented by about 200 ash layers interbedded in a marine clayey diatomite of the Fur Formation (mo-clay). Cliff exposures occur in northern Jutland/Denmark, especially in the vicinity of the Limfjord. Some of the basaltic ashes are partially carbonate-cemented. These concretions, which were formerly used for cement production, are called 'cement stones'.

The Danish ash layers are normal graded and vary in thickness from only 1 mm to 19 cm. They are traditionally subdivided into negative and positive series. Geochemical analyses suggest the existence of different magma sources and allow to distinguish 4 stages of volcanic evolution (Larsen et al. 2003). (1) Basalts and peraluminous rhyolite (layer –39 to –22), sources on the NW European shelf. (2) Trachytes, rhyolites, alkali basalts, nephelinites, and phonolite (layers –21b to –15), sources on the western shelf of the British Islands or in East Greenland (Gardiner complex). (3) Alkali basalts (only layers –13, –12, –11), a source near the opening rift between Greenland and NW Europe. (4) Tholeiitic ferrobasalts and rhyolites (layers +1 to +140), the emergence of Proto-Iceland. Two layers have been dated using the ^{39}Ar–^{40}Ar method. The phonolitic layer –17 has an age of 54.52 ± 0.05 Ma, and the rhyolitic andesite layer +19 is slightly younger as indicated by an age of 54.04 ± 0.14 Ma.

Similar ashes are widely distributed in northern and central Europe, especially in the North Sea. Volcano-clastic layers are known from former clay pits and wells in northern Germany, either characterised as unconsolidated bentonites or as carbonate-cemented concretions with heavily altered glass shards (e.g., Illies 1949, Henning & Kasbohm 1998). Furthermore, carbonate-cemented ashes occur on the small Baltic Sea island Greifswalder Oie, situated in the Pomeranian Bay between Rügen and Usedom. They either can be found as single erratic boulders or as concretions in disturbed glacial rafts of early Eocene clay. The source area of these glacially transported rocks is a few 10 km to the NE, where graben structures of the Pomeranian Fault System occur, in which Tertiary deposits could have been preserved. Cement stones of Greifswalder Oie type can be divided into two sub-groups on basis of their mineralogy, facies and fossil content (cf. Obst & Ansorge 2010).

Cement stones of Greifswalder Oie type I occur exclusively as erratic boulders in glacial tills exposed at the south-eastern cliff of the island or as beach boulders respectively. The fresh rock is blackish-grey in colour, however, due to weathering the boulders often have greyish-brown rims. Type I represents carbonate-cemented basaltic ashes that form black layers up to 12 cm in thickness. They are often intercalated with rather thin yellow-brownish layers of a fine-grained mudstone, which is composed of clay and volcanic dust, but is carbonate-cemented as well. The glass shards are about 100 to 200 µm in size. Their colour varies between light brown and black according to the degree of alteration into palagonite. Well-developed gradation is not discernible. The tuffite layers show, however, parallel and cross lamination, documenting repetitive depositional cycles under conditions of decreasing hydraulic energy; from upper plane-bed conditions to current ripples and, finally, asymmetric oscillation ripples. In addition, distinct biogenic traces (e.g., *Planolites*) and other faint features of bioturbation occur, suggesting reworking of the waterlain air-fall ashes. The matrix consists of clay, volcanic dust and micritic cement of calcite and minor siderite. Besides a few distinct horizons with enrichment of diatoms (*Fenestrella antiqua*), only non-calcareous microfossils occur sporadically, e.g., different diatoms, benthic foraminiferans and sponge spicules. Typical macrofossils are agglutinated polychaete worm tubes and remnants of insects and plants.

Cement stones of Greifswalder Oie type II occur as ellipsoidal concretions in a glacial raft of early Eocene greenish-grey clay. The largest reaches 1.40 m in length with 25 cm thickness. Beach boulders of this type are rare. The colour of type II is light grey, or brownish-yellow due to weathering. The concretions consist of carbonate-cemented fine-grained sand or silt. Therein a few centimeters thick ash layer is interbedded. The epiclastic rocks are heavily bioturbated but usually lack other fossils. The ash layer is normal graded and contains mostly black glass shards. The background sediment consists of detritic, angular-shaped quartz and feldspar suggesting short transportation distances from the Fennoscandian High. Subordinate well rounded quartz and glauconite grains occur; often rimmed with a thin layer of limonite. They probably represent re-worked older Palaeogene marine sediments. The matrix of the concretions is made of calcite and sphaerosiderite indicating a rather shallow marine environment. The formation of sandy concretions in a clayish matrix is difficult to explain. They could, however, represent intertidal drainage-channel deposits.

To compare with the Danish ash layers, two samples of ashes from the Greifswalder Oie (only type I) were geochemically investigated by Larsen et al. (2003). The results suggest a correlation with tholeiitic basalts of stage 4 representing the positive series. New XRF analyses of both types I and II were carried out after solution of the rock powder using hydrochloric acid. They indicate that the ash layers have different compositions. The geochemical composition of type I is similar to those reported earlier. Type II is slightly enriched in SiO_2 compared with type I. Furthermore, the concentration of TiO_2 is very high (about 6 %), while the MgO content is rather low (about 1 %). Together with trace element distribution, the data fit best ash compositions of the Danish stage 2.

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Petrochemical analyses and Ar/Ar dating of doleritic basalts from Banefo-Mvoutsaha area (ENE Bafoussam) Cameroon. Evidence of Mesozoic volcanism within the Cameroon volcanic line and it interpretation in the Gondwana evolution

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The Banefo-Mvoutsaha dolerites are two distinct petrochemical types: The olivine-bearing dolerites which are the most representative, are dark green, showing characteristics of alkaline basalts and the calcite-bearing dolerite which are grayish green, showing characteristics of tholeiitic basalts. Their geotectonic context inferred to be intraplate and the contrast between the two types is probably due to a diverse source: crustal source for calcite-bearing dolerites and mantle source for olivine-bearing dolerites. The studied dolerites are less differentiated ($1<FeO^t/MgO<2$); they present the evolution of a subalkaline magma following a calc-alkaline series (alkaline dolerites) and the tholeiitic series (tholeitiic dolerite). The $^{40}Ar/^{39}Ar$ dating yields an age of 229.03 ± 7.07 Ma. These Mesozoic volcanism activities related to the studies dolerites may be correlated to the opening of Atlantic Ocean during the break-up of Gondwana.

Keys words:

Cameroon Volcanic Line, Dolerites, Ar/Ar dating, Mesozoic, Gondwana.

Basic magmatic formations within the eastern part of the Bükk Mountains, Hungary

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The Bukkium is a paleo-mesosoic tectonostratigraphy unit consists of principally Oligocene and Miocene molass basin sediments bounded by compressional crustal thickening and subduction that forms the basement rock of NE Hungary, and it is a subject of intense research coundected by the University of Debrecen's Tardona Research Group for 15 years. Basement metasediments intercalated with volcaniclastic successions interpreted to represent the Bukk sedimentary basin.

More than 20 000 micro tectonic measurements have been done in this area (Kozák et al 2000). it became apparent that within the platform carbonates of the marine sediment, the basaltoid rocks (basalt, metabasalt, metaandesite) determine their morphological tectonic environment. They strongly contributed to the regional deformation which was caused by the regional compressions of SW, SE and E direction.

The primary subject of the study was the basaltic rocks. These types of formations lie in a curve from Szarvaskő to the city limit of Miskolc and do not form a continuous chain of bodies. The metabasaltic rocks orientations fit into the morphological tectonic direction of the Bükk Mountains. Among them we studied the materials of the easternmost edge around the Szinva spring.

On the east and west sides of the Szinva spring we can observe the basalt bodies along approximately 200 meters (E-W orientation). We examined the area with the size ratio of 1:1000 sufficient detail traversal on the spot. Both sides were examined by micro tectonic observations on the field (Kozák et al 2000) where we also studied the contact, appearance, development, and other structural characteristics of the exposed rocks. On this basis, we collected samples from the matrix environment where the metabasalt and the limestone mix with each other and from the basalt body where the alteration is not so high. They were processed in the laboratory of the Department to be prepared for the microscopic including the stereo-microscopy and geochemical analyses. We would like to answer the following interesting questions:

- Is there any palaeoenvironmental relationship between the embedding environment and the magmatic rocks?
- What kind of plate tectonic and volcanic processes can be reconstructed?
- How can we get a more accurate reconstruction of the region by determining their absolute and relative ages and petrogenesis?
- What levels of erosion occurred in the simultaneous and post-magmatic processes during the structural evolution?

The results of the macro- and microscopic studies show that this body of basalt is tectonically heavily loaded by the changing deformations within the Bukk Mountains, strongly altered by clay minerals mainly chlorite and characterized by hydro-metasomatic alteration.

The geochemical analyses (*TG, DTG*, DTA) revealed that the original magma could be of mantle origin basalt with high iron and magnesium content (tholeiites, with 10-15% iron and magnesium content).

Due to the periodic transgression which was in the Eocene and Miocene, it pushed into a low lying area covered with sediment, where the surrounding areas were uplifted (like tuffs exposed near Bukkszentkereszt and Bukkszentlaszlo).

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Earthquake swarms in West Bohemia/Vogtland as a swansong of recent volcanism?

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The western part of Eger rift manifests the most active geodynamic activity within the Bohemian Massif in present times. The rift is the result of young, deep-seated geodynamic processes manifested by episodic Cenozoic volcanism (the youngest at 0.2–0.5 Ma), repeated earthquake swarms, numerous mineral springs, CO2 emissions with high mantle-Helium content, and abundant dry CO2 mofettes. It is also typical by a shallow crust-mantle boundary and also increased heat flow.

The earthquake swarms with magnitudes not exceeding ML 5 are probably the most pronounced manifestation of the region's activity. Two periods of increased seismicity are documented in modern times: 1897 – 1908 and since 1985 till the present days. The most recent earthquake swarms 1985-86, 1997, 2000, 2008 and 2011 occurred along the same N-S oriented and steeply dipping fault zone with hypocenters occupying the depth range from 6 to 12 km. All the swarms display migration of hypocenters that indicate a fluid-driven activity. Numerous models have been presented to explain this type of event migration. Two mechanisms driving the activity are discussed: the stress transfer between the individual earthquakes and additional external forcing that is necessary to bring the fault zone to the critical state and possibly also keep the swarm running. The evidence for the activity of pressurized fluids comes from the models of the 2000 and 2008 swarms based on fluid diffusion and hydraulic fracture growth. The latter provided estimate of underlying fluid pressure in the level of 20 MPa, which agrees with the pore pressure needed to compensate for stress deficits generated by precursory ruptures. While these interpretations presume that a fluid of low viscosity drives the swarm activity, also models presuming a magmatic intrusion as an underlying mechanism of the swarm activity have been presented. All the existing models of fluid role in the seismogenic process are however based on analysis of the seismicity and thus represent only indirect proof of the activity of deep originated fluids. Magmatic origin of these fluids is however supported by high 3He contents in the surface emanations of CO2, which is most probably transported to the surface along permeable faults that might play role in the seismogenic process.

We analyse the space and temporal evolution of the seismicity and present a review of the swarm models to point out that activity of high-pressurized crustal fluids of magmatic origin is probably the most plausible condition for triggering and driving the earthquake swarm activity.

Reflection seismic investigation of the geodynamically active West-Bohemia/Vogtland region

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The West Bohemia-Vogtland region in central Europe attracts much scientific interest due to recurrent earthquake swarms and continuous exhalation of CO_2 dominated fluid from the subsurface. Seismological and geochemical studies reveal (1) significant upper mantle derived content of the emitted fluid, (2) an updoming of the MOHO below that area (3) possible existence of a magmatic fluid reservoir in the upper mantle and (4) fluid activity as a possible trigger for the swarm earthquakes. In this study the subsurface structure beneath the region is investigated by reprocessing the deep reflection seismic profile 9HR, which runs almost directly across the swarm area. The migrated image confirms the upwelling of the MOHO known from receiver function studies. Directly below one of the major gas escape centres, channel like fault structures are observed which seem to have their roots at the MOHO. They may represent deep reaching degassing channels that allow direct transport of mantle-derived fluid. The middle and lower crust appears highly fractured below the swarm area. This may result in mantle fluid ascending through the crust and then getting blocked in the crust. Such blockage could result in building up of an over-pressured fluid zone at the bottom of near surface rocks. After a critical state is reached, the over-pressured fluid may have sufficient energy to force its way above into near surface rocks and to trigger seismicity. Since the swarm seismicity is found to be restricted along a plane only, such intrusion might have taken place along a semi-permeable zone that extends from the fractured lower crust into the near surface rocks. A comparison of the spatio-temporal evolution of the recent swarms in the years 2000 and 2008 with the subsurface reflectivity shows that in both cases the swarm activity initiates at the upper edge of a highly diffuse reflectivity zone, moves upward, bends at a bright spot above and finally stops after travelling a few kilometers along the bright spot. This correlation indeed resembles movement of an overpressured trapped fluid forcing its way into a less permeable volume above it and thereby generating a swarm of earthquakes. These observations and in particular their joint interpretation give new insight into the causes and driving mechanisms of the West Bohemia-Vogtland earthquake swarms.

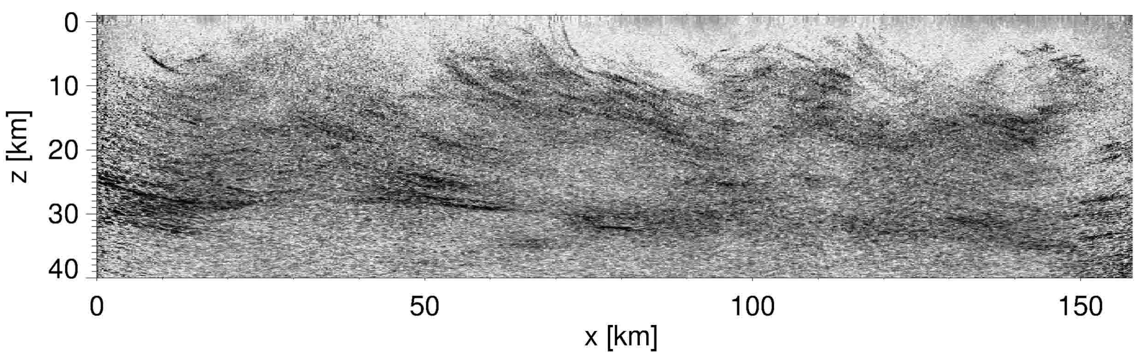

Fig. 1. Migrated section of 9HR profile.

2b

Active magmatic processes traced by fluid migration through the crust in Central Europe

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Our investigation area is part of the European Cenozoic rift system and is located at the Czech-German border close to the earthquake swarm region Nový Kostel. Fluids are involved in most active geological processes and play an important role for the understanding of complex geodynamic processes in the earth's lithosphere.

Comprehensive isotope studies (CO_2, He) of free fluids have been started more than 20 years ago and have in particular included extended chemical and isotope monitoring studies lasting for several years each. They were aimed at shedding some light upon the origin of the fluids (Weinlich et al. 1999, Bräuer et al. 2004), the possible locations of the fluid sources in the lithospheric mantle (Geissler et al. 2005), as well as the role of fluids as a triggering mechanism for earthquake swarms in the Vogtland and NW Bohemia (Bräuer et al. 2003, 2007, 2009, 2011).

CO_2 is the major component of the emanating magmatic volatiles. Three degassing centers - the Cheb basin, Mariánské Lázně and Karlovy Vary - could be distinguished there. They are characterized by high CO_2 fluxes having the same level of $\delta^{13}C$ values, but different contributions of upper mantle derived helium (Bräuer et al. 2008).

In 2000 an increase of mantle-derived helium was observed at degassing locations in the Cheb basin, whereas at locations in the Mariánské Lázně degassing center the mantle helium contributions remained nearly the same (Bräuer et al. 2005). The repeated annual sampling (from 2003 to 2009) indicated a progressive increase of the $^3He/^4He$ ratios - temporally and spatially – in the eastern part of the Cheb basin. These findings were interpreted as indication for a hidden active magmatic process beneath the Cheb basin. Superimposed upon this long-time trend, in spring 2006 an increase of $^3He/^4He$ ratios (up to 6.3 Ra) at locations in the eastern part of the Cheb Basin was observed over a three month period, indicating fluid supply connected to the ascent of fresh magma from a deeper reservoir. Overall, a hidden magmatic process in a non-volcanic region has been traced and may improve our knowledge about the connection between intraplate seismicity and repeated magma injections.

Detailed gas flow measurements at the central mofette Bublák, for the first time in 1993 and repeated between 2007 and 2009, support these findings. They show a clear increase in the gas emission rate of more than 40% (Kämpf et al., 2012), correlating well with the increase of the $^3He/^4He$ ratios from 5 Ra to approximately 6 Ra at this location (Bräuer et al. 2009). The Bublák mofette field is characterised by the highest gas emission rate along the Počatky-Plesná fault zone (PPZ) and exhibits a helium isotope signature within the range reported for the European subcontinental mantle. Therefore, this area is clearly identified as a deep-reaching fluid injection zone.

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Velocity structure of the West Bohemia Seismic Zone

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The West Bohemia Seismic Zone is located on the border between the Czech Republic and Germany. This region has several areas which experience periodic microseismic swarm activity. The installation of the West Bohemia Seismic Network (WEBNET) has allowed constant monitoring of the town Nový Kostel and surrounding area. Nový Kostel is one of the most active areas. Larger swarms, such as those in 1997, 2000, 2007 and 2008, have been studied in terms of source mechanisms and swarm characteristics (e.g. Fischer & Michálek 2008, Fischer et al. 2010, Vavryčuk 2011). Despite these analyses, questions remain regarding the subsurface structure within and around the focal zone. Results of time series studies tracing the $^3He/^4He$ ratios of CO_2-dominated spring and mofette gases gave evidence for a currently-ongoing magmatic process in the lithospheric mantle beneath the West Bohemia Seismic Zone (Bräuer et al. 2005) and hint towards a fluid-controlled swarm trigger.

In this study, we investigate the velocity structure within and around Nový Kostel using double-difference tomography (Zhang & Thurber 2003). In order to reduce bias and artifacts introduced in the tomography parameterization, we use Weighted Average Model (WAM) post-processing analysis (Calò et al. 2011). The WAM analysis uses tomography models calculated with a variety of reasonable starting parameters and calculates a weighted averaged model. This reduces starting model bias and artifacts. In addition, it is possible to assess the average Vp and Vs (and therefore also Vp/Vs) models in terms of the weighted standard deviation, indicating regions with high stability or areas with poor resolution.

An initial averaged Vp/Vs model was produced using a subset of the 2008 swarm. This model included a low-Vp/Vs layer overlaying the focal zone and high Vp and Vp/Vs values along the fault. This contrast may indicate the base of a low-permeability layer acting as a fluid trap and potentially triggering the swarms. Here, we further the investigation by using the full WEBNET catalog. We calculate inversions of individual swarms to produce a detailed structural model with the goal of interpreting the role of fluids in Nový Kostel.

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Determination of magma storage conditions: contribution and limitations of petrological approaches

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Our quantitative understanding of magmatic processes has increased considerably in the last decades because a variety of petrological and geochemical tools have been calibrated and parameterized, allowing us to constrain pressure (P), temperature (T), volatile and oxygen fugacity, residence time in magmatic systems. The accurate determination of magma storage conditions and of differentiation conditions is of particular interest because it is a pre-requisite to understand eruptive processes and it is useful to model the structure and rheology of the continental crust. Depending on the mineral assemblage and the geochemical composition of the magmas, several geothermometers can be used, (e.g., two pyroxenes, Fe-Ti oxides, olivine-melt, zircon solubility, Ti-in-quartz). If adequate thermometers are chosen, the pre-eruptive temperatures can now be determined accurately for a large compositional range of magmatic systems. However, in contrast to thermometers, it is difficult to find well calibrated barometers to constrain pressure from mineralogical and geochemical analyses and the exact depth at which magmas may have been formed and stored before eruption is often under debate. The models predicting pressure from mineral compositions may lead to pressures which differ significantly (more than 1000- 2000 bars) from direct calibrations using experimentally determined phase equilibria. Problems are mainly expected for alkali-rich compositions (basanite, tephrite, phonolite) because the compositional range is wide (Na, K, Ca) and because the calibration database is scarce. The analysis of glass inclusions, including the concentrations of H_2O and CO_2, is another common method used to constrain the pressure prevailing when melts were trapped in host minerals. However, several studies showed that melt inclusions may not be closed for water and pressures estimated from the volatile concentrations are probably underestimated in most cases. An additional factor influencing the pressure determined using H_2O and CO_2 is the solubility model for H_2O and CO_2 which is applied. It has been shown that models based on typical MORB basaltic compositions are not suitable to determine pressures in alkali-rich compositions. Possible ways to overcome the problem of pressure estimation from phase assemblages are shown.

In addition to the analysis of phases in selected samples, the differentiation trends of magmatic suites can be used to extract information on magma storage conditions. Several thermodynamic and empirical models have been developed to predict melting-crystallization relations in basaltic to rhyolitic melts in a wide range of thermodynamic conditions in closed to open magmatic systems (*e.g.* MELTs, COMAGMAT, Petrolog). In practice, however, despite the great efforts in improving models, calculations still yield unsatisfactory results in the prediction of the calculated liquid lines of descent, especially in the presence of H_2O at elevated pressures. On the basis of new experimental data the COMAGMAT model has been recently refined, allowing one to predict effect of H_2O on phase equilibria more accurately. This type of work, which is mainly relevant for the interpretation of calc-alkaline systems, needs to be extended for alkali-rich series.

Clinopyroxene mineral chemistry and thermobarometry of Tertiary alkaline volcanics in the Trabzon-Giresun areas, NE Turkey: Implications for shallow to deep crustal magma chamber processes

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Tertiary volcanics are widespread and show temporal and spatial variations in both northern and southern parts of the Eastern Pontides (NE Turkey). The studied Tertiary alkaline volcanics of the northern part are separated in three suites: Middle Eocene aged mildly alkaline (1) basalt, trachy-basalt and basaltic trachy-andesite (BTB) and (2) trachyte and trachy-andesite (TT) suites, and Upper Miocene aged moderately alkaline, (3) basanite-tephrite (BT) suite. Eocene suites contain clinopyroxene, olivine, plagioclase, hornblende, biotite and Fe-Ti oxides, whereas Miocene suite consists of clinopyroxene, analcime, plagioclase, hornblende, biotite, olivine and Fe-Ti oxides with microlitic porphyritic, hyalo-microlitic porphyritic, intersertal and glamerophorphyritic textures. Clinopyroxene, the most abundant mafic anhydrous phase, is observed in all discriminated suites. Some textural evidences of disequilibrium crystallization are also observed in the clinopyroxenes such as zoning, resorbed cores and mantles, inclusions and embayment in rims. The mineral chemistry studies indicate that the clinopyroxenes from each suite have similar compositions as augite, diopsite, salite and minor fassaite with $Wo_{40-54}En_{29-48}Fs_{5-27}$ and moderate-high Mg-numbers varying between 0.53 and 0.91. Clinopyroxenes have also 0.70-10.01 wt.% Al_2O_3, 0.00-3.35 wt.% TiO_2, 0.12-0.85 wt.% Na_2O and 0.00-1.32 wt.% Cr_2O_3 contents. Using Cr_2O_3 vs Mg#, TiO_2 vs Mg# and Al vs Ti (apfu) diagrams, the clinopyroxenes are divided into three groups. Group 1 is characterized by high Cr_2O_3, Mg# and relatively low TiO_2. Group 2 has relatively low Cr_2O_3 content and show negative trend in Mg# vs TiO_2 and positive trend in Ti(apfu) vs. Al^{tot}(apfu). Group 3 shows lower TiO_2 and Cr_2O_3 than Group1 and Group 2 but similar Mg# and Al (apfu) content. 0.00-0.94 values of $Al^{(VI)}/Al^{(IV)}$ suggest relatively low and moderate crystallization conditions of magma. The more quantitative pressure and temperature estimates can be obtained by using clinopyroxene only thermobarometer of Putirka (2008). The mean temperatures obtained varies from 1151.51 ± 51.86°C for BTB, 1176.16 ± 8.55°C for TT (Eocene suites) to 1128.22 ± 60.91°C for BT (Miocene suite). The mean pressure ranges from 3.61 ± 2.05 kbar for BTB, 3.52 ± 2.03 kbar for TT to 4.99 ± 2.11 kbar for BT suite. Thermobarometer studies as well as textural and mineral chemistry data may suggest that the parent magma(s) of the Tertiary alkaline volcanics from the Trabzon-Giresun area have undergone shallow to deep crustal magma chamber processes at polybaric crystallization conditions.

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Magma mixing with basanitic melt is the source for peridotites in the Heldburg phonolite

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With the exception of the East Eifel and the Rhoen volcanic fields, magmatic differentiates such as trachyte and phonolite are volumetrically subordinate to mafic volcanics within the Cenozoic Central European Volcanic Province. The phonolite of the Heldburg castle mountain represents the only known occurrence of differentiated magmatic rocks within the Heldburg or Grabfeld dike swarm area. However, the Heldburg phonolite is famous foremost for containing mantle xenoliths (spinel lherzolite) (Irving & Price 1981). Former studies proposing a cogenetic relationship between the phonolite and the peridotites, concluded that the phonolite magma must have evolved under upper mantle conditions (Kunzmann 1996).

In the current study we present clear petrographic and geochemical evidence for magma mixing and mingling in the Heldburg phonolite melt due to the intrusion of mantle derived basanitic magma which is exposed today as a dyke at the foot of the Heldburg mountain. Only during this process the mantle xenoliths were introduced into the phonolite melt as they all contain a rim of basanitic magma. . Detailed field investigations in the Heldburg mountain area and subsequent lab work we identified three major lithologic units, ranging in composition from basanite over tephrite to phonolite. Extensive mingling features (e.g., schlieren layers, load casts, flame structures, mafic enclaves) are developed between these units, indicating that all of them were melts at the time of mixing.

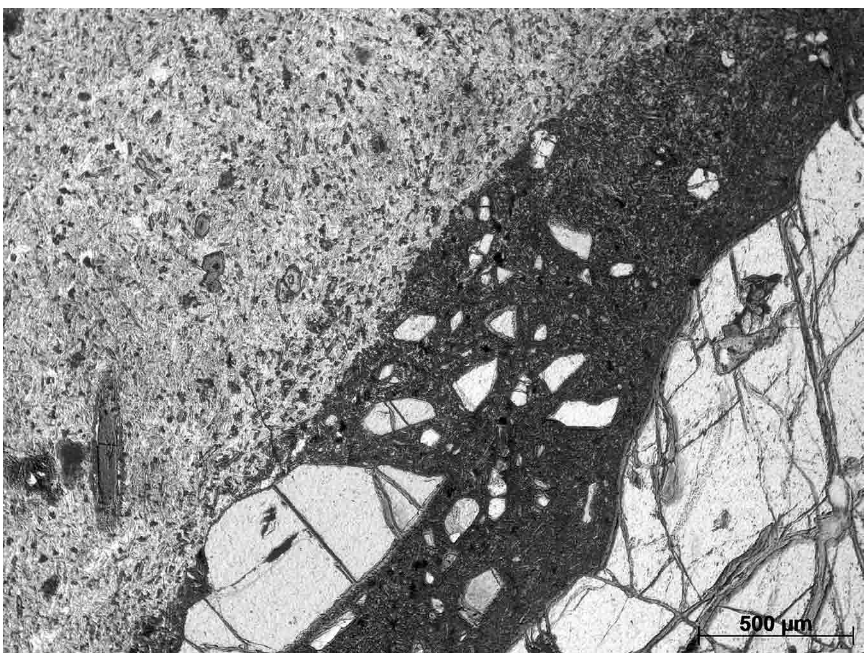

Fig. 1a. Thin section micrograph of the Heldburg phonolite containing basanitic melt enclaves with peridotite xenoliths. Xenolith: upper left, phonolite: lower right, basanite: in between. Plain polarized light.

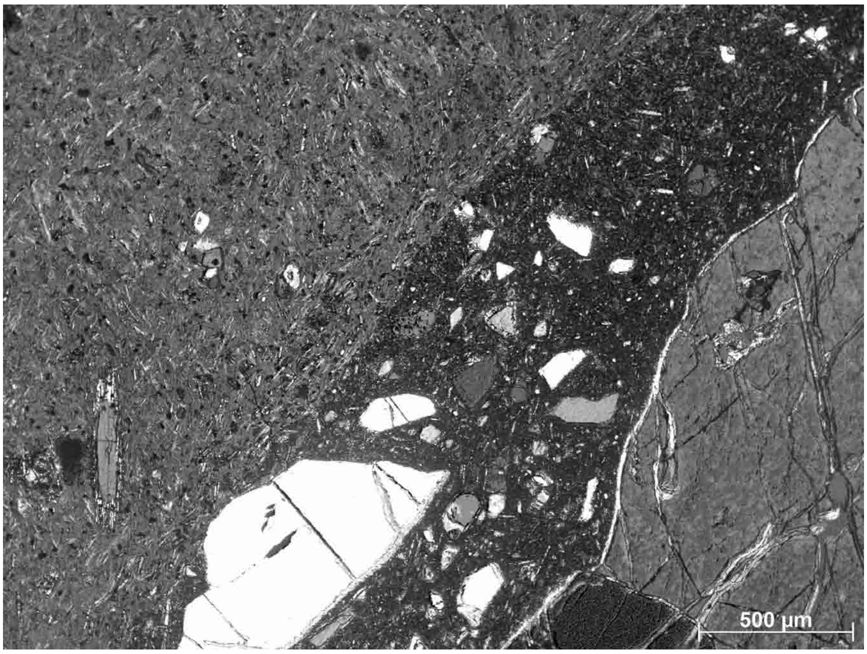

Fig. 1b. Same thin section detail as in Fig. 1a) under crossed nicols.

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2b

Mineral chemistry of chevkinite group minerals from andesitic rocks of the Western Outer Carpathians

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Andesitic rocks from the Western Outer Carpathians sampled at Uherský Brod (Moravia, Czech Republic) and Pieniny (Poland) have unusually high contents of incompatible trace elements, particularly Nb (up to 122 ppm), Zr (up to 249 ppm), La (up to 97 ppm), Ce (up to 152), and Th (up to 31 ppm). The whole-rock geochemistry of the andesites from Uherský Brod defines these rocks as intermediate between andesites from the Carpathian and Pannonian area and the CEVP volcanics of the Bohemian massif and southwestern Poland (for details of age and geochemistry of both volcanic suites, see Birkenmajer, Pécskay 1999, Pécskay et al. 2006, Trua et al. 2006, Harangi et al. 2007, Seghedi, Downes 2011, Ulrych et al. 2011, Nejbert et al. 2012).

The high concentration of Nb and other incompatible elements in some samples from Uherský Brod is demonstrated by the occurrence of numerous zirconolite and chevkinite group minerals (CGM) within the andesite matrix (Nejbert et al. 2012). In the Pieniny area CGM are very rare and only a few grains were recognized in the andesite from Wżar Mt. The CGM grains are generally small, from submicroscopic to 50 µm in diameter. They crystallized contemporaneously with the potassium feldspar, and commonly are overgrown by quartz and/or volcanic glass. Most the chevkinites have strong internal zonation formed during magmatic crystallization; the outer zones are progressively ThO_2–enriched (up to 1.4 wt.%). Two paragenetic mineral associations of Nb-REE phases have been distinguished: **(I)** chevkinite – zirconolite – Nb-rich ilmenite, and **(II)** zirconolite – monazite-(Ce). The aim of this presentation is to summarize the mineral chemistry of the CGM in order to show their potential usefulness in petrological studies.

The chevkinite group minerals in the Western Outer Carpathian andesites have SiO_2 content ranging from 19.05 to 20.50 wt.% (3.92-4.07 apfu), TiO_2 from 15.46 to 19.74 wt.% (2.39-3.09 apfu), La_2O_3 from 11.37 to 23.17 (0.85-1.75 apfu), Ce_2O_3 from 14.40 to 22.31 wt.% (1.05-1.70 apfu), Nd_2O_3 from 1.08 to 5.12 wt.% (0.08-0.37 apfu), CaO from 2.75 to 7.03 wt.% (0.61-1.48 apfu), and FeO from 5.56 to 10.67 wt.% (0.95-1.84 apfu). The amounts of Nb_2O_5, ZrO_2, ThO_2, Y_2O_3 and Gd_2O_3 reach up to 4.10 wt.%, 3.38 wt. %, 2.34 wt.%, 0.43 wt.%, and 1.84 wt.% respectively. Tb, Dy, Ho, Yb, and Lu are high and the concentrations of each element vary around 0.20 wt.%. The total REE oxides range from 34.61 to 45.36 wt.%.

The compositions of the CGM plots within the perrierite and chevkinite fields of the discrimination diagram of Macdonald and Belkin (2002). The CGM in the andesite from Nezdenice, Wdżar Mt. and a few analyses from the andesite at Bojkovice plot in the chevkinite field. Most analyses have $La/Ce_{[apfu]}$ ratio in the range from 0.87 to 0.97. In two samples from Nezdenice, which plot within the chevkinite field, the La exceed Ce ($La/Ce_{[apfu]}$ from 1.28 to 1.39), perhaps pointing to the occurrence of an undescribed La variety of chevkinite. The perrierite shows variable $La/Ce_{[apfu]}$ ratios that range from 0.85 to 1.62. The compositional data of CGM in the andesites indicate the occurrence of chevkinite-(Ce), perrierite-(La) and perrierite-(Ce). Compositional variation in the CGM is best represented by substitution scheme $(Ca)_A + (Ti + Zr)_C \leftrightarrow (REE)_A + (M^{3+}, M^{2+})_C$.

So far as we know, this is the first report of chevkinite in the andesites from the Carpathian-Pannonian area. The CGM in the andesites have a predominantly perrierite composition, whilst chevkinite is subordinate; equal amounts of both the La and Ce varieties of perrierite have been recognized. The CGM together with monazite-(Ce) and zirconolite control the concentration of incompatible elements (Y, REE, Nb, Ta, Zr, Th, U). Hence, the study of the internal texture of the CGM is an efficient monitor of metasomatic and/or hydrothermal processes which potentially could be responsible for local redistribution of these elements. The occurrence and composition of the chevkinite/perrierite are influenced by the simultaneous growth of monazite-(Ce). Monazite crystallization scavenged most of LREE from the vicinity of the growing monazite grains and effectively excluded chevkinite from the accessory assemblages. The distribution of the two CGM paragenetic mineral associations on the thin section scale is not known at this stage of our investigations. The distribution of CGM against monazite can be used to monitor the composition of the crystallizing melt during the latest stages of magmatic crystallization. Assuming that phosphorus distribution reflects the local composition of the melt, and is not affected by diffusion processes significantly, we speculate that distribution of the CGM could be a potential tool for monitoring mixing processes on the thin section scale. The extensive mingling textures in the andesite outcrops at Bojkovice support such a possibility.

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2b

Geochemistry and petrology of the Neogene rhyolites from the Central Slovakia volcanic field, Western Carpathians

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The Central Slovakia volcanic field (CSVF) is a product of Neogene volcanic activity linked to the collision of the Western Carpathians with the stabilized European platform. The volcanic activity started in the Middle Miocene with the production of andesites. The rhyolite volcanism operated during the Upper Sarmatian with the production of pyroclastics, extrusive domes and lava flows. After the rhyolitic volcanism ceased, an activity proceeded with the eruption of subalkaline basalts and later alkaline basalts. The ryolites are mainly of porphyric textures, but aphyric types and obsidians are also present. Phenocrysts consist of amphibole and plagioclase, Fe-Ti oxide (scarce), biotite, sanidine and quartz, which have crystallized in order how there are named. Accessory phases include zircone, allanite and rare apatite. The important petrographical feature is a separate presence of plagioclase, plagioclase with sanidine, or sanidine in phenocryst assemblages. These phenomenas tend to create a special rock names such as plagioclase rhyolites and sanidine rhyolites. Thermobarometric calculations based on two feldspar thermometry, Pl-Amf thermometry and Amf barometry yield magma temperatures between 830-760°C to 730°C. Barometric results correspond with pressure of 4,4-3,1 kbar, but only for rhyolites with amhiboles. The chemical composition of glass corresponds with haplogranitic system equilibration in near surface conditions below 0,5 kbar. Rhyolites chemically respond to subalcalic high-potassium peraluminous rhyolites with normative quartz and corund. The major composition is varied by volume and phenocryst types. The main chemical heterogeneities between rhyolites are based on Nb-La-Ti-Zr-Y systematics, where three petrogenetic groups are identified. The group I corresponds by petrography to sanidine – plagioclase and sanidine rhyolites, while plagioclase rhyolites correspond to the most primitive group III. The group II is combined by mix of the group I and the group III. Every one of these groups has typical geochemical features dictated by their petrogenesis and degree of fractionation. Focused to RE and HFS trace element data, chemistry of rhyolites were affected mainly by fractionation of zircon and amphibole. As for rhyolite petrogenesis, it is difficult to generate them by classical differentiation processes such as crystal fractionation, magma mixing and contamination or more complex MASH or filter pressing liquid extraction. Beside to basalt - andesites and rhyolite chemical differentiation, it is not possible to derive acid melts from parental intermedial liquids. The observed rhyolite chemical trends are results of melting, probably of a high solidified basic amphibole bearing pluton, by heat input from new injections of primitive magma. These ideas are in good agreement with radiogenic isotope study. Rhyolites belong to two isotope groups, but not corresponding with previous petrography and HFSE-REE systematics. The first one has $\varepsilon Nd_{12.5}$ between -4.93 and -3.19 with $87/86Sr_{12.5}$ 0.706414-0.709978 and the second one has $\varepsilon Nd_{12.5}$ between -1.39 to -1.24 with $87/86Sr_{12.5}$ 0.705697-0.705884. The isotopic composition of CSVF rhyolitic rocks overlaps other volcanics, such as andesites and basalts (*data of Harangi et al. 2007*). The rhyolite and basalt-andesite similarities of CSVF and strong differences with Western Carpathians basement rocks (metapelites, gneisses, granites) suggests petrogenetic relationship of all CSVF volcanics or continual source development. Looking for a global model of CSVF isotopic development and petrogenesis, radiogenic composition of previous andesites gradually changes through rhyolites to more primitive basaltic andesites and basalts. Rhyolite volcanism display physically connection during hiatus of intermediate and basic volcanism. All volcanic activity is affected by tectonics. Two pulses of previous intermediate and the next basic volcanism respond with higher tectonic interaction of the Western Carpathians and the European platform. The rhyolite volcanic pulse was derived during reduction of tectonic activity and changing of tectonic style from compression to transtension regime.

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Nature of the Pseudoleucite within the Alkaline Basalts, Akçakent, Central Anatolia, Turkey

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2b

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Pseudoleucite is a result of an interaction of leucite with the host source of magma forming an implication of nepheline and K-feldspar within the leucite form. Leucite can be formed at high temperatures and then by falling the temperature under the considerable partial pressure of water it breakdown into hexagonal nepheline, orthoclase and sanidine in the same system. The presence of water, aqueous solution or vapor is necessary for the formation of pseudoleucite. Pseudoleucite crystals occur in three stages as initial crystallization of leucite ($KAlSi_2O_6$), transformation of leucite to nepheline ($NaKAlSiO_4$) through reaction with sodium rich fluids and crystallization of orthoclase ($KAlSi_3O_8$) with an increasing P_{H2O} (~2 kbars). These decay processes of leucite occur within a cooling magma chamber. Pseudoleucite was usually formed after the magma reached its present position and layover in shallow depths. Pseudoleucite crystals occur before complete cooling of the magma. Pseudoleucites are formed the main mineral composition of the alkaline basalts of Akçakent region (Kırşehir). The alkaline basalt has a sharp contact with the syenitic rocks and cutting the pelagic limestones in the form of a dyke in Çiçekhane Hill of the region. These mafic volcanic units have a high topographic elevation in the top of Çiçekhane Hill. Porphyritic phaneritic texture with a dark green color is typical features of these units in the field outcrops. They are hyalophitic textures under the microscope and composed of plagioclase, pyroxene, leucite, neosean, pseudoleucite and opaque minerals. Whole rock geochemical data reveal that these units are a product of silica undersaturated alkaline magma with metaluminous in character. Tectonic variations diagram suggests Within Plate nature. MORB normalized elemental patterns of these units reveal an alkaline nature. Furthermore; they have enrichments in both LILE and LREE with respect to HFSE and HREE. The geology, petrography and geochemical data suggest that the Çiçekhane Hill alkaline volcanic rocks are products of silica undersaturated magma and may derived from the crustal thinning during Early Cenozoic of Central Anatolia.

Composition of gas phase in rocks and minerals of Neoproterozoic flood basalts in western part of East European Platform

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Formation of East European Platform passive margin in Upper Proterozoic time was accompanied by massive volcanic eruptions and, as result, flood basalts were formed. Neoproterozoic flood basalts occupied vast territory and its area is up to 200000 km^2 and spread in the eastern Poland, the south-west of Belarus, northern Moldova and western Ukraine. Neoproterozoic flood basalts are consists of basalts, gabbro-diabase, olivin and pyroxene gabbro-diabase, dolerite, tuffs and lavobreccia. Volcanic rocks formed interbedding with volcanic-sedimentary and sedimentary rocks in marginal parts of the volcanic area (Bakun-Czubarow 2002, Shumlyanskyy 2006)

There were several stages mineral formation in flood basalt (magmatic, autometasomatic, parahydrothermal and hydrothermal) which is characterized by specific mineral association.

The temperature of mineral formation during magmatic stage was close the solidus temperature of basalt (1083^{o}C). The next stage of mineral-forming process is autometasomatic (after cooling basalt) with less then 100^{o}C and at pressure 1 atm. The temperature of mineral forming process grew from 100 to 335^{o}C at parahydrothermal stage. Then the temperature again fell from (~ 300^{o}C) to 150-100^{o}C during the formation of carbonate-sulfide mineralization on stage hydrothermal. Isotopic composition of oxygen and carbon mineral forming fluid shows deep origin of gas phase and possible involvement of formational waters.

Chromatographic analysis was used to determine the composition of basaltic magma gas phase. The gases which entering to analysis due to the gradual heating (pyrolysis) up to 1050^{o}C rocks were studied.

H_2, CO_2, H_2O are dominated in rocks and minerals. CO, N_2, CH_4 was also found but in a much smaller amount. The presence of H_2, CO, CH_4 indicates reduction of gases and their deep nature. Most of gases are typical for rocks (basalts) and not for minerals. This fact shows that gases entered to system with magma and, actually, had weak influence on the mineralising solutions. It is significant that the largest amount of gases released from the basalt at the heating temperature 1050^{o}C (on conditions that close to the melting point - 1100 ^{o}C). Since at the temperature 1050^{o}C rocks released more gases (except nitrogen) than at the temperature 450 ^{o}C, we can assume that gases are not from gas-liquid inclusions in minerals. They can be part of rock-forming mineral lattice. Perhaps they were also partially sorbed by new-formed (zeolites, analcime, wairakite etc.). The presence of nitrogen gas can be an evidence of capturing it from the air (but this fact denies by the lack of O_2), and about the deep nature of the nitrogen (presence of traces of ammonia (NH_3)).

Based on current understanding of the fumaroles and our results, we suppose that there were: dry fumaroles – chloride and other compounds (T≈500^{o}C), carbonate fumaroles (mofette)-carbon dioxide and hydrocarbons, and 3) alkaline fumaroles which formed ammonia (T≈100^{o}C) in Upper Proterozoic. The last fact indicates the results of gas analysis and confirming by presence of ammonia (NH_4) in newly formed minerals in basalts from the tonsils.

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Origin and ascent history of unusually crystal-rich alkaline basaltic magmas from the western Pannonian Basin

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The last eruptions of the monogenetic Bakony-Balaton Highland Volcanic Field (western Pannonian Basin, Hungary) produced unusually crystal- and xenolith-rich alkaline basalts which are unique among the alkaline basalts of the Carpathian-Pannonian Region, furthermore similar alkaline basalts are only rarely known in other volcanic fields of the world. These special basaltic magmas fed the eruptions of two closely located volcanic centres: the Bondoró-hegy and the Füzes-tó scoria cone. Their extreme enrichment in diverse crystals is resulted in their unique textures and modified whole-rock compositions (13.09-14.21 wt.% MgO, 459-657 ppm Cr, 455-564 ppm Ni contents).

Detailed mineral-scale textural and chemical analyses revealed that the studied alkaline basaltic magmas have a complex ascent history and most of their minerals (~30 vol.% of the rocks) represent foreign crystals derived from different regions of the underlying lithosphere. The most abundant xenocrysts (olivine, orthopyroxene, clinopyroxene, spinel) were incorporated from different regions and rock types of the subcontinental lithospheric mantle. Megacrysts (clinopyroxene, spinel) can originate from pegmatitic veins / sills which probably represent crystallized magmas got stuck near the crust-mantle boundary in the uppermost part of the lithospheric mantle. Green clinopyroxene xenocrysts could have derived from lower crustal mafic granulites. Minerals crystallized in situ from the alkaline basaltic melt (olivine with Cr-spinel inclusions, clinopyroxene, plagioclase, Fe-Ti oxides) are only represented by microphenocrysts and overgrowths on the foreign crystals. The vast amount of peridotitic (most common) and mafic granulitic materials indicates a highly effective interaction between the ascending magma and wall rocks at lithospheric mantle and lower crustal levels. However, fragments from the middle and upper crust are absent from the studied basalts suggesting a change in the style (and rate) of magma ascent in the crust. These xenocryst- and xenolith-rich basalts yield divers tools for estimating magma ascent rate that is of great importance for hazard forecasting in monogenetic volcanic fields. According to the estimated ascent rates and times the studied crystal-rich alkaline basaltic magmas could have reached the surface within hours to 1-2 days that is similar to the estimations from other eruptive centres in the Pannonian Basin which were fed by “normal” (crystal- and xenolith-poor) alkaline basalts.

The deep origin of cores of clinopyroxene phenocrysts from the Księginki (SW Poland) nephelinite

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The Cenozoic Księginki nephelinite in Lower Silesia (SW Poland) belongs to the Central European Volcanic Province. The nephelinite forms three lava flows, all of the Miocene age (Kozłowski & Parachoniak 1960). We studied nephelinite from the deepest part of the Księginki quarry, which probably represents the volcanic vent. The nephelinite consists of phenocrysts of olivine and clinopyroxene embedded in the groundmass consisting of subsilicic titanian diopside, nepheline, and, subordinately, magnetite-ulvöspinel and post-magmatic analcime and feldspar (Puziewicz et al. 2011). Groundmass grains do not exceed few tens µm in size. The nephelinite is a host for numerous mantle xenoliths and clinopyroxene megacrysts (Puziewicz et al. 2011).

Phenocrysts of clinopyroxene vary in size from few hundred µm to few mm. Four phenocryst types have been recognized basing on their chemical composition and internal structure. Type I has chemically homogenous diopsidic core (mg# ~90), spongy and/or patchy mantle and homogenous outer rim. The crystals are up to 1000 µm in size (except one grain, which has ~ 2000 µm), and the cores are from ~ 300 to ~ 2000 µm in size. The cores are always anhedral, and surrounded by the mantles, which are from 40 to more than 100 µm thick. The mantles are sub- to euhedral, and are surrounded by the euhedral, zoned outer rims. Chemical composition of the cores is different from any other clinopyroxene kinds in the nephelinite. Phenocryst type II is characterized by spongy and often also patchy core, which size differs significantly from grain to grain (few hundreds µm to few mm). The core contacts sharply with the outer rim, or the contact is marked by thin patchy and sometimes spongy transition zone. The chemical composition of spongy cores varies strongly. The type II phenocrysts have the composition of augite or diopside. The phenocrysts of type III rarely exceed few hundreds µm (most often are <200 µm), their patchy core is surrounded by well-developed zoned rim. The latter often consists of more than ten zones, which chemical composition slightly differs from each other and corresponds to chemical composition of clinopyroxene from the groundmass. Spongy cores of phenocrysts of type III are chemically similar to the spongy and patchy cores of the phenocrysts of type II. The type IV phenocrysts have homogeneous core (mg# ~84), surrounded by mantle and outer rim. Their internal structure is similar to the phenocrysts of type I, whereas the chemical composition I is less magnesian and more aluminium-rich. The zonation in mantles and outer rims in all kinds of phenocrysts is related to increase in Fe, Al and Ti contents and decrease in Si, Mg and Ca contents outwards.

Major element composition of cores of type IV phenocrysts corresponds to that of clinopyroxene occurring in the olivine clinopyroxenites, occurring as xenoliths. The olivine clinopyroxenites are mantle cumulates originated at depth of 35 – 50 km from the nephelinitic magma contemporaneously with the volcanism (Puziewicz et al. 2011). Thus, we suggest that the phenocrysts of type IV contain cores which crystallized at mantle conditions. The cores of type I phenocrysts are extremely magnesian and are similar, but not identical, to the composition of clinopyroxene occurring in the mantle peridotites. Thus, they supposedly are the remnants of the xenocrysts coming from lithospheric mantle peridotites. However, another origin cannot be excluded basing on our data and further study is needed. The patchy and spongy textures of cores in type II and III suggest chemical reequlibration due to the changing conditions of the host lava. That resulted in significant variation in chemical composition which supposedly is not representative of the primary composition.

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2b

Zircon megacrysts associated with alkaline volcanic rocks from Saxony and Northern Bohemia – new aspects of typology, chemistry and mineral inclusions

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Zircon megacrysts associated with alkaline volcanic rocks are known in eastern Saxony (Germany) from the Elbsandsteingebirge (Seufzergründel diatreme) and from the North Bohemian gem stone placer localities (Podsedice and Jizerká) for a long time. Furthermore, there are some new localities described from the Upper Lusatia (Hofeberg quarry, Hutberg quarry) and the Zittauer Gebirge Mountains (hills from Buchberg, Ottoberg and Plessenberg). The zircons derived from alkaline basalts (basanites/nephelinites) and phonolithes/trachytes. From the Hofeberg locality in the south of Görlitz town could provide evidence for *in situ* discoveries. All other occurrences exists as secondary deposits from little creek placers near volcanic remnants (basanites or phonolithes).

The origin and the genesis of these zircon megacrysts derived from alkaline intra-plate volcanic rocks are currently unknown and discussed controversial. Recent there are favoured following two models: a cogenetic and a non cogenetic origin to the host rock melts. Therefore, investigations about the mineral chemistry and isotopy from these basaltic zircons may supply important information about melt processes in the Earth mantle and about processes of magma differentiation and mixing.

The investigated zircon megacrysts derived from alkaline basaltic rocks have a mean size from 2 up to 4 mm (min. 1 to max. 9 mm) and show a gem stone quality. Many crystals are broken and/or intensive rounded. The rounding is the result of a magmatic corrosion in the basaltic transporter rock. This is an argument against the genesis of these zircon megacrysts in the basaltic melt. The broken crystals (splinters) are probably the result of the fast cooling during the basaltic eruption. The zircons from phonolithic rocks are smaller (0.2-0.8 mm) and with mostly idiomorphic shape. But SEM images show an intensive surface corrosion features, probably the result of a postmagmatic hydrothermal alteration.

According zircon typology we can observe two or in some cases three subpopulations at the localities in eastern Saxony and North Bohemia: the first are S- and J-types (nomenclature after Pupin 1980) with predominant 100-prisma and blunt-angled 101-dypiramid in crystal form. The second subpopulation is with 1% to 5% rare, but at the Hofeberg locality very common with 41% from all zircon-typological investigated crystals. Only these crystals from the second subpopulation are mostly non-transparent. After Pupin (1980) this are G1-, P1- and P2-types with 110-prism and blunt-angled 101-dypiramid.The third subpopulation only observed at two locality is composed by D- and P5-types after Pupin (1980) with exclusive 110-prisma and blunt-angled 101-dipyramid. The prism is very small and is missing sometimes, so that only double-pyramids exist.

The first zircon subpopulation is formed through the small and idiomorphic phonolitic zircon type in three localities and through the large and xenomorphic basaltic zircon type in four localities. At the Hutberg quarry these both types occur together in peperite samples at the basis of a basanite lava flow. These observations indicate a petrogenetic relationship between alkaline basaltic and phonolithic melt for the geneses of these zircon megacrysts. Additionally, SEM-EDS investigations could proof, that the phonolitic zircon type derived really from phonolithic host rock, because phonolite/trachyte melt remnants was found in crystal hollows.

Furthermore, inclusions from "strontiopyrochlore" and fergusonite-like mineral could found in two zircon mega crystals from North Bohemia with electron microprobe investigations as relatively large and euhedral grains. These primary inclusions must be a protogenetic or syngenetic origin to the zircon host and indicate an alkali silicatic parental rock, probably carbonatite, nepheline syenites or fenites (Seifert et al. 2012). This assumption where also performed by the trace-element characteristics of the zircon matrix, so from the localities in North Bohemia and Saxon Switzerland.

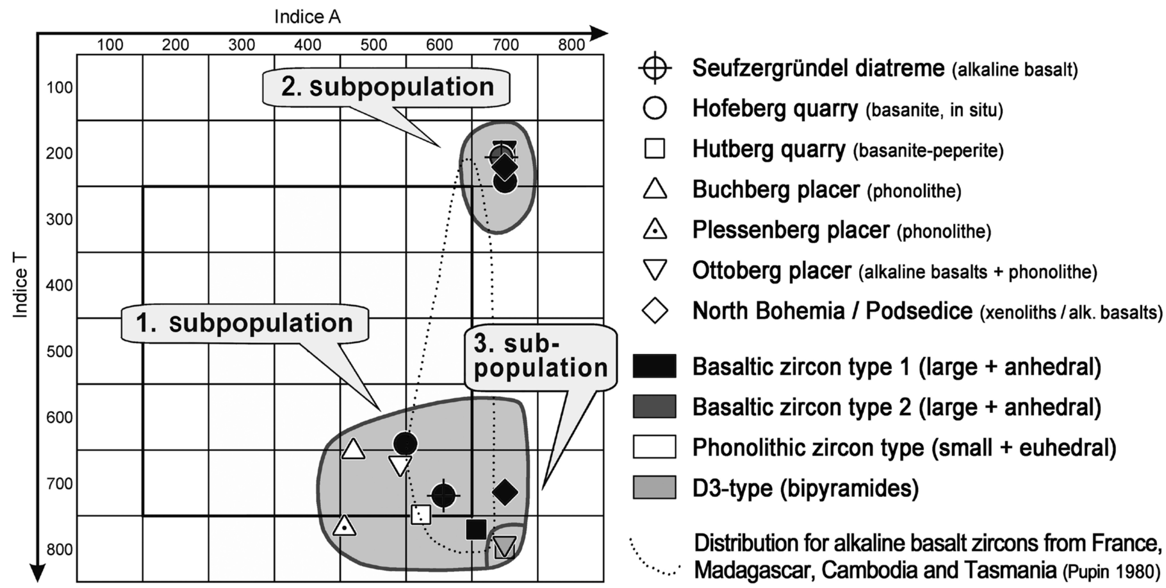

Fig. 1. Typological distribution of zircon megacrysts from Saxony (Germany) and North Bohemia derived from alkaline magmatic rocks according to the classification of Pupin (1980).

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Tertiary volcanism in the western part of the Eger rift and their secondary minerals

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Tertiary volcanic rocks in the western part of the Eger rift are well known because of their secondary minerals found in many quarries.

Not only their interesting geological setting is of particular interest but also their rare mineral occurrences in low temperature and pressure formation conditions. Especially their xenolites with varying metamorphic and metasomatic mineral reactions formed different new interesting minerals often accompanied by zeolite minerals.

Some of these occurrences were summarized recently by Pöllmann & Peterek (2010). The newly found zircons in stream sediments of the Reichsforst are also extremely interesting (Siebel et.al. 2009). The various different minerals formed during the many processes can be schematically summarized:

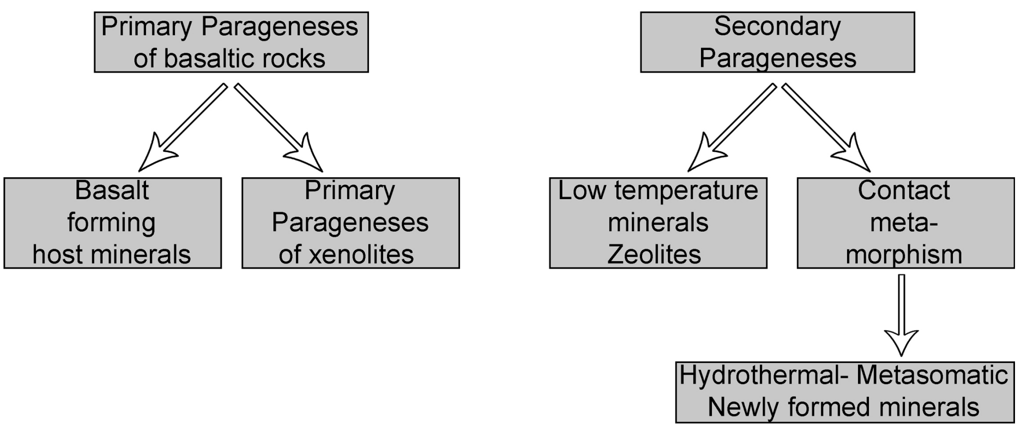

Fig. 1. Mineral parageneses and their formation conditions

These minerals are formed at different temperatures and can be divided into the following temperature scheme:

Tab. 1: Temperature dependant mineral formations in basaltic rocks

< 1200˚C	Crystallisation of basaltic melt
1000˚C	Pyrometamorphosis and Metasomatosis Reactions
< 400˚C	Hydrothermal Transformation reactiosn of minerals
< 300˚C	Zeolite formation
< 100˚C	Weathering of all mineral paragenesis

The widespread different chemical compositions and p,T conditions lead to some unusual mineral associations. Aside of these complex reactions many zeolites, zeolite intergrowth, epitaxial intergrowth, pseudomorphoses of zeolites and decomposition reactions can be described.

An epitaxial overgrowth of magnetite on pyroxene is given in figure 2.

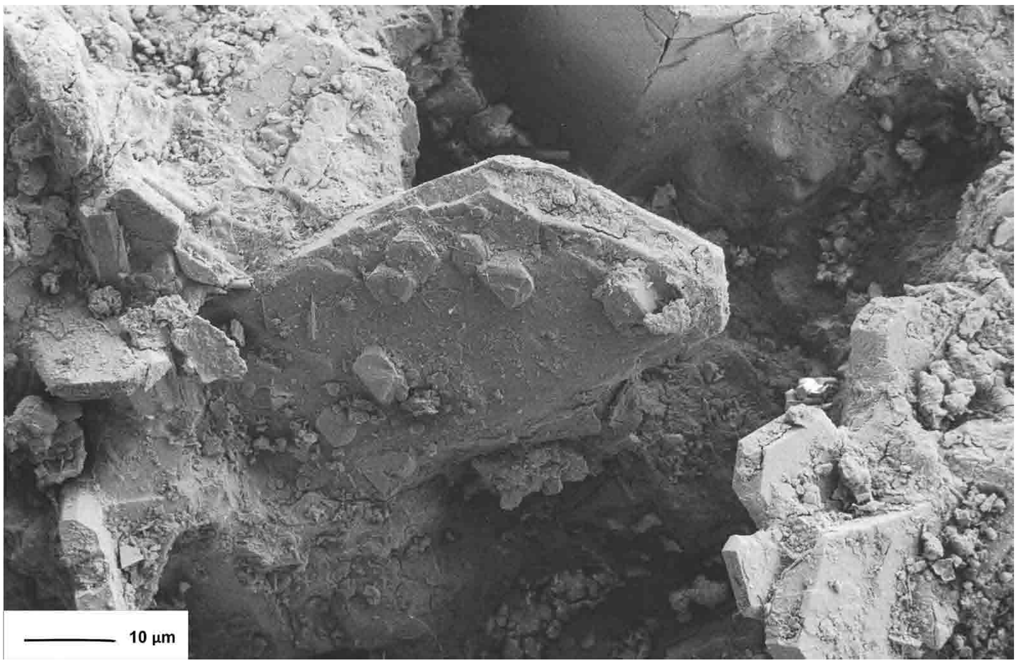

Fig. 2. Epitaxial overgrowth of magnetite on pyroxene, Silberrangen, Upper Palatinate

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2b

Geochemical and petrographical investigation of basanite from the northern margin of the Eger Graben

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We report geochemical-petrographical data about the locality Spitzberg near Cotta, 20 km SE of Dresden, which forms part of a series of Tertiary basaltic intrusions on the northern margin of the Eger Graben. The Cottaer Spitzberg is a volcanic neck and was mentioned e.g. by Tröger (1934), but no analytical data were given. It consists of ultramafic volcanic rocks of surprisingly homogenous basanitic composition despite the variable appearance of the rocks. The rocks contain 31-33% clinopyroxene, 17-20% olivine, 15-18% nepheline and 15-17% plagioclase as major CIPW-normative components, normative orthopyroxene is absent. Major and trace element contents are remarkably constant (e.g. TiO_2 2.98-3.05 wt.%; Ni 135-194 ppm wt; Cr 250-332 ppm wt) in our sample set, with one exception (Ba09; Ni 1432 ppm wt; Cr 577 ppm wt) probably due to accumulated olivine-pyroxene crystals. In contrast to this chemical homogeneity, the samples are structurally diverse. They contain xenocrysts of quartz, which show intense reactions with the surrounding basanite. Vitreous rims suggest that the quartz grains must have been cool when they were assimilated by the magma that was relatively close to its liquidus. Additionally, many of the large clinopyroxene xenocrysts in the otherwise fine-grained Cpx-Ol-Pl matix show intense zoning with idiomorphic outer zones and strongly rounded or even amoeboid green or colorless inner zones. These features suggest partial digestion of early Cpx cores prior to overgrowth by late rims.

Strontium isotope compositions of three samples are between $^{87}Sr/^{86}Sr$ 0.70349 and 0.70353 and show little influence of weathering (acid leaching of sample BA05 shifts the $^{87}Sr/^{86}Sr$ from 0.70349 to 0.70340). The small $^{87}Rb/^{86}Sr$ of 0.22 to 0.26 imposes only minor changes on the initial $^{87}Sr/^{86}Sr$ for Tertiary ages ($^{87}Sr/^{86}Sr$ initial at 60 Ma as an assumed maximum age are between 0.7032 and 0.7033). $^{87}Sr/^{86}Sr$ isotope ratios are slightly more radiogenic than average depleted mantle at Mid Ocean Ridges ($^{87}Sr/^{86}Sr$ 0.7026; e.g. Workman and Hart, 2005), but are within the range of the depleted mantle compositions. Small additions of crustal material to the basanite are indicated by the presence of quartz xenocrystals in the basanite, but the effect on the high Sr (830-860 ppm) melts cannot be evaluated with the present data set. The Pb isotopic composition (sample Ba09; $^{206}Pb/^{204}Pb$ 19.81; $^{207}Pb/^{204}Pb$ 15.62; $^{208}Pb/^{204}Pb$ 39.39) could equally indicate derivation from a young, e.g. Phanerozoic mantle with elevated U/Pb or addition of crustal material (the Pb isotope signature of the local basement and depth of potential assimilation of crust is not known).

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Geophysical and geological survey of the inner and outer structure of the Mýtina maar, western Eger Rift

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Mýtina maar located southwest of the Cheb Basin (Eger Rift) at the Czech–German border is the youngest Quaternary maar at the Bohemian Massif. Comprehensive geophysical investigations of electrical resistivity tomography, gravimetry, magnetometry and seismic methods were accomplished. The results obtained together with a field geology revision and additional geological data from seven drill cores up to 9 m depth; provide a detailed picture of the structure this maar-diatrem volcano, the post-eruptive maar infill sequence and the eruptiva distribution in the surroundings. Geophysical and geological data show the following features:

1. Anomalies in the geoelectric tomography and magnetic survey indicate cone shaped substructures around the maar Mýtina whereby normal faults as radial structures were created.
2. A broad structure of tuff/tephra filled depression identified by geophysical profiles and outcropped by 3 drills confirms a NW-SE striking of the Tachov fault zone between both Mýtina maar and Železna hůrka scoria cone.
3. The deposition of tuff at the base and tephra at the top is proved in some cases by geoelectrical tomography and magnetic survey also in comparison to local drill sites and one trench. So the palaeovolcanic crisis with different phreatomagmatic eruptions affected an area of about 6 km2 with pyroclastic deposits of different thickness.
4. The distribution of eruptive of possibly phreatic origin ca. 1 km north of the maar proved by one drill core and field geology revision gives a preliminary assumption for palaeovolcanic pyroclastic flow deposits.

Quaternary volcanism in Central Europe: new results from Železná Hůrka/Eisenbühl (Czech Republic)

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The youngest expression of volcanism related to rifting in Central Europe occurred in the Cheb Basin area, (Komorní hůrka/Kammerbühl and Železná hůrka/Eisenbühl) from 0.7 to 0.3-<0.1 Ma (Mrlina et al. 2009, Schwarzkopf & Tobschall 1997). Here we present the first geochemical analyses of fresh glasses from the Eger rift. These glasses have been recovered from phreatomagmatic scoria layers of Železná hůrka/Eisenbühl. We have measured major elements, trace elements and short- and long-lived isotope data to place constraints on the eruption ages and the petrogenesis of Železná hůrka/Eisenbühl. In contrast to previous studies we analysed glasses and whole-rock samples to check for potential effects of fractional crystallisation and assimilation on their geochemical composition.

Modern analytical techniques were used to determine the precise chemical composition of glasses and whole-rock samples in terms of their major (electron microprobe and XRF) and trace element compositions (ICP-MS), Sr-Nd isotope ratios and possible U-Th(-Ra) disequilibria (TIMS and MC-ICP-MS). In addition, we have analysed oxygen isotope compositions of olivine and clinopyroxene crystals (laser-fluorination).

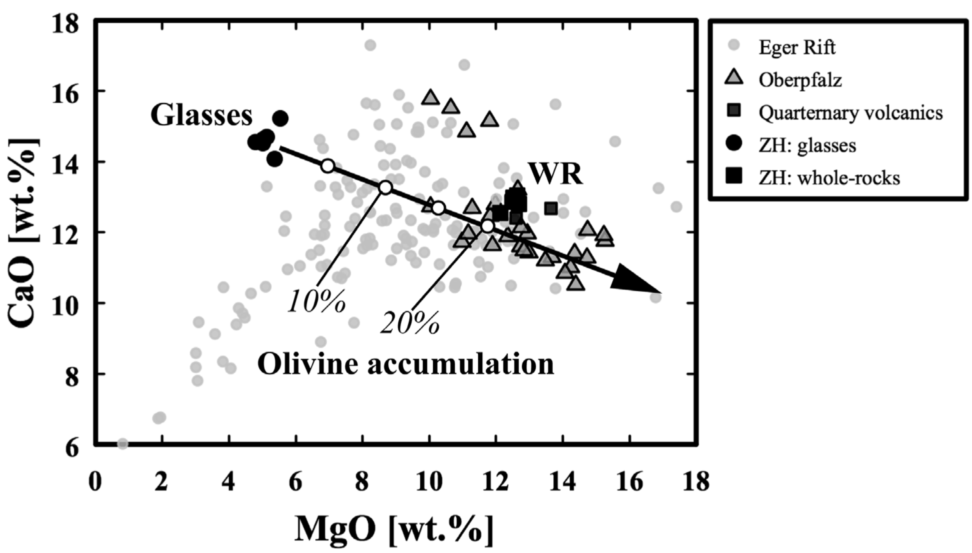

Fig. 1. MgO versus CaO. Grey dots and triangles represent published data from the Eger rift and Oberpfalz, respectively. Dark grey squares are quarternary volcanic rocks from Komorní hůrka/Kammerbühl (this study) and Mýtina (Geissler et al. 2007). Our recent data from Železná hůrka/Eisenbühl are shown by black squares (ZH: whole-rocks) and dots (ZH: glasses). Note the large discrepancy between these two types of samples that is at least partially an effect of crystal accumulation of olivine in the whole-rock samples.

A first major observation is the difference in the major element composition between whole-rock and glass samples that is most likely an effect of significant olivine crystal accumulation in many of the whole-rock samples (see figure above). First results from Sr-Nd isotope analyses confirm data from previous studies and assign an invariant isotopic composition to the volcanic products of Železná hůrka/Eisenbühl. Chlorine concentrations in glasses from Železná hůrka/Eisenbühl are unusually high (3000-3500 ppm). This enrichment in Cl is probably an indicator for the involvement of phlogopite and is also supported by petrographic observations. The range in oxygen isotope composition of olivines ($\delta^{18}O \approx +5.1$-$6.5$ ‰ V-SMOW) is a strong indicator for the assimilation of significant amounts of older crustal material in these young lavas.

Uranium-Th(-Ra) disequilibria will allow to put further constraints on the eruption age of Železná hůrka/Eisenbühl. Potassium-Ar and Ar-Ar data obtained by analyses of phlogopites may provide ages that might not represent the true eruption age since they have not crystallised from the parent magma. This observation is only speculative at the current stage of this research project but work is in progress to resolve this problem.

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2b

Tracing and quantifying magmatic gas discharge in the diffuse degassing area of Hartoušov (westen Eger Rift), based on combined CO_2 soil gas flux studies and geophysical surveys

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The Western Eger Rift is known as the geodynamically most active area in the European Cenozoic Rift System (Bankwitz et al. 2003). Only a few km to the north (Nový Kostel) of the area of interest are recurring earthquake swarms, which are triggered by uprising mantle-derived fluids (Bräuer et al. 2003). Along the assumed N-S-oriented Počatky Plesná fault zone (PPZ) (Bankwitz et al. 2003) there are also different CO_2-degassing related phenomena like diffuse degassing, dry and wet mofettes (Kämpf et al. in press). Because of the high gas fluxes at diffuse degassing structures (DDS) in the Hartoušov area this region is of high interest, considering the yet unknown level of hazard to humans and animals alike in this region, as the amount of degassed CO_2 is as high as in volcanically active regions (Chiodini et al 2008) and the structure of the vent system below the surface is rather complex and unique within Central Europe (Flechsig et al. 2008).

Kämpf et al. (in press) featured systematic research on the central part of the Hartousov area and found out that ca. 95% of the total amount of degassing CO_2 can be related to small (<1m diamteter) isolated vents. As a follow-up study, the research was extended to a larger area to check if these results also apply to the rest of the area. Additionally, a geophysical approach in which electrical resistivity tomography and gravity measurements have been applied to the area is used to relate CO_2-gas fluxes to subsurface anomalies found in the geophysical measurements.

At the DDS we found CO_2 vents with gasfluxes of up to >100kg/d/m², while featuring diameters of only some few dm. Detailed research has to be done on these vents to correctly quantify the gasflux. Furthermore, repeated measurements on the same spots indicate a yet unknown change in the gasflux throughout time that cannot be related to meteorological effects.

A morphological step following interpreted as a marker for the PPZ (Bankwitz et al. 2003), seems to be a natural border for the degassing, forcing the CO_2 to degas along this step and thus leading to concentrated gasfluxes parallel to the fault zone. This leads to a N-S-oriented degassing in the southern part and a NNW-SSE-oriented degassing in the northern part of the Hartousov mofette area.

Areas of high gasfluxes also correlate with anomalies in the electrical resistivity and local gravity field, indicating a reservoir in some tens of meters depth below the CO_2 vents and with several meters in diameter.

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2b

Local seismicity in Saxony – Swarm earthquakes and (magmatic?) fluids

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More than 100 years ago the terminus Swarm Earthquake (*Schwarmbeben*) was created by Josef Knett in 1899 describing a series of nearly 100 felt earthquakes in the region W-Bohemia/Vogtland close to the German-Czech border. On a global scale the occurence of earthquake swarms is mostly related to areas of active volcanism and migrating fluids. In the W-Bohemia/Vogtland region magmatic processes in the intra-continental lithospheric mantle currently take place in absence of any presently active volcanism at the surface. However, besides earthquake swarms they are expressed by a series of phenomena distributed over a relatively large area, like surface exhalations of mantle-derived and CO_2-enriched fluids, mofettes, mineral springs, and enhanced heat flow.

Since 2000 Leipzig University operates a local seismic network in W-Saxony to monitor the local seismicity. Additional stations of other local (W-Bohemia, Thuringia, Bavaria) and regional seismic networks (German, Czech) are available. The sensistivity of these networks is high enough to detect microseismic events with magnitudes below zero.

Seismicity is mostly concentrated in the focal region of Nový Kostel and Luby (CZ). But the epicentral map of the region shows a more or less dense band of seismicity stretching from Northeastern Bavaria (Oberpfalz) in the South over W-Bohemia/Vogtland in the centre and Zwickau (Saxony), Gera and Altenburg (Thuringia), Zeitz (Sachsen-Anhalt) up to Leipzig (Saxony) in the North. The region of Gera is the place with the largest earthquake hazard, and is ordered to hazard zone 2 out of 3 possible zones according to German regulations.

The swarmlike behaviour of seismicity decreases with the distance from the W-Bohemia/Vogtland region, but is clearly observed up to Marktredwitz (Bavaria) in the South and Zwickau/Werdau in the North. There is no clear border between regions with and without swarmlike seismicity. Beside the prominent swarms of the Nový Kostel/Luby focal area we investigated smaller swarms in Saxony near Bad Brambach (2011) and Zwickau/Werdau (2006). The Bad Brambach swarm contains ca. 150 events during a few days. After relocation using the *HypoDD* algorithm the cloud of epicenters shows a lateral extent of ±200 m in N-S direction, and ±400 m in E-W direction; the vertical extent amounts ±600 m relatively to the centre of the cloud at a depth of approximately 10 km.

Following the results of other reaearch groups there is evidence for an upwelling of the asthenosphere below W-Bohemia/Vogtland and of degassing more or less directly from the upper mantle. There is a clear link between fluid migration and swarm earthquake activity. Fluids seem to be important for earthquake triggering, and hypocenter migrations during a swarm may indicate the location of fluid pathways. On the other hand gas springs are generally separated from earthquake epicenters. However, the near-surface hydraulic system responds to seismicity, and groundwater level changes have been repeatedly obsereved in Bad Brambach before earthquake swarms. Seismology can help to image the fluid migration paths through the brittle part of the crust, and to explore the true spatial extend of the zone with active fluid upwelling.

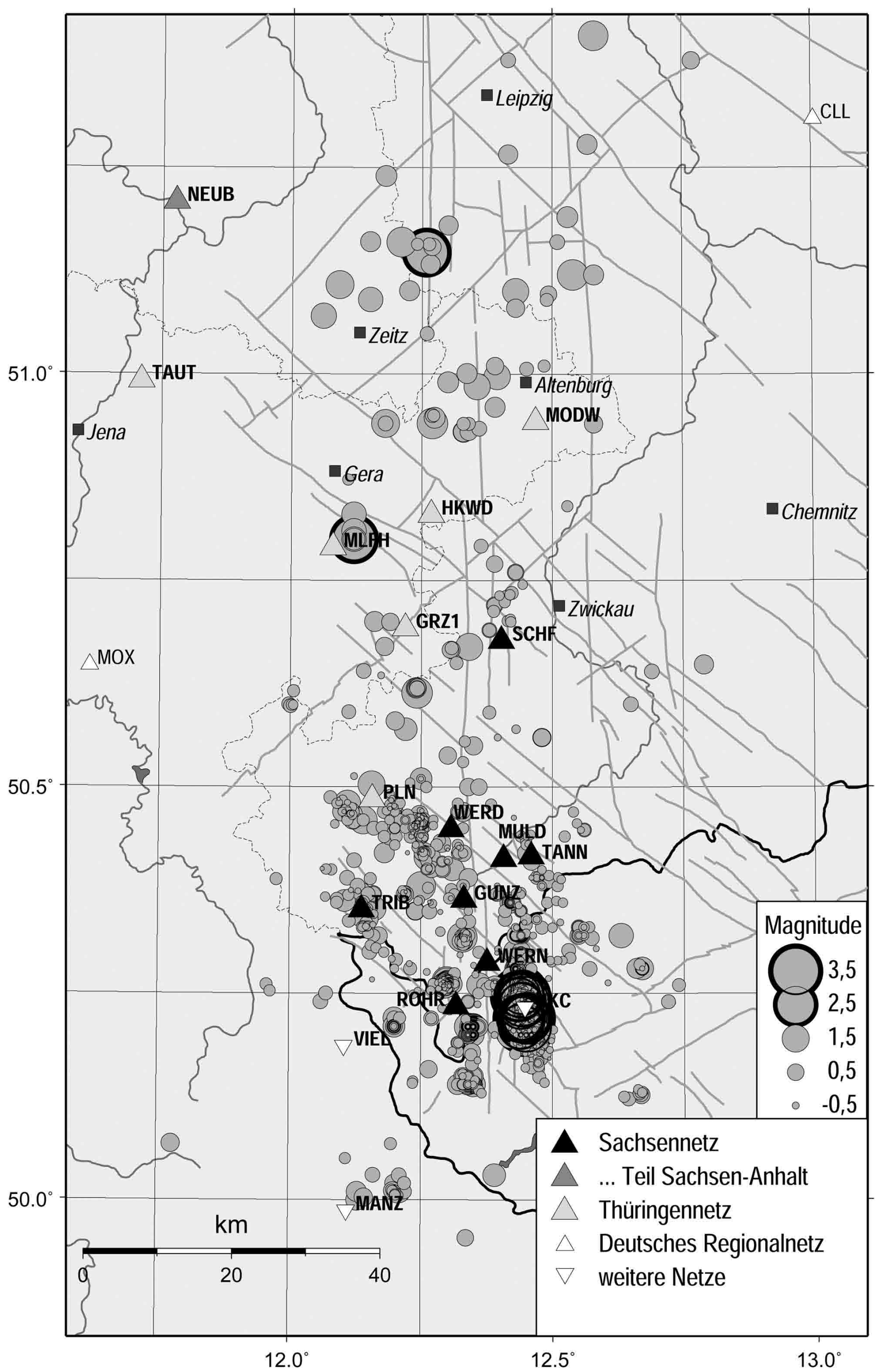

Fig. 1. Seismicity of western Saxony (D) and W-Bohemia (CZ) during the years 2007–2011, earthquake stations and pattern of geological/tectonic faults. The catalogue contains 4951 events with local magnitudes from -0.9 up to 3.9.

The ”Triasscholle” near Greiz, E Germany – A volcanic origin?

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Near the city of Greiz in Eastern Thuringia, Germany, exists a stratigraphically non-coherent breccia bedded in shales from the Lower Carboniferous, which includes larger blocks of Triassic sediments, the so-called “Triasscholle”. The formation’s origination has previously been interpreted tectonically.

The two geophysical methods of the geomagnetics and the gravimetry have recently been applied to the area. We found out, that the formation is characterized by no noteworthy magnetic but a distinct, spatially small gravity anomaly of about -2 mGal and whose shape hints for a structure roughly twice the previously suggested size. Most of the information available is derived from older drillings located in the SW part but not near the gravity low. In addition, SEM investigations on drill core samples from breccia of different depths show a cataclastic deformation in the upper parts, while we find indications for a plastic deformation below 95 m depth both on macroscopic and microscopic scales, indicating an anomalous increase of heat with depth. Judging from the gravimetric minimum and the SEM investigations on the breccia samples we assume the Triasscholle near Greiz to be a deeply eroded maar-diatreme-volcano (Nickschick et al., submitted, Fig 1.), similar to the one near Ebersbrunn, Saxony, Germany (Kroner at al. 2006, Schmidt et al, submitted). Most interesting however, are blocks of several meters in diameter of Middle Triassic limestone encountered in the drillings, which we interpret as crater wall slides at the diatreme’s edge.

Due to the results from pollen analyses on sedimentary remnants the formation can be considered to have Santonian age (≤ 85 Ma), wherein little is known about Upper Cretaceous volcanism in Central Europe, aside from the Delitzsch Complex which was also dated to be of Late Cretaceous age (Krüger et al. 2012).

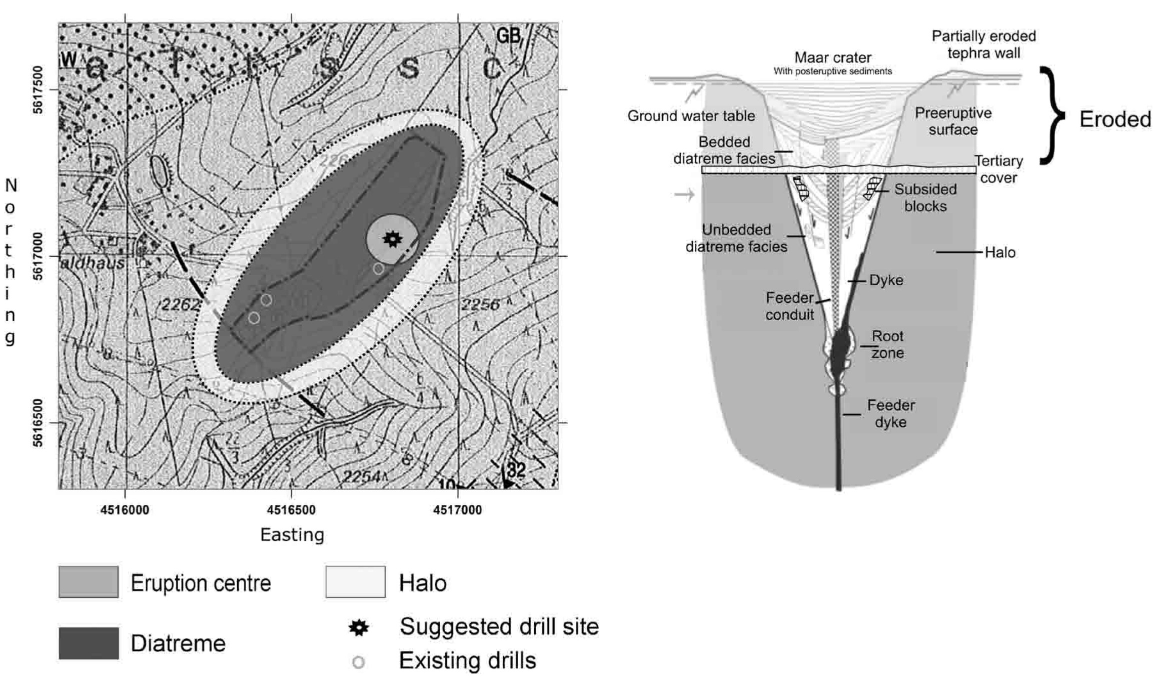

Fig. 1. Left: Assumed size of the diatreme and the position of the eruption center and the brecciated area around (halo). Right: Model of a maar-diatreme-volcano, where the topmost part is eroded to (at least) the sub-maar area and to be surrounded by a halo (Nickschick et al., submitted).

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Investigations on the origin of the magnetic anomalies at the Ebersbrunn diatreme (W Saxony, Germany)

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The Ebersbrunn diatreme is located 10 km SW of Zwickau, western Saxony. It is a deeply eroded diatreme structure and has a diameter of about 1.2 km (Berger 2008; Kroner et al. 2006). This gives us the chance to investigate a deeper section of a partly eroded diatreme what may reveal insights into processes during the maar diatreme formation.

In the 1960´s the Ebersbrunn diatreme was detected as a magnetic anomaly (Jäger 1964) and later studies revealed a complex composition of positive and negative magnetic anomalies. Our investigations aim to explain the origin of well-defined positive and negative magnetic anomalies. To identify the possible causes for the single magnetic anomalies rock magnetic studies were performed on 3 drill cores. The studies include bulk susceptibility and its anisotropy, temperature dependent susceptibility, various remanence measurements (NRM, ARM and IRM) and alternating field demagnetization. Additionally scanning electron microscope (SEM) imaging and energy-dispersive X-ray spectroscopy (EDS) were performed for a better characterization of the magnetic minerals (Schmidt 2011).

The magnetic anomalies represent diverse environments within the diatreme. They have different proportions of magmatic material and therefore different concentrations of magnetic minerals. Further, different mineralogical groupings and grain sizes play an important role. Hydrothermal overprinting also influences the magnetic signal. Samples from the positive magnetic anomalies have a relative high degree of anisotropy, but no preferred orientation of one of the principal axes can be seen. The positive anomalies are interpreted as the feeder conduit(s). The negative magnetic anomaly has a sedimentary-, compaction-like magnetic fabric but without a visible bedding. It seems to be part of the marginal area of the lower unbedded diatreme outside of the feeder conduits (Fig. 1).

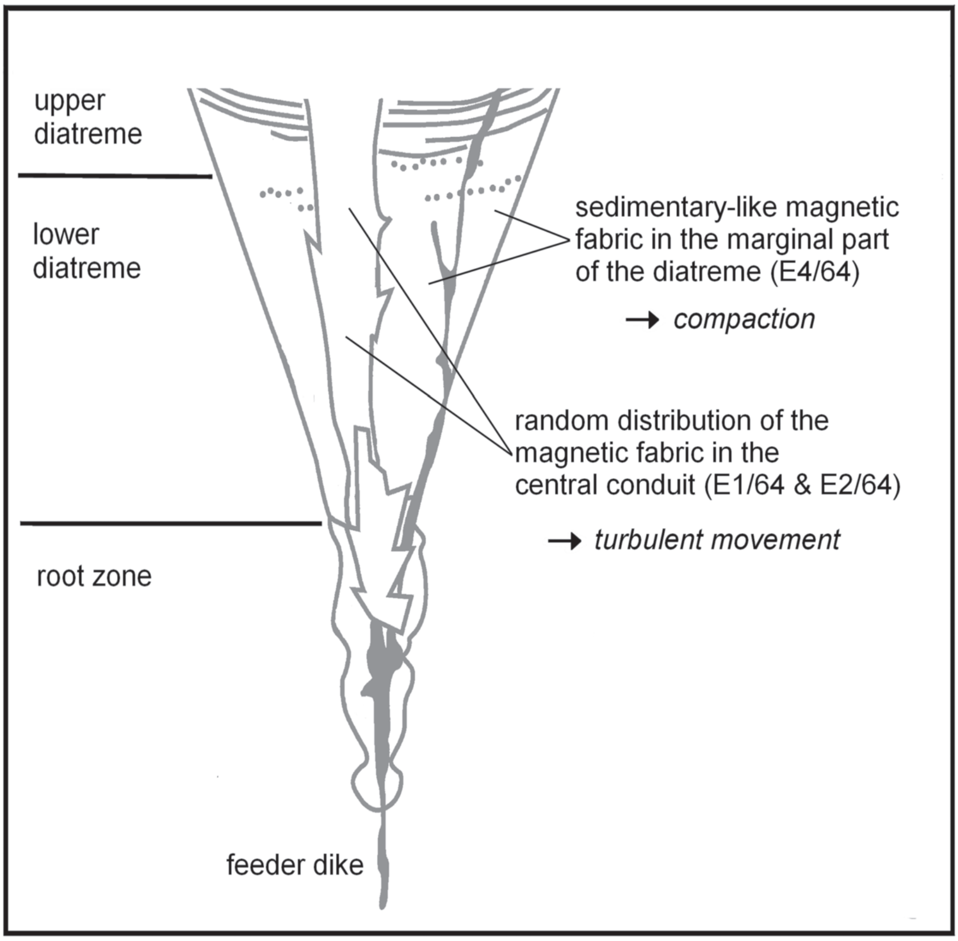

Fig. 1. The AMS results correlate with structural units within the diatreme. The model explains differences in magnetic fabric as well as concentration variations.

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Juvenile fragments in the diatreme breccia of the Ebersbrunn diatreme (West Saxony, Germany)

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The Ebersbrunn diatreme is the deep eroded (Berger 2008) residual part of a former maar-diatreme-volcano. The structure is located SW of Zwickau, Western Saxony, Germany, with an oval surface outcrop of 2 km × 1.5 km (Kroner et al. 2006, Matthes et al. 2010).

This work aims at explaining the paleo magma formation and describing the transport processes of the juvenile material. Petrographic studies of three drilling cores of the diatreme breccia, including scanning electron microscope (SEM) imaging and energy-dispersive X-ray spectroscopy (EDS) have been performed. The diatreme breccia contains spheroidal juvenile fragments (Junqueira Brod et al. 1999) - namely spinning droplets with sizes up to 2 mm and magmatic autoliths which are much larger up to several cm. There are different kinds of spinning droplets included with varying chemical compositions which belongs to a continuous mixing series. The first ending part presents only silicic contents (type 1-a), see Fig. 1 and on the other side there are mostly carbonatitic minerals (type 2-c). The magmatic autoliths also present a variation of the ratio of included minerals between more silicic and carbonatitic dominated rocks. We assume that all juvenile fragments indicate a differentiation of the magma into carbonatitic and silicic melts in the magma chamber. The small sizes of the crystals in the juvenile fragments indicate a fast cooling of the magmatic material what points to a location of the magma chamber in the upper earth crust. The ascent of the melt probably caused a turbulent motion of the material and forced an orientation of the included prolate shaped crystals, in this case mostly apatite, in every single spinning droplet.

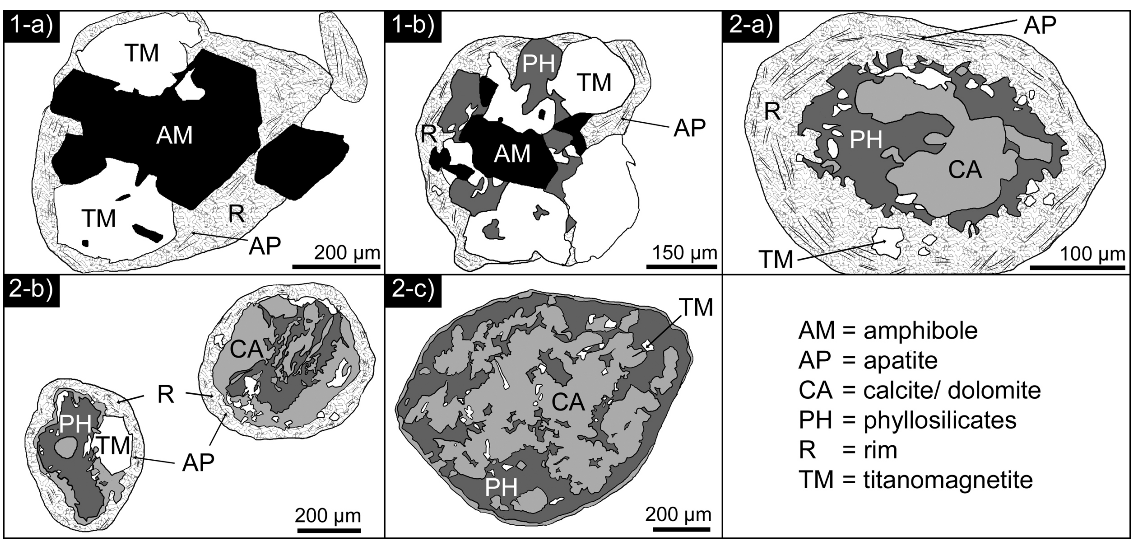

Fig. 1. Schematic illustration of the five main types of spheroidal droplets belonging to a mixing series between 1-a (silicic ending part) to 2-c (carbonatitic ending part) in the Ebersbrunn diatreme breccia.

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San Venanzo intrappenninic volcanic complex, Part I: textural constraints and preliminary definition of volatiles in kamafugitic magmas

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The San Venanzo volcanic complex is located 30 km NNE of the Vulsini Complex and represents one of the most important and well preserved intrappenninic kamafugitic center and can be subdivided into three major vents: San Venanzo, Pian di Celle and Celli.

Pian di Celle represents the major vent (< 2 Kmq) of the San Venanzo complex; it has been classified as an explosive-effusive center. The pyroclastic-ring is overlain, in continuity, by the final production of a kamafugitic/venanzitic (Lct+Ol+Mel+Kls+Phl+Cpx) lava flow.

The field analysis has highlighted three major features within this venanzitic lava-flow: one first episode, recognized only at the vent (SV3), characterized by a strongly vesiculated scoriaceous lava-bed; a well developed macrocrystalline facies (PEG) with venanzitic mineral association enriched in Ap+Bt+Kls+Cc, visible at the head of the venanzitic flow; microamygdules (< 3 cm in diameter) with mineralogy similar to the macrocrystalline facies, observed in the whole lava flow (SV4, SVX).

Given the widespread occurrence of volatiles in these eruptions (first phase characterized by explosive event, second phase represented by emission of lavas enriched in vesicles and amygdules), we decided to investigate in greater details volatile distribution and evolution during the eruptive phases via textural analyses. For this purpose, we selected samples from different phases recognized in the lava flow: the scoriaceous bed (SV3), the macrocrystalline facies (PEG), a microcrystalline lava with presence of micrometric amygdules (SVX), and the last emitted portion of venanzite lava at the vent (SV4). Different percentages of each phase (vesicles and amygdules-minerals) were calculated to obtain preliminary constraints on the relationship between vesicle and crystal distribution.

Preliminary results indicate that:

- the total percentage of vesicles plus amygdules is constant throughout the flow, (16-19% with a mean value of 17.2%);
- the highest vesicles contents (17%) are obtained for scoriaceous venanzitic bed (in which amygdules are absents);
- the maximum value of amygdule-like assemblage (15.3%) is related to the macrocrystalline facies (PEG);
- SVX and SV4 samples, present a vesicle content of approximately 4% and an average of 12% of amygdules, corresponding to the microcrystalline sample and lava at vent that represents the last erupted product.

The continuous evolution of the textural features investigated, the similar total percentage of vesicles plus amygdules throughout the flow, and the absence of structural controls or correlation between fragile elements and macrocrystalline facies (Lucci et al. 2011), suggest that the macrocrystalline facies cannot be interpreted as a dykelet intrusion of lava (Stoppa et al. 1997). Alternatively, on the basis of our preliminary reports on vesicle distribution in the lava body, and in agreement with the models by Melnik (2000), Spieler et al. (2003) and Mueller et al. (2004), we suggest that the effusive phase of the San Venanzo kamafugitic/venanzitic lava is originated from a continuous discharge of a fluid-enriched magma. The activity initiated by the discharge of a bubbly flow in which volatiles were completely exsolved from the magma, generating the scoriaceous lava present in proximal location. Following this initial event, macrocrystalline (PEG) and microcrystalline (SVX and SV4) lavas, with the low vesicles percentage (4%), were erupted, representing the magma, enriched in dissolved volatiles, approaching to the volatile-exsolution level. Macrocrystalline facies, (PEG), could be interpreted as a macroamygdula itself and represents the first emission of lava after the scoriaceous event. Chemical and petrographical analyses of the macrocrystalline amygdules also support this interpretation and are presented in a second related abstract (Lucci et al 2013, this volume).

Textural analyses of the crystal distribution along the flow are underway to further investigate the dynamic and evolution of San Venanzo activity.

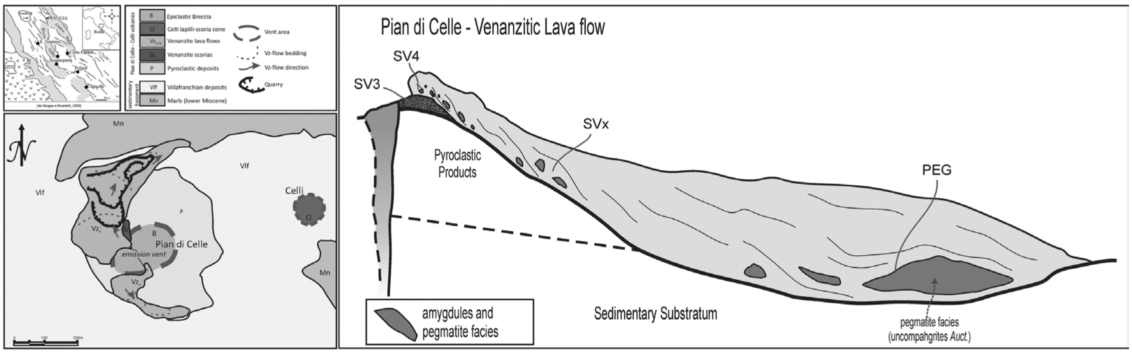

Fig. 1. Distribution of intrappenninic kamafugitic centers. Geological map of Pian di Celle ring (San Venanzo Volcanic Complex) and schematic sketch of Venanzite lava flow (Modified from Lucci et al. 2011).

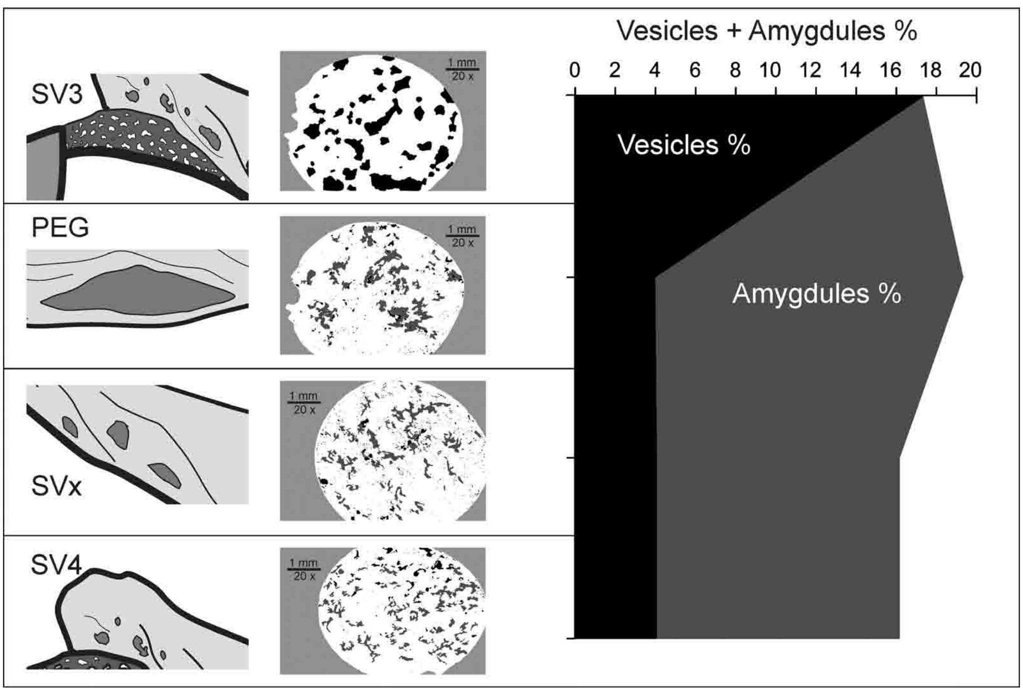

Fig. 2. Table showing vesicles and amygdules content in venanzite selected samples: for every sample is presented i) position (from the top to the bottom, in order of emission from the vent) along venanzitic flow (modified from Lucci et al. 2011), ii) representative binarized image used in texture analysis (black as vesicles, dark gray as amygdules), iii) schematic plot for cumulative vesicle and amygdule distributions in analyzed samples.

2b

San Venanzo intrappenninic volcanic complex, Part II: mineral chemistry evolution related to volatiles in kamafugitic magmas

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The San Venanzo volcanic complex is one of the most famous Pleistocene kamafugitic intrappenninic centre (for more detail see Campagnola et al. in this volume). All volcanic products have been classified by authors as a kamafugitic Venanzite: an ultrapotassic volcanic rock characterized by leucite+olivine+melilite+kalsilite+phlogopite+clinopyr oxene. The venanzite lava flow is famous for the presence, at the head of the flow, of a venanzitic pegmatitic facies (PEG) with enrichment of apatite+biotite+calcite. Lucci et al. (2011) and Campagnola et al. (2013 – this volume) have suggested that the hypothesis of Stoppa et al. (1997), who considered this facies to represent a minor intrusion in the cooled lava, may be in error: *i)* joints and fractures invariably demonstrate a posteriority character in respect of PEG lava (Lucci et al. 2011); *ii)* at microscale a rapid progressive continue transition from porphyric microcrystalline (lava) to equigranular pegmatite has been observed (Fig. 1); *iii)* microcrystalline amygdules distributed along the lava flow present the same mineral assemblage as the PEG facies. These data strongly suggest that PEG facies and the amygdules, are the consequence of different cooling and crystallization processes in the melt. A preliminary texture analysis presented by Campagnola et al. (2013 - this volume) describes how the number of vesicles plus amygdules is consistent throughout the flow, thus suggesting that the volatile composition in the kamafugitic non-fragmentated melt was constant and equally distributed. What kind of volatiles are responsible of this localized macrocrystallization? Considering the evolution of mineral chemistry from micro to macro textures we suggest these volatiles dissolved in magma:

- $F+PO_4$: Abundance of F-Apatite with "skeletal morphology", typical of precipitation from a cooling liquid (Wyllie et al 1962);
- H_2O*: i)* Enrichment of biotite mats together with evolution from leucite to Low P-T pseudoleucite are tupical of H_2O oversaturated ultra-alkaline evolved melts (Hogarth, 1997); *ii)* Evolution from Cr-spinels to Ti-Magnetites; *iii)* Olivine evolution from forsterite to fayalite+tephroite; *iv)* Progressive enrichment of hedenbergite in clinopyroxene, together with increase of aegirine;
- CO_2: *i)* Apatites presents melilite and calcite coats, indication of CO_2 in the melt (it is beyond the scope of this discuss on the origin of the CO_2 in the melt); *ii)* Anomalous enrichment of Monticellite is reported in amygdules and in PEG; *iii)* Anomalous enrichment of wollastonite compound in clinopyroxene from macrocrystalline amygdules; *iv)* Presence of calcite crystallization in the inner core of amygdules.

We can conclude therefore that PEG facies and amygdules were developed by a relative volatile enrichement that inhibited nucleation and favored the rate of crystal growth (Galliski et al. 2004). In this light vesicles, amygdules and lava represent a melt system separated in three immiscible phases in which vesicles correspond to already exsolved volatiles, amygdules correspond to the melt enriched in dissolved fluids and microcrystalline lava represents the normal anhydrous kamafugite. The same volatile compound under overpressure conditions, probably triggered the initial explosive activity of Pian di Celle volcano.

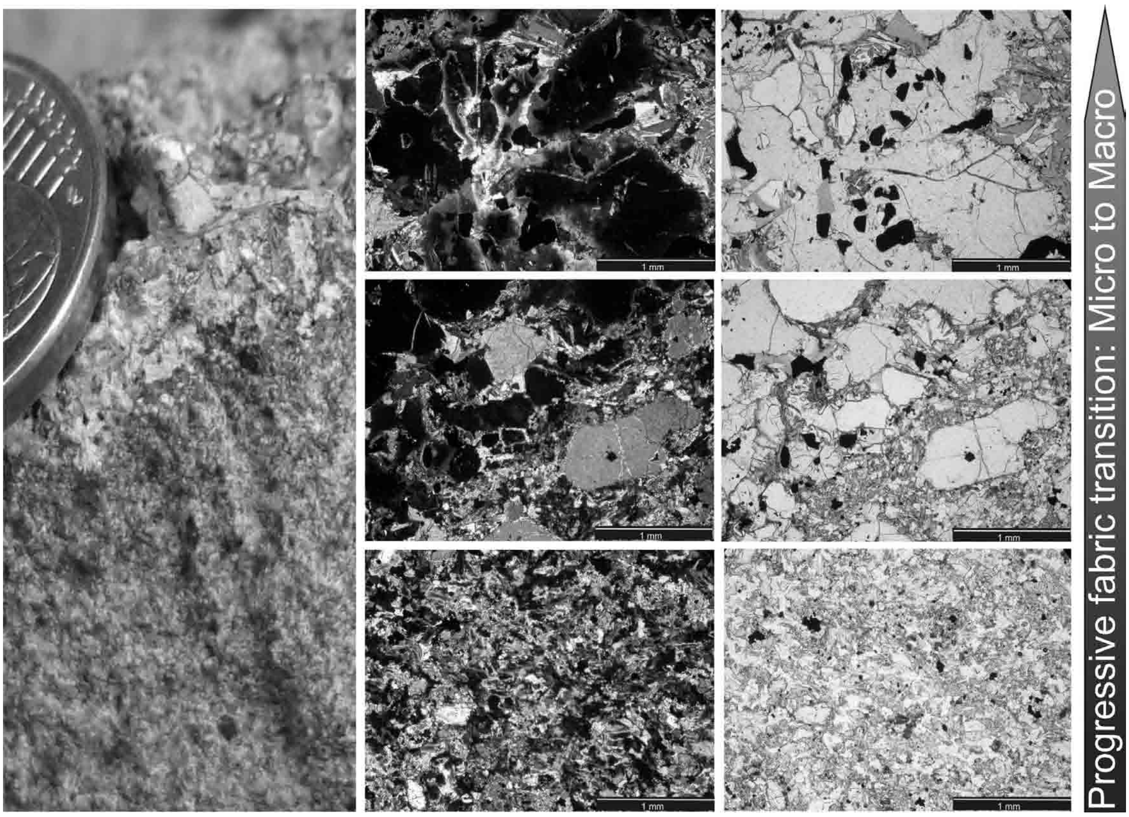

Fig. 1. At microscale, a progressive continue rapid fabric transition from porphyric microcrystalline to equigranular macrocrystalline is observed. (Modified from Lucci et al. 2011).

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Session 3 – Surface

Session 3a

Volcanism & landscape evolution

(Talks and Posters)

Session 3b

Volcanology & Geophysics

(Talks and Posters)

Session 3c

Volcanism and society: geotourism, hazards & resources

(Talks and Posters)

New advances in understanding the role of internal versus external forces on the eruption mechanisms, growth and destruction of monogenetic volcanoes

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3a

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Intense research over the past decades on volcanic fields and their volcanoes of various chemical compositions erupted in diverse tectonic settings, eruptive environments and climates has revealed the complexity of the eruption mechanism, evolution and degradation of small-volume volcanoes, commonly referred to as monogenetic volcanoes. Monogenetic volcanoes traditionally erupt only once during their eruptive history; however, their eruption may follow eruptive phases of increased or decreased magma discharge rates, fluctuation of external versus internal influences on eruption styles, and commonly repeated cyclic periods controlled by complex threshold parameters may alter specific eruption styles (eg. magmatic versus phreatomagmatic). The resulting volcanic edifice is small in volume (< 0.5 km^3) as is the tephra dispersal area (<10^3s km^2; <0.1 km^3 DRE). Monogenetic volcanoes are one of three morphotypes: scoria cones, tuff cones/rings, and maars, reflecting the dominant eruption style during their construction. Their common characteristic feature is that the duration of the eruption forming these small volcanoes is usually shorter than the solidification time required for freezing their feeding system (Valentine & Gregg 2008). Therefore, these short-lived eruptions are envisioned to tap the same melt column through the entire duration of the activity. Recently, it has been recognized that the volcanic facies architecture of volcanoes conventionally viewed as monogenetic, such as those on Jeju Island, South Korea (Brenna et al. 2011) and Auckland, New Zealand (McGee et al. 2012, Needham et al. 2011), can reflect the involvement of evolving melt or even multiple deep melt sources. It has also been recognized that chemical variations may depend on the total volume of melt produced and involved in the eruption. Conversely, external controlling parameters on magma fragmentation and eruption styles have a greater effect on volcanoes produced by smaller volumes of melt (Németh et al. 2012). To fully understand the eruption mechanism of monogenetic volcanoes, we need to understand their plumbing system, fragmentation styles and the eruptive/depositional environment into which they erupt. In this “*source-to-surface*” approach, small monogenetic volcanoes can be produced by a combination of critical parameters, involving magma internal (eg. physical and chemical) versus external conditions, such as the forces acting on the magma on the near-surface environment (eg. upper 500 m). On the basis of this new view, key areas have been identified where major advances are expected in our understanding of monogenetic volcanism: 1) to understand how monogenetic are the volcanoes traditionally viewed as monogenetic volcanoes (eg. including chemical variations and stratigraphical evidence to demonstrate eruptive changes and breaks in the otherwise quickly formed small volcano); 2) to quantitatively express the relative role of the internal (eg. magmatic process-related) and external (eg. the eruptive near-surface and surface environment) parameters in the formation of an individual monogenetic volcano; 3) to determine the role of long term (hundreds to millions of years timescale) variations of the near-surface and surface - so called “*external environmental*” - conditions that may affect the overall manifestation of volcanism over the whole duration of the eruption history (and subsequent volcanic-influenced sedimentation in the same environment) of a volcanic field, including any climatic and hydrogeologic variations (Kereszturi et al. 2011); and 4) to understand the volcanic landform evolution in order to identify governing parameters responsible for syn-eruptive edifice growth and modification (eg. the role of dominant magma fragmentation style on the resulting volcanic morphology) through to post-eruptive erosional phases a specific monogenetic volcanic landform can go through (Kereszturi & Németh 2012). Here we present numerous examples to demonstrate the complexity of monogenetic volcanism and provide a critical model of how we can better understand the Earth’s most common form of volcanism.

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La Crosa de Sant Dalmai: an example of a quaternary maar in a mixed setting

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Maar volcanoes are the result of explosive magma–water interactions (Waters & Fishers 1971). Maar pyroclastic ejecta consist of a mixture of juvenile clasts, and a large proportion of country rock clasts (Lorenz 1985). Lithic clasts in maar tephra rims contain information on the lithology of the substrate and the depth of the explosions.

The type of substrate controls the type of aquifer in which the external water sits (fracture-controlled vs. porous aquifers); the overall shape of the volcano including the diatreme; the post-eruptive lacustrine architecture in the maar crater; and some characteristics of the pyroclastic deposits of the tephra rim and diatreme (Lorenz 2003, Auer et al. 2007, Martín-Serrano et al. 2009)

La Crosa de Sant Dalmai maar (Catalonia, Spain) is an asymmetrical tuff ring belonging to La Selva tectonic depression (7.9–1.7 Ma) bounded by an ENE-WSW and a NW-SE fault systems. This area belongs to the the Catalan Volcanic Zone, one of the Quaternary alkaline volcanic provinces belonging to the European rifts system (Martí et al. 1992).

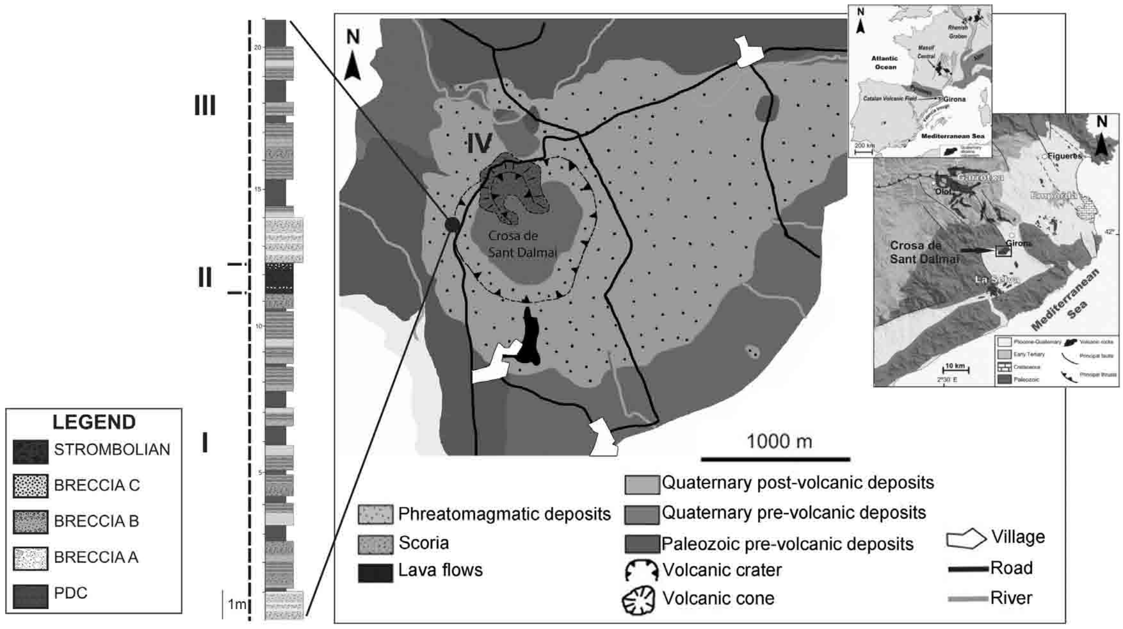

Fig. 1. Geological setting (modified from Martí et al. 2011) and geological map (modified from Bolós et al. 2012) of La Crosa de Sant Dalmai maar. At the left side a synthetic column shows the deposits outlining the main phases of the eruption (I and III hydromagmatic, II Strombolian, IV scoria cone). The different types of breccia of the sequence (BRECCIA A with lithics up to 70%, BRECCIA B with lithics up to 50-60%, BRECCIA C with lithics up to 50% and vesiculated scoriae) are shown in the legend along with PDC and Strombolian deposits.

The deposits cover an area of about 7 km^2 showing an asymmetrical distribution from the vent reaching distances of 4 km towards the east and only of a few hundred metres towards the west. Granites and metamorphic rocks of Paleozoic age form the basement of this area whilst Pliocene and Quaternary sediments filled the depression.

A detailed reconstruction of La Crosa de Sant Dalmai succession have made possible to recognize at least 4 eruptive units. The lowermost corresponds to thick hydromagmatic deposits made of coarse lithic-rich breccias alternated with thin, crudely stratified, coarse-grained PDC deposits. The following unit is constituted by a Strombolian, no welded scoria lapilli deposit. The third unit shows the same characteristics observed in the first. A small strombolian scoria cone and associated lava flow inside the maar crater represent the last phase of the eruption.

La Crosa de Sant Dalmai maar is a tuff ring developed in a mixed setting due to the presence of a hard (Paleozoic granites and schists) and soft (quaternary filling) basement with heterogeneities and differences in hydraulic properties and fracturing patterns. This might suggest the major role played by the external environment for the different forms of water/magma interaction influencing the style of the eruption and the associated deposits.

Due to the mentioned characteristics, the high explosivity of hydrovolcanism is an important reason to consider the potential hazard of hydromagmatic eruptions in volcanic risk assessment.

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Phreatomagmatic basaltic volcanism in Central and Western Europe and its relevance

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After the scoria cone the maar-diatreme volcano is the second most common volcano typye on continents. Maar-diatremes formed no matter what the geochemistry of the magma type reponsible for their formation. The majority of maar-diatremes are related to basaltic monogenetic volcanic fields and thus occur usually associated with scoria cones and their associated lava flows. In the many Tertiary and Quaternary volcanic fields related to the European Continental Rift System (ECRIS) "basaltic" maar-diatreme volcanoes are usually more common than originally assumed.

The best known maars in Central and Western Europe are the alkalibasaltic to foiditic maars in the Quaternary West Eifel volcanic field and the maars in the Quaternary Chaîne des Puys and some other young volcanic fields in the Massif Central in France. In both classic maar areas this volcano type has been studied since c. 200 years. Diatremes are widespread in the Tertiary volcanic fields of the ECRIS.

Since the 1960s it has been increasingly recognized in Central and Western Europe as well as worldwide that maar-diatreme volcanoes are the result of thermohydraulic explosions when rising basaltic magma interacts with groundwater. Many volcanic fields have formed on rather impermeable hard rocks, no matter what their composition. In such areas a large percentage of the groundwater is located in more or less vertically oriented hydraulically active fracture zones that have been shaped by erosion into valleys as happened, e.g., in the Eifel volcanic fields, in the Swabian olivine melilitite volcanic field, and in many volcanic fields in the Massif Central in France. However, on average smaller maar-diatremes also formed on fracture zones that contained less groundwater and, thus, were not shaped by eroson into obvious valleys. Therefore, in those cases groundwater was usually already used up in an initial phreatomagmatic maar-forming phase that was then folled by a magmatic scoria cone- or lava lake-forming phase.

In soft sediment environments as, e.g., in many sediment-filled grabens of the ECRIS and also in many Permocarboniferous late Variscan intermontane basins, as, e.g. the Saar-Nahe Basin, water-saturated sediments can provide sufficient groundwater for the thermohydraulic explosions only when they are coarse enough, when they can liquefy – or when they are cut by hydraulically active fracture zones, as, e.g., by synsedimentary fault zones.

Maar-diatremes start as small volcanoes and, under rather normal groundwater-conditions, they penetrate explosively downwards. Many thermohydraulic explosions cause fragmentation of country rocks and consequent ejection of large amounts of these fragmented rocks. Ejection of these clastic materials at the surface results in repeated mass deficits in the zone of explosion chambers, i.e. in the root zone of the volcano, and cause repeated subsidence of the overlying rocks. A cone of subsidence forms, i.e. the diatreme, within which tephra and collapsed country rocks accumulate and subside. At the surface this subsidence consequently causes formation of a crater, i.e. the maar crater. Thus the maar crater mainly forms by subsidence as a consequence of the ejection of country rock clast-rich tephra during the eruptions. With the exception of the very initial maar-forming eruptions the maar crater does not form by direct ejection of the country rock material that originally existed at the site of the final maar crater – as has frequently been assumed. Hundreds to a few thousands of these small volume tephra ejecting eruptions result in the formation of the rather well- and thinly-bedded tephra ring surrounding the maar crater. As is typical for all volcano types and all subvolcanic structures maar-diatreme volcanoes grow in size – maar crater, tephra ring, diatreme – the longer they are active.

Maar-diatreme volcanoes are not only of touristic interest but provide ground water, road metal, and most importantly they provide diamonds in kimberlite and lamproite diatremes. Other ore deposits, as, e.g., Au, Cu, Pb, Zn, Fe, Sb, F, Ba, V, Te, Bi, Hg, U, REE, formed also in diatremes. Maar-diatreme volcanoes can provide samples from subsurface crustal and upper mantle rocks and also, in case of partially eroded diatremes, of former overlying rock units that became eroded posteruptively.

In respect to the planning of subsurface localizations of HLRW repositories in more or less hard rock environments the formation of maar-diatreme volcanoes tells us about the general existence of hydraulically active fracture zones below valley systems that have formed in uplifted regions, as, e.g., in the uplifted regions associated with ECRIS in Western and Central Europe. To give an example: during their formation the root zone of many maar-diatremes of the Swabian Alb penetrated from near-surface levels downwards on hydraulically active fracture zones – located below valleys - even through the c. 100 m thick Opalinus Clay that is considered to be a potentially safe site for the construction of HLRW repositories.

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The Perşani Mountains Na-alkalic basaltic volcanic field-revised volcanology

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The Perşani Mts. basaltic field, showing a modest extent of 176 km^2 (ca. 22 x 8 km) is the most important in the East Carpathians (Romania). It consists of several monogenetic volcanic centers, arranged parallel to a ~ NE-SW normal fault system and a complex volcanic field, variably affected by erosion and degradation (Seghedi & Szakács 1994). Some old deposits were covered by soil or lacustrine sediments, either inside or outside the initial volcanic edifices. The volcanoes were built-up on hard basement formations of various age, represented by Miocene and Mesozoic sedimentary rocks and volcaniclastics. According to combined K/Ar dating and palaeomagnetic investigation (Panaiotu et al. 2004) the volcanism took place in two phases: between 1.5 - 1.2 Ma, peaking around 1.2 Ma, and at 0.67 - 0.52 Ma. However, recent Ar/Ar dating (Panaiotu et al. in print) suggests that the eruptions took place in four episodes (pulses) occurring at 1162-1220, 1049-1059, 815-817, and 669-687 Ka (isochron ages), respectively. These new dating results, together with a field volcanology revision provide a better picture of the eruptive sequences of the individual monogenetic volcanoes, as well as of the initial maar-related structure of the complex volcanic field. They suggest that all monogenetic volcanoes were rapidly constructed and each one, no matter of timing, started with a phreatic/phreatomagmatic explosive phase. Thinly-bedded pyroclastic deposits with plan-parallel, undulatory or cross lamination and frequent bomb-sags, sometimes associated with beds of sorted scoria lapilli indicate near-vent phreatomagmatic explosion-derived dilute density currents, co-surge fall-out deposition and occasional Strombolian tephra dispersal mechanisms. The hydromagmatic processes that resulted from the interaction of ascending magma with the shallow phreatic aquifer, sometimes associated with magmatic eruptions, characterize the inception of the volcanic activity. This phase was followed by a less energetic explosive one (Strombolian), generating cinder cones with agglutinated spatter deposits emplaced around the emission center and massive to bedded scoriae lapilli deposits, with decreasing particle-size on the outer slopes of the cinder cones. At all locations the final activity was effusive, represented by lava flows that strongly disturbed the initial explosive edifices. The formation of the initial maar structure of the complex volcanic field was followed by several volcanic pulses that show Strombolian, effusive and sometimes initial phreatomagmatic activity. The morphometric variability of the scoria cones, in particular the decreasing of the flank's slope angles was most probably caused by erosion and degradation and could be correlated with the age of their generation. The largest scoria cone (Gruiu) found inside the initial maar of the complex volcanic structure, displays well-preserved slopes close to the original shape, suggesting that this cone could be the youngest structure in the Perşani volcanic field.

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Locating phreatomagmatic eruptive centers by "inverse ballistics": A new methodological approach applied in the Persani Mts., Romania

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Ballistic calculations and modeling of coarse airborne tephra fall processes is by now widely used in volcanic hazard studies. Starting from a known starting point (i.e. a volcanic vent) of coarse ballistic ejecta, the models calculate and display transport trajectories, distances and landing sites of blocks and bombs depending on a number of factors (e.g. block size, shape, density, air drag, ejection angle and velocity) considered as input parameters of the models. As a result, areas of risk from ballistic fallout processes can be outlined and visualized on maps as precious tools in risk mitigation activities at active volcanoes. In an "inverse" approach, one may start from actual impact sites of ballistic clasts found in the field and trace back the ballistic trajectories toward putative ejection points. Measurable impact block/bomb characteristics (size, shape and density) are used to calculate ballistic air transport distances from source to the actual impact feature found in the field. Other input parameters which cannot be inferred from field-measurable properties (e.g. ejection angles and velocities) can be taken into account according to values measured at active volcanoes worldwide from the relevant literature. Introducing reasonable values of such parameters in the ballistic computer simulations, the distance ranges to emission points are constrained with acceptable uncertainty; in particular, the maximum travel distance is fairly well constrained. Whenever asymmetric impact sags are found in the field offering the possibility of 3D observations, transport directivities can also be inferred and used in eruptive center identification.

Pleistocene phreatomagmatic pyroclastic deposits resulting from explosive eruptions of alkali basaltic magma are widespread in the Persani Mts., East Carpathians, Romania (Seghedi & Szakács 1994). They were emplaced by both air-fall and density current mechanisms during early stages of monogenetic edifice construction, likely forming maar-type volcanic features (Seghedi & Szakács 1994). However, no obvious topographic expressions of such features are found nowadays in the Persani Mts. monogenetic volcanic field. Numerous ballistic impact features ("bomb sags") are present in two areas of the field. In the continuation of earlier studies (Soós et al. 2004) using the "inverse ballistics" approach, a number of three areas (two in the Bogata area and one in the Mateias area) likely enclosing maar-type phreatomagmatic eruptive centers have been tentatively identified and outlined. The ballistic calculations and simulations were run by the EJECT computer code of Mastin (2001). Further field observations (e.g. asymmetrical sedimentary structures of base surge deposits used to infer tephra transport directions in pyroclastic density currents) and analysis of remote sensing imagery were considered later in the investigation in order to validate the results obtained from the "inverse ballistic" study.

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Tentative location of maar-type phreatomagmatic alkali-basaltic volcanic centers in the Mateias area (Persani Mts., Romania)

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The alkaline basaltic volcanism in the Persani Mts. represents one of the youngest activities of the Neogen/Quaternary volcanism in the East Carpathians. K-Ar datings shows that a monogenetic volcanic field developed with modest dimensions in the western part of the Persani Mts. during the latest Pliocene and Pleistocene times (ca.2.25-0.5 Ma). Four stages of volcanic activity have been identified, represented by four partly overlapping sequences of volcanic products originating from a small number of eruption centers. The studied, area near Mateias village belongs to the northen part of the volcanic field. In the left side of the Olt river, along the Mateias creek valley well-exposed phreatomagmatic pyroclastic deposits occur. The outcrops are represented by plan-parallel bedded tuffs and lapilli tuffs, with a large number of impact sags in the underlying plastically deformed tephra beds frequently containing the accidental ballistic impact blocks. The deposits are also characterized by multiple normal grading, rarely reverse grading and in places typical dune-bedded base surge sequences. Various types of accidental clasts can be found. All these features are characteristic for subaerial fallout and base surge deposits resulting from phreatomagmatic explosions. The object of this study is to identify and localize the hidden eruptiv center of these deposits. The study is based on careful field examination of the lithology and structure of pyroclastic deposits. Special attention has been given to asymmetrical structures from which clast transport directions can be deduced. For the location of the volcanic center the following criteria have been taken into account: (1) interpretation of pyroclast transport directions from (1a) bomb-sag asymmetry and (1b) depositional structures of base-surge deposits, (2) spatial distribution of clast size of ballistically emplaced products, (3) examination of remote-sensing materials and (4) correlation with other pyroclastic deposits. Statistical evaluation of these indicators strongly suggest that at last part of the investigated pyroclastic deposits originated from a maar-type phreatomagmatic center located east-northeast to Mateias village which add to the previously located centers of the same type elsewhere in the Persani Mts. Because no obvious ring-like or circular-geomorphological features can positively be identified in the present-day local topography, further investigations are needed to confirm this hypothesis.

The Maar of Hammerunterwiesenthal – a "Complex Monogenetic Volcano", Saxony

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The Hammerunterwiesenthal Maar is a complex Tertiary structure with three phases of volcanism documented. It is situated in the Variscan Ore Mountains at the border between Germany and the Czech Republic. Závada et al. (2011) showed the widespread occurrence of phonolite intrusions in former maar structures. Hammerunterwiesenthal is a good example for that.

The local country rocks are gneisses, marbles and mica schists.Tertiary volcanism in this area is connected to the Ohře Rift subsidence from the Upper Eocene to the Middle Miocene. The deep reaching faults of this structure gave way to different magma types and the volcanic activity lasted from the Upper Cretaceous till the Quaternary. The Hammerunterwiesenthal Maar is situated near the north-east shoulder of the Ohře structure by the crossing point between the fluorite veins of the Niederschlag/Kovařska zone and the thalweg of a palaeovalley.

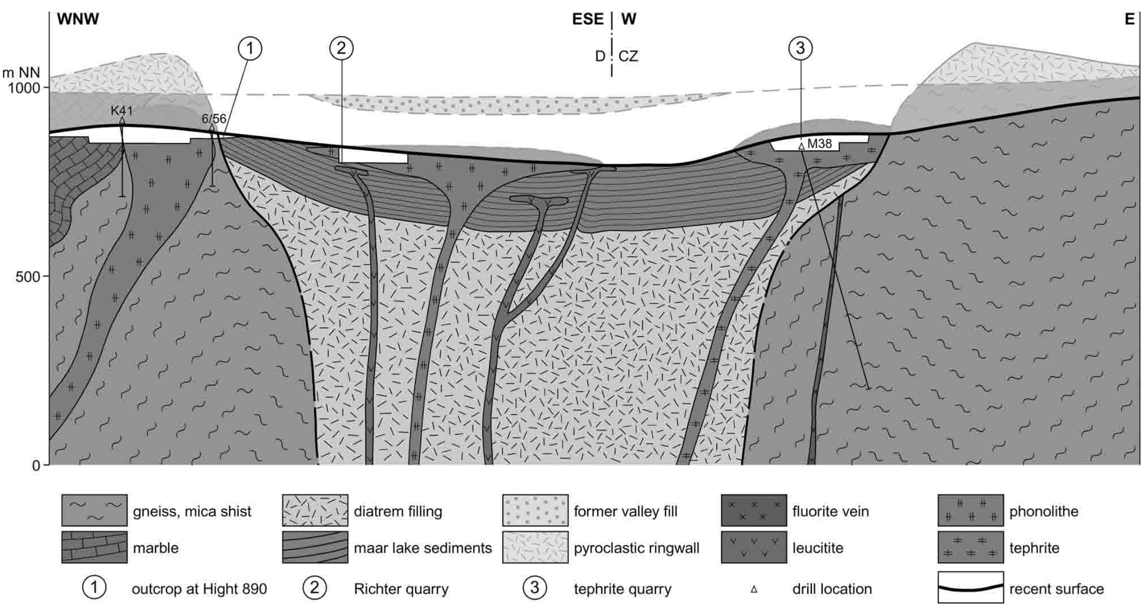

Fig. 1. Cross section through the maar-diatreme volcano of Hammerunterwiesenthal with three generations of volcanic events.

1. The first volcanic event at **30.5** Ma in the Lower Oligocene were phreatomagmatic explosions of a **leucitite** magma and formed a typical maar-diatreme volcano with a 1.4 km wide crater. The crater was refilled with lake sediments.
2. At **28.4** Ma a **phonolite** laccolith took place in these lake sediments.
3. **22.8** Ma ago another subvolcanic intrusion tooks place in the southern part of the maar crater filling, now of **tephritic** composition.

The phreatomagmatic explosions in 30.5 Ma caused a huge maar crater in a palaeovalley. The crater was refilled afterwards. Its lake sediments are exposed in the "Richter Quarry". Three sediment types occur: coarse debris flow deposits, turbidites and laminated limestones. The debris flows deposits consist of unsorted clasts of the crystalline country rocks and some volcanics (leucitite). The turbidites have a similar composition, but the material finer grained and graded. In one distinct layer a lot of fossils have been preserved: compressions of leaves, twigs and fruits as well as gastropod shells and two amphibians. In the deepest level of the quarry a black laminated limestone crops out. This lake sediment has pyritic interlayers between the calcite laminae and is party silicified. In contrary to most of the laminates in other sites this limestone is nearly sterile. One bedding plane shows ichnofossils which are characteristic for lacustrine turbidites. Having only the lower part of the crater filling preserved the younger history of the lake remains unknown.

About 2 Ma later phonolite magma intruded the soft and water saturated lake sediments and formed a laccolith. Along the boundaries of the laccolith peperitic structures occur. On top of the laccolith several pockets with fritted lake sediments survived the excavation in the still running phonolite quarry. An alkali lamprophyre magma penetrated the still plastic phonolite, forming a 60 cm thick dyke crossing the quarry at about 45°. We add this syngenetic dyke also to the second event.

The third volcanic phase produced another laccolith of tephritic composition in the SE of the diatreme, today in the Czech Republic. With an absolute age of 22.8 Ma these rocks are quite younger than the others. The tephrite was quarried in former times but is used as a waste dump today.

Starting in the Miocene the Ore Mountains lifted up and the crater filling and the intrusions as well were eroded. Today the intrusions are exhumed and form low hills. Two of them are quarried to gain pavement material.

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Volcano instability: causes, processes and consequences

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Edifice instability-related issues are in the forefront of volcano research during the last few decades or so. Scientists gradually realized that volcanoes are much more fragile constructs than previously thought. Edifice instability spontaneously emerges as a natural consequence of long-lasting eruptive activity and volcano growth. As such, it can conveniently be viewed as the evolution of the volcano system toward a critical state at which the growing edifice will inevitably respond through some sort of re-equilibration behavior. The critical state is reached by the gradual accumulation of "instability quanta" represented by tiny shifts of a number of parameters during various volcanic and non-volcanic events to which the edifice is subjected while growing. The succession of events leading to instability might be either intrinsic (internal instability factors) or extrinsic (external instability factors) to volcanic evolution. Those "critical parameters" include the position of the gravity center of the edifice, fissure density, volume percentage of hydrothermally altered volcanic rocks, yield-strength and plasticity of rocks in the edifice and in the basement, etc. The relative contribution of each of the "critical parameters" is variable according to the particular volcano history and local conditions. The volcanic edifice thus evolves toward the unstable state by a self-organized critical behavior similar to that described by Bak et al. (1987) at growing sand-piles. Unlike the sand-pile model, where a single critical parameter (i.e. the slope angle) defines the stability status of the system, volcanoes are systems with multi-parametric source of the spontaneously emerging instability and critical state. Besides factors leading to instability, other factors counteracting instability are also at work at growing volcanoes. Symmetry and compositional homogeneity are such "stability factors". The actual state of the edifice is actually a consequence of the net balance between "instability factors" and "stability factors" acting on the same volcano. When instability factors prevail and the edifice evolves toward, and finally reaches, the critical state, re-equilibration processes start to operate. Edifice failure/sector collapse is such a phenomenon which resolves instability through a sudden, often catastrophic, avalanche-like process. Much slower and gradual volcano-basement interaction processes including basement flexure or volcano spreading are equally able to re-equilibrate the unstable volcano system. Intensive erosion at low eruption frequency volcanoes may also effectively counteract instability. Particular local conditions decide which of these re-equilibration processes will actually occur or, eventually, whether and how they combine. The consequences of volcano instability and related re-equilibration processes are multiple, profound and far reaching. Such processes are able to influence and radically modify further eruptive behavior and volcano evolution, volcano topography and topography of the surrounding areas, the hydrographic network, basement tectonics and structure, hydrothermal activity and related ore genesis in both volcanic edifice and basement. Some of these consequences, in particular those related to edifice failure, are by now unraveled by field studies, analogue and numerical modeling, while others, especially such as those related to the slow-acting volcano-basement interaction processes, are still to be subjected to more field and experimental investigation to be fully understood. For instance, the influence of volcano spreading on the style and location of hydrothermal ore formation by causing deformation and changing stress regimes within the volcanic edifice and its basement is largely unknown, hence provides a promising avenue of future research in the area of ore genesis studies.

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Sector spreading of eastern part of the Doupovské hory Volcanic Complex caused by heterogeneous substrata

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Doupovské hory Mountains is an erosional remnant of the Oligo-Miocene (34–20 Ma) Doupovské hory Volcanic Complex (DHVC), situated in western part of the Eger Graben in Czech Republic. Basaltic predominantly effusive activity created series of overlapping shield volcanoes. The thickness of basaltic lavas sequences reaches 500 m (Rapprich & Holub 2008). The lavas were frequently accompanied with lahars (Hradecký 1997). The eastern sector of the DHVC is clearly separated from the rest by straight and deep canyon of Liboc creek. This creek flows first to the NW, and then in the central part of the DHVC sharply turns to NE. Position of the creek and its canyons well corresponds to the position of Liboc and Střezov Faults limiting the Permo-Carboniferous sedimentary infill of the Žatec Basin in the basement of the DHVC (Mlčoch & Konopásek 2010). The thickness of sediments in the basement of the eastern DHVC reaches 800 m, and these consist of claystones, sandstones and conglomerates. Rest of the DHVC sits upon crystalline hard rocks, namely paragneisses, orthogneisses, granulites, amphibolites, etc. (Mlčoch & Konopásek 2010).

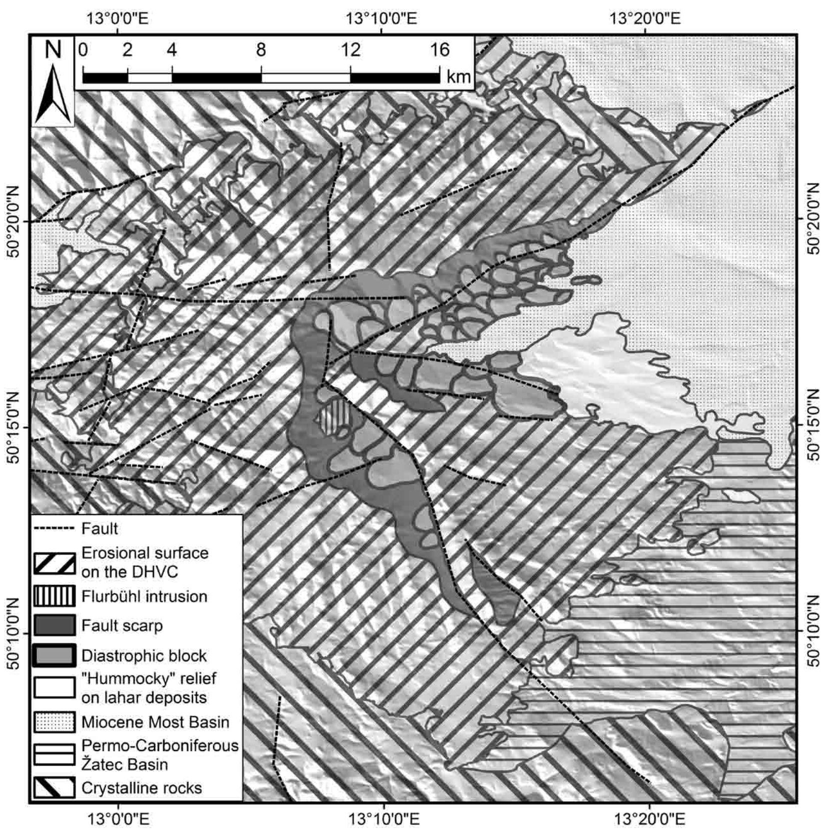

Fig. 1. Morphology of the DHVC with evidence for sector spreading of the eastern segment and lahar fan.

Large fossil alluvial fan at the mouth of the recent Liboc creek valley is built up of up to 200 m thick sequence of lahar deposits. The lahars are interbedded by three trachybasalt to trachyandesite lavas dated around 25 Ma. The lahars were studied in detail from sedimentological point of view and diverse facies of lahars were observed. Highly cohesive lahars with reverse grading, non-cohesive ones with normal grading, clast-supported as well as matrix-supported. With increasing distance from the source, significant decrease in grain size is prominent. At distal facies of these deposits, well sorted volcanigenic sandstones predominate.

We interpret the observed structure – morphological separation of the eastern segment – and large lahar fan as a result of a sector spreading. The sector spreading was likely triggered by two conditions. Heterogeneity of substrata played an important role. Very similar morphology was analogically modeled by Sandouly (1999) on a cone set upon heterogeneous basement (¾ solid basement, ¼ plastic basement). Displacement of the eastern sector due to sliding and asymmetric sinking to plastic sedimentary substrata created significant valley. Dynamic tectonically induced relief produced series of debris flows those sedimented in an extensive alluvial fan on the volcano's piedmont. The process of volcano decay was probably even enabled by early phase opening of the Most Basin (effect of the E-W trending Obrovice Fault under N-S extension – Rajchl et al. 2009).

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Volcanically influenced terrestrial ecosystems of the Westerwald Basin (Upper Oligocene, W Germany)

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The Westerwald region belongs to central European Volcanic Province (CEVP). Herein, the Westerwald Basin is an aggregation of small basins, mainly situated within the former variscan Mosel, Lahn and Dill Synclines. Sedimentation started in the Paleocene (Hahnstätten karst fillings), extends in the Eocene to a maximum in the Oligocene, and locally endured to the Pliocene. In the Upper Oligocene, volcanic activity started in the Westerwald with trachytic intrusions, phreatomagmatic maar (Enspel) and tuff eruptions. They were followed by basic shallow intrusions, lava flows, phreatomagmatic maar (Elbtal, ?Elz) and thick tuff eruptions (Schreiber 1996). Locally, the eruptions and minor intercalated sediments covered the landscape up to 50 m high (Schäfer et al. 2011).

Reischmann (2011) correlates the oligocene volcanism to the alpine orogenesis and the north atlantic rifting; main reason is the extension and thinning of the lithosphere, resulting in a passive uplift of the asthenosphere; herein, partial melts are produced due to pressure relief, with the effect that eruptions occurred in the CEVP.

The volcanic activities lead to changes in the local drainage systems, e.g. dammed valleys with subsequent lake formation. Together with temporary high Chattian sea level, palustrine to lacustrine facies becomes widespread, and often lead to thick brown coal seams and formation of laminated lake sediments. Hygrophileous plant communities covered the lowlands.

Upland resp. dryland floras and faunas are also influenced by volcanic activity. Forests died under heavy ash load, their remnants washed into the lowlands. Isolated reptile and mammal bones and teeth are found right within coarse volcanic ash, demonstrating heavy pyroclastic and/or lahar activity. Subsequent ecosystems start with pioneering plants like Cyperaceae, Poaceae and Betulaceae (Köhler 1998, Herrmann et al. 2003). Resettling of fauna is not investigated in detail up to now.

The intercalation of partly dated volcanic educts with well investigated fossil bearing sediments bears the excellent possibility of:

- combining isotope dating with biostratigraphy (as shown at locality Enspel and Kärlich, Mertz et al. 2007)
- investigation of ecosystem recovery in detail
- correlation of sea level in neighboring marine basins with groundwater highstand in this terrestrial basin, as demonstrated for the Lower Rhine Embayment and the volcanically influenced Rott Fossillagerstätte (Mörs 2002).

Several scientific drillings (Enspel 1996, Merenberg 1998, Elbtal 2003, Norken 2009), scientific excavations (Enspel 1990 up to now, Elbtal 2004, Haiger-Langenaubach 2008, 2009) and well documented outcrops – mainly clay pits – yield valuable data to be combined and correlated leading to a dense timing of events within this volcanically influenced basin.

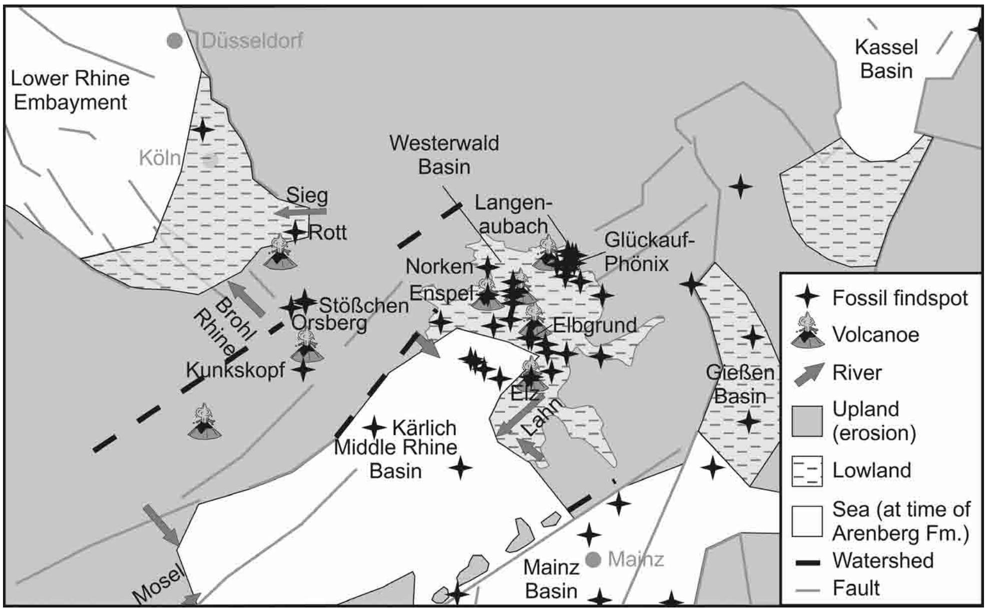

Fig. 1. Chattian palaeogeography of the Westerwald Basin (Arenberg, Breitscheid and Heckholzhausen Fm.) and neighboring areas with fossil findspots and estimated watersheds.

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3a

The Westerwald Volcanic Field and its fossil floras – important taphonomic windows into Late Oligocene vegetation and climate

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The Late Oligocene was characterized by pronounced climatic changes, which were accompanied by vast vegetational changes. The Westerwald region belongs to central European Volcanic Province (CEVP). A variety of volcanic activities during the Late Oligocene led to the formation of a number of excellent Fossillagerstätten in this area. The scientific value of most of these localities has so far not been explored in full width but different projects dealing with a number of the fossil (especially plant) bearing localities are currently in progress. To demonstrate the potential of this area for reconstructing Late Oligocene vegetation and climate patterns and changes this contribution focusses on two selected localities:

Enspel: The well preserved macroflora from Lake Enspel, a volcanic lake formed within a maar or a caldera, is composed of more than 70 taxa. The vegetation is dominated by zonal assemblages of a mesophytic forest, with a strong East-Asian influence. The forest consisted of four storeys and reached the lake which was characterized by mostly steep margins. Azonal elements (aquatic and semi-aquatic plants, riparian forest) make up only about 1/7 of the taphoflora. Banks of potential creeks or small rivers feeding into the lake or shallow marginal areas can be assumed as the potential growth areas of these plants, as most of the banks of the lakes itself were probably rather steep due to its volcanic origin. Due to excellent age control by biostratigraphical dating (MP 28) as well as absolute dating of basalts on the base and top of the Enspel sedimentary sequence (24,79 - 24,56 Ma) this flora is an important point of reference for the development of terrestrial climates and vegetation in the Late Oligocene of Central Europe. The results of the Coexistence Approach fit with the occurrence of fossil crocodiles in the same sediments as an independent climatic marker. Thus we can conclude that mean annual temperature was about 15 – 17° C, the warmest month mean was about 25° C, the coldest month mean was about 5 – 7 °C and mean annual precipitation was at least 900 mm/a (up to 1355 mm/a) (Uhl & Herrmann, 2010).

Norken: This locality only a few km north of Enspel is more or less contemporary to the locality Enspel but represents a different depositional environment (swamp and non-volcanic lake). The macroflora is dominated by leaves of *Acer* cf. *tricuspidatum* Bronn and twigs of the conifer *Glyptostrobus europaeus* (Brongniart) Unger. Both taxa are typical elements of riparian vegetation during the Oligocene, an observation that is in agreement with the assumed sedimentary setting. The occurrence of fossil charcoal can be regarded as direct evidence of palaeo-wildfires. The wood exhibits clear growth rings probably pointing to some kind of seasonality (Uhl et al., 2011).

Together with a large number of additional fossil localities from the Late Oligocene of the Westerwald area (Fig. 1) it will become possible to reconstruct regional scale patterns but also the development of vegetation and climate in this area.

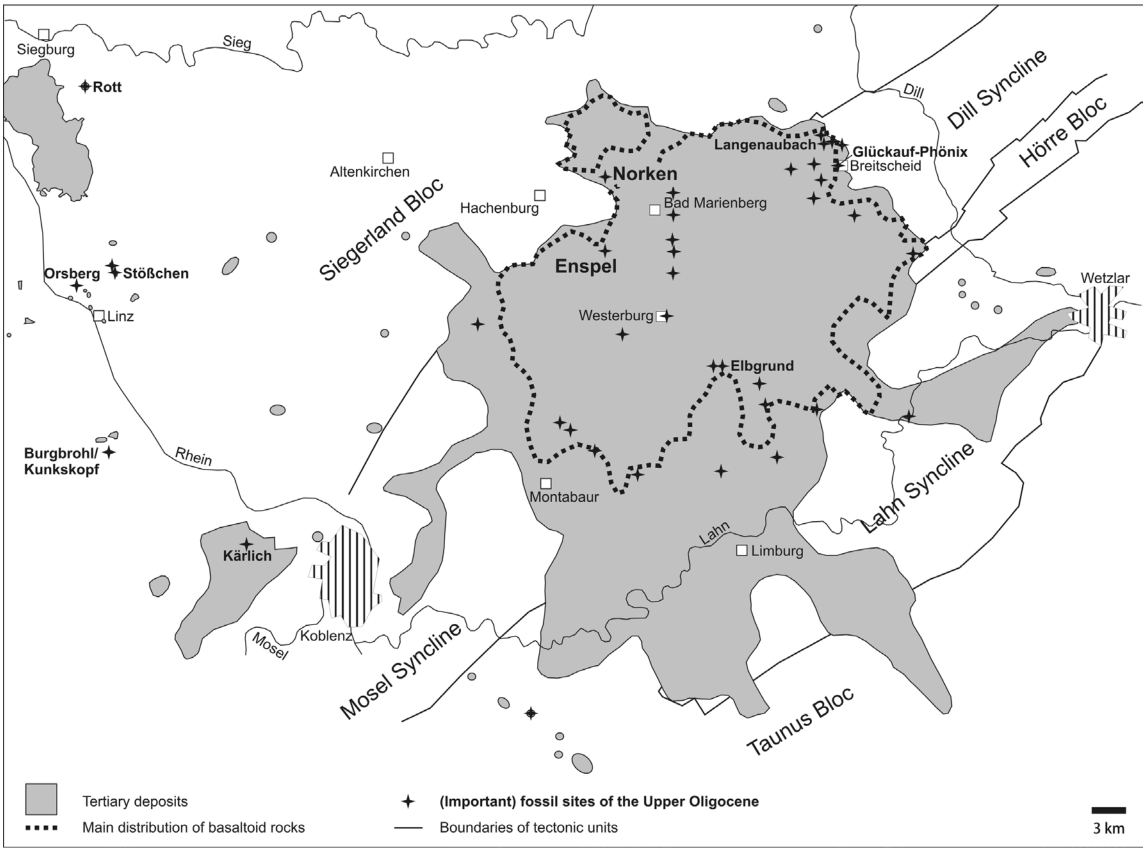

Fig. 1. Geological map of the Westerwald Tertiary. Outlines of Tertiary deposits and of basaltoid rocks simplified; important fossil localities marked by stars (modified from Schindler & Wuttke, 2010).

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3a

3a

The extinct volcanoes of Central France – Nicolas Demarest's famous volcanological map in a so far unrecorded copy printed in his lifetime in 1811

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Nicolas Desmarest (* 1725 – † 1815) is one of the most prolific pioneers in the early history of volcanology (e.g., Taylor 1971, Rudwick 2005). For the first time in science he stated that basalt is a rock of volcanic origin and thus indicating the existence of extinct volcanoes wherever we find it, and he defined three (actually four) geological "époques", based on the erosion stage of volcanic landforms and on the topographical interrelationships between lava flows and valleys (Desmarest 1768, 1806, Taylor 2007 2009). The maps which he produced to illustrate his publications are of outstanding importance as well. From his start in 1763 until his death in 1815 Desmarest continued mapping the volcanic districts in Auvergne and adjacent regions. Taylor (1994) calls his first, still fragmentary "CARTE D'UNE PARTIE D'AUVERGNE" (Desmarest 1774) "a landmark in the early history of geological mapping". This "volcano-geomorphological" map finally accompanied in its finished state as "CARTE GÉNÉRALE OU TABLEAU D'ASSEMBLAGE" (scale c. 1:111400; c. 52 x 52 cm) a large map in six sheets (scale c. 1:43400; complete size c. 150 x 124 cm) which, however, appeared posthumously, since Nicolas Desmarest "wanted to bring it to perfection and finally died without giving it into print and on the market" (Geikie 1962). These spectacular maps have been published by his son Anselme Gaëtan Desmarest (* 1784 – † 1838) not until 1823, i.e. eight years after his father's death. That is what librarians and geo-historians took for granted so far (e.g. Taylor 2007).

Recently, in 2010, a complete set of these maps turned up on the antiquarian book-market with the large map bearing 1811 (!) as year of publication (Desmarest & Desmarest 1811). So, this set has already been printed during Nicolas Desmarest's lifetime! At first sight all maps look like the "official" ones but in fact they differ from these in several details. The small overview map is a pre-version of the "CARTE GÉNÉRALE OU TABLEAU D'ASSEMBLAGE". It has no title and different legends whereas the terrain shows only minor distinctions (Anonymus [1811]). The large map, besides some differences e.g. with respect to the legends, the spelling of mountains and villages and still without the heights of mountains published by Ramond (e.g. 1811), shows some rather curious and important peculiarities: At three places in the title on sheet No. 1 printed words have been deleted. Ultraviolet light revealed that the words "Par Mr. DESMAREST", "*& Desmarest Fils*", and "imperial" have been shaved. This means that his son here appeared as co-author and not as editor as on the version printed 12 years later. So, did Nicolas' son give the maps into print without his father's knowledge and permission? Or is this 1811 version something like a proof sheet as a few pencil annotations indicating corrections might suggest? But who deleted the author's names and why? Unfortunately, there is no evidence which could tell us about former owners and the fate of these maps during the past 200 years. Even Kenneth Taylor and Martin Rudwick never found any hint on their existence (pers. comm., January - April 2011). So, for the present, this set remains enigmatic. Nevertheless, we have to take into account now, that some geologists / volcanologists in the personal environment of either Nicolas or Anselme Desmarest themselves or of the cartographer and printer Charles Picquet might have seen and been influenced by them already 12 years before these maps have officially been available on the market.

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Response of eruption style on changing external controls during monogenetic volcanism – New insights of spatial location of vent on the Bakony-Balaton Highland Volcanic Field (Hungary)

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Sister or analogue volcanic fields are commonly used for comparative analysis in order to better reconstruct and understand the original dimensions and volume of eroded monogenetic volcanic edifices exposed to erosion on a Ma time-scale. There are also practical physical characteristics, such as spatial location of vents within the field, which could particularly be useful to reconstruct the spatial aspects of magmatism, magma outputs and tectonic environment, where monogenetic volcanism occurred in the past. Volcanism at the Bakony-Balaton Highland Volcanic Field (BBHVF) formed about 50 volcanoes of maars, tuff rings and scoria cones (Martin & Németh 2004). These volcanoes were subject of erosion since the Mio/Pliocene (Balogh et al. 1986, Wijbrans et al. 2007, Kereszturi et al. 2011), hence the majority of the volcanic edifices are moderately to heavily degraded (Martin & Németh 2004). The long-lasting erosion (~2 to 8 Ma) exposed the lower and upper diatremes and the core of scoria cones. Due to the advanced stage of erosion, the recently estimated Digital Elevation Model-based volumes for the volcanic field (2.9 km^3) should be considered as minimum value of the original eruptive volumes (Kereszturi et al. 2011). However, a realistic magma output value is likely to be more than 3 km^3, erupted over 5.4 My. On the other hand, the analysis of spatial distribution of landforms within a volcanic field could also reveal some differences between eruption mechanism and condition of external parameters during the construction of a monogenetic volcano. In the present study, a new database is constructed for the BBHVF. This extensive dataset contains major physical characteristics of each eruptive centre (e.g. statigraphy-based eruptive volume, age reconstructed paleo-elevation, eruptive styles and resultant landform, type and approximate thickness of underlying country rocks). Based on this database, two kinds of maps for the BBHVF have been created. One is about spatial total magma output of the BBHVF, while the second visualizes the spatial distribution of eruption styles (i.e. eruptive complexity map). The spatial distribution of the magma output shows that the majority of the eruption products were focused to the northern part of the field, where two scoria cones and associated large lava flow fields have been developed (Agár-tető and Kab-hegy).

The eruptive complexity maps have revealed that most of the transitional landforms (i.e. scoria cones and lava flows with initial phreatomagmatic stages) are located over those areas where the Late Miocene (Pannonian) unconsolidated siliciclastic sediments are thinner then couple of tens of metres over the fracture-controlled basement including karstic Mesozoic carbonates. Further studies should focus on understanding of spatial location of erosion remnant in connection to the substrate geological conditions and investigate the landform-dependence on substrate geological properties such as type of underlying country rock and its thickness or hydrological conditions.

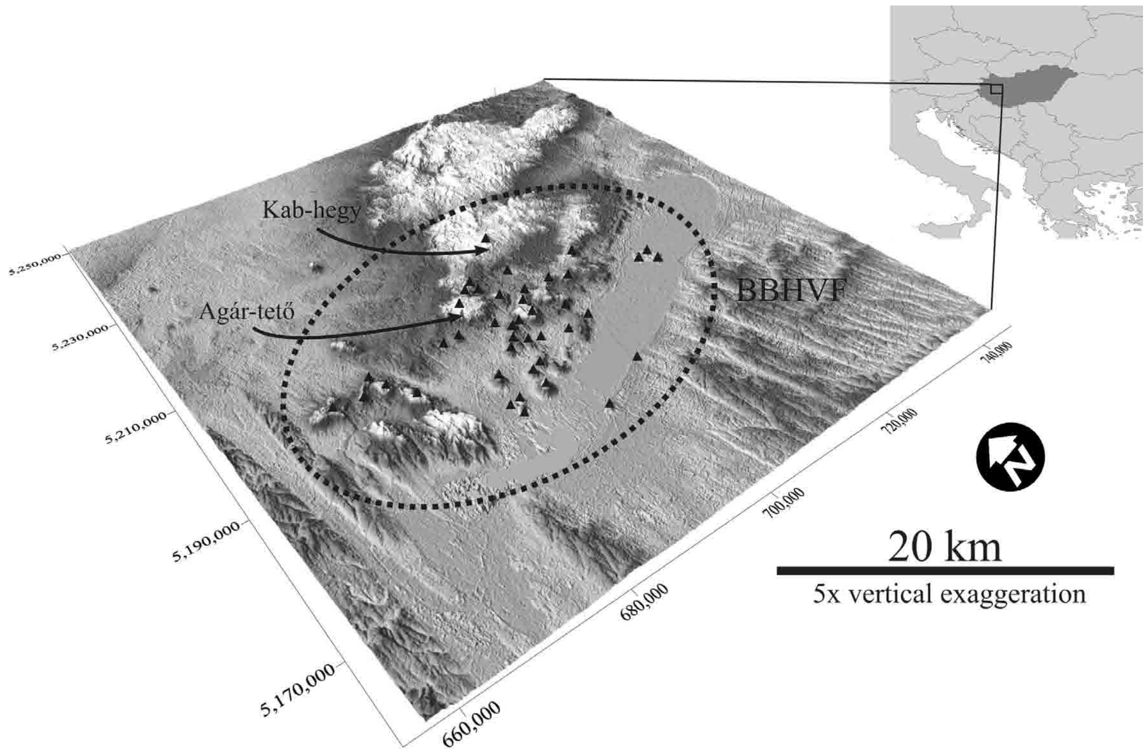

Fig. 1. Overview map of the Bakony-Balaton Highland Volcanic Field. Black triangles are the major erosion remnant of monogenetic volcanoes after Martin and Németh (2004).

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Lava Tubes – presence on the Earth and Solar System, origin and morphology

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Lava tubes are known from volcanoes surrounding areas. Most popular lava tubes are found on Hawaii, Iceland, Azores Archipelago, Galapagos Archipelago, Canary Islands, Korea and Japan islands, Reunion, and also continental tubes, for example, from Italia, Siberia, United States, Kenya and Australia. Out of Earth, lava tubes are known from Moon, and Mars, which are considered in future colonization plans.

Lava tubes are formed during lava flow and often are connected with basaltic lava flows. Generally, lava tubes are created from pahoehoe lava flows, but some of them are "aa-tubes" type. Few different mechanisms create the lava tubes, the most often is solidifying of top and sides the lava flow, and creating a crust roof above flowing lava.

On the poster are distinguish five morphological types of lava tubes: interior tube, surface tube, true trench tube, semi-trench tube and rift tube. Differences between this morphological types comes from differential ways of lava flow and kinds of bed-rock.

Lava tubes are good thermal isolators and mostly they are responsible for further lava propagation. Effects of this propagation are lava caves (pseudokarst), which can be as an one-tube caves, combination of few tubes, and even as a multi-level caves. Propagation of lava within tube create many different karst and erosion formation, such as e.g. tubular lava stalactites, shark-tooth lava stalactites, drip stalagmites, lava roses, skylights, lava-falls, lava balls, sinuous passages, tube-in-tube structures, internal levees.

Main difference between karst and lava formations is amount of time needed to create each one of them. Karst cave is an effect of thousand years of corrosion processes, and lava caves are fully developed in few months.

Most common minerals occurring in lava tubes are opal, gypsum, calcium carbonate.

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Oligocene maars and scoria cones in East Saxony, the Guttau Volcano Group

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About 10 km south of the Oligocene North Sea coast 5 volcanoes erupted within a time interval of 3 my, named Guttau Volcano group: 3 maar-diatreme volcanoes (Kleinsaubernitz, Baruth, Buchwalde) and 2 scoria cones (Schafberg, Eisenberg). The palaeogeography of the area is well known due to numerous drills for lignite exploration. As observed in the extent Eifel volcanic field the maar-diatremes are situated in valleys, the scoria cones at the hills (Fig. 1).

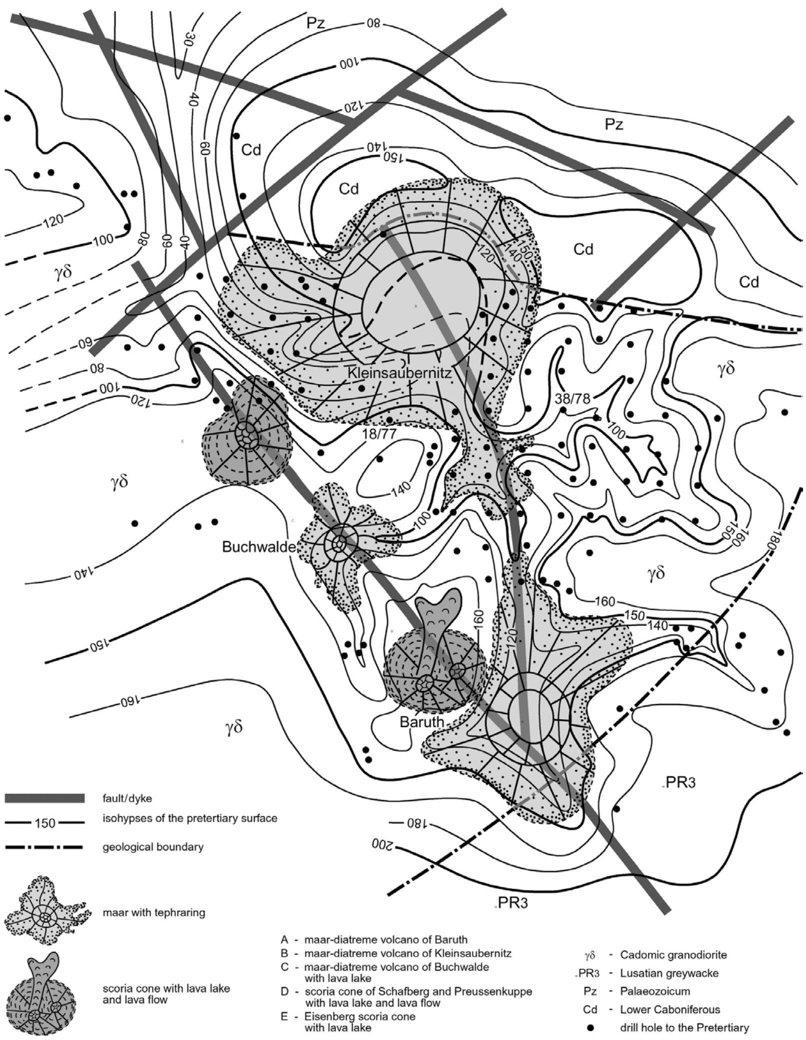

Fig. 1. Guttau Volcano Group within the pre-Tertiary geology and the pre-eruptive morphology.

The Eisenberg hill is the rest of a lava lake entrapped in a scoria cone. Only the basalt columns survived weathering. At the Schafberg/Preussenkuppe hill (Fig. 2) the development is quite more complicated with at least 3 eruptions of different ages (Tietz et al. 2010).

The larger maar-diatremes (Kleinsaubernitz, Baruth) produced considerable negative anomalies at the gravimetric survey. In 1970 a nearly 500 meter core was drilled into the Kleinsaubernitz structure to clear the anomaly. A research drill into the Baruth maar sediments 1998 produced a nearly complete core and revealed the full history of this structure. The annually laminated lake sediments of these maar lakes allowed estimating a time span of more than 300000 years for filling up the depressions due to the extreme reduced sedimentation rates. The compaction and subsidence history of the sediments above the maar-diatreme volcanoes started immediately after the eruption (Suhr et al. 2006). By comparing the thickness of correlated beds above the structure and in the surrounding area it was easy to reconstruct the space and time relations of the subsidence of the diatreme fill. For the Kleinsaubernitz maar e.g. the entire amount of the subsidence in the last 27 my reaches nearly 300 meters. So it's not a miracle that the surface above the maar structures today is a drainless depression.

Fig. 2. Arial view to the the Schafberg/Preussenkuppe volcano (quarry) with the lava flows (Dubrauker Horken); in the background the village of Baruth.

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On the deposits and structure of the Großschönau Tertiary basin (southeastern Saxony, Germany)

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Introduction – Local occurrences of tertiary sediments (carboniferous clay, lignite) in shallow drillholes and excavations near Großschönau have been interpreted as deposits of a subordinate basin of the large Zittau Basin in the Southeast (Siegert 1897: 41). The supposed extension of these tertiary sediment deposits in the Großschönau basin were first drawn on the subsurface Geological Map Görlitz-Děčín 1 : 200.000 from 1964 (GK 200) as an area measuring approximately 2 km (N-S) and 1,6 km (W-E). This map presentation shows the basin boundary without faults. Herein the basin is bordered in the South and partially in the North by granitic basement, and in the West, North and East by outcropping basaltic tuffs, basaltoids and phonolites. These volcanic rocks belong to the Lusatian Volcanic Field which is located in the region of intersecting of the Ohře rift and northern faults of the Elbe-Odra fault system (see Ulrych et al. 2011). According to the Zittau basin the tertiary sediments are of supposed lower to middle Miocene age (Lotsch et al. 1969). They are covered by quaternary deposits. Up to present time there is only few information about the basin infill and basin structure.

Bentonite exploration activities by core drilling investigated areas with outcropping tuffs outside the Großschönau basin in the years from 1977 to 1985. The deepest drillhole located in the East of Großschönau (Grsh 41E2/75) shows 57 m thick re-deposited phonolitic rocks (lithic tuffs?) with a basaltoidic intercalation (Heinrich 1977).

More recent drillholes are only cutting drills. A deep drill from 1993 at the eastern border of the basin (Grsh 1/93) reveals a 90 m thick profile (inferred from cuttings and video film inspection) of phonolites and predominantly phonolithic ash and lapilli tuffs and lithic tuffs, with tuffitic and sandy intercalations. The pyroclastic and partially the effusive rocks are strongly altered by bentonitisation. A second borehole (Grsh 2/93) located in the East of drillhole 1/93 has a completely different profile showing foiditic tuffs with foidite intercalations.

A drill from 2006 (Grsh 1/06) at the northwestern border of the basin shows tuff and tuffite layers down to a depth of 54 m underneath a 26 m thick basaltic cover.

A drill from 2008 (Grsh 1/08) located *inside* the northern basin reveals granodiorite down to a depth of 75 m underneath the quaternary deposits, and therefore, indicating a cross fault.

Geochemical analysis of only slightly weathered tuff/tuffitic samples from those two drillholes in 1993 plot in the fields of trachyandesite, alkalibasalt and foidite using the Zr/Ti–Nb/Y diagram.

Microscopy by thin section analysis of microcrystalline effusive volcanic rocks results in dominating phonolite and foidite types, and tephrites (Lapp 2004).

Geophysics – Based on regional gravimetric measurements from 1986 (compiled in the scale 1: 100.000) Wiemeier (1993, unpublished) interpreted a fault controlled contour of the Großschönau basin with an extension of about 4 km (SW-NE) by 2 km (NW-SE). The basin represents a Bouger minimum. Following Wiemeier most of the above mentioned drillholes are situated inside the border fault zones or close outside the basin.

Age dating – K-Ar dating of volcanic rocks in the broader surroundings of the Großschönau basin resulted in 29–30 Ma for older basaltoids, 26–30 Ma for the phonolites, and 24–26 Ma for younger basaltoids (e.g. Pfeiffer et al. 1984). So, the volcanism of the Lusatian Volcanic Field belongs to the syn-rift stage after Ulrych et al. (2011).

Pollen analysis of tuff(ite) and silt samples of the borehole Grsh 1/93 showed only a nonspecific pollen assemblage which indicates an Oligocene to Pliocene age (Goth 1995).

Conclusions – Although deep drillholes at the centre of the basin are missing it can be concluded that

(i) the Großschönau basin probably hosts predominantly pyroclastic and volcanic infill (for at least most of the the southeastern margin) of pre- to syn-phonolitic (Oligocene) age

(ii) at least partially the thickness of these deposits does reach more than one hundred meter

(iii) the basin is bordered by faults (and is isolated from the Zittau basin)

(iv) the profiles of the drills Grsh 41E2/75 and Grsh 1/93 compared with different profiles of other bentonite drills (Heinrich 1977) indicate its position *inside* the basin, near the margin.

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The landscape evolution of the Lausitz Massif – results from neovolcanic edifices from the Lausitz Volcano Field (Eastern Germany)

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Three Cenozoic volcanoes (Baruth, Landeskrone, Sonnenberg) were investigated in the Lausitz Volcano Field (climax 30-25 Ma) for the reconstruction of the uplift and denudation history for the Lausitz Massif, a Cadomian-Variscan consolidated block-faulted area. The volcano remnants mark and save the synvolcanic paleosurface.

The Baruth Complex Volcano is situated in the northern Lusatia and contents of three deeply eroded scoria cones. Only in glaciofluviatile Saalian-1-Glaciation sediments appear greater amounts of scoria pebbles in this place. This suggest greater scoria bodies for the 33-27 Ma old volcanoes at the time about 250 000 years ago. Such observation implies a young uplift of the Lausitz Massif.

The Landeskrone Volcano also gives indications for neotectonic movements. The reconstruction of this large monogenetic scoria cone in the eastern part of the Lausitz Massif allows in connection to adjacent volcano edifices the estimation of an average denudation rate from 3 mm / ka for the last 34 Ma. Probably, this uplift and denudation rate increased in the upper Middle Pleistocene. Otherwise, the recent 200 m high basaltic hill would destroyed by the overriding of two Elster glacial ice streams. Furthermore, a 28 km long geomorphologic N-S profile which incorporated 7 additional volcano edifices, showed a tectonic differentiation between uplift and subsidence areas inside of the Lausitz Massif in the last 30 Ma. Therefore, a rigid and en bloc movement of this Variscan Basement unit can be excluded.

The Sonnenberg Volcano is situated in the Elbe Zone 1.3 km southward the Lausitz Fault. On this fault the Lausitz Massif is uplifted up to 1000 m against the Elbe Zone. This elevation direction got an inversion to synvolcanic time; therefore today the Zittauer Gebirge Mountains overtop the Lausitz Massif by 200 m. In contrast, the Sonnenberg Volcano (30-27 Ma) and the adjacent volcanic edifices show little erosion. Therefore, the maximal 50 m deep erosion of the Zittau Mountains should also be induced by a young uplift with a rate of 7 to 10 mm / ka.

This important role of neotectonic processes for the Lausitz Massif is supported by some new ephemeral outcrops in Pleistocene deposits. Such outcrops proof a temporary covering and lowering of volcanological edifices to Elsterian Glacial Stage (400 000-320 000 a) and a tectonical subsidence of the Lusatian brown coal basins for the Pleistocene time by 25 m.

In further, it is planed to investigate about 50 volcanoes of the Lausitz volcanic field and make a 2D and 3D modelling. The volcanological study of neovolcanoes represents a helpful tool for the uplift and denudation history for the last 30 Ma and completes the results of the fisson track data (85-50 Ma) and the Pleistocene deposit investigations.

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Phreatomagmatic volcanism in the Bruntál Volcanic Field

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The easternmost Cenozoic Volcanic Field of the Czech Republic is located in the area of Nízký Jeseník Mountains (northern Moravia) near Bruntál. The age of this volcanic field spans from Pliocene to Pleistocene (3.5–1 Ma). Magma was emplaced into Upper Paleozoic rocks. The Sudetic Marginal Fault is one of main tectonic line in North Moravia and Silesia on which the magmatic activity were concentrated during the Pleistocene or even earlier (Barth 1977). Volcanic activity in Bruntál area started as somewhat explosive one and produced scoria cones. The explosiveness was partly influenced by contact with water during magma ascent. The Bruntál Volcanic Field consists of several scoria cones (Uhlířský vrch, Venušina sopka and Velký Roudný volcanous). Velký Roudný is rising above other in size and good preservation. Velký Roudný Hill (780 m a. s. l.) is a horse-shoe shaped scoria cone rising 130 m above surrounding landscape. This scoria cone has emitted several basaltic lava flows, some of them partly filled the valley and dammed the Paleo-Moravice River. Volcaniclastic deposits exposed at Razová, some 2.6 km north of Velký Roudný were formerly interpreted as water-environment re-sedimented pyroclastics from Velký Roudný (Barth & Zapletal 1978). Our research leads in different interpretation. The volcaniclastic deposits at Razová are characterized by poor sorting, clast supported texture and absence of ash fraction. The clasts reach up to 40 cm in diameter, these are angular and two lithologies can be observed: non-vesicular massive basalt and greywackes of Lower Carboniferous, which is the country rock of this area. Scoria fragments are scarce, that is the main difference from the volcanic products of the Velký Roudný Volcano. Angular fragments of non-vesicular basalt and abundance of country rocks xenoliths suggest the hydroclastic fragmentation. Poor sorting and presence of large fragments argue for very short distance from source vent. The deposits hence better correspond to an erosional remnant of a tuff cone. Feeder of a tuff cone has been detected by the ground magnetometric survey in the center of the extent of the pyroclastic deposits. The phreatomagmatic (Surtseyan) eruption was influenced by presence of shallow lake, possibly dammed by lava from Velký Roudný Volcano. Additional exposure of volcaniclastic deposits can be found at Karlov, 1.2 km northwest of Razová locality. This second exposure displays deposits of significantly finer grain-size, better sorting with obvious diagonal bedding. This diagonal bedding in former times was understood as an evidence for fluvial sedimentation. In contrary to fluvial epiclastics, volcaniclastic deposits from Karlov still not well sorted, and their fragments are angular. More likely, these deposits represent base surge deposits associated with the Surtseyan eruption of the Razová Tuff Cone. Razová Tuff Cone is the first described phreatomagmatic volcanic cone from the area of Bruntál.

The volcanic structures in the Bruntál area were indicated by geophysical survey – gravity and airborne magnetometry (Děďáček & Gnojek 1980, Kadlec et al. 1972). The volcanic intrusion represents the source of the local positive or negative anomalies in the magnetic and the gravity filed. Positive magnetic anomalies correspond to the normal polarization and negative anomalies to the reverse polarization. The basalts vents correlate with the gravity positive anomalies and maar volcanic structure with the negative anomalies. Razová locality was not detected in the airborne magnetometry. Consequently the ground magnetic measurement was realized in year 2012 with the aim localized of the eruption centre. The maximal value of the magnetic field was detected close of the southeastern part of the abandoned quarry.

Recently the relicts of the volcanic occurrence are subjects of interest in the tourism. The volcanic history of this region is described on the educational path and posters in the individual localities.

The volcanological research in the area of Bruntál was supported by the Strategic Plan of Research of the Czech Geological Survey (project no. 321140).

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On the variety of Mio-Pleistocene root zones of monogenetic volcanoes of the Pannonian Basin

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Direct observations of exhumed ancient diatremes and geophysical modeling of diatremes underlying young maars have revealed that diatremes are a vital part of a maar-diatreme volcano and can host a dominant (>50 vol. %) proportion of the volcano's "bulk" erupted material. Therefore, to calculate the total magma output of a maar-diatreme volcano, it is important to fully characterize the diatreme by determining its juvenile content, as well as the volume of fragmented country rocks accumulated in it. While numerous studies have been published on diatreme architecture, there are only limited quantitative data available on the juvenile particle proportions and/or the volumes and types of country rocks preserved in diatremes. Here we document diatreme textures and provide semi-quantitative data on juvenile and accidental lithic volumes of diatremes from two Miocene – Pleistocene volcanic fields from the Pannonian Basin: the Bakony - Balaton Highland Volcanic Field (BBHVF) and the Nógrád-Gömör/Novohrad-Gemer Volcanic Field (NGVF). Each of these fields hosts about 50 volcanoes that formed over a combined aquifer with a hard-rock basement covered by a maximum 200-m thick, semi-consolidated sedimentary succession. For this study, we selected locations in both volcanic fields that are dominated by pyroclastic rocks forming easily distinguishable features a few tens to a few hundreds' metres across in map view areas. The selected locations are the smallest preserved pyroclastic rock-dominated occurrences in both fields. The identified pyroclastic rocks are predominantly lapilli tuffs and minor pyroclastic breccias and they are rich in accidental lithic fragments picked up from the former conduit wall-forming rock/sediment units (Fig. 1). Juvenile fragments are both tachylitic and sideromelane glass shards, indicative of a variable degree of magma/water interaction, as well as variable travelling time through air. Accidental lithic clasts are particles derived dominantly from the uppermost siliciclastic/volcaniclastic sediments with a minor volume of rock-fragments derived from deep hard-basement rocks. Diatremes, especially in the NGVF, are commonly preserved by dykes and sills that invaded the host soft-sediments forming peperite and sediment fluidization. Dyke-related diatremes are commonly dominated by lava spatter and vesicular lapilli which are hosted in a strongly fluidized/homogenized mud that also sporadically contains glassy pyroclasts. Point counting on thin-sections and rock slabs revealed that the juvenile pyroclast content of the diatremes in both volcanic fields are high, ranging between 30-60 vol %. Applying model-diatreme geometries to estimate the total juvenile pyroclasts "*stored*" in a diatreme indicate that they could account for about 30 % of the total magma output estimates of a single volcano, and therefore we need to input these data to estimate dense rock equivalent (DRE) values of total magma involvement in the formation of these phreatomagmatic volcanoes. It has also been revealed that the dominant proportion of the accidental lithic fragments of the studied diatremes are sediments derived from the uppermost sediment units ("soft" rocks), indicating magma-water interaction and that the dominant fragmentation level was probably located near the contact zone of the hard basement rock and the sediment cover. The matrix of the diatreme rocks is composed of mineral phases and mud derived from unconsolidated rock units inferred to be the Late Miocene siliciclastic successions; intact fragments from the same rock units are relatively rare in hand and microscope scales. The variety of diatreme rocks of the Pannonian Basin's Mio-Pleistocene volcanic fields are great and range from juvenile fragment dominated dyke and sill associated versions to well-sorted and homogenized sideromelane-rich lapilli tuff varieties. These textural variations are likely to be associated with the range of magma-water interaction sites and the variations in the exposed diatreme rocks reflecting the position of the exposed section in relationship to the main vertical pipes of clastic rocks.

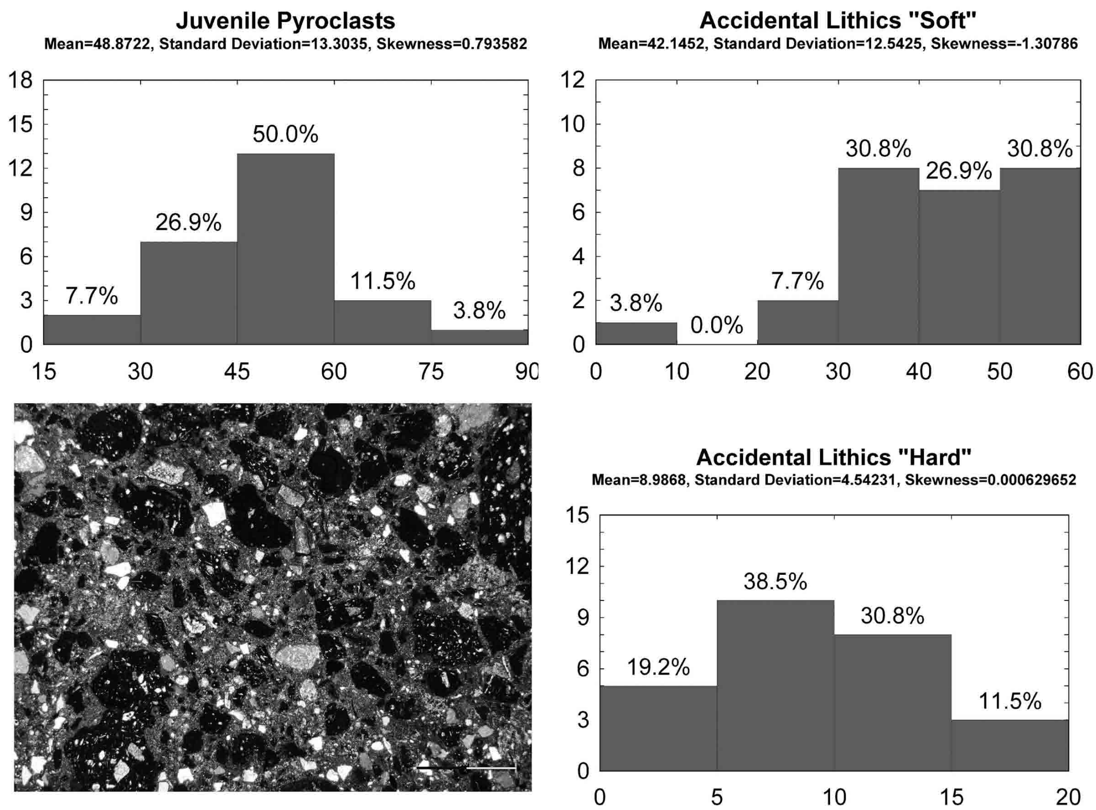

Fig. 1. Statistical summary of juvenile and accidental lithic particles measured by point counting on rock slabs and thin sections (27 samples from 14 locations). Each value was recalculated to cement/pore free basis. Matrix was dominantly composed of mineral phases derived from mud, sand and silt from the topmost Miocene to Pliocene "soft" sediments (Pannonian Sediment). "Hard" rock fragments were dominated by Mesozoic carbonates, and Paleozoic sandstones, meta-sediments/crystalline rocks. Representative thin section (cross polarized light) is shown in the bottom left corner. Black clasts are juvenile particles. Scale bar is 1 mm long.

3a

Eruptive volume estimate of the Nógrád-Gömör/ Novohrad-Gemer Volcanic Field (Slovakia-Hungary)

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The estimate of magma output and its flux for a monogenetic volcanic field can bear important constraints for understanding short- and long-term evolution of a magmatic system. The knowledge on the short and long-term eruptive behavior and range of magma output altogether contribute information on volcanic hazard, which essential for a better assessment of susceptibility of volcanic eruption. An ancient and volcanologically inactive field the magma output and other volcano-volume estimates can help us to understand the spatial and temporal aspects of the geologic environment in where the monogenetic volcanism took place. Emphasizing the geologic importance of eruptive volume estimates several studies have used these volumes for detecting causes for melting at the source region and to reveal long-term trends in the melt taping events. This approach has recently adopted for the Bakony-Balaton Highland Volcanic Field (BBHVF) (Kereszturi et al. 2011), which is one of the largest intraplate, monogenetic volcanic field in the Carpathian–Pannonian Region. Based on the erupted volumes as a function of geochronology, there is a clear trend for the time-predictability of Miocene to Early Pleistocene monogenetic volcanism within the Carpathian–Pannonian Region. In the BBHVF, there were six independent volcanic cycles been recognized, each with up to eight individual monogenetic volcanoes (Kereszturi et al. 2011). The time-predictability could be implicative for the second largest volcanic field in the Carpathian–Pannonian Region, the Nógrád-Gömör/Novohrad-Gemer Volcanic Field (NGVF). The NGVF consists of about 40 eroded volcanic remnants of maar-diatreme volcanoes, tuff rings and scoria cones with lava flows (Konecny et al. 1999, Lexa et al. 2010), similar to the volcanic architecture of BBHVF (Martin & Németh, 2004). The formation of NGVF started at 8 Ma ago, and ceased about 0.5 Ma ago (Konecny et al. 1999) slightly longer as it is known from the BBHVF (Kereszturi et al 2011). In the present study, the NGVF is investigated in the terms of magma outputs, by applying volume calculation method from Digital Elevation Model (DEM). Due to long-lasting and advances erosion of the volcanic remnants some correction to establish the original landform geometries were applied in order to get more realistic magmatic bulk volumes estimates.

The obtained volumes were corrected for effects of erosion using volumes of young analogue volcanoes from the Quaternary Auckland Volcanic Field in New Zealand as well as point counting and vesicularity calculation on thin-sections. The total bulk magma output is estimated at least 1.9 km^3. The NGVF can be assessed as time or volume predictable volcanic field, similar to the BBHVF.

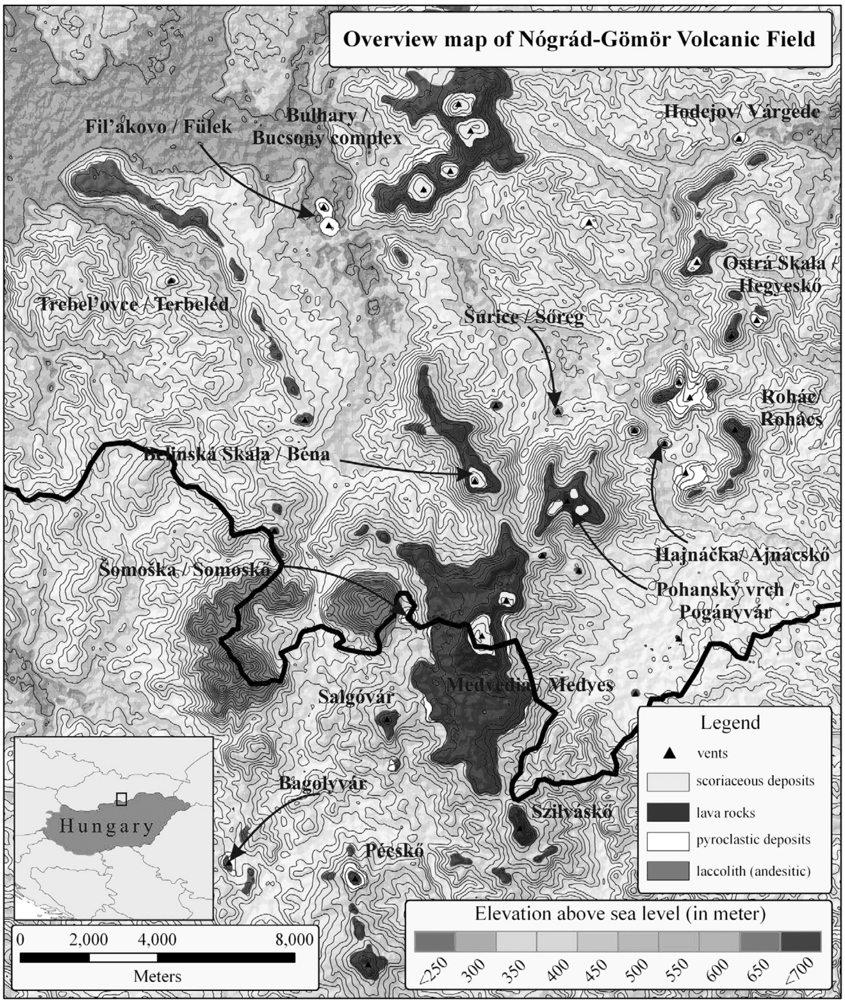

Fig. 1. Overview map of the Nógrád-Gömör/Novohrad-Gemer Volcanic Field (Note that the andesite laccoliths (green) are not part of the studied basaltic volcanic field.

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Episodically rejuvenating Cenozoic subaqueous mafic monogenetic volcanism in the Chatham Island (SW-Pacific)

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3a

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New volcanological mapping in the northern Chatham Island – located on the eastern margin of the Zealandia micro-continent of the Pacific Plate ~700 km E of New Zealand, has revealed a complex volcanic facies architecture in preserved volcanic successions. Coherent volcanic rocks commonly form sheet-like volcanic bodies or dykes that vary in their thickness and/or are associated with peperites. Dykes transform to sills that feed hyaloclastite piles composed of angular, dark lava fragments that are hosted in a finer grained glassy volcaniclastic matrix. This facies architecture is common to most of the preserved volcanic hills grouped into the Northern Volcanics or Rangitihi/Rangiauria Tuff stratigraphic units (Fig. 1). Volcanic successions along the northern shore of Chatham (eg. Cape Young) form thick piles of alternating lapilli tuff and tuff beds resembling those formed through episodic explosive volcanic eruptions on a sea floor, building pyroclastic mounds that occasionally emerged above sea level to form tuff cones. Near-vent tuff breccias that grade laterally into fine grained tuffs exhibit features indicative of a shallow marine depositional environment. Irregularly shaped dykes mingle laterally with the host volcaniclastic sediment to form peperitic textures mark vent locations. "*Master*" dykes commonly grade laterally into fragmented clastic dykes as the result of fragmentation of the rising melt in contact with the wet, water-saturated host sediment. Currently volcanics on Chatham are grouped into distinct stratigraphic units, Red Bluff Tuff (c. 53-48 Ma), Northern Volcanics (c. 41-35 Ma), Rangiauria Breccia (c. 7-6 Ma and Rangatihi Tuff (c. 6-4 Ma). New K-Ar age dating (Fig. 1), however, reveals that most of the volcanic erosion remnants in Chatham are complex landforms composed of volcanic units that represent multiple generation of subaqueous-to-emergent volcanoes through distinct episodes in the Cenozoic, consistent with the complex facies architecture of each centre. We suggest that rejuvenation of Surtseyan-to-emergent style volcanism took place in well-defined time-zones in Northern Chatham leading to a formation of coalescing volcanic piles of texturally similar volcanic units but which are of strikingly different age. Such volcanic piles were preserved by dykes, sills or lava flows that penetrated or covered the earlier-formed volcanic successions and partially preserved them from further erosion. Such complex volcanic and geomorphic evolution resulted the present day "*butte-pitted*" landscape in northern Chatham. The similarity of the morphology of these remnant volcanic landforms gives a misleading impression that they are of similar age; grouping these individual volcanic centres into a single stratigraphic unit only on the basis of their volcanic facies architecture and degree of preservation is therefore misleading and the stratigraphic relationships of the northern Chatham volcanics needs to be revised significantly.

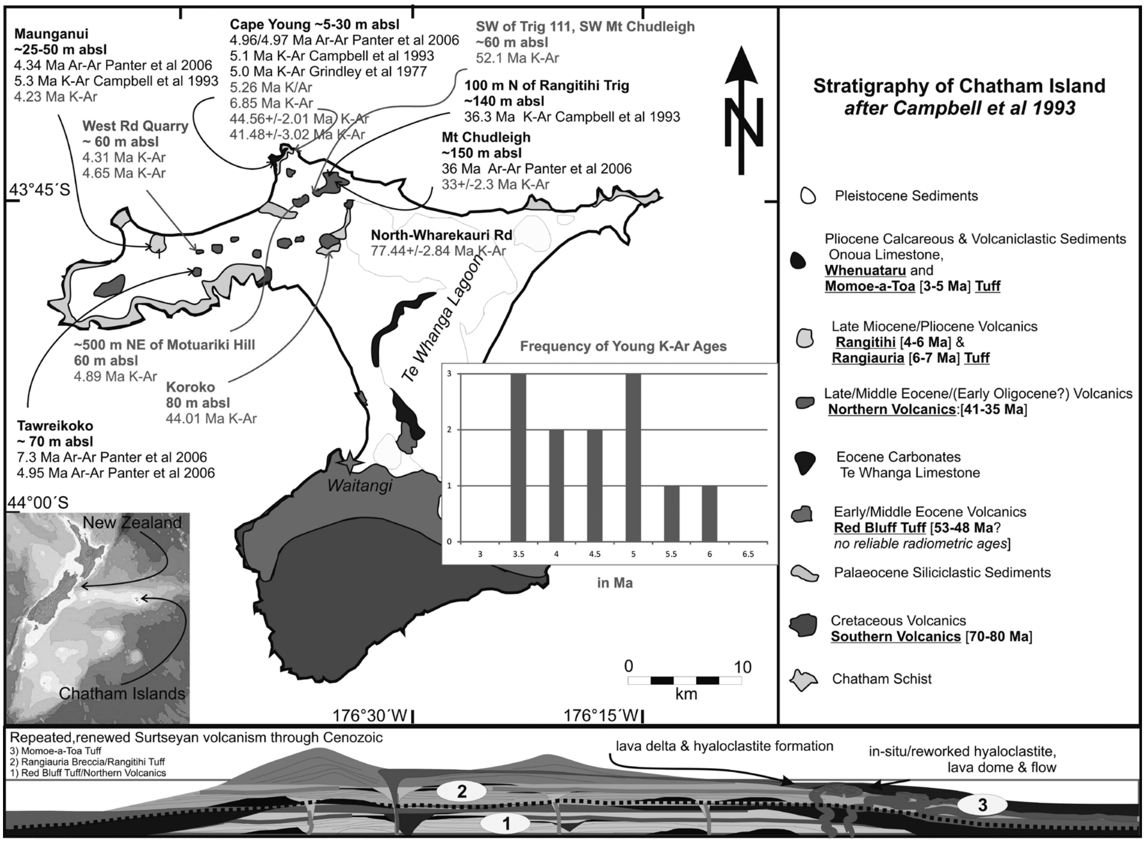

Fig. 1. Geological map of the Chatham Island (Campbell et al. 1993) with age data of volcanic units.

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3a

Volcanic construction of North Head (Auckland Volcanic Field, New Zealand) a scenario for emergent volcanism in the Auckland Harbour

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North Head is a small basaltic volcano located within the <250 ka Auckland Volcanic field. Its lowermost visible 15 m of sequence (starting below current sea level) is phreatomagmatic. The basal units (Fig. 1a), comprise palagonitised, well-sorted sub-angular to angular, moderately vesicular, fine to coarse juvenile lapilli (>90 vol. %) beds that are crudely parallel bedded on a cm to dm scale. These lapilli beds pass upward into poorly sorted med-coarse lapilli-bearing tuff beds (Fig. 1b), which are weakly consolidated and interbedded with firm cm-thick tuff layers (juvenile content of >80 vol %). The tuff is overtopped by a 20 m-thick, scoria fall and spatter sequence, including a small lava flow. We interpret that the eruption began with wet, tephra-laden jets forming the lapilli-dominated beds, typical of the earliest manifestations of Surtseyan activity (Kokelaar 1986). As the eruption progressed the access of water to the vent was reduced, perhaps by the construction of a tephra rim (Kokelaar 1986, Sohn & Chough 1993). This led to a combination of tephra jets and base surges being produced by ongoing magma-water explosive interactions (e.g. Sohn & Chough 1993). During this phase, subordinate magmatic-gas expansion driven fragmentation also occurred, as indicated by pyroclast surface features. Eventually, water-magma interactions ceased and the latter stages of the eruption were characterized by the "dry" ejection of scoria, spatter, and a small lava flow. Compared to other observed phreatomagmatic volcanoes in the AVF, the early North Head sequence is highly distinctive in containing such high proportions of juvenile material in well-sorted deposits. In several other cases, even where the volcanoes are at or near sea level (e.g. Maungataketake & Orakei; Nemeth et al. 2012 Agustin-Flores et al., in review) deposits are dominated (>60% by vol.) by pulverized country rock and magma-water interaction was clearly underground associated with groundwater aquifer systems. Therefore, these volcanoes must have been erupted at times when the mean sea level was lower than the present day. North Head, by contrast, appears to represent an eruption when the mean sea level was somewhat higher. North Head is located along the northern flank of an ancient river valley carved up to ~30 m below current sea level into Miocene sandstones and siltstones (Waitemata Group) (Searle 1958). For most of the last 200 ka there is evidence for stable tectonic conditions in Auckland and climate-related changes in the sea level are thought to have caused it to be at least 20 m below current elevations. Only during brief periods has it been high enough to engender conditions for the North Head eruption: in the Last Interglacial ~140 to 120 ka when it was 5-8 m above current levels, ~101 ka when it was around 11 m below current sea level, and the mid-Holocene warm period when it was up to 1 m higher than present (Pillans 1983, Hanna et al. 2011). This constrains the potential timing of the North Head eruption to when shallow surface water existed to set up the conditions for Surteyan activity. North Head thus provides one of the few local examples of an eruption scenario in shallow offshore areas such as the present day Auckland or Manukau Harbours. Presently approximately 30% of the AVF underlies water, indicating that the probability of this type of eruption is quite high.

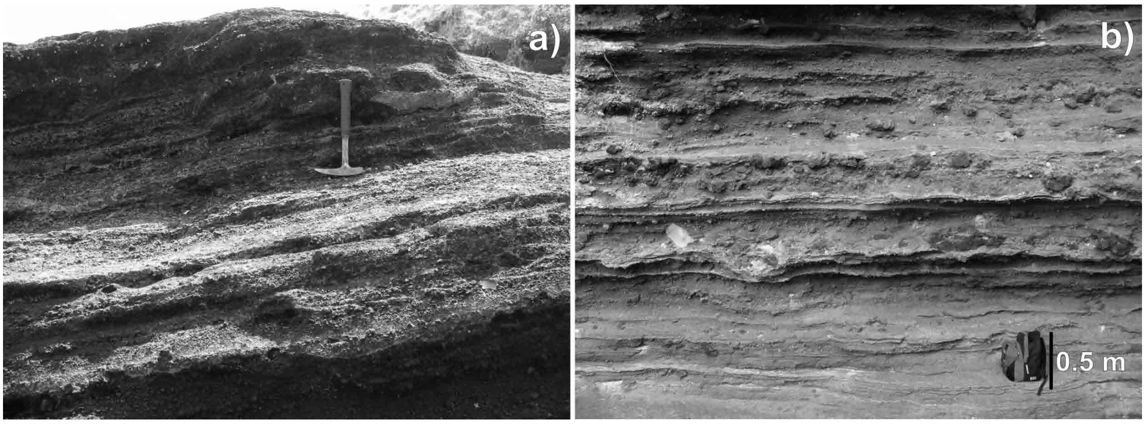

Fig. 1. Deposits of the lower phreatomagmatic deposits of the basal portion of North Head volcano: a) lower lapilli-dominated sequence, b) upper laplli tuff and tuff beds.

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3a

Complex isolated-to-nested pyroclastic cones and cone rafting in the AD 1256 Al-Madinah fissure eruption in the Kingdom of Saudi Arabia

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The most recent eruption in Al-Madinah Volcanic Field, Saudi Arabia, occurred in AD 1256 just ~20 km southeast from the center of Al-Madinah city (Camp et al., 1987). The volcanic activity was concentrated along a ~2 km long NNW-SSE-aligned fissure generating a lava flow field, a chain of isolated and nested pyroclastic cones, and extensive pyroclastic falls covered an area of about 10 km across. The lava-flows travelled a distance of 23 km to the north. They developed a wide variety of lava surface textures including tumuli, pressure ridges, skylights, and local lava tubes especially in proximal areas. The proximal pyroclastic facies were accumulated along the active fissure forming seven aligned pyroclastic cones (Figure 1), one of them reaching up to 100 m height forming the main nested edifice

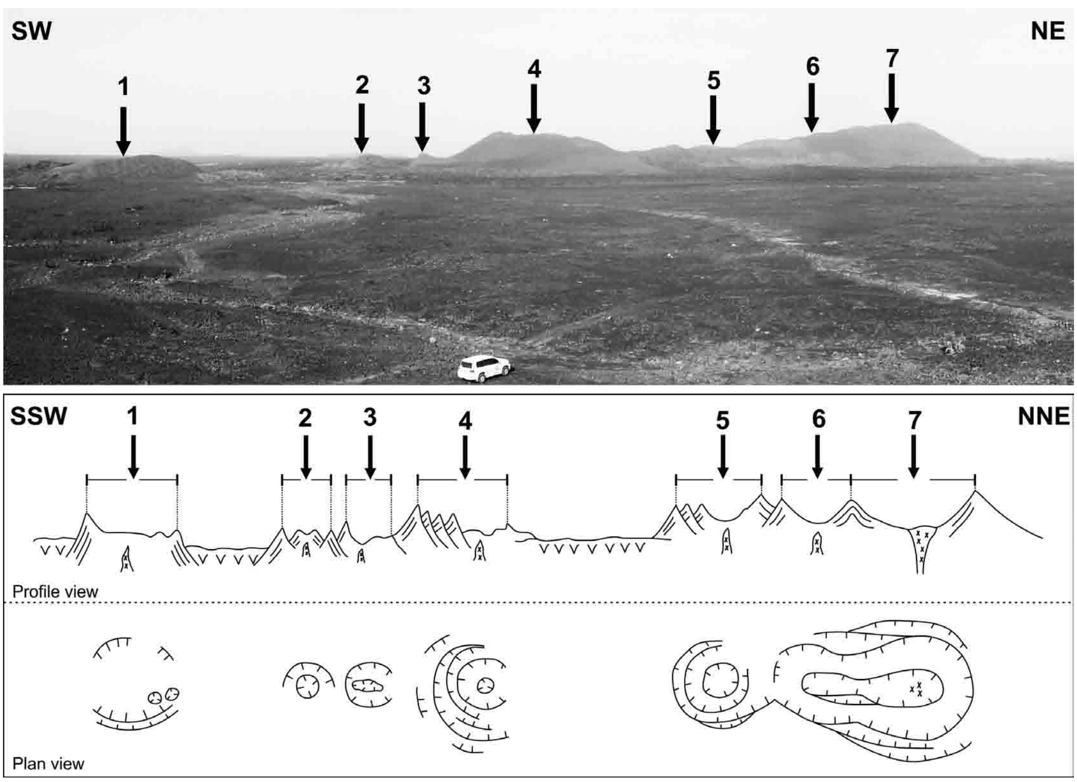

Fig. 1. Overview of the 7 cones (numbers 1-7) formed during the 1256 AD eruption. From SW to NE the first four are isolated but complex and the others are nested cones. The profile represents about 2.5 km.

in the northern part of the volcanic chain. Pyroclasts were also ejected beyond the cone edifices (referred here as medial-to-distal pyroclastic succession) forming a tephra cover composed of angular-to-fluidal pyroclasts as well as Pele's tears, Pele's hair and reticulate. Besides the cone and tephra-plain building volcanic processes, cone rafting (Figure 2) as well as central crater floor subsidence took place frequently leaving truncated cones and pyroclastic raft covered lava flows behind. Medial-to-distal ash and lapilli were accumulated on and below lava flows indicating coeval lava effusion, pyroclastic fall producing explosive eruptions and lava flow outbreaks in cone-flank regions shaping the final cone morphologies preserved today. Therefore, horseshoe shaped cones, multiple rafted cones and isolated/nested cones created a diverse and complex volcanic facies distribution along the fissure. The arid climate in the region preserved the volcanic features in their pristine, unmodified mode recording a very dynamic syn-eruptive cone growth and destruction that shaped the volcanoes along the AD 1256 fissure eruption.

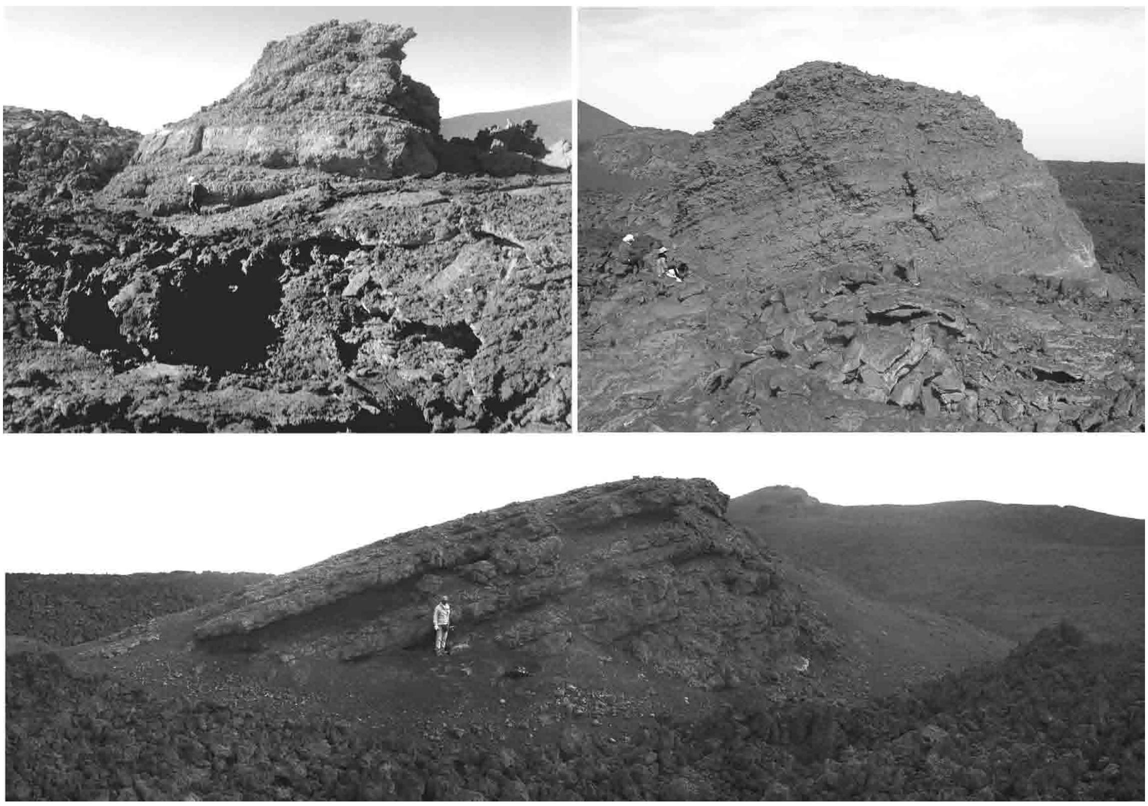

Fig. 2. Rafted cone material atop of the lava flows in the northeast area of the fissure.

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Three abundant types of Icelandic basalt

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Three conspicuous classes of basalt can be easily distinguished in the landscape of Iceland by inspection. These classes are, of course, not exclusive but are most abundant and therefore deserve description. The description is basically empirical and largely ignores geochemical and mineralogical aspects

- Flood basalt is the most abundant class; sections are best observed in the Tertiary rock pile of western and eastern Iceland on the slopes of glacial valleys; Holocene post-glacial flows can be observed in the central active volcanic zones.
- Shield basalt builds the volcanic shields (type: Skjaldbreiður) and is abundant at the surface of post-glacial shields; near-vertical sections are well exposed at the walls of Holocene gorges (Àsbgyrgi) and in some gaping tensional fissures cutting the flows (Allmannagjá, Þinvellir).
- River basalt has filled river valleys by flows coming down along river valleys mostly from distant sub-glacial volcanic centers, best observed in section in Holocene gorges formed by catastrophic floods (Jökulsárgljúfur, Hjlóðarklettar, Aldeyjafoss, Goðafoss).

The basalt columns are distinct and seem to be related to the rates and modes of cooling (dry, wet from rain or river water). The observations can be used to scale the parameters of a law derived from experiments (Müller 1998a, b) for basalt indicating some aspects of cooling. Pseudo-craters on the surface of flood basalt indicate heating of subjacent water (swamps) and steam vents (chimneys near Selfoss and Dettifoss; pseudo-craters in Mýrdalssandur). The natural sections through piles of shield basalts display differences from flood basalts in the character of the strata and the nature of columnar jointing; they indicate differences of basalt deposition by more frequent basalt flows and fast temporal sequences of flows. The spectacular river basalts show clear signs of the competition of flowing lava and water.

The three types are described by written text and photos.

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Rock Glacier, Block Field or Block Slope? A Periglacial Block Accumulation on the Basaltic Schafstein (Rhoen Mountains, Germany)

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The biggest extension of block accumulation locality in Germany is known from the basaltic hill of the Schafstein, in the central part of the Rhoen Mountains. This block accumulation was described in the 1960ies, for example by Mensching (1960), who called it "Blockmeer" (Block Field), and in the 1990ies, for example by Halfmann (1991), who called it "Blockhalde" (Block Slope). Due to its altitude (831.8 m a.s.l.) and predominantly northern exposition, due to its extension and its dam-like surface, a hypothesis was developed, that the Schafstein might also be a rock glacier formed during the Pleistocene. The first step of this study was to collect literature information about the features of different forms of block accumulation (cf. Table). A second step was to realise different analyses (micro-scale geomorphological survey, temperature measurements, refraction-seismic measurements and mineralogical analyses) to clear the genesis of the Schafstein block accumulation.

Feature	Block field	Block slope	Rock glacier
general feature: accumulation of blocks with only a few or no amount of fine particles, with only rare or no vegetation cover			
Size	no details	some 10m up to some 100m long, > 20m broad	60...1,500 m long, 60....3,000 m broad
thickness	no general details; mostly > 1 m	no general details; some meters	10...100 m
slope inclination	< 20°	> 20°	seldom more than 10°; border slopes 35°
relief location	on plateaues and slopes; not necessary close connected to the source of blocks	below a rock bare	on slopes
Block size	no general details, different	at least head size, > 2 m	mostly 0.6...1 m
Block form	edged or shaped	edged	no details
Block formation	in situ chemical and physical weathering with transport	in situ chemical and physical weathering with transport	physical weathering, primary by frost
Block transport	solifluction, sliding	falling, sliding	cohesion transport of the ice cement
Surface structure	no details	no details	longitudinal and transverse bulges, depressions
Necessary climate	tropic or periglacial	periglacial, arid, semi-arid	periglacial

The micro-scale survey of the block forms shows, that the central part of the Schafstein block accumulation has edged blocks at the upper part and shaped blocks at the bottom. A special feature at the bottom is a characteristic wall and depression structure, with more than 30° inclination between the walls, caused by different tensions of different ice cement saturated parts of the block accumulation. With the help of refraction seismic measurements we could prove, that the central part of the block accumulation has a thickness of about 30 and 40 meters. During summer time, when air temperature was about 30°C, we have measured -1°C air temperature in between the blocks. Nearly all studied features prove, that the central part of the Schafstein block accumulation represents a fossil rock glacier (c.f. Fig.), while the western part represents a block field, and the eastern part is a block slope.

The genesis of the Schafstein block accumulation can be described by Pleistocene and Post-Pleistocene weathering and transport processes. First, besides insolation, hydrolysis and bio-genetic destruction, frost weathering and frost action have caused a block separation from the basaltic columns. Still during the Pleistocene the basaltic blocks were moved by rock sliding, by creeping of the ice-cemented block masses and by solifluction processes. Ablation of the ice core, outwash of the fine particles and partly settlement of the blocks with lichens, mosses and trees are characteristic processes during the Post-Pleistocene. The extreme climatic conditions during the whole Holocene, the block bedding and the specific air circulation between the thick block accumulations are responsible for seasonal ice formation up to nowadays.

Fig. 1. Rock glacier features on the bottom of the north and north-west slope of the Schafstein block accumulation (upward view).

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Basalt in Albania

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The Volcanic sequence of ophiolites forms the upper part of ophiolite cross-section and can be distinguished in two series according petrologic and geochemical criteria : 1) basaltic MORB (***western ophiolites)*** and 2) dacitic-basalt (***eastern ophiolites***, SSZ) (Shallo 2002, Hoeck 2002, Koller 2006).

The Basalt series (MORB) of western ophiolites is distributed over an area of about 100 km2; is placed over the gabbroide rocks, sometimes through gabbro-diabases or over ultramaphic sequence of western ophiolites through oceanic metamorfites (metabasalts), and is covered normally from radiolaritic siliceous of middle-upper Jurassic, or transgressively from heterogeneous ophiolitic mélange of upper Jurassic.

Basalt series is composed by pillow lava and basalt lava flows and rarely basaltic pyroclastics and hyalobasalts in the upper part of cross-section; rarely there occur thin interlayers of radiolaritic siliceouses. The sequence is represented by basalts, basaltic porphyrites, olivinic basalts, variolitic hyalobasalts, basalt-andesites that are mostly fresh or partially and rarely entirely replaced by the hydrothermal metasomatites. Geochemical data show clearly for magmatic affinity of the type of basalts of middle-oceanic ridges (MORB) and for the similarity of their chemical composition with that of plutonic sequence of western ophiolites, and also with the composition of basalts of volcanogene-sedimentary preophiolitic formation.

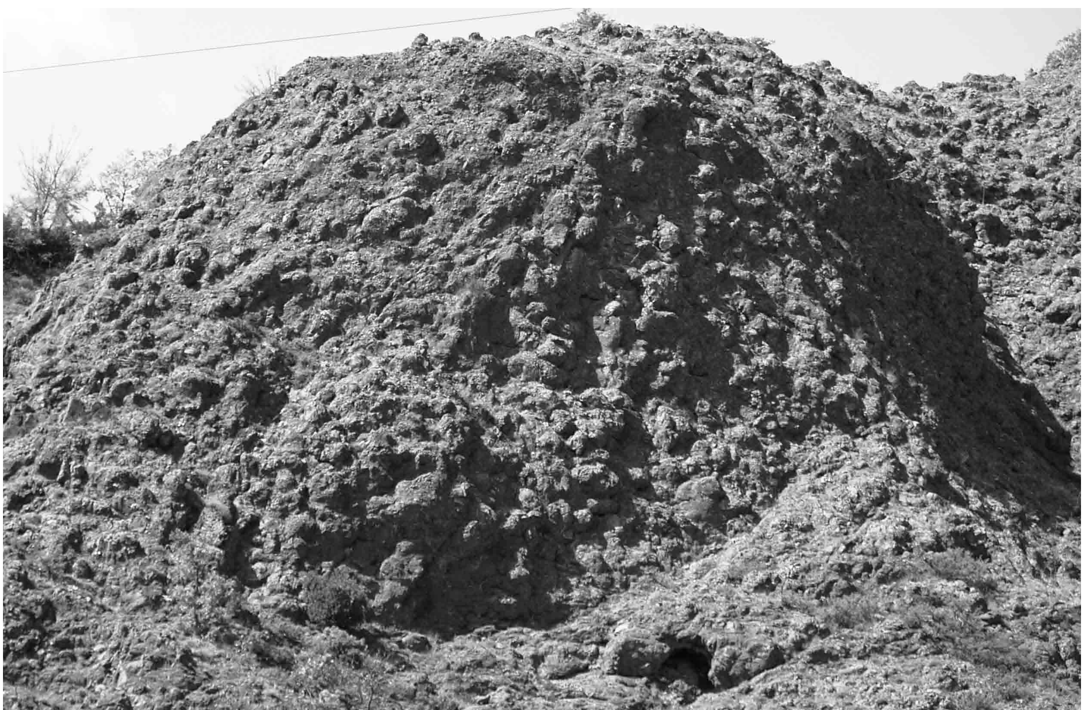

Fig. 1. Pillow lava (Peshqesh, Albania)

Basalt-dacite series of eastern ophiolites together with the parallel dikes complex are distributed over an area of about 620km^2 composed by pillow lava and basalt to basalt-andesitic lava flows. The latter built upthe lower part of the sequence and form pillow lava(Fig.1) and lava flows and pyroclastic, andesitic-basaltic and boninitic and also dacitic, rhyodacitic and rhyolitic rocks, that constitute the upper part of the basalt-dacitic many sectors is saved the earlier sedimentary cover represented by radiolaritic siliceous of middle-upper Jurassic placed over tuff-agglomerates of the top of cross-section of this series; in some places is observed a transgressive placement of heterogeneous ophiolitic mélange of the Upper Jurassic (Titonian) over the upper levels of cross section.

Volcanites of this series are touched from hydrothermal metamorphism in many sectors and are transformed in hydrothermal metasomatics of schists zeolite green facies, that usually constitute aureoles of sulphur-volcanogene mineralization. Geochemical data of the lava of basalt-dacitic series show for magmatic affinity of arch-boninitic toleites type, similar with volcanites of over-subduction medium (SSZ) and are distinguished clearly from basaltic lava of western ophiolites; are closed to chemical content parallel dikes complex and of the plutonic gabbros plagiogranite series.

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Geological and physical-mechanical characteristics of basalts in Central Mirdita, Albania

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Basaltic volcanism. Basaltic volcanic formations, are spread to the central part of the region, where also find passages from diabase to gabbro, through gabbro-diabase, representing an uninterrupted continuation from the more oblique basic rocks of the depth, in those of surface area. - Jurassic ophiolites, with their main petrologic features (western type ophiolites - MOR, transitional type ophiolites - MORB (Western ophiolites)-SSZeastern type ophiolites SSZ, intrusions ultramaphic in ophiolites, acid intrusive magmatic, oceanic amphibolites, in Western and Eastern Mirdita contact. Based on field observations and petrologic, geochemical and metalogenic data, in ophiolitic belt, of central Mirdita are distinguished western type (MORB) and eastern (SSZ) ophiolites, with corresponding to typical cross sections, that show significant differences between both types.

The volcanic section of Western ophiolites, is represented from pillow lavas lava basaltic currents rich in titanium. In eastern ophiolite, it consists of basalt with low to very low Ti-content, and boninites associated with andesite, dacite, riodacite, riolyte and content of sulphure mineralization, in stockwerk and massive type. Phenocrysts are represented by fresh twinned plagioclase. Groundmass with ophitic texture consists of small plagioclase prisms and xenomorphic isometric grains of clinopyroxene.

Basaltic pillow lavas constitute the greater volume of volcanic rocks. The biggest thickness are measured in the region of Vagur Rrëshen-Derven, Gëziq- Bukël, Cekaj-Ndërfane – Shtanë, etc.. In petrographic rock's package composition are distinguished basalts, diabase, mikrodiabase, variolyte, porphyrite. Often, in diabase types are encountered secondary titanomagnetite, in fact that constitutes the distinctive features for vulcanite Mirdita basaltic. Rocks of this package have been solidified in shapes of pillow and sphericoidal lavas, which predominates significantly, and less often in shapes of breccia lavas, tuffites, siliceous tufites etc. Pillow lavas have dimensions 0.4x0.8 to 0.7x1.0 meters, and rarely, as north Geziqi, Shtanë, etc., have the biggest dimensions, which reach up to 1.5x2.5m. The microscopic study shows that small granulitic diabase, are characterized by microdiabasic and mikrodoleritic structures. These rocks are intersected with varyolites, characterized by a spherolythic construction of the basic bulk. In several cases we note almond texture variolythe with. Thickness is around 1000m. Qualitative indicator of basalts. SiO_2 = 48.8%, CaO = 12.42%, MgO = 7.62%, Fe_2O_3 = 10.74%, Al_2O_3 = 13.88%, TiO_2 = 1.4%, Na_2O = 2.8%, MnO = 0.13%, Hk = 2.03%, K_2O = 0.15%. From the studied samples, for the physic-mechanic properties, results the following characteristics of those basalts:

Specific weight	γ_o= 2.925 g/cm^3
Volume weight	γ = 2.91 g/cm^3
Skeleton volume weight	γ_d = 2.899 g/cm^3
Natural humidity	W_n= 0.37 %
Porosity	n = 0.88 %
Resistance to pressure	τ = 1280–1410 kg/cm^2
Withdraw resistance	τ_w= 148–165 kg/cm^2
Friction inner angle	$\varphi = 68^\circ$
Angle of inner rubbing in matrix	$\varphi = 58^\circ$
Module of elasticity	E_{el}= 127000 kg/cm^2
Strain Resistance	σ = 237 kg/cm^2
Los Angeles	LOS = 16–18

Deccan Traps associated obsidian glass: a nuclear waste containment

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Basaltic glass is considered as a natural analogue for nuclear waste glass to contain fission products. It provides data on the alteration behaviour of vitreous material over the geological time-scale. However, a good quality of obsidian that occurs in Osham hill, Gujarat, India is considered as potential natural analogue of the long-term alteration of nuclear waste glass. In contrast to several studies focused on the dissolution rates of basaltic and borosilicate glasses, the corresponding studies on acid volcanic glasses such as obsidian, rhyolite and impact glasses are rare, thus, present study is justified. To address these issues and to understand chemico-mineralogical changes occurring at or near the surface, experimental study on obsidian glass is attempted in this paper and performed under high temperatures to generate hydrothermal-like conditions in a Parr reactor. Alteration mechanism is quantified by key parameters to assess its performance in the repository. The induced micro-textural and mineralogical changes were compared with the obsidian undergone weathering in a natural environment after its formation (~ 65 Ma) and discussed in this paper. Alteration of obsidian (from Osham Hill, Gujarat, India) after treatment under hydrothermal-like conditions is compared with the naturally altered obsidian for its performance assessment as nuclear waste glass. Experimental data obtained for glass alteration, ionic release and their retention in the residue were analysed. Geochemical evolution of glass particles show partial to complete leaching of all the ions but profusely of Si and Na ions. The ionic release is of the order - Na>Si>K>Ca>Al = Mg>Fe>Mn>Ti. Back scattered electron images show distinct microstructures of smectite, montmorillonite and illite inside as well as outside of the secondary layers, represent paragenesis of alteration products. It is observed that the octahedral cation occupancies of smectite are consistent with the dioctahedral smectite. The secondary layer composition indicate retention for Si, Al, and Mg ions, indicating their fixation in the alteration products, but, remarkably high retention of Ti, Mn and Fe ions suggesting release of very small fraction of these elements in to the solution. At the initial stage, the process and extent of palagonitization and at later stage formation of smectite is comparable with the experimentally altered as well as naturally weathered obsidian. The mode of glass dissolution and the properties of the secondary phases played significant role in the rates of ionic release, thus, critical in establishing the long-term alteration process that affects obsidian glass, suggest its suitability as a natural analogue of the long-term alteration of nuclear waste glass. Devitrification of glass along the cracks, formation of spherulite-like structures and formation of yellowish brown palagonite, chlorite, calcite, zeolite and finally white coloured clays yielded after experiments that largely correspond to altered obsidian in the natural environment since ~ 65 Ma.

Small-volume monogenetic volcanism in Argamasilla and Calzada-Moral basins (Campo de Calatrava Volcanic Field, Spain)

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This work focuses on the influence of Mio-Pliocene volcanism from Campo de Calatrava Volcanic Field (CCVF) on the sedimentation of siliciclastic and carbonate deposits of two intra-continental basins in Spain (Argamasilla and Calzada-Moral basins). The volcanism in the CCVF is typically monogenetic according to the small-volume volcanic edifices of scoria cones generated and the occurrence of tuff rings and maars. The geochemistry of the volcanism in CCVF ranges between an early ultrapotassic episode (8.7 and 6.4 Ma, Upper Miocene) and a later alkaline and ultraalkaline in composition episode, dated between 3.7 and 0.7 Ma (Plio-Pleistocene) (e.g., Gallardo-Millán 2004, Ancochea 2004, among others).

Taking into account variations in lithology, colour, composition, grain size and sedimentary structures seven types of pyroclastic lithofacies were distinguished. The facies closest to vents (pyroclastic fall deposits) are characterised by the disorganization of the deposits, their breccia-like aspect, presence of large bombs, poor sorting and lack of tractional sedimentary structures. Up to four different lithofacies were interpreted to be the product of low-density (dilute) pyroclastic surges, all of them showing textural features that point to fluctuations in flow regime. Similarly, a conspicuous lithofacies was interpreted as a secondary volcanic deposit. The latter was related to volcanic sediments that were reworked by transitional hyperconcentrated flows and dilute fluvial processes, finally accumulated in braided fluvial systems. Finally, intra-maar scoria/spatter cones were related to the development of maars.

The occurrence of small-volume volcanic edifices and volcaniclastic layers with small thicknesses point to short periods of syn-eruption volcanic activity in this area. These stages were separated by longer inter-eruption periods, where the accumulation of fluvio-lacustrine sediments was prevalent. The latter could be a consequence of the composition of the CCVF volcanism (alkaline to ultrapotassic) that led to explosive to effusive Strombolian eruption styles and explosive phreatomagmatic eruptions. The volcanic activity was strongly controlled by previous basement faults that favoured magma feeding and the location of volcanoes themselves. The occurrence of volcanoes into the continental basins studied led to drainage-pattern disruption, the modification of sedimentological intra-basinal features, internal changes in fluvial system and the creation of shallow lakes related to maar formation.

3a

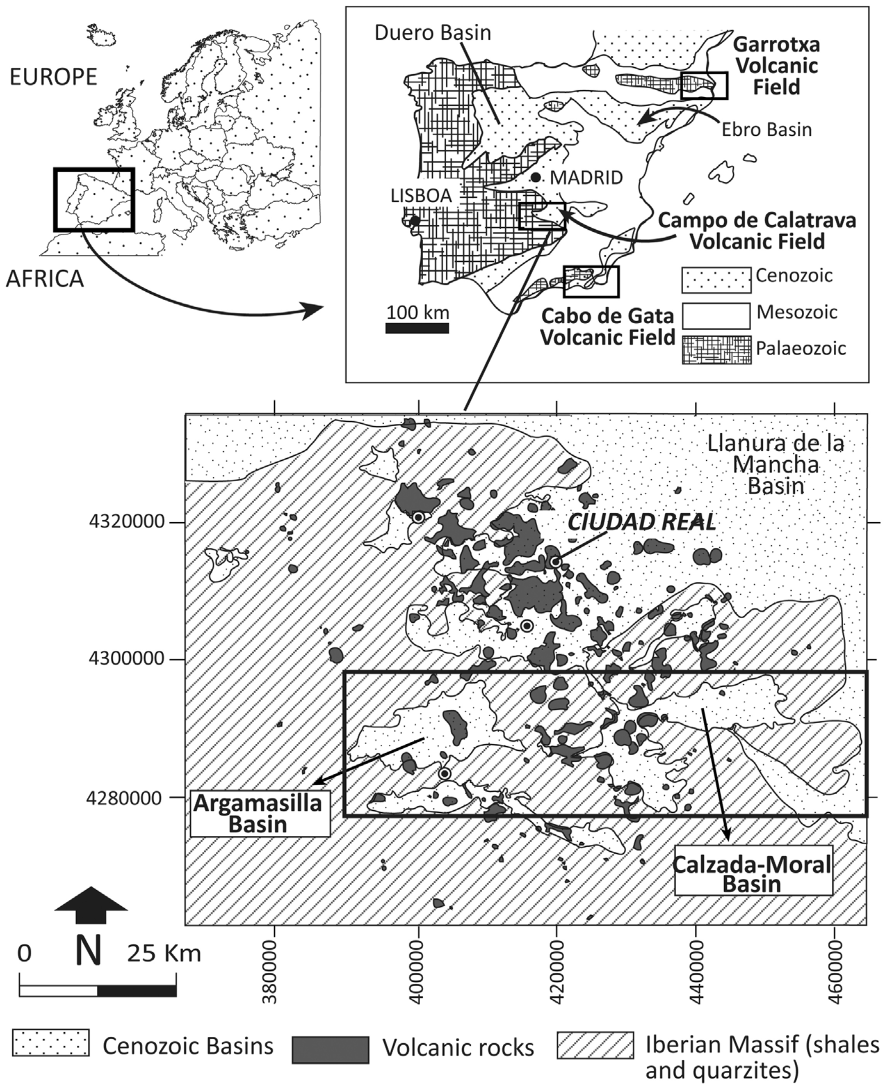

Fig. 1. Location of the main Neogene basins and volcanic fields in the Iberian Peninsula. General geology of the Campo de Calatrava Volcanic Field.

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Search for volcanoes based on constraining geophysics and geomorphology

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3b

Volcanoes are extremely important geological phenomena attracting attention of not only geoscientists, but a big part of common population as well. The reason is the beauty and interesting (morphological) features of (active) volcanoes, but first of all the threat and hazard they represent for the region and inhabitants.

Volcanoes are usually forming striking morphological shapes, mainly cones, calderas or lava flows. But what if not? Then we need some tools to recognize a volcanic structure hidden in the normal or not-typical topography. Geophysical techniques definitely play a significant role in volcanic investigations. As the most important we consider gravity and magnetic surveying. The reason is that these techniques can indicate, locate and delineate a hidden volcanic body that may have no clear morphological expression on surface. A volcanic body often exhibits anomalous petrophysical properties of the rocks (hard volcanic rock, breccia, tuff, tephra, etc.), like density, porosity, magnetic susceptibility, etc. that can be recognized by geophysical measurements. This may happen during a specific volcano-oriented survey, but also during any other surveys performed in a volcanic region.

We identified a volcanic structure during the gravity mapping in the scale 1:25.000 where a single point with negative anomaly gave origin to a detailed survey discovering a small complex volcano. The structure was located in a negligible topographic depression, with no real indication as for morphological shape (Mrlina et al. 1989). On the contrary, volcanic craters in the Coastal Mts. in Syria are forming extreme inverse conical shapes with flat bottom in great size up to 3 km length and 300 m depth. However, only thanks to geophysical surveying it was possible to locate the volcanic chimneys (investigation target) on the craters' floor (Mrlina 1993).

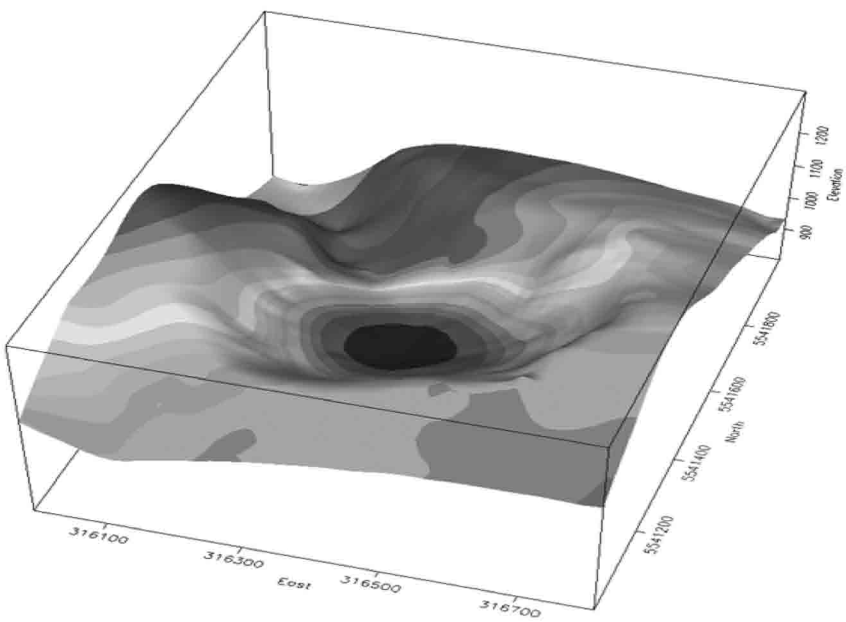

Fig. 1. Indication of a volcanic structure from gravity map contours printed over digital elevation model.

One extraordinary volcano we have recently found in West Bohemia. Based on observing an unusual topographic element – an almost circular depression (hardly to be seen in the field due to forest), and a gravity-magnetic scouting survey (Mrlina et al. 2007), we found a Quaternary maar near Cheb (Fig. 1). The follow-up detailed geophysical survey enabled to position an exploratory well that confirmed the existence of a maar-diatreme volcanic structure filled by Quaternary lake sediments with organic substance that provided material for paleoclimate investigations (Mrlina et al. 2009).

In conclusion, many volcanoes can be recognized from morphology. However, there are also numerous volcanic structures without any characteristic topographic expression, and therefore many are still unknown. In such case, they may be discovered by a volcano-search oriented geophysical investigation, or even by good luck during geophysical surveys focused on other geological targets.

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Identification of Paleo-Volcanic Rocks on Seismic Data

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While exploring for hydrocarbons in rift related basins, volcanics, volcaniclastic deposits or their erosional products are common lithologies. The presence of rock types derived from volcanism and/or affected by post-volcanic re-deposition may lead to complex lithologies with complex diagenetic overprints at the reservoir level. Partial or complete reservoir substitution, alteration by circulating hot fluids and addition of mineral components have led to a number of unsuccessful wells, both in exploration and field development projects. Furthermore, volcanic rocks may form lateral seals or migration barriers, providing both positive and negative impact on the petroleum system. Non-permeable volcanic layers can seal the top of the reservoir, preventing it from breaching, or they can build a migration barrier for the fluid on its way from the source rock into the trap. In most cases, highly varied lithologies with wide ranges of inherent rock properties occur. It is therefore essential to understand the distribution of volcanics in the vicinity of the reservoir.

Published examples of volcanic reflectors identifiable from seismic data are still very sparse, and there is no systematic compilation of information and knowledge available. Free air gravity maps, as well as other potential field methods, may show anomalies caused by volcanic and sub volcanic bodies if they are really massive geobodies. Unfortunately, the majority of volcanic features are rather thin (some tens of meters thick). At a reservoir depth of more than 3 km the resolution of standard potential field data is not good enough to delineate the individual units.

A close cooperation of specialists from different disciplines is required in order to resolve specific problems related to seismic interpretation and reservoir prediction within such a complex environment. Sedimentology and fieldwork studies of recent analogues provide the basis for recognition of the depositional environment used for seismic interpretation. Special seismic processing must be utilized to calculate attributes from prestack data, showing amplitude variations with increasing offset from the energy source (commonly referred to as AVO analysis). These data are interpreted using results from rock physics analysis - elastic parameters of different lithology types and seismic forward modeling. The AVO analysis is used to support the lithology identification from seismic geometries. The input for the rock physics is delivered by the petrophysicist – log derived properties and interpretations. Petrography is used for provenance analysis, as well as analysis of diagenesis and fabric. In many cases, this turns out to be the key to understanding the anomalous AVO behavior of sandstones. Finally, sequence stratigraphy relates the different levels of sandstones to periods with and without volcanic activity.

Our experience from working in different basins around the world has shown that there are certain distinct features that can assist in the identification of volcanics and volcanic related lithologies from seismic data. These features can be divided in two main groups: (1) geometry, specifically in comparison with observed morphology of recent volcanics and (2) amplitude expression, particularly the AVO behavior. Modern seismic interpretation technologies, such as 3D imaging, spectral decomposition, analysis of elastic rock properties and AVO analysis in combination with sound geological understanding of recent volcanism reveal completely new insights into the geological past. There has been a lot of activity centering upon sub-basalt imaging, but this does not really help to overcome the problems we have in identifying and predicting volcanics from 3D seismic data at reservoir level. AVO investigations have typically concentrated on sandstone-shale intercalations and carbonates. The pure visual identification of volcanics within the seismic is very difficult. Either they appear to be similar to carbonates (basalts) or to siliciclastic rocks (volcaniclastics).

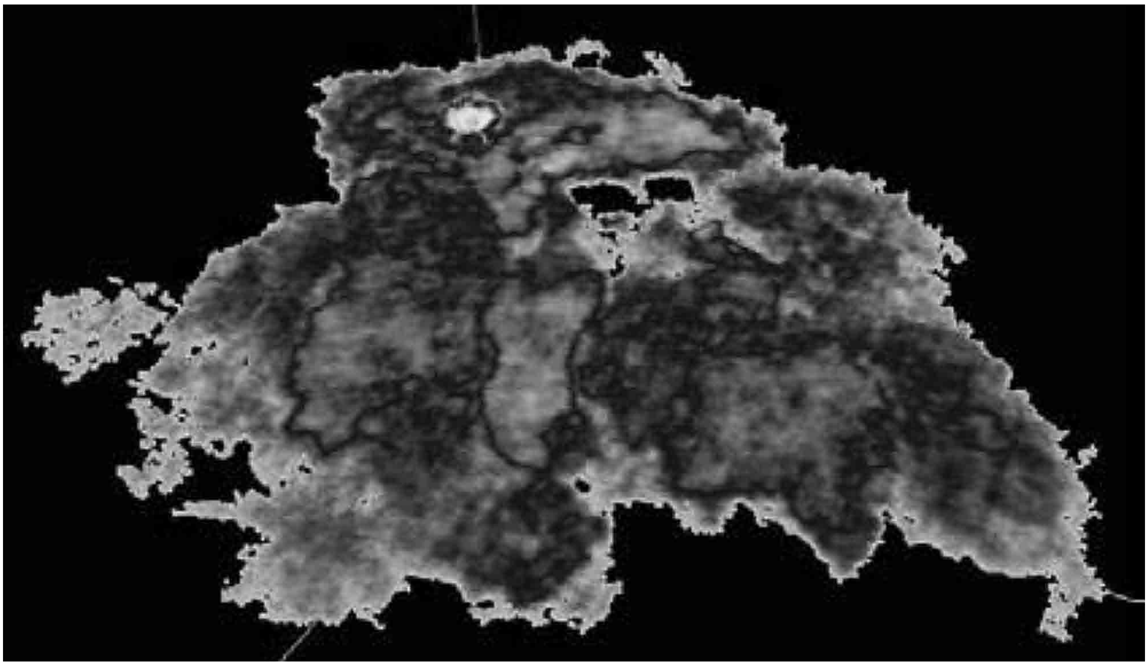

Fig. 1. Seismic image of a Cretaceous basalt layer, extend app. 15 km; Santos basin, offshore Brazil

However, due to the different acoustic and elastic properties of clastic and carbonate reservoir rocks versus volcanics, there is a realistic chance to develop an approach for the identification of volcanics in seismic data:

1. Basalts, even relatively thin layers, show typical geometries known from surface observations that can be identified on seismic data.
2. Basalts may display extremely high acoustic impedances and high vertical heterogeneity. They can be responsible for attenuation effects, which would be discovered by spectral decomposition/ spectral ratio analysis.
3. Volcanic layers and small edifices could be identified by differential compaction analysis, using curvature and high frequency structure images.
4. Volcaniclastics are multimineral, proximal, immature, poorly sorted sediments with a matrix-supported fabric. They exhibit significantly higher Vp/Vs ratios than cleaner and better sorted grain-supported siliciclastics.
5. Due to the high Vp/Vs ratio, basalts and volcaniclastics are likely to produce increasing AVO effects on hard kicks (high acoustic impedance layers) – porous sandstones usually show these effects on soft kicks.
6. The images and seismic response modeling of intrusive bodies, varying in dip and thickness, will help the seismic interpreter to identify them on his data set. In frontier areas, they could give indications as to whether we are dealing with volcanics.

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First paleomagnetic results from Cenozoic volcanics of Lusatian region, Saxony/Bohemia

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The Lusatian area is situated in the NE continuation of the Ohře/Eger Graben/Rift (OR) course. Compared to the neighbouring volcanic complex of the České středohoří / Böhmisches Mittelgebirge Mts. (CS) inside the OR, the basaltic bodies in Lusatia represent scattered occurrences and they are spread on wider area. This can be caused by different tectonic development of the regions and from derived erosional conditions. The Lusatian Overtrust, high-order tectonic structure running across the course of the OR, separates Lusatian region into two different geological areas where Cretaceous sediments or granodiorites of Lusatian Massif represent the country rock of the Cenozoic volcanism, respectively. As the continuation of the OR tectonic structure across the Lusatian Overtrust is not so clear, it is more problematic to define the position of the Lusatian volcanics related to the tectonic structure of the OR. The age of volcanic activity ranges from 19 to 33 Ma, due to the newly obtained K-Ar data from Debrecen and Ar-Ar data from Freiberg. This span covers the time of maximum volcanic activity and origin of three stratigraphic Formations in the CS (Cajz 2000). The Lusatian and the CS volcanics are similar in geochemistry, as well.

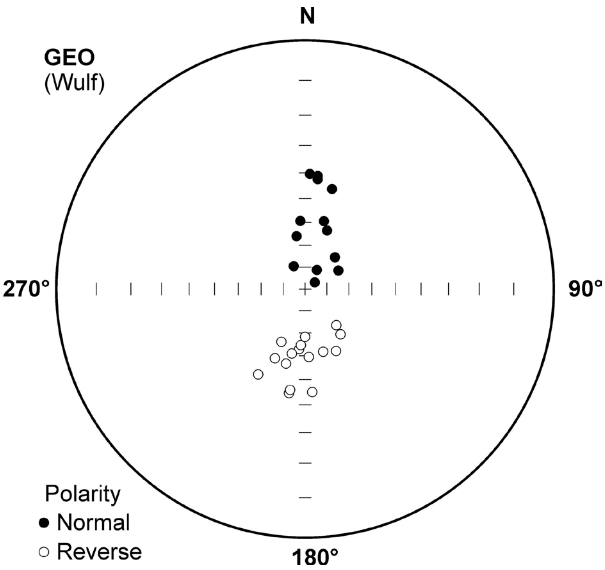
Scattered remnants of Cenozoic volcanic products in Lusatia were sampled to get paleomagnetic data. The sampling places in Bohemia were oriented only on basaltic rocks (15 sites) and this rock group also prevails among samples from Saxony (27 sites). The superficial volcanics with detectable geological position and volcanology were chosen preferentially, several dykes and separate vents were sampled as well. Paleomagnetic research was processed on more than 350 samples using alternate field demagnetization in the range 0-80 mT up to now. Thermal demagnetization and rock magnetism is in process.

The Königsberger parameter (Q-ratio) was counted to prevent the lightning influence – solitary volcanic occurrences build positive morphology and thus, they are prone to be targeted by lightnings. The values of Q-ratio predominantly span from 0.1 to 7.0; those samples having the value over 10, were excluded for this evaluation. The mean paleomagnetic direction (MPD) was acquired from several samples on each sampling site. Declination and Inclination show values of 11.8° and 62.7° ($\alpha95 = 9.3°$) for normal polarity, or 182.1° and 59.2° ($\alpha95 = 6.1°$) for reverse polarity, respectively. From the Inclination, the corresponding paleolatitude of 41.9º was counted. This is 1000 km to the South, compared to recent position. The dispersions of the MPD are relatively wide (Fig. 1). This coincides well with the idea of long-lasting volcanic activity in Lusatia and supports the radiometric results. Duration of volcanic activity in the Lusatian region is more similar to the CS Volcanic Complex development than to the volcanic activity which products are situated outside the OR structure, like Jičín and Bruntál Volcanic Fields (Cajz et al. 2009; Cajz et al. 2012).

In combination of reversal test and the wide dispersion of MPD, the centred secular variation was proved. It allowed counting of the virtual geomagnetic pole (VGP – (Fig. 2) position on coordinates 79.9°N and 167.5°E ($d_p = 6.1º$, $d_m = 7.9º$), which agrees with the Late Tertiary apparent polar wander path (APWP) for Europe (e.g. Irving and Irving 1982; Van der Voo 1990). The VGP counted from volcanics in Lusatia is relatively close to the data obtained mainly from the CS Volcanic Complex (85.09ºN and 160.88ºE), published by Chadima et al. (2006).

The paleomagnetic results of volcanics from the Lusatian region, obtained up to now, show great similarity to that ones from the CS Volcanic Complex. This is another argument for an idea of joint volcanic development of these regions. It also contributes to the entitled use of the CS lithostratigraphic units also in the Lusation region.

Acknowledgement: This research was supported by project IAA 300130612 of the GA AS CR "Combined magnetostratigraphic studies of Cenozoic volcanics, Bohemian Massif". It falls within the Research Plan of the Institute of Geology, Academy of Sciences CR, v.v.i., AV0Z30130516.



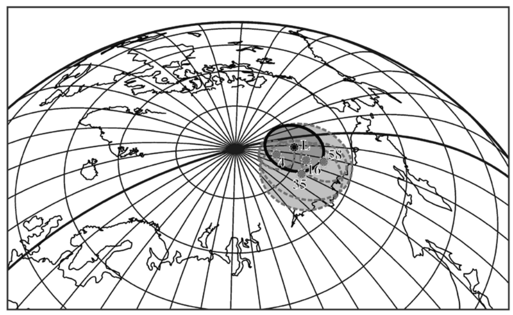


Fig. 1. (left) – Projection of the mean paleomagnetic directions (MPD) of the Lusatian Cenozoic volcanics.

Fig. 2. (right) – Virtual geomagnetic pole (VGP) of Lusatian Cenozoic volcanics (L) plotted against the apparent polar wander path (APWP) for Europe during Tertiary (4-16-35-58 in Ma).

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Magnetic investigation of the volcanic intrusions and maar-diatreme volcanoes in the Czech Republic in the years 2009–2012

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The volcanic rocks are one of main sources of the strong anomalies in the magnetic field. The high volume of the magnetic minerals (magnetite, titanomagnetite and maghemite) in basalts implicate high magnetic susceptibility. The airborne magnetic data were collected and analyzed for detailed geological survey in the scale 1: 25 000. The local positive or negative anomalies were following verified in the field by the ground magnetic survey. The airborne magnetic anomalies were correlated with the gravity data for the selecting of the potential maar volcanic structures.

Within the frame of the Cenozoic volcanic activity in the Bohemian Massif, several maar-diatreme volcanoes were formed. The eruptions of maar-diatreme volcanoes produce negative topography often become buried by subsequent sediments. As the diatreme filling is rarely harder than country rocks, these are only exceptionally exposed by selective erosion. For that reason, detection and research of maar–diatreme volcanoes is often highly dependent on geophysical methods.

In order to obtain reasonable data, combination of several ground geophysical methods is required. Within the framework of our research, we have combined ground magnetometry, ground gravimetry and multi-electrode resistivity measurements. We have measured four selected localities, where maar-diatreme setting had to be confirmed.

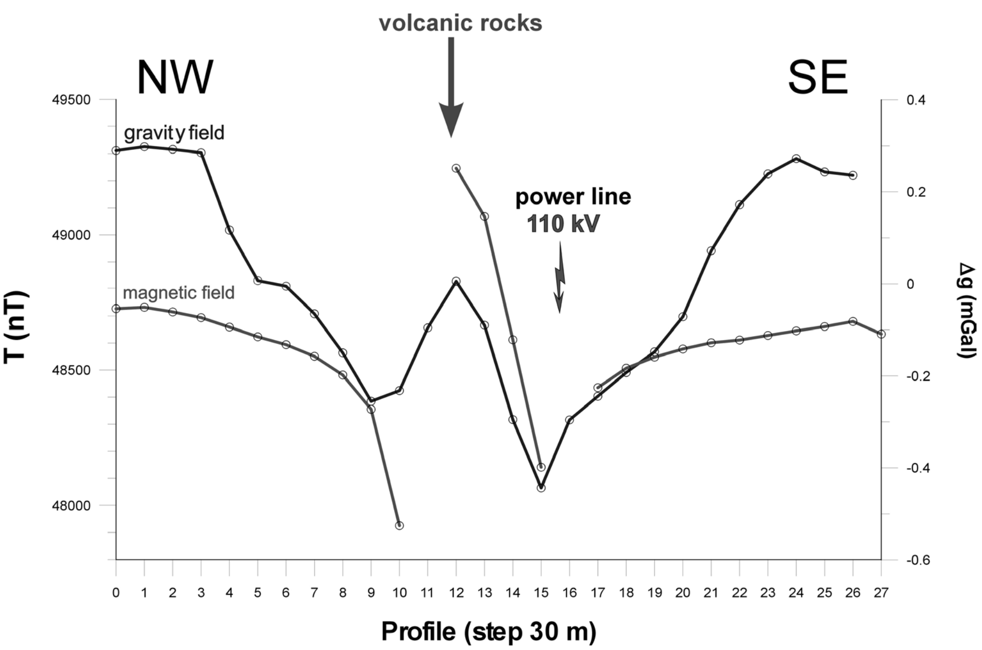

Fig. 1. The profile with the magnetic and gravity data in the Rajov maar volcanic structure

According to obtained data, we have discredited the possible existence of maar volcano around Semínova Lhota (Rapprich, Skácelová & Valenta. 2011). in Bohemian Paradise area (NE Bohemia).

We have confirmed the supposed existence of Rychnov maar near Jablonec nad Nisou (N Bohemia). This Oligocene maar is still preserved including sedimentary fill, possibly due to its position in crystalline complex protecting the maar from erosion (Skácelová et al. 2010).

The pyroclastic deposits at Hnojnice in the southern part of the České středohoří Mts. (NW Bohemia) correspond to inward bedded upper diatreme facies. The shape and structure of the diatreme is visible on multielectrode images. The magnetic survey has detected NW-SE feeder dyke and several smaller branch-dykes (Skácelová et al. 2010).

Magnetometric indication of possible volcanic conduit north of Podhorní vrch Hill near Mariánské Lázně (W Bohemia) required detailed geophysical research. Combined ground geophysical survey identified possible feeding system and also thick horizontal basaltic layer filling prominent part of the maar crater. This basaltic layer could be lava from Podhorní vrch Hill which filled the maar crater.

The small volcanic vents were identified in Proterozoic rocks southern of the Doupovské hory Mts. Ground magnetic measurements localized the Cenozoic basalt with normal and also with reverse polarization.

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Reconstruction of the great episodes of destabilization of Stromboli volcano (Italy) by coupling methods of electrical resistivity tomography, diffusion of gases in the soil and bathymetry survey

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3b

Stromboli (38.789°N, 15.213°E y 924 m.a.s.l.) is the northernmost island of the Aeolian Island Arc, located the northern side of Sicily (Italy), with a surface area of 12.2 km^2 and a depth of about 2000 m in the Tyrrhenian Sea (Segre 1968). It one of the seven major islands (Alicudi, Filicudi, Salina, Lipari, Paranea, Stromboli & Vulcano) and it is one of the four active volcanoes (with Vulcano, Lipari & Paranea) of the Aeolian archipelago.

The subaerial and submarine features of Stromboli volcano show preferential NE-SW aligned growth and similar patterns of marine erosional, structural and magmatic developments since Late Pleistonce times, this direction also corresponds to the elongated shape of Stromboli Island and preferential dyke orientation inside the edifice (Kokelaar & Romagnoli 1995). The fault N41° and N64° have been also evidenced at the scale of the island thanks to CO_2 soil diffuse degassing (Finizola et al. 2002, Revil et al. 2011). At the scale of the island, a detailed marine bathymetry survey evidence bilateral flank instability (Romagnoli et al. 2009). A relationship has been hypothesized between dike injection on the regional N40° direction and these lateral instabilities (Romagnoli et al. 2009, Tibaldi et al. 2003).

The aim of this work is to combine different techniques in order to find interpretations to the CO_2 anomalies (Figure 1) not well understood until now in the eastern flank of the edifice (Finizola et al. 2002). This survey include new CO_2 measurements and also several new techniques, such as 2D electrical resistivity tomography (ERT), giving a vertical imaging of this area and submarine bathymetry, allowing a large view of all the island, including the topography information below sea level. The first step will allow recognizing the most important boundaries structuring the eastern part of the island.

In a second step, in this area affected by several collapses a better assessment of the volumes involved during these flank destabilization will be attempt based on this new structural boundaries consideration.

3D volume assessment of flank collapse is one of the major information in volcanology to understand, assess, and model the most deadliest phenomenon in volcanology: tsunami related with flank collapses.

Thanks to the soil CO_2 concentration measurements it was possible to identify the boundary of the head of the gliding planes, appearing as more permeable areas. These latter are preferential drains for the CO_2. The ERT technique allowed giving the geometry at depth of this collapsed areas. A total of six major collapses of Stromboli have been reconstructed in 3D. The volume of all the collapses of the Eastern flank has been estimated to ~332x10^6 m^3, an equivalent value to the volume calculated for the Western side of the island ~546x10^6 m^3.

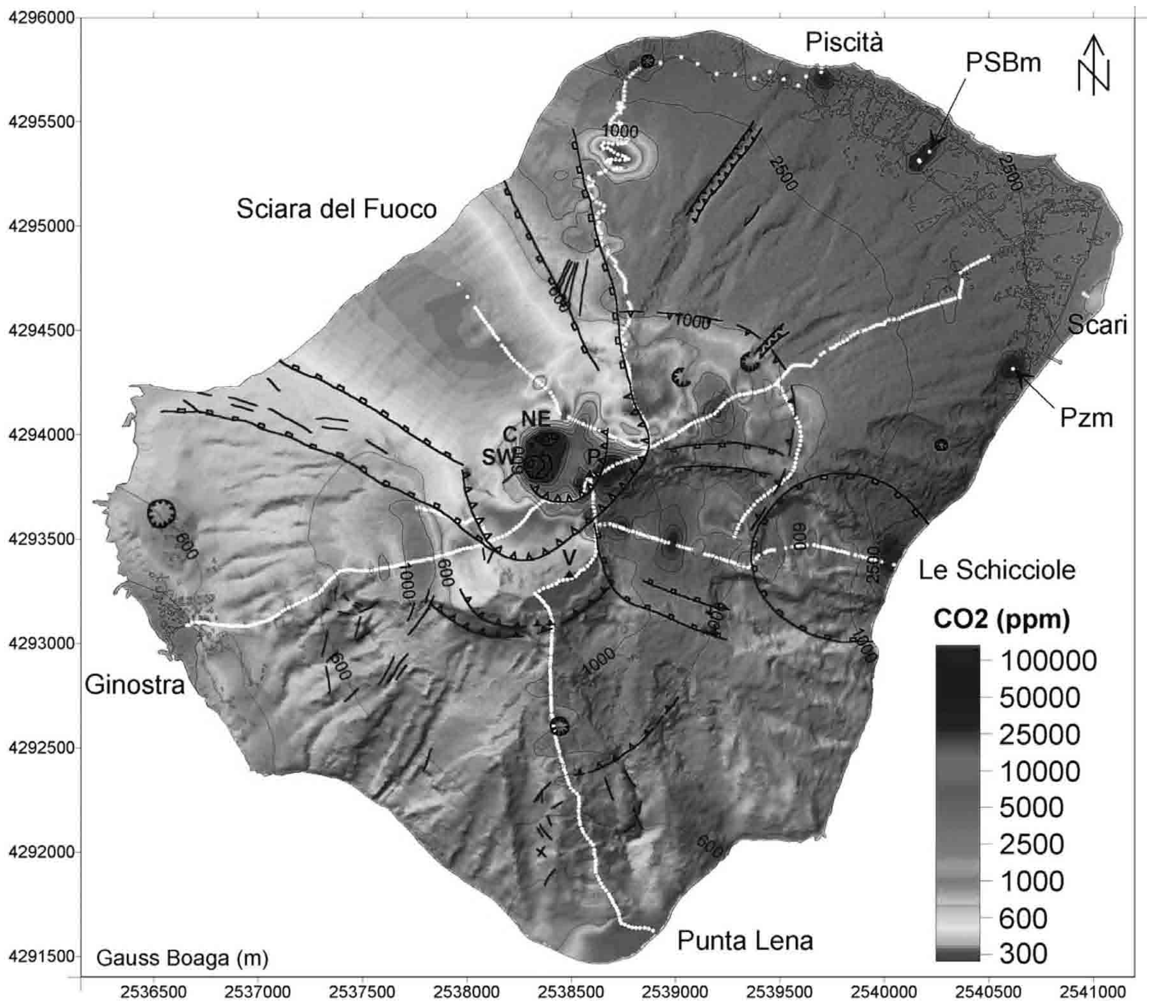

Fig. 1. Soil CO_2 concentration map showing a huge anomaly near the coast on the eastern flank of Stromboli (from Finizola et al. 2002).

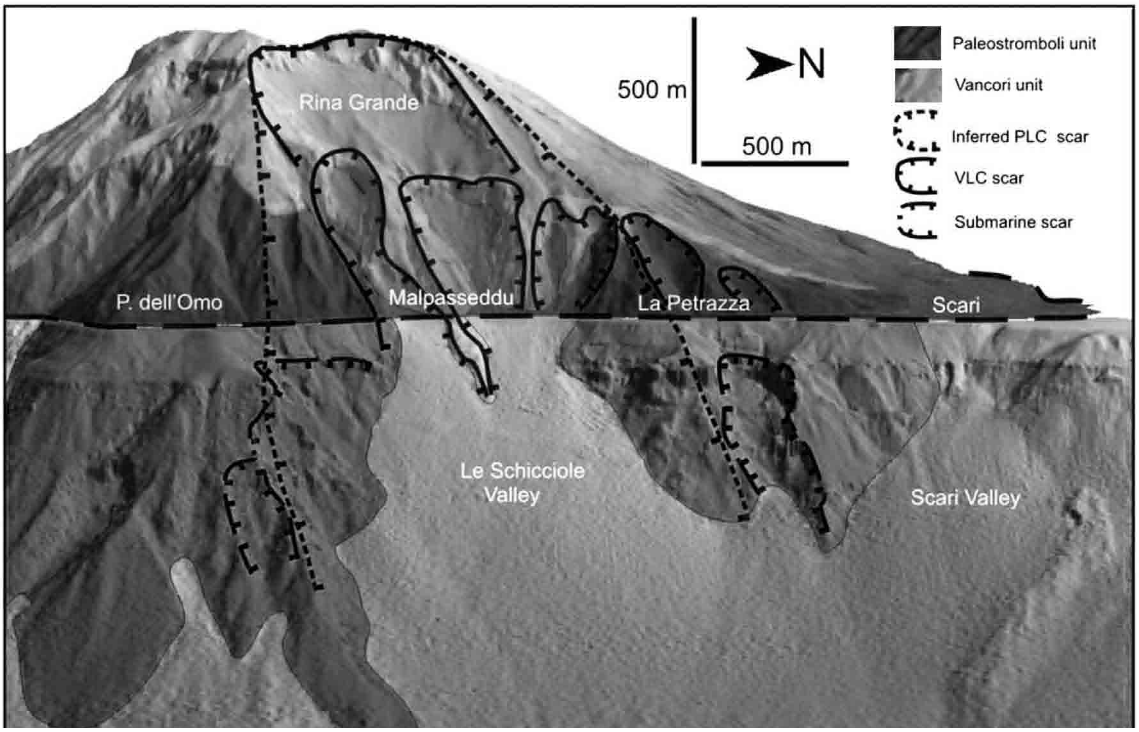

Fig. 2. 3D view of subaerial and submerged eastern flank of Stromboli (from Romagnoli et al. 2009)

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Is the structure of Börnersdorf a possible maar diatreme volcano?

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3b

Due to magnetical and gravimetrical local anomalies in the Osterzgebirge Mountains south of Dresden near Bad Gottleuba a structure was recognized, which displays characteristics of a maar diatreme. Within that gneiss area, Cretaceous deposits covered by Quaternary sediments were proven by drill holes in the 2nd half of the last century. Recently, 15 new short wells were drilled, three seismic profiles were shot as well as detailed gravimetric and geomagnetic investigations were carried out. The results support the assumption of a possible maar origin (Horna et al. 2011).

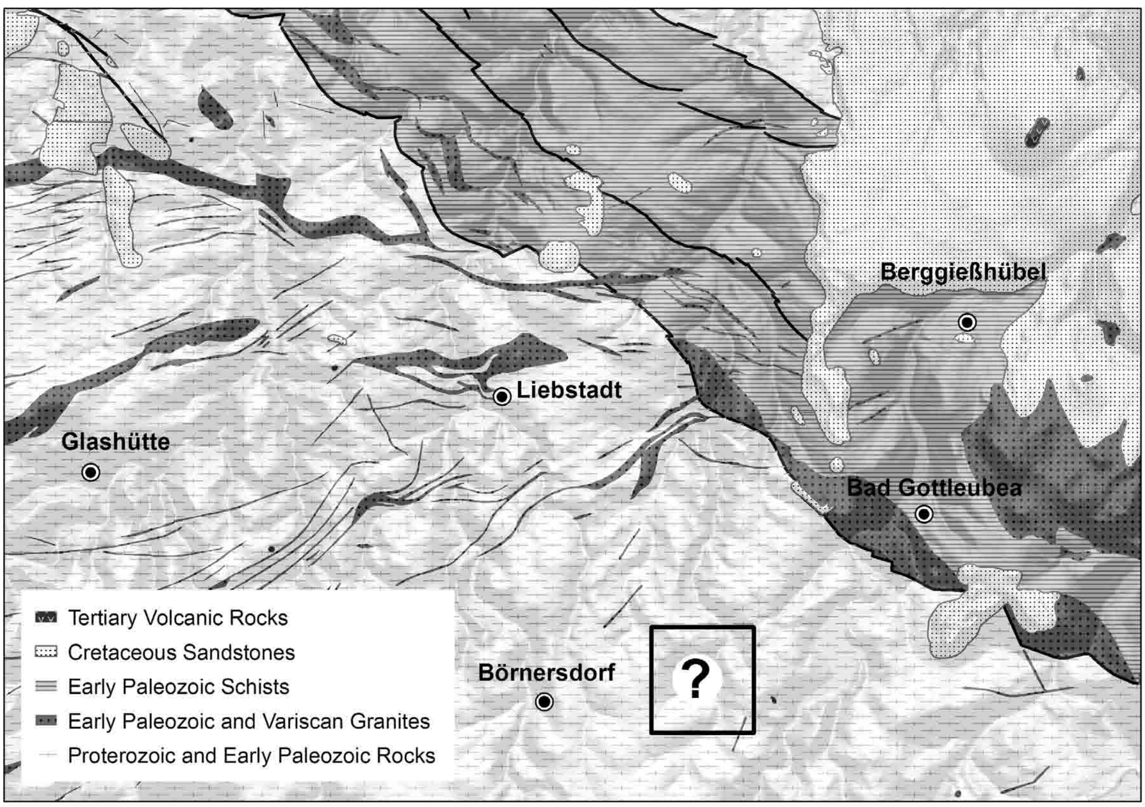

Fig. 1. Study site near Börnersdorf (black square, edge length 1km) in the Osterzgebirge Mountains displayed on a geological map without Quaternary deposits.

The existence of Upper Cretaceous marls with a lateral extent of about 500 by 600 metres was proven by the above mentioned short wells. Due to the results of the geophysical and stratigraphic interpretation, a thickness of 250 to 300 m of sediments can be assumed. The foraminifera assemblage indicates Early to Middle Coniacian age of the marls. From the occurrence of Cenomanian and lower Turonian sandstones nearby, a fairly complete upper Cretaceous succession can be concluded.

The structure is limited by concentrical steep dipping surfaces. The gravity and the geomagnetic anomalies present a sub circular structure. The gravity minimum and the geomagnetic maximum coincide and are therefore the strongest argument for a maar origin (Fig.2).

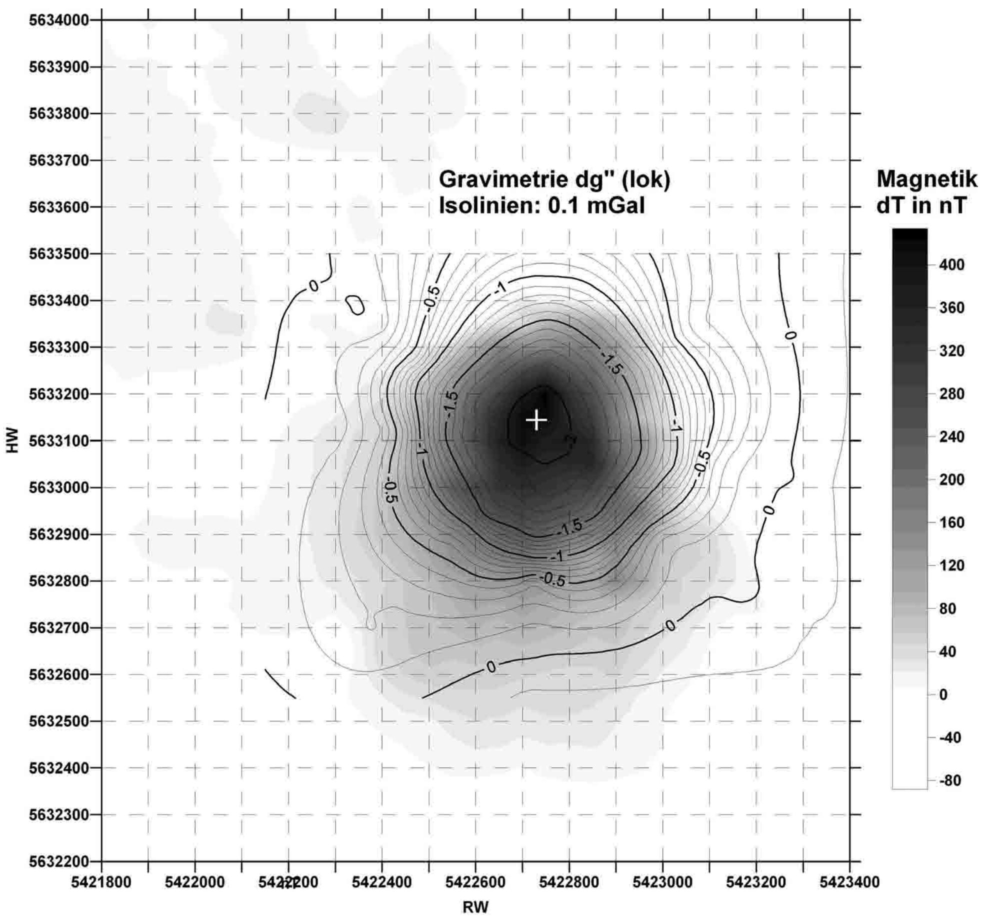

Fig.2. Magnetical and gravimetrical anomalies at the study site, the gravity minimum and the geomagnetic maximum are located in the centre of the structure (after Käppler 2012).

The age of this structure is still uncertain and in discussion. It could be of Late Cretaceous age, but the marine Coniacian sediments do not fit well in a maar origin. If the cretaceous sediments are reworked and not in situ, a younger age seems possible. Even a tectonic origin of this structure can not be excluded so far.

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3b

Comparison of Cenozoic and Silurian basalts in magnetomineralogic properties and implication for Silurian paleogeography

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We compare two groups of basalts produced in similar conditions of environment, but significantly different in age. The younger ones represent the Ústí Fm. volcanics of the České středohoří Mts. (Böhmisches Mittelgebirge), situated inside the Eger Graben; and the others are developed in Silurian of the Prague Basin (Barrandian). Rocks of both groups were produced into the wet environs, mostly. Hyaloclastesis is commonly observable feature, documenting the environment in the time of origin of the rocks. We suppose similar primary composition of magnetic carriers because both groups represent the same petrologic type. The only difference is in their age – during the time, some secondary changes on magnetic carriers could take place. The set of Cenozoic basalts consists of 292 samples (23 locations) and the Silurian set includes 485 samples (32 locations). This research was supported by project P210/10/2351 of the GA CR and by IGCP 580.

	NRM [A/m]		MS [10^{-3} SI]		UT [°C]		MDF [mT]		Q-parameter	K-parameter	
group	aver.	+ / -	aver.	+ / -	min.	max.	min.	max.	aver.	min.	max.
Silurian	1.1	3.8	7.0	16.1	200	580	4	22 (58)*	3.93	7	102
Cenozoic	2.0	2.1	24.4	11.5	150	580	3	32 (60)*	2.05	14	643

** samples with magnetically hard magnetic carrier*

For the comparison (see the table), we have used magnetomineralogical properties like natural remanent magnetization (NRM), magnetic susceptibility (MS), unblocking temperature (UT), mean destructive field (MDF), Q-parameter (Königsberger ratio) and K-parameter (precision parameter coming from Fisher statistics). NRM reflects the quantity of ferromagnetic minerals; MS represents total amount of paramagnetic and ferromagnetic minerals; UT is the temperature of the steepest degrease of NRM-demagnetisation curve and it is close to transition between para- and ferromagnetic behaviour; MDF represents stability character of NMR during alternating field demagnetization when 50% of initial value is reached; Q-parameter is the ratio of the remanent magnetization to the induced magnetization (product of susceptibility and the Earth's magnetic field strength – a large Q-value indicates that the magnetic material will tend to maintain significant remanent magnetization and indicates simultaneously small mineral grain size); and K-parameter is counted from group statistics of paleodirections as their dispersion (0-value indicates maximal dispersion) and it allows evaluation of possible mineralogical changes on magnetic carriers. The Silurian basalts differ from the Cenozoic ones during the laboratory thermal demagnetization procedure – being heated over 400 °C they produce very often newly constituted magnetite from previous magnetic carriers.

From these magnetomineralogical parameters is clear that the carriers of paleomagnetic record are the same for both Cenozoic and Silurian volcanics. It implies that the paleomagnetic directions are most likely primary. However, the tectonic history of the Silurian rocks is very complicated because of Variscan orogeny – see Fig. 1. The paleolatitudes of studied Silurian rocks correspond to the northward movement of this tectonic unit, as visible in Fig. 2.

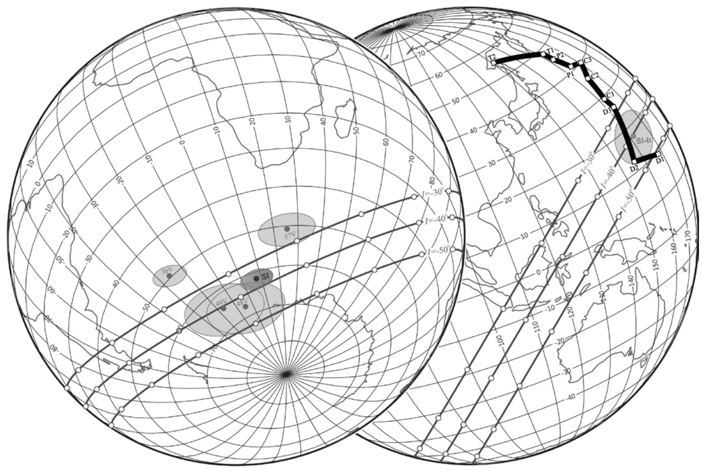

*Fig. 1. Virtual geomagnetic pole (VGP) for Palaeozoic of Prague Basin. **SI** Svatý Jan, Řeporyje & Kosov volcanic centres; **36V to 49V** - Ordovician VGP for Volcano-sedimentary sequences from previous studies. Virtual pole position **SI b** calculated from b-component of magnetization. Apparent Polar Wandering Path inferred from East European Craton for Devonian to Triassic time span is presented by a thick black line. Full small circles denote pole positions for the paleomagnetic declination step of D = 20°. The dotted lines indicate distribution of pole positions due to paleotectonic rotations for the same paleomagnetic inclination.*

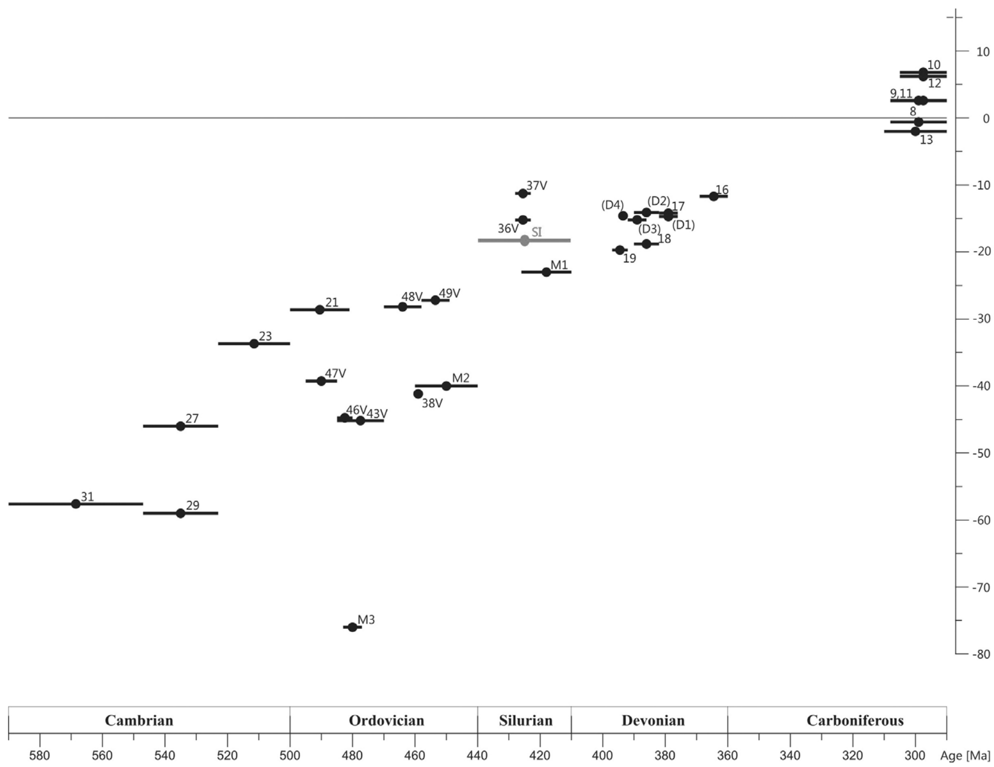

*Fig. 2. Prague Basin: paleolatitudes extrapolated from different sources. **SI** - data recently inferred from VGP for Silurian volcanics (grey), Black full circles belong to values derived from databases.*

3b

Palaeomagnetic, low field AMS and rock magnetic evidences from the lower part of the lava flow sequence from the Mandla lobe of the eastern Deccan volcanic province, India

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Palaeomagnetic studies carried out in the last four decades resolved normal-reverse-normal (N-R-N) magnetostratigraphy, straddling the chrons 30N-29R-29N; however, major part of the eruption is confined to chron 29 R. Precise age, duration and northward movement of India during Deccan volcanism still remain inconclusive. To derive expected differences in the "Characteristic Remanence Magnetization" directions and there correlation with chrons 30N-29R-29N, the palaeomagnetic, rock magnetic and low field AMS investigations have been carried out on oriented block samples (3-5) collected from six flows as defined by Pattanayak & Shrivastava (1999) around Jabalpur, where trap-basement contact is at 364 m. a.s.l. Identification and collection of oriented block samples from the lava flows is based on the physical and mineralogical properties discussed by Shrivastava & Pattanayak (2002). Block samples were reoriented, cored and cut to standard size (2.2 cm length and 2.5 cm diameter) cylindrical specimens. For paleomagnetic direction, determinations of minimum two and four to eight specimens were used in pilot and blanket studies respectively. Samples were cleaned magnetically by the alternating field (a.f.) and thermal demagnetizations procedures using JR-5A spinner (3 pT sensitivity) and molspin magnetometers. To monitor changes in the magnetic property of measured specimens during thermal demganetization treatments, the susceptibility of representative specimens were measured with a Bartingtion susceptibility meter after the NRM and remanence measurements during the thermal treatments. Total 162 specimens were studied for paleomagnetic study and 206 specimens were used in the AMS measurements. For cross check of the data, similar lava flows collected from two or three locations. In comparison to thermal demagnetizations, AF demagnetizations were found more effective in isolating the statistically significant ChRM directions. The mean NRM intensity and mean magnetic susceptibility values were noticed as 7.09 A/m and 2.5 x 10^{-2} SI units, respectively. The mean Q-ratio calculated, using NRM intensities and magnetic susceptibilities, was found as 7.5, indicating suitability of the rocks for palaeomagnetic investigations. The characteristics magnetization of dominant normal polarity (D_m = 336°, I_m= -47°, α_{95} = 14, k = 30.17) is isolated from all the flows from the lower part of the succession, except third flow show transitional polarity. Although, the mean polarity of six lava flows is correlative with the chron 30N and previous work in Jabalpur and Dindori area. Results from the low field AMS studies revealed that the maximum susceptibility axes (K1) grouped with the steep inclinations (>75°), whereas, the intermediate (K2) and minimum (K3) susceptibility axes are spread along the peripherals of the stereogram. A plot of the shape parameter (T) against degree of anisotropy parameter (Pj) indicated equal distribution of 'prolate' and 'oblate' shaped magnetic fabrics in the rock specimens. Single domain (SD) and Pseudo single domain (PSD) type magnetite/titano-magnetite is the major remanence carrying magnetic minerals based on investigation of the IRM curves and LF test.

Structural controls on volcanic activity in the Garrotxa Volcanic Field inferred from geophysical methods

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3b

The Garrotxa Volcanic Field (GVF) is part of the Catalan Volcanic Zone (CVZ), situated in the NE of the Iberian Peninsula (Girona Province). This zone is one of the Quaternary alkaline volcanic provinces belonging to the European Cenozoic Rift System (Martí et al. 1992, Dèzes et al. 2004). The CVZ ranges in age from >12 Ma to early Holocene and it is mainly represented by alkali basalts and basanites (Martí et al. 1992, Cebriá et al. 2000). This basaltic monogenetic volcanic zone comprises more than 50 well-preserved monogenetic cones including scoria cones, tuff cones, tephra rings, and maars (Martí et al 2011). In the CVZ volcanism, small-sized cinder cones formed along widely dispersed fissure zones during monogenetic, short-lived eruptions. Hydromagmatic events were also common. Each eruption was probably caused by an individual batch of magma that was transported rapidly from the source region, each batch representing the products of an individual partial melting event (Martí et al. 1992, 2011).

We conducted new gravimetric, self-potential and electric resistivity tomography surveys in order to improve knowledge of the relationship between the local geology and the spatial distribution of the monogenetic volcanoes. In particular, we aimed at identifying the distribution of the subsurface structures associated with monogenetic volcanism in the GVF.

The main finding of this study is that the central part of the volcanic field is underlain by low-density material, which partly can be interpreted as the root of surface manifestations of volcanic activity. We image a gravity low just NW of the Croscat volcano, the youngest volcano of this zone. Ground water infiltration along a fault or fissure, coinciding with the transitions from low to high gravity has been identified from the self-potential measurements. Also the electric resistivity tomography in this area shows high resistivity values with a well-defined geometry that we interpret as a dike. This coincides with the fissure zones identified with self-potential and gravity measurements. Our data show that volcanism appears to be controlled by NE-SW and NW-SE tectonic structures roughly perpendicular to the main structural limits bounding the study area to north and south.

We assess the potential for volcanic reactivation of the area with major implications for understanding of the geodynamics of this zone, which until now lacked detailed geophysical data to support decision–making processes for disaster preparedness and response.

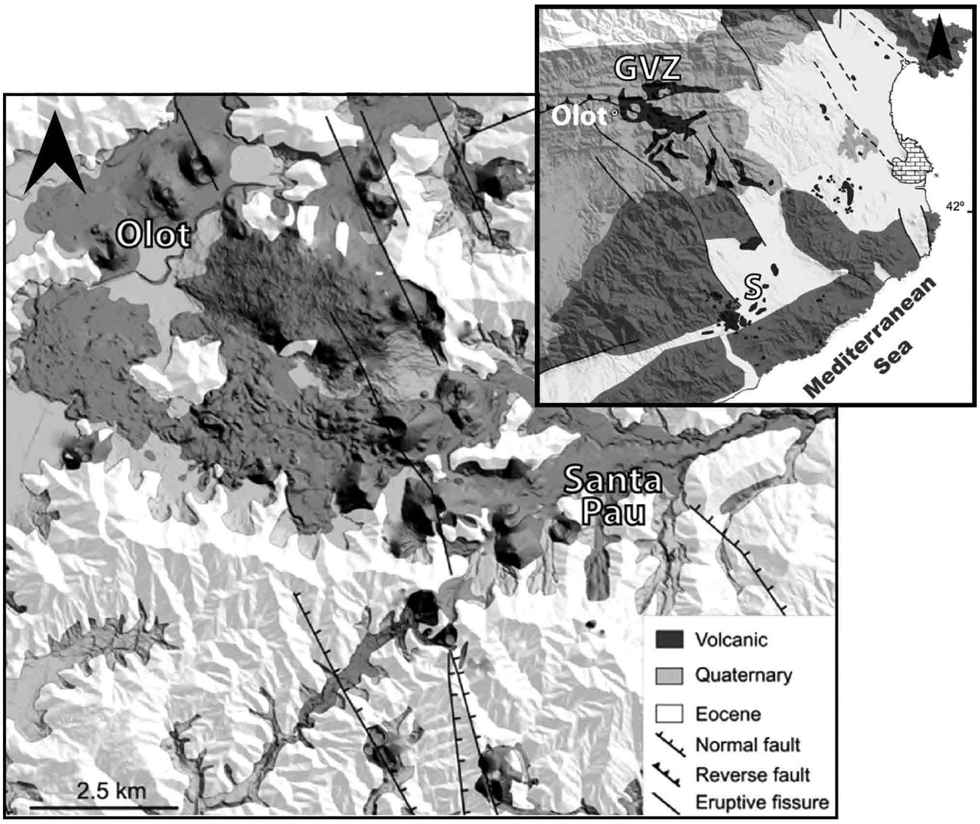

Fig. 1. Simplified geological and structural map of the studied area and surroundings (modified from Martí et al 2011). In the upper right inset is a simplified geological map of the Catalan Volcanic Zone and its surroundings (modified from Guérin et al. 1986). GVZ stands for Garrotxa Volcanic Zone and S for La Selva.

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The establishment of a volcanic geopark in the Kingdom of Saudi Arabia: Harrat Al Madinah Volcanic Geopark

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Through the creation of a world network of natural parks with significant geological features, labeled UNESCO Geoparks, UNESCO promotes conservation of our geological heritage. Volcanic geoparks are increasingly popular projects worldwide and play a substantial role in geohazard education, including facilitating the dissemination of current research results on the volcanic processes that the ever increasing human society is faced with. Geosites, geomorphosites and geotops are the smallest "units" of intact geological features that are identifiable through their uniqueness or because they are graphic examples of specific volcanic phenomena or form a vital landscape representative of a specific volcanic processes. Here we identify significant volcanic features that bear not only regional, but global, volcanic value in a confined area that could be organized and promoted as the first volcanic geopark in the Kingdom of Saudi Arabia: the Harrat Al Madinah Volcanic Geopark. Harrat Al Madinah ("*harrat*" in Arabic means lava field) has many volcanic geosites including the last historically erupted volcanoes in the Arabian Peninsula. In addition, Harrat Al Madinah is located in a culturally significant place close to Al Madinah city (~ 1.5 million population), which is one of the holiest places to Muslims. The area is accessible through highways and in the near future by a train line linking Jeddah (the main port and air hub on the Red Sea coast) with Al Madinah. Overall, the proposed geopark would provide significant economic benefit to the city of Al Madinah. Pilgrims arrive from every corner of the globe, including countries where volcanic hazard is an everyday aspect of life (e.g. Indonesia); therefore, the proposed geopark would serve as a significant geoeducational hot spot. To begin with, a major geotop tentatively named as "*The AD 1256 Al Madinah Historic Eruption Site*" with distinct geosites/geomorphosites has been selected to demonstrate the diversity of volcanic phenomena associated with the intraplate volcanism of the Al Madinah Volcanic Field. Hawaiian to Strombolian type eruptions created lava spatter and scoria cones visible from major highways, allowing visitors to stop near the AD 1256 historic eruption site just 10 km SE of Al Madinah (Fig. 1). The 52 day-long eruption formed a ~2.25 km long NW-SE-aligned fissure, which emitted mainly alkali-olivine basalt (~0.5 km3) a'a lava flows (Camp at al. 1987) and formed fissure-aligned chain of lava spatter-dominated pyroclastic cones. At least seven vents have been identified, which made nested lava spatter and scoria cones. The central cones had more energetic explosive eruptive episodes that generated pyroclastic fall deposits, forming an ash-plain covering an area of about 10 km across. The vents are inferred to be hosted lava lakes. Lava lake outbreaks initiated crater wall collapses, as traced on circular fissures along the crater margins. The growth of the individual cones was repeatedly interrupted by lava flow outbreaks in the tip of the fissures by rafting away large pieces of the cones that were subsequently reheated, resulting in a nested and complex volcano morphology. This geotop is probably the best exposed and accessible site on Earth to show the diversity of volcanic features a fissure-eruption can produce. The recent increased seismic activity in 2009 in the region also justifies the establishment of an educational site that could play a significant role in the dissemination of scientific knowledge to the public, which could help the population better understand the potential outcome of any volcanic unrest the region may face.

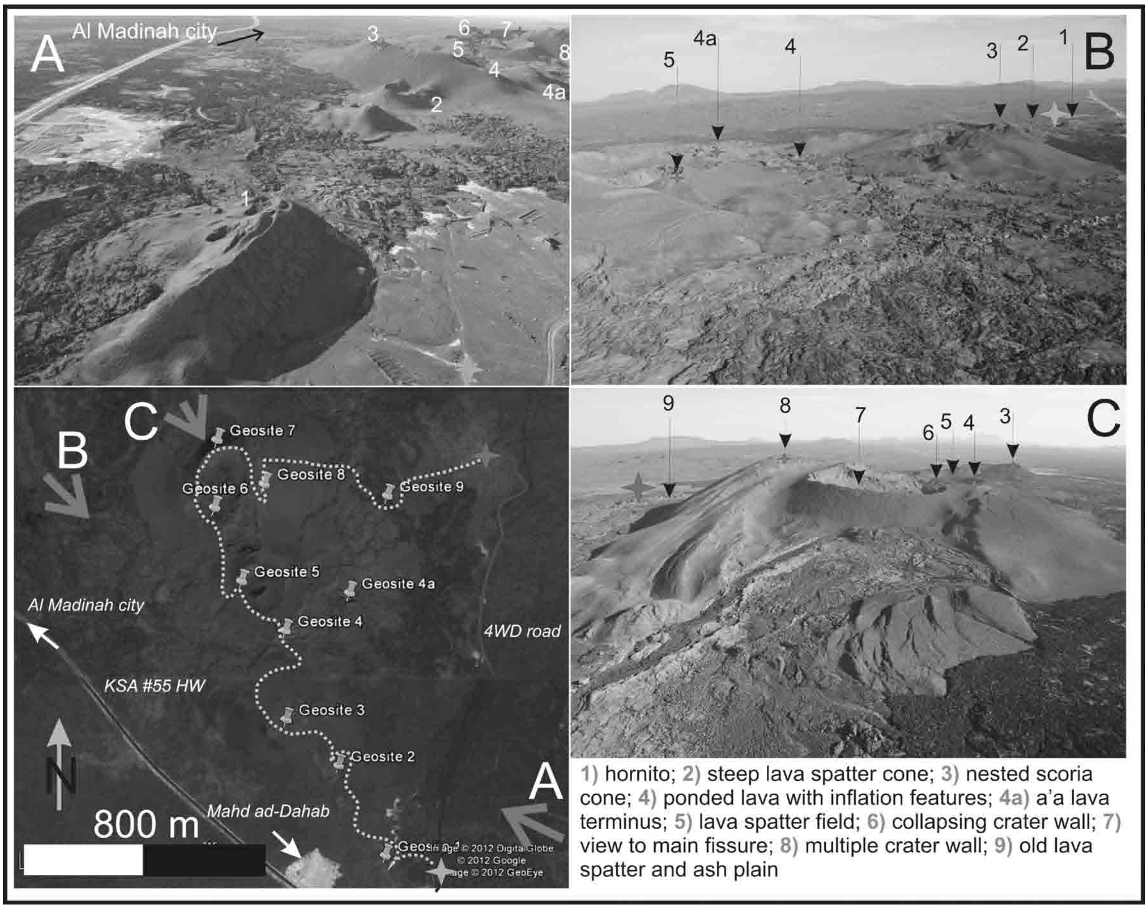

Fig. 1. The historic eruption site of the Al Madinah AD 1256 eruption with proposed geosites.

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The role of volcanic heritage in the geotourism of Hungary: perspectives and limitations

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Is there a sense to establish a volcano park and perform outreach activities on volcanoes in a country, where no active volcanoes exist? The answer is clearly, yes! The Carpathian-Pannonian region consists of a wide range of volcanic formations from basaltic to rhyolitic volcanic products and offers a unique opportunity to investigate them in detail and of course to use them to develop geotourism. In 2010, the Novohrad-Nógrád Geopark, whereas in 2012 the Bakony-Balaton Geopark became the official member of the Geopark community and also in 2012 a part of the Kemenes Volcano Park has been opened. This will be the first thematic volcano park in central Europe and as far as we know the third one in Europe.

In the Carpathian-Pannonian region, there are seemingly no active volcanoes, yet it is an open book for visitors who want to have an exciting insight into the wide range of volcanic phenomena within small distances. Furthermore, this is the area where volcanic heritage meets historic, cultural, gastronomic and winery pleasures, among others. Nevertheless, this area is a challenging destination also for those people who want to visit only active or potentially active volcanoes. The last volcanic eruption occurred here at the dacitic Ciomadul volcano at 30 ka. A large subplinian-plinian eruption resulted in a deep explosion crater where now the picturesque St. Ana Lake is found.

The volcanic heritage played a primary role in the application of both geoparks and of course it has a crucial role in their success. The plan to establish a volcano park in Hungary goes back to the early 1990's, when our volcanological studies of the Ság Hill revealed the complex history of the 5.5 Ma basaltic volcano. This can be found at the western part of the Pannonian basin and belongs to the extensive alkaline basaltic volcanism of this region occurred between 11 Ma and 0.1 Ma. The remarkable volcanological features of the Ság Hill as well as of the nearby extinct volcanoes provide a strong background for the idea to establish a volcano park. A detailed realization plan has been worked out in 2003 and this was the basis of the proposal of the Council of Celldömölk, the town next to the Ság Hill. Our plan, which is financially supported by an EU-based fund, involves a Volcano House at the foot of the Ság Hill, where the visitors could get a general picture about the volcanic processes and the 20 Ma long history of volcanic activity in the Carpathian-Pannonian region. There is going to be an opportunity to take a journey into the interior of the Earth and to have a short visit in a magma chamber. The volcano-horror room will show the destructive force of the volcanoes and gives place for a memorial of the destroyed settlements from Pompeii to Plymouth. An important part of the volcano park is the construction of the Volcano path, which leads to the Ság Hill and shows the main volcanological features. An open-air volcano-playground and rock exhibition could provide further opportunities to science education. The latter ones have been already opened in May, 2012. The Kemenes Volcano Park as a tourist attraction could initiate the recovery of economy in this otherwise poor region.

All of these efforts mean that volcanic heritage could be a driving role to open a new way in the tourism. However, there are some limitations what it is necessary to mention. A successful use of volcanic heritage can be achieved only if the local community, the decision-makers and the business-mans recognize the advantages of such novel projects. This is not straightforward, since people have rather poor knowledge on volcanism and how the Earth works.

Furthermore, they have no experience how natural heritage can be involved in the local touristic offer. Most of the local council members and mayors do not understand that an investment into the protection and exhibition of natural heritage could result in a novel opportunity to attract people and as a consequence it could enhance tourism and supply money into the local economy. Unfortunately, there are many bad examples in this field in Hungary, although a successful story has been shown by the enthusiastic people of the Bakony-Balaton geopark. This experience can be used to improve the involvement of natural and volcanic heritage in the policy of the Novohrad-Nógrád Geopark and also the management of the Kemenes Volcano Park.

In order to strengthen the geological support of such projects, it is important to enhance the outreach activities that could help people understand how the Earth work, what is the significance of the volcanic activity in our planet and of course why we have to protect the natural heritage. The Volcanology Group of the Eötvös University Budapest performs Volcano shows at various events such as during the Researchers' nights and Science days. The Tűzhányó blog ("Volcano blog"; http://tuzhanyo.blogspot.com) provides regular information about volcanic activities and give background explanations deliberately in Hungarian language. It is quite popular now and often referred by various news portals.

The basalt quarry Klöch – a geological fundament for the region and trademark "Styrian volcano land", Austria

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The Styrian volcano land (Steirisches Vulkanland) comprises an economic region and trademark in eastern Styria, Austria. The morphology of this region is characterized by the remnants of two volcanic phases in the Neogene. While the ascent of andesitic magmas produced a voluminous volcanic system (a basis with about 30 km diameter is postulated) in the Miocene, a second volcanic phase produced basalts and their explosive variations in Plio-/ Pleistocene times (Fig. 1). Starting in the 19th century several authors mapped this region and it was Prof. Arthur Winkler-Hermaden, later on Professor at the Technical University of Graz, who published the first comprehensive paper about the volcanism of the region (Winkler 1913). Modern geological and geophysical investigations,

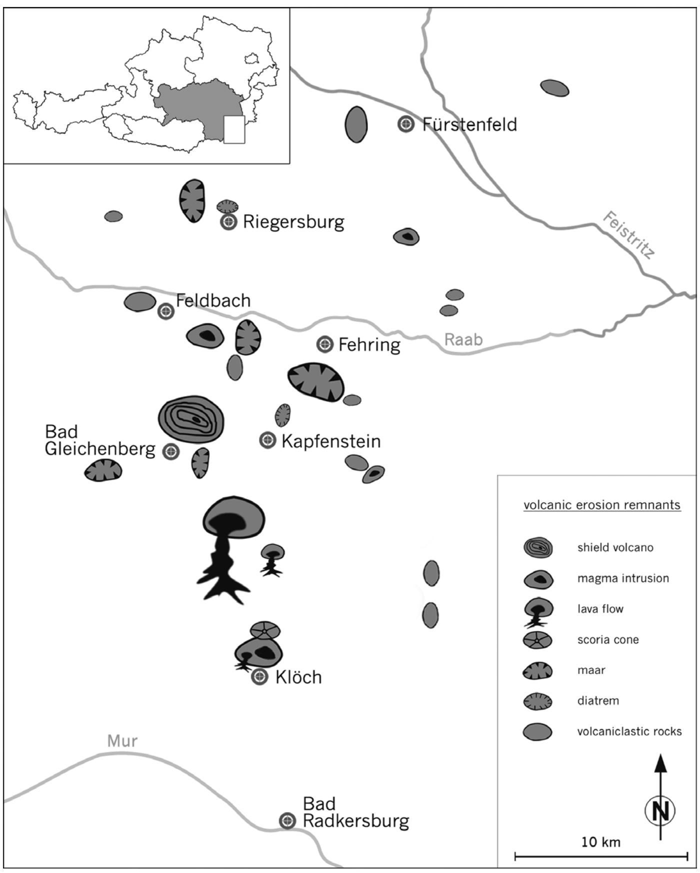

Fig. 1. Volcanic remnants in the Styrian volcano land.

e.g. in the volcanic field near Fehring and in Klöch/Tieschen, focus on the younger volcanic successions (summarized in Gross et al. 2007). The studies aim at accomplishing geological fundaments for the economic region and trademark "Steirisches Vulkanland". In 2001 a Geotrail was arranged as a "path through a volcano" and based on the regional rock – collection of Prof. Winkler -Hermaden a small museum was installed in Kapfenstein (http://www.museen.vulkanland.at/museen/38.htm).

The volcanic system of Königsberg - Klöch is interbedded in Sarmatian sediments. The volcanic succession starts with well bedded ash- and ash-lapilli tuffs followed by pyroclastic rocks of scoria type. Dunes, accretionary lappili and bomb-sag structures give hints for phreatomagmatic eruptions at the beginning of the volcanic development. The basalt quarry of Klöch (Asamer Holding AG) opens internal structures of basaltic intrusions with voluminous scoria layers which are locally covered by lake sediments. At the present time there are at least 5 small vents exposed in the quarry, which show a complex system of ascending magma. At the base of the quarry, with an up to 150 m high rock face at present, a massive basaltic complex with different intrusions and columnar cooling structures is exposed. In the frame of geophysical field exercises of the Montanuniversitaet Leoben geomagnetic and geoelectric prospection and paleomagnetic investigations were carried out in the southeastern part of the volcanic system. Both, the compilation and interpretation of the geophysical results and the monitoring of the mining as a photo - documentation are in progress and supported by the company.

The "Traminerweg", a hiking trail around the volcanic system of Klöch is another example for Geotourism in the region. At different locations, e.g. old tuff – quarries, plates inform about the geological development of the region. In September 2013, a symposium on the heritage of Prof. Winkler – Hermaden (1890 – 1963) will be held in Kapfenstein, on the occasion of the centenary of his first publication about the volcanic region in Styria (Winkler 1913). Kapfenstein is well known since the beginning of the 19th century for its "olivinbombs". The main intention of the symposium will be the communication between scientists, teachers, regional tourism managers and all persons who are interested in geosciences, especially volcanism.

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Basalts and Volcanoes – Edutainment in the West Eifel Volcanic Field (Vulkaneifel European Geopark)

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The West Eifel Volcanic Field is a roughly 60 x 25 km wide intra-continental volcanic area with monogenetic multiphase alkali basaltic volcanoes featuring maars, tuff rings, scoria and cinder cones, and lava flows. Tectonically, the setting is intraplate extensional; geochemically and mineralogically the rocks comprise basanites and nephelinites with rare phonolite and carbonatite; the time span for volcanic activity started somewhere around 700.000 years ago and ended only 11.000 years ago.

It was in the West Eifel Volcanic Field, where the term "maar" was coined early in the 19th Century, where a rich xenoliths assemblage was used to decipher the continental crust and its subcontinental lithospheric upper mantle; Germany's last volcanic eruption occurred here 11.000 years ago at Ulmen Maar, and Germany's top selling premium mineral water, Gerolsteiner mineral water, has its origin in the West Eifel Volcanic Field. Germany's first Geopark, Geopark Gerolsteiner Land, was set up here in the late 1990ies, later converging into today's Vulkaneifel European Geopark. And, besides the "Blue Eyes of the Eifel" as the maars are perfectly described, Germany's probably most complete volcano, Rockeskyller Kopf, emerges right at the heart of the West Eifel Volcanic Field (Bitschene et al. 2012). The Vulkaneifel Geopark also holds Germany's first museum, the Eifel Vulkanmuseum at Daun, dedicated exclusively to the volcanoes and their rocks, and the Museum of Natural History at Gerolstein holds one of the most complete collections of glazed sandstones and other xenoliths.

No doubt, there are enough basaltic and volcanic assets to educate and entertain families with kids and senior citizens, and to attract distinguished scholars and eminent scientists. The problem is not with the scientists, they will find their way to the basaltic treasures. The problem is: How to facilitate petrologic stuff to innocent visitors keeping in mind that geology and petrology do not occur in school curricula, and volcanism is only a side-dish in school's 8th grade curriculum? A geopark is the solution!

The first step is to set up a collection of geosites and interconnect them with circular trails starting and ending at parking lots that eventually also have a restaurant or cafe, and toilets. The identification of the right geo-sites out of a plethora of similar sites, and the implementation of a proper guidance system are vital steps for setting up a geopark (Bitschene & Schüller 2011).

The second step is to explain the volcanic and basaltic features to the visitor with geo-panels and geo-leaflets. Obviously, there is a strong need for proper and simple explanations that at the same time satisfy the visitor's curiosity and show that basalts and volcanoes are beautiful. Among other things it is about the natural beauty of volcanoes and outcrops, and the challenge to show that basalts and volcanoes really have a story to tell.

The third step is to develop experiments, shows and games that educate and entertain the public with explicit basaltic and volcanic content. No doubt, this is a not easily done keeping in mind that most of the visitors are not familiar with the nomenclature used for basalts, their grain sizes, their chemical and mineralogical compositions, and their geotectonic and volcanologic significance. This talk will focus on the ideas and tools of how to simultaneously educate and entertain the public with geosciences; it is about basaltic and volcanic "story telling". The latter is a discipline geo-scientists must learn and master when working actively and successfully in a geopark!

And the fourth step is, of course, the selling of all these attractions and activities. This is by far the most difficult step, and the topic of just another lecture on "marketing of basaltic and volcanic edutainment" in the next "Basalt Conference"!

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Geotourism at the basalt of Stolpen in Saxony

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The outcrop of the Tertiary Stolpen Basalt is situated only 25 km eastern from the city of Dresden. The castle hill of Stolpen is 357 m above the sea level but very good visible in the landscape. “Stolpen” is an old-Slavonic word and means “columns”. The castle of Stolpen at the top of the Stolpen hill has about 120.000 visitors every year, in the city of Stolpen live 1.900 inhabitants. Most guests visit the castle of Stolpen because of its changeable history as a castle, a palace, a fortress and especially because of the countess of Cosel. She was a mistress of the Saxonian elector August der Starke in the 18th century and was arrested at the Stolpen castle, where she died after 49 years in prison. Her grave is situated in the former castle chapel.

The basalt columns fascinated natural scientists at the castle and in the city since the 15th century. Already in 1546 the Saxonian natural scientist Johannes Bauer (better known as AGRICOLA) stipulated in his publication “De natura fossilium libri X”, that the Stolpen Basalt is type locality (reference locality) for the petrographical term “Basalt” worldwide. The well known German poet Johann Wolfgang von Goethe visited the Stolpen basalt in connection with the debate about neptunism and plutonism/volcanism; both of them were geological theories about the genesis of basalts. In the whole city and parts of the castle are historical cellars/vaults located, built from basalt columns in the 15th century and earlier. A special outcrop in the Basalt of Stolpen is the deep well at the castle. It was sinked from 1607 until 1630 by miners from the eastern Erzgebirge (village Berggießhübel). The well is 84 m deep. The surface of the joint aquifer only in the basalt varied between 70 and 66 m under the well-surface.

Stolpen has some geological attractions and in the last 8 years it became possible, to use this for tourism – for the geotourism. Geotourism is meanwhile an important argument for travelers. We know because of statistical researches by questioning in Stolpen, that more than 80 % of adults are interested in geology. The main target groups are families with children and senior citizen. It is very important, to explain geological contexts for interested amateurs but not for specialists. Geological Exhibitions needs different parts for adults and children.

It is necessary to have a good prepared web-page, because most of the guests expect information before visiting an exhibition or a geological locality. It is also necessary to organized further information about interesting regional geological localities. Helpful are additional information materials, local features or special offers for groups, families and children. If possible, I recommend selling products about geological topics like books, posters or toys. I also recommend cooperation with local partners like the tourist information, restaurants, hotels, touristic associations or local companies.

A few examples for steps to a successful geotourism in Stolpen are for instance:

- A modern geological exhibition at the castle of Stolpen with haptical tests like “density of several rocks” and “magnetism in the basalt of Stolpen”
- A special publication about the Basalt of Stolpen as a small booklet with all important information – tourists can buy it at the castle and in the tourist information centre at the market square (Scholle & Gaitzsch 2007)
- Questioning of guests at the castle of Stolpen and in the city of Stolpen take place every year to improve the service for tourists
- Quiz with questions about the Basalt of Stolpen (main leadings price is a weekend free of charge in the Castle-Hotel)
- More and better information at the web page about the Basalt of Stolpen in German, English, French, Czech and Polish. Information in Russian and other languages are in preparation (www.stolpen.de).
- Guided tours for all target groups and further education by the local geologist for all leaders of guided tours annual until 2012
- Using of the „European Heritage Days“ as an special attraction in Stolpen since 2005
- Using of the “Day of Geotop” (annual in September)

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- Special products like "Basalter – a beer with the power from the volcano", "Basaltus – our ghost in the city and at the castle" and other products from local companies in connection with the subject Basalt of Stolpen
- Labeled as national geotop since 2007 (Goth & Suhr 2007)

Today it is possible to deduce, that in the last years Geotourism became a very important attraction for tourists in Stolpen. The number of tourists who are interested in geology and the Basalt of Stolpen is increasing every year. Of course it is possible, to look for a way to find new attractions. To make all this possible in we have a close and successful cooperation between the local geologist, the castle-management, the city-council, local companies and associations.

I want to encourage local geologists to use the chances of geotourism. In Stolpen it was and is very successful.

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Mines in the landscape of Strzelin County – native rock materials in local architecture

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Strzelin County is situated in the south-eastern part of the Lower-Silesian Province and it consists of the Township and Commune of Strzelin, the Township and Commune of Wiązów, Kondratowice Commune, Przeworno Commune and Borów Commune. The area of the county has interesting geology. This refers particularly to the southern part of the region, lying within the Strzelin Massif. The Neoproterozoic and Lower Palaeozoic metamorphic rocks of this area (gneisses, granite gneisses, schists, quartzites, amphibolites and marbles) enclose a granitoid massif, represented chiefly by granites and biotite granodiorites. Tertiary basalt intrusions represent a much younger igneous formation. Apart from the elevated part of the Strzelińskie Hills, the entire area is covered by Tertiary sediments of marine origin: bluish clays as well as kaolinite clays and sands. The surface layer in most of the area is composed of Pleistocene glacial sediments, sand-gravel sediments, tills and loess – like clays.

Rock material extraction in this area dates back to the 10th century, when granite started to be quarried in Strzelin and Górka Sobocka. These are chiefly granitoids (granite) that have been extracted in the area of Strzelin County since then, but basalt, gneiss and quartzite schist deposits and also quarried here. Moreover, there are traces of marble and quartzite quarries in the region. Rock materials extracted in Strzelin land have been widely used in local architecture and civil engineering. Stone has been used, among other purposes, to build road surfaces, street furniture, architectural details, sculptures, windowsills, stairs, fence basements, low walls, building foundations or whole buildings. The latter could be made entirely of stone or only have external wall claddings made of this material. Rock materials from Strzelin land (chiefly granite) were used in the construction of the first cathedral in Wrocław (c. 1000 AD), the columns in Berlin's Deutsche Bank building, stairs and floors in the Reichstag building, as well as for constructing the Northern Port in Gdańsk, to mention just a few examples.

The paper provides a description of selected stone-clad buildings made of Strzelin rock materials. It also presents different uses of rocks quarried in the region: basalt (as road surface element), marbles (decorative elements), quartzite schists (wall cladding), granitoids, gneisses and quartzites (walls of buildings).

The Study of ephemeral outcrops: the example of the Garrotxa Volcanic Field

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The study of ephemeral outcrops is an important tool to reconstruct the geology of highly urbanised areas in which increasing construction and occupation of soil difficult direct observations. During the last decade, the Natural Park of the Garrotxa Volcanic Field (NE Spain) has undertaken a pioneering activity aimed to study and catalogue all new ephemeral outcrops in order to improve geological mapping and volcano-stratigraphy of the area. An inventory of the geological information obtained from these temporary outcrops in construction sites, that rapidly disappear, as well as water wells and geotechnical boreholes has been collected, analysed, classified, and recorder in an open GIS database for public use.

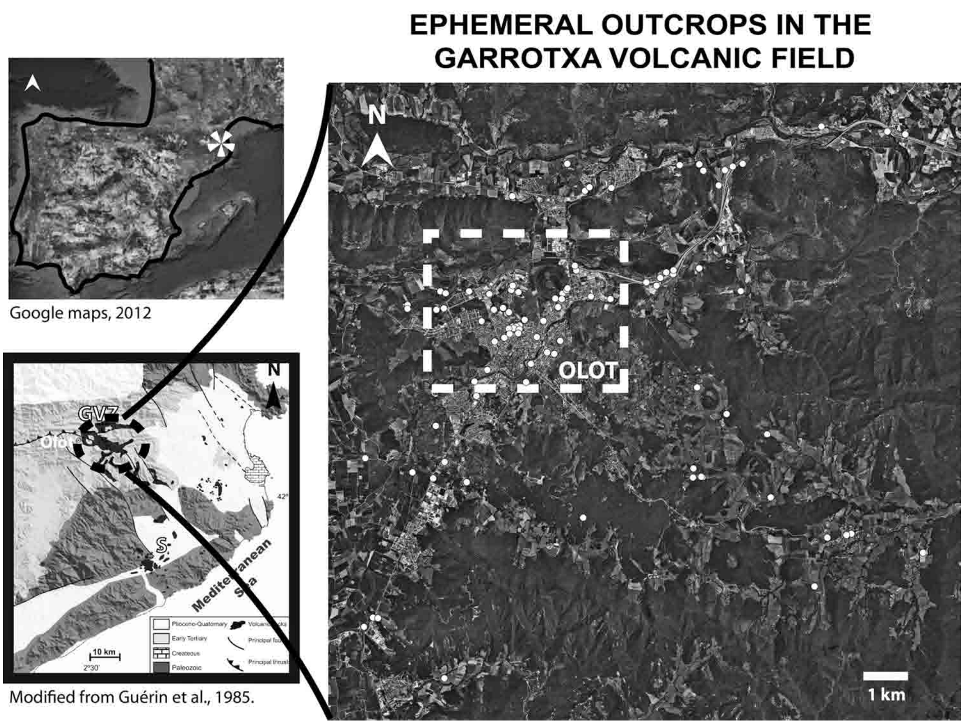

Fig. 1. Geographical and geological setting of the studied area. White dots represent locations of the ephemeral outcrops.

This field study consisted in the collection of data registered as standardized field forms. The data necessary to build the ephemeral outcrops catalogue are: geographical location, geological description, stratigraphic columns, geological sections and photographs of the ephemeral outcrops. Each outcrop was sampled for further analysis. This detailed geological information is registered in a database.

As a case study we applied this methodology in the Natural Park of the Garrotxa Volcanic Zone. During 8 years we have been describing and cataloguing 85 ephemeral outcrops in this area. With key outcrops we have been able to make a detailed mapping of the city of Olot around the Montsacopa volcano. This mapping allowed reinterpreting the eruptive events in the area and describing new eruptive vents. Furthermore, this methodology provided new data on the volcanic alignments in the Olot city evidencing the significance of the structural controls. This study has provided new data for geological research in the volcanic area and it has improved significantly our knowledge on the relative geochronology and extension of the most recent volcanic deposits. This method is also a useful tool to improve the preservation of the geological patrimony in the area.

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Basalt in Strzegom – Landscape changes of Szeroka Mountain

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Geological resources of the Strzegom area are mostly granite as well as kaolin. These two resources are currently mined on a commercial scale. Basalt also used to be mined in the past. The now closed former basalt quarry gives a possibility to take a closer look at the full life cycle of the quarry especially its final stage of life. The basalt quarry in Strzegom has a total land area of 51,434 ha. The basalt mining in Szeroka Mountain in Strzegom on a commercial scale was started in the Nineteenth Century. The first mining was performed by Central Management of the quarries. The last managing body was the Quarries of Road Recourses in Wrocław, which was conducting the mining till the 80's of the Twentieth Century. According to the data in the resources registration card, mined materials of 1330 005 tones were registered in the Central Geology Office on the 10th July 1958. Mining finished in 1981 after about 86% of the registered (proved) basalt resources had been mined. In 1986 the chief geologist in the country revoked the decision from 1964 and finally shut the quarry down due to significant resource exhaustion and assigned the area for environmental protection (Wieczorek 1971).

The geological structure of the area is a typical example of old lava (Bierkenmajer K. et al. 2004) which had cracked because of its slow cooling down, creating the forms of posts adjoining each other. Comprehensive observations and measurements were taken in 2003, the analysis of the great columns proved that it was a lava stream. After the research the nomenclature was changed into alkaline basalt with the certain characteristics of basanite. The radiometric research has shown that there is a link between basalt from the quarry and the volcanic activity in the area. The volcanic origins of Strzegom basalt are very important for the final stage of quarry activity (meaning its re-cultivation and re-use).

The final stage of the quarry's activity is done without human interference; the re-cultivation has been made only by natural development. At the moment the pit is filled with water and partly covered with reeds and with bluffs descending directly down to the water's surface. Leaving the quarry to re-cultivate naturally has yielded valuable environmental effects. The geological structure of the area caused some groups of precious stenothermal rock plant species to develop. Floristic research has proved the occurrence of Rock Whitlow, the Northern Whitlow, Veronica, Melica Ciliata and many other species. The fact that there has been no significant human interference in the land shaping of the bluffs caused no damage to the quarry. The landscape analisys proves that it is an area of great scenery and natural beauty.

All the features mentioned above make the quarry worthy enough to be a part of the Historical Quarries Project making sure that the final stage of its life is as important as when it was still open for mining. At present the quarry is being looked after by the Basalt Foundation which is currently preparing a developement project to convert it into an area of touristic, educational and cultural significance. The above article gives the chance to discuss the proposed ways for the re-use of the quarry after its closing down.

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Physicochemical properties of rock fiber, Basalts from Turkey

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Rock fiber is a type of fiber produced from rocks such as basalts, andesitic basalt and dolomites. Rock fibers have good physicochemical properties that it is used for a fireproof texture in the industrial manufactures and construction buildings.

Basalts are the most common volcanic rock types and they have so much qualified specialties for being used in fiber industry. They are characterized by their high temperature crystalline, high fluidity, high density, and high conductivity with high solid textural features in the frame of all the volcanic rocks. The mineralogical composition and textural features of the basalts yield them durable to the weathering and alteration factors. Moderate silica contents with Fe and Mg contents led them to increase their elasticity and the residence to the atmospheric conditions. All these properties of the basalts show that they are one of the most demand rock types in the producing of rock wool. Basalt fiber can be produced by the directly melting around 1600 ^{0}C or contributing with some materials and then melting them for the better production. Basalt fibers attribute by have high elasticity residence, high heat residence, sound isolation, residence to acidic and alkali effects, low cost production and health features causing to use them in variable production and constructions. Another material made from basalt fiber is basalt steel bar. Basalt steel bar using building construction and boat lagan insisted of steel or steel like production.

Turkey has a wide basalt and basaltic exposure starting from Alpine orogenesis till of Quaternary period. These are changing in composition from alkaline to subalkaline. They have mainly characterized by the presence of labrodorite, pyroxene and rarely olivine in composition. The fiber basalts should have a composition of SiO_2 48.8-51%, Al_2O_3, 14-15.6%, FeO+Fe_2O_3 7.3-13.3%, CaO 10%, MgO 6.2-16%, Na_2O + K_2O 1.9-2.2%, TiO_2 0.9-1.6% and MnO 0.1-0.16%. These chemical compositions have more similarity to most of the basaltic rock of Turkey. Because of these characteristics; basalt can be more attractive raw materials for industrial manufacture productions in the future.

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Revision of potentially hazardous volcanic areas in southern Ethiopia

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Eastern branch of the East-African rift system extends from Tanzania across Kenya and Ethiopia to the Afro-Arabian uplift domain with center in the Afar area. The Afar area is characterized as a triple junction of three rifts: Red-sea rift, Aden rift and the Main Ethiopian rift (MER). Doming and extremely rapid extension has caused intensive volcanic activity with magmas transiting from continental-rift to ocean-rift characteristics (e.g. Ayalew & Gibson 2009). Rapid extension and high magma production attracts most of the volcanological studies in Ethiopia to the Afar area. On the other hand, quaternary volcanoes of the MER in southern Ethiopia are studied much less intensively. For this reason the Czech Geological Survey and the Geological Survey of Ethiopia started on research and mapping of natural risks (apart of volcanic risks includes also seismic, landslide and erosion risks) in southern Ethiopia. The research is financially supported by the Czech Development Agency and Ethiopian Ministry of Finances and Economic Development.

Our research is focused on the area of the MER between the towns of Ziway (N08°) and Arba Minch (N06°). Aim of the volcanology study in the project is to evaluate the potentially hazardous volcanic zones in the study area. The area of interest covers about 35 000 km^2 and comprises several active and dormant volcanic systems. The main difficulty in the area is absence of any historical and lack of geochronological data. Two distinct types of volcanic systems can be identified in the area: i) predominantly silicic large volcanic complexes; ii) fields of predominantly mafic monogenetic volcanoes.

Alutu Volcano represents one of the large volcanic complexes with numerous vents. Voluminous obsidian lavas were produced during numerous eruptions, many of which are buried by younger pumice fall deposits. The youngest pumice fall was dated about 50 BC (Gianelli & Teklemariam 1993). Hydrothermal activity is prominent till nowadays and is in the focus of geothermal exploration and power industry. O´a Cladera (Lake Shalla) is another volcanic complex formed by voluminous eruption 240 000 ka (Mohr et al. 1980). After formation of the caldera, several monogenetic cones, tuff rings and lava domes were formed inside the caldera. Fumarolic and hot spring activity is described from all parts of the caldera. The southernmost caldera - Corbetti Caldera seems to be the most hazardous volcano of the area. Inside the caldera, two new volcanoes emerged. One of them found to the east, called Chabbi (syn. Chebi) Volcano, is a shield volcano consisting of widely spread obsidian lavas. The Urji (syn. Wendo Kosche) Volcano to the west is dominantly explosive with reported fumarolic activity in its crater. This volcano produced widespread young pumice fall deposit covering the area between Shashemane and Aje. This pumice layer covers also fresh-shaped scoria cones south of Lake Shalla.

Eight monogenetic volcanic fields span the rest of the southern part of the Main Ethiopian Rift, but the Mega volcanic field at the Kenyan/Ethiopian border is not studied within framework of current project. East Ziway Volcanic Field consists of approximately 55 scoria cones aligned in N-S direction, oblique to general trend of the rift-margin faults. Prominent soil layer has evolved on all of these cones and the surface of these cones is significantly affected by erosion. No fumarolic activity has been reported in this area. Even the freshest-looking cones are seen to be overlain by the pumice from Alutu Volcano. We presume a pre-Holocene age for these cones posing no volcanic hazard in the future. Awassa Volcanic Field is a group of 7 basaltic scoria cones, tuff cones and tuff rings inside the extinct Awassa Caldera. All these small monogenetic volcanoes are significantly weathered and we suppose this field as extinct. South

Shalla Volcanic Field is group of about 10 basaltic scoria and spatter cones and 2 maars arranged on N-S trending faults between the Shalla Lake and Corbetti Caldera. The scoria cones have basaltic composition and some of them display fumarolic activity. Bilate River Volcanic Field comprises three maars (one with scoria cone inside) arranged N-S on the eastern bank of the Bilate River. These three maars are associated with 6 scoria and spatter cones, some of them with short basaltic lava flows. Five more scoria cones and tuff rings are located on southwestern bank of the river. North Chamo Volcanic Field comprises about 7 scoria cones with intermediate composition. Magma zoning is frequently seen, with eruptions starting about trachytic composition shifting towards the trachybasaltic composition. Many of these scoria cones had significant initial phreatomagmatic (Surtseyan) phase. These cones are located on the northern banks of the Chamo Lako, but also form islands in the lake and extend as far as to the NechSar Plains on the southern banks of Abaya Lake. About 50 scoria cones can be found north of the Abaya Lake near the Town of Humbo. The Humbo Volcanic Field has not been reported before. Among many scoria cones, a Korke Seluwa obsidian dome complex rises. The obsidians are rich in phenocrysts and hopefully will be dated using U-series disequilibria method. More than 80 basaltic scoria cones are arranged in the 70 km long row (NNE-SSW) of the Butajira-Silti Volcanic Field. Some of the scoria cones have basaltic lava flows. Spectacular is the Shetan maar with crater hosting a lake. According to the satellite data, Debes Qoto scoria cone seems to be the youngest member of this volcanic field. The Debes Qoto Volcano emitted a 6 km long lava flow, filling up the river canyon.

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The German Volcano Route – concept model for a geotouristic project interconnecting geosites of Cenozoic volcanism across Germany

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Volcanism is one of the most exciting geological topics for the general public. It is thus only self-evident that many active and dormant volcanoes are exploited for geotourism world-wide. Within Germany, this touristic potential has been recognized for the currently inactive but volcanically young area of the Eifel already since the late 1980ies. Likewise, the Vogelsberg region currently seeks to attract tourists based on the volcano concept. Furthermore, only a few years ago geoparks which are substantially related to volcanism were created in the Swabian Alb as well as in the area of the western Eger Rift (Bavaria-Bohemia).

However, most of the other Cenozoic volcanic fields stretching across Germany such as the Siebengebirge, Westerwald, Hessian Depression, Rhön, Heldburg and Lusatia are not likewise present within the public awareness. We, the German Volcanologic Society (Deutsche Vulkanologische Gesellschaft, DVG), want to change this disparity by creating the extended German volcano route which will interconnect isolated Cenozoic volcanic fields within one tourism theme route stretching east-west across Germany. Tourism theme routes have proven to be powerful tools for tourism (e.g. Briedenhann & Wickens 2004, Meyer-Cech 2003, 2004) and a successful first section of the volcano route was already developed in the Eifel region due to the initiative of the DVG (Blum & Meyer 2006). The geotouristic and geoeducational value of the Tertiary volcanic fields along this route are, however, their unique potential to give insights into all structural levels of a volcanic system. Gaps in between the Cenozoic volcanic fields may be filled by scenic exposures of older magmatic rocks such as Permian intrusives and subaerial rocks or Devonian submarine extrusives.

With the volcano theme route we aim for:

- raising the public awareness of volcanism and volcanic structures
- offering the opportunity to experience a complete volcanic system to a broad public
- mediating volcanism as a key part in the dynamic earth and its potential for geohazards
- supporting the protection of existing geosites and geoparks as well as the creation of new ones
- linking isolated geoparks with each other and with tourism centres
- promoting the publicity of geoparks and geosites on a trans-regional and trans-European level
- enhancing regional touristic values
- enhancing the perception and attractiveness of geosciences as a field of research

Evaluated geosites for the volcano route were assessed for their educational, aesthetic and touristic value, on a regional, national and European scale. For planning and realisation of the project we will collaborate with regional authorities for geology, local geologists, local authorities and tourism professionals. Additional modern volcanologic studies are still needed in some of the volcanic fields.

The German volcano route is planned as a first step towards a projected European volcano route which will interconnect Cenozoic volcanic fields in Spain, France, Czech Republic, Poland, Slovakia, Hungary, Slovenia and Italy on a conjoint tourism route. The backbone of this route will be existing geoparks related to volcanism.

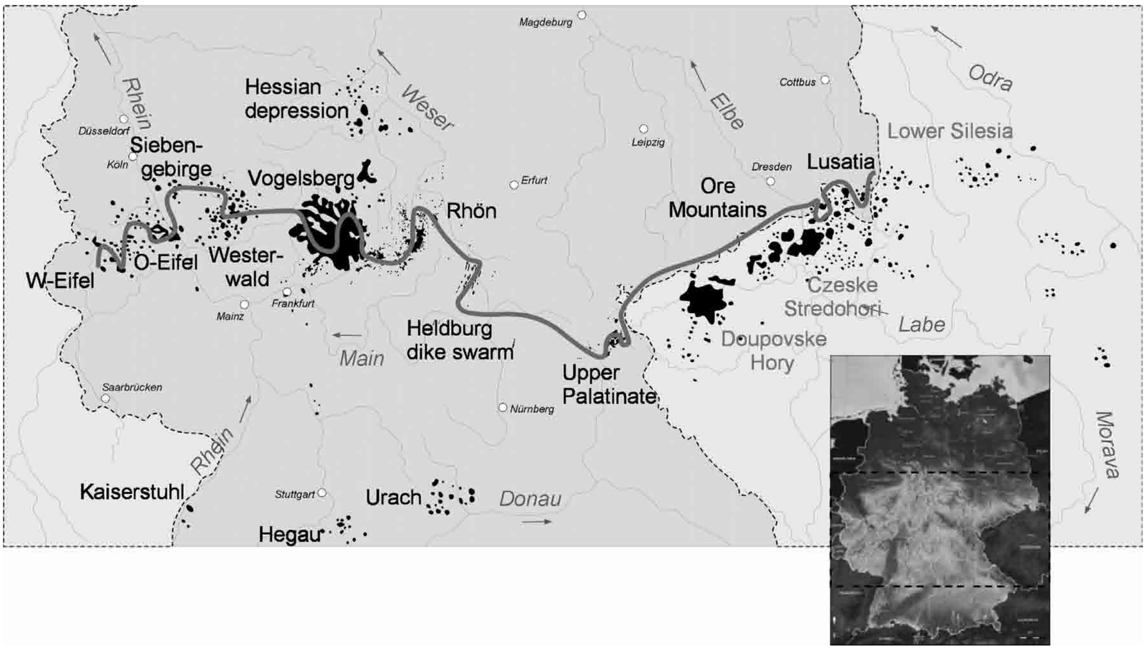

Fig. 1. Fields of alkaline intraplate volcanics in Central Europe and the potential course of the German Volcano Route.

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Volcanism of the Vogelsberg and its touristic valorization

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Looking at Central Europe there is a large volcanic field in the middle of Germany and Hesse called Vogelsberg. With about 2300 km² it is real giant between the neighbouring volcanic fields. It is located in the continuation of the Upper Rhine Graben, where this structure hits the south margin fault of the Variscan Taunus. The volcanism has an age of 19-15 million years and a large number of volcanoes were active.

Searching at geological maps for an overview one can get the impression of a "basalt massif" – a misleading impression. Indeed at the earth's surface there are almost exclusively basalts (in the farthest sense). Nevertheless, in quarries or by drillings with opportunity to have a look in the subsoil, products of explosive volcanism with volcaniclastic sediments (colloquially „tuff") are found. The whole complexity of the Vogelsberg became clear during the scientific investigation of the last decades, which is related to the importance of the delivery of drinking water in the Vogelsberg.

The slogan „Vulkan Vogelsberg" is already used for touristic marketing, for example, by the cycle route „Vulkanradweg" and the footpath „Vulkanring". However, up to now the volcanic past is not obvious for visitors and local inhabitants.

To make the volcanic past recognizable and understandable, geotopes are of major importance. The rather theoretically hint, that basalt - to be found everywhere in the Vogelsberg - is a volcanic rock, is not enough. Not before I myself see a cooled off lava flow (see Fig. 1) and recognize the basalt there in its context, I can really admit the truth of this explanation. Without concrete proof of the geological past (visible and touchable) efforts in geotourism remain cursorily and without authenticity.

The Vogelsberg is a „green volcano". Outcrops have to be searched. Nevertheless, the Hessian geological survey (HLUG) already found 138 geotopes and described 80 of them in detail (Reischmann & Schraft 2009). The spatial distribution of the different kind of geotopes show an accumulation of the geotope kind „natural rocks" in the central high Vogelsberg and the geotope kinds „actual or former quarries" in surrounding deeper locations. These different kinds of geotopes have very different characteristic features and restrictions to their development for touristic or educational use. Especially quarries after end of mining tend to be interesting for the geotourism.

Scale and kind of „valorization" is determining for the touristic use of geotopes. First of all there has to be a path to the geotope and it has to be signposted and as well there need to be a popular-scientific explanation on site. There has to be a description of what is recognizable in this geotope. It is helpful to explain also the geological context and to point out relations to subjects which could be expected as theoretical knowledge of the visitors. Necessary are pictures illustrating the described topics and texts easy to understand, but not wrong in its simplification. Aim is to induce the interest and to provide an „educational experience". That's not easy.

The base for a longer-term use of geotopes is their protection. Especially protection of regional or national rarities is important. Thus volcaniclastic sediments are seldom exposed in the region Vogelsberg these sites should be protected where it is possible. Also exposed relicts of soil formation from the age of the Tertiary as documents of geological climate changes are rare. Tholeiitic lava flows with low viscosity and typical pahoehoe structures (known from Hawaii) are a very particular speciality compared with the neighbouring volcano areas of Central Europe and should be protected, too.

Geotope protection and geotourism need people who campaign! Examples of commitment are the quarry Hungen-Langd (showing different stages of an outbreak), the quarry Nidda-Michelnau (red agglomerate), the "Kunstturm" Mücke (conversion of a tower used for loading iron ore) and the „Erzweg", the geopath of the nature reserve "Hoher Vogelsberg" or the info centre „Alte Schmiede" in Gedern with the „Eisenpfad". Several other examples could be listed here.

The German Society of Volcanology (DVG) with her section Vogelsberg supports the geotouristic development of the Vogelsberg, has a linking up function for the varied activities and is involved in general planning like the German Volcano route. During six years since the foundation of the section a lot of things have been pushed. A development concept for touristic label „Vulkan Vogelsberg“ was instructed by government of the local administrative units Vogelsbergkreis and Wetteraukreis and the town of Schotten. The concept verified that there is a good base for a geopark (ARGE Abraxas & e.t.a. 2009). The result was also, that a geopark could assume the desired integrative function for this region. At the end of 2012 the association „Geopark Vulkan Vogelsberg“ was founded by Vogelsbergkreis and different municipalities of the Vogelsberg region and it will be exciting to see, in which way the geotouristic development will continue.

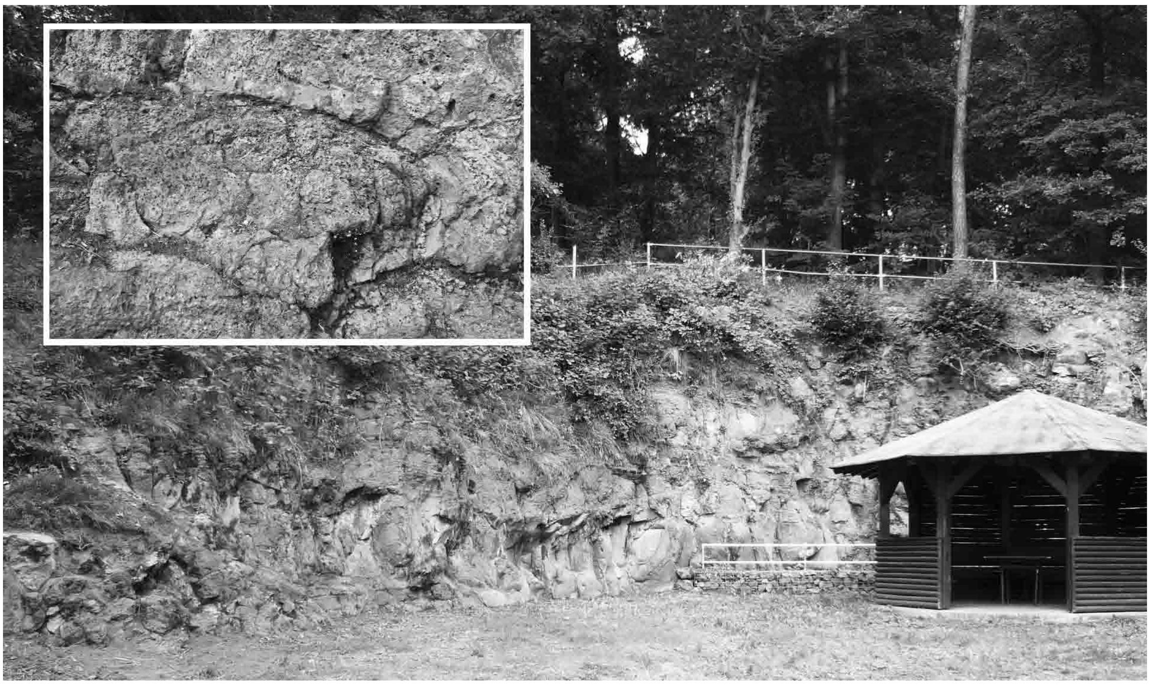

Fig. 1. Little quarry at the Glauberg: Tholeiitic basalt in pahoehoe lava flows. Small picture: forefront of a lava flow (size of picture about 20 x 30 cm) (photos: K. Bär)

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Session 4 – Scheumann anniversary

Scheumann and the ultramafic rocks –100 years after the Polzenite definition

(Talks and Posters)

Type and important localities of ultramafic and associated dyke rocks in northern Bohemia

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The area of ultramafic volcanic rocks in northern Bohemia has been the object of interest of volcanologists and petrologists for more than 100 years. Despite their indisputable value the volcanologists and petrologists have failed to preserve the most unique locations in a condition which is suitable for revision research and the application of new analytical and documentation methods. Neither the most important of them have even been made accessible to the general public. During the subsequent field research at the selected sites, the current condition was recorded by new geodetic measurements (e.g., the protected area of the Great Devil's Wall) and photographic documentation. In localities with destroyed or buried outcrops ground magnetic measurements were carried out and the walls of several old outcrops were exposed again, documented and sampled. In several cases, a permission to enter the site and make necessary landscaping was obtained from the owner. For all major sites, detailed topographic and geological maps have been prepared. For storage and organization of the material for documentation a special archive in the state company DIAMO in Stráž pod Ralskem is expected to be set up. Results from the published and unpublished petrographic and geochemical analyses were summarized in three interconnected databases: one including data on geochronology, another one on mineral composition and one comprising chemical composition. For a large part of the data, which could not be completely identified before, we managed to obtain the missing information from such archival sources as had been inaccessible in the past. If time and financial framework allowed, additional petrographic, chemical and geochronological analyses were performed at selected locations.

There are 11 surface outcrops and the Osečná-intrusion - a sill located at depths between 100 and 200 m, from which one may execute drill cores and well-logging measurements. It is clear from the following brief selection what the goals of the present research work are.

The G r e a t D e v I l ' s W a l l and the Zone of Devil's Walls between Český Dub and Osečná - the most important result of these efforts is represented by the start of extensive documentation of a dyke of olivine-melilitic nephelinite of nearly 12 km's length, including its assumed continuation in northeast in the area of Liberec Town and southwest all the way to the assumed end of the dyke penetrating the phonolite of Bezděz hill. The more southerly branch of the dyke reaches to the volcanic objects between Kuřívody and Bělá pod Bezdězem (Jezovská horka hill, Lysá hora hill, Šibeniční vrch hill). This dyke of olivine-melilitic nephelinite, which is at points 2 meters thick, originally rose to a height between 2 and nearly 10 meters above the ground level, but it was destroyed by exploitation especially in the 19th century. Only a small residual object has been preserved and is today protected as a National Natural Monument. In the shape of the dyke, local anomalies have been identified, which indicate a flat shape of the dyke, i.e. one that is discontinuous lengthwise. Various forms of structure (especially «fold-like» forms) can be attributed importance for the reconstruction of the process of penetration of the melt to the overburden while cooling and crystallization took place. A heterogeneous structure in the transverse direction of the dykes has also been identified, manifesting itself in the orientation of minerals and the fluctuations of the chemical and mineral content, and in the disintegration of rock discontinuities along the axis running parallel to the dyke. The yet unsolved problems include conflicting results of the K/Ar dating (at a distance of only 5 km in longitudinal section significantly different values were returned: around 60 to 30 million years). Based on the revision of an earlier mapping of uranium ore deposits in the vicinity of Stráž pod Ralskem, additional mapping and an evaluation of surface geophysical measurements, a system was identified of at least twenty true dykes, running parallel to the Great Devil›s Wall and forming a swarm called the Zone of the Devil›s Walls.

O s e č n á – i n t r u s i o n - thrust bearing boreholes south of Osečná. Considerable effort has been devoted to detailed documentation of this "bowl-shaped" sill which is around 12 km wide and up to 40 m thick and which was found in the 1970s and 1980s by drilling southeast of Osečná at depths between ca. 100 and 200 m (only in the peripheral part the "finger-like" apophyses of small thickness reaches the surface). Attention has already been drawn to its heterogeneous structure based on mineralogical and geochemical research. Occurrences of rock type of ijolite, flogopitite, glimmerite, pegmatoide (besides prevailing variants of polzenite/melilitolite) were attributed either to metasomatic processes applying in the final stage of volcanic body or to postgenetical hydrothermal effects. These findings, however, could be made only on the basis of analyses of samples taken singularly (often one sample representing the entire thickness of the dyke). However, in a cross section of the volcanic dyke its heterogeneous structure manifests itself in striking anomalies in the course of logging curves (resistivity, gamma-logging), whose interpretation and comparison, reproduction and publication is the focus of ongoing research. The Western Devil›s Wall is considered the main-feeder of the Osečná intrusion. It is a dyke of the length of approximately 5 km and thickness of up to 10 m, composed primarily of polzenite/melilitolite. As a result of intensive weathering this dyke does not form significant outcrops and it was possible to locate it only by using ground geophysical measurements and tranches. The nature of this dyke can be identified on the surface only through solidified facies of cretaceous sandstone which is quartz-rich and thus resistant, silicified at contact with volcanic rock. In the locality of the Zábrdský kopec hill near Osečná at the southwest edge of the dyke a tens-of-meters thick pyroclastic material was encountered in trenches.

During the creation of the Osečná-intrusion, overlying formations (especially Lower Turonian marlstones of the Bílá Hora - Formation) were deformed, which allow the reconstruction of the stress with the effects of an «arch» of the rock massif. In this context it becomes important to calculate the vertical component of the tension by using a gravitational vector and its geological interpretation, which leads to the conclusion that the overlying formations were (and still are!) under significant isostatic stress causing the uplift of the Stráž tectonic block, in which Osečná-intrusion is located, of up to several hundred meters. His probably Neogene origin is not consistent with the results of the K/Ar data, according to which the Osečná-intrusion were formed in the early Paleogene.

Significant mineral composition of ultramafic and associated dyke rocks in northern Bohemia and their variations.

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The results published in studies of dyke ultramafic rocks in northern Bohemia (Kopecký 1987/88, Ulrych et al. 2008 etc.) allow discussing questions arising from the comparison of different research projects (geochemical, mineralogical, and structural investigations). We consider the following to be beneficial for future studies:

- Revision of amounts of individual minerals in rocks regarding to different methods in determining.
- Verification of relationship between the chemical composition of rock samples and their mineral composition.
- Investigations to crystal size distribution (CSD) within the dyke body and their petrogenetic relevance.

The paper highlights possible errors in determining and conversions between percentage amount of a mineral either as a „geometric" parameter in 2D or 3D, or a „physical" parameter, i.e. a percentage of the mass.

The estimation of CSD shows gradients and anisotropy of mineral amount in different directions within several decimetres in cross section (e.g. differences of melilite in the middle and at the margins of an approx. 2 metre thick dyke of nephelinite of the Great Devil's Wall) to dimensions of several meters (for example, in the cross-section of the Osečná intrusion).

The spatial orientation of minerals and its dependence on the size and shape of grains and their position within the volcanic body is indicative for the rheological behaviour of the melt while intruding and cooling. The resulta observed particularly in the nephelinic dykes of the Great Devil's Wall, probably indicate the rheological process of "creep" of the melted mass, which is still able to move, but in which most of the larger grains have already been crystallized. The physical conditions of this transposition must taken place deep in the laminar flow range and suggest small velocities because all elongated grains are oriented in the direction of the movement (the lateral position caused by the effects of the flow field on bodies in transition field of flow has not been observed anywhere). The movement in this state was enabled by the remaining, still-non-solid phase of the matrix.

The results could be extended and supported by thin sections oriented in three spatial directions. The observations and measurements can be projected on the background of the characteristic tabular structure in parts of the dykes which are grouped into shapes which are similar to folds. The above mentioned rheological process of "creeping" has been continuously transferred into plastic deformation process leading ultimately to the creation of mechanical discontinuities (i.e. platy joints).

A detailed determination petrographical characteristics and subsequent investigation of chemical composition of minerals with electrone microprobe (Ulrych et al. 2008 etc.) offers the possibility to assess the balance relations taking place during the crystallization, i.e. the procedure and of the consuming of different chemical components of the inventory that were available in the melt at various stages of development. The reconstruction of this process highlights the "compensatory" effects (e.g. contamination, magma mixing). Absolute increments of e.g. the CaO component had to be compensated proportionally by a decrease in other components (e.g. MgO in this case). This phenomenon can be quantified by using functions with the independent variable of SiO_2 which include regionally integrated units - in this case, the area in which polzenites / melilitolites and nephelinites occur and secondary in limited extent tephrites and basanites. Defining these functions as a product of linear regression did not lead to a satisfying results because of the large dispersion of the values. The authors therefore proceeded to trace non-linear functions, which could be described in an analytical form. Their use allowed the plausibility of the functions to be checked using checksums. However, to avoid an overestimation of their evidence, they were called "lines" of the trend (trend-lines).

These “trend lines” describe the functions:

(CaO, MgO, FeO + Fe_2O_3, Al_2O_3, Na_2O + K_2O) = f (SiO_2).

There it is possible to recognize the characteristic states, apparently corresponding to the crystallization of certain minerals. Corresponding to the Bowen’s reaction scheme, the process of crystallisation started with olivine, whose source can be found in the peridotite rich mass. However, it is not yet clear whether this primary melt contained other mineral components, or whether these have been adopted under other, yet undefined conditions. The magmatic corrosion of olivine) have already been pointed out by Scheumann (1913). In spatially varying sequence the order of crystallisation starts with clinopyroxene followed by melilite, monticellite, nephelinite and other minerals. The significant amount of CaO in many of them is still difficult to explain clearly due to lack of data. However, it could be observed, that carbonates (in this case $CaCO_3$) mostly originated as secondary minerals (there are many examples of intensive transport and crystallization of calcite in the area). If we assume, however, that e.g. Early Paleozoic metamorphic rocks (phyllites with crystalline limestone) that were found in the ground of Upper Cretaceous deposits by drilling at depths of around 200-300 m (their original depth was about 500 m) are the source, then we can assign the polzenites of North Bohemia, as compare to many other ultramafites, a specific, significantly different position.

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Age and time mode of ultramafic and associated dyke rocks in northern Bohemia

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The current state of research of the radiogenic age of ultramafic volcanic rocks (polzenites / melilitolites, nephelinites) in northern Bohemia using K-Ar-method reveals a lot of unresolved questions and contradictions. One conclusion can, however, be made: revised measurements have confirmed the previously established values corresponding to Paleogene in some of studied. If it is possible to suppose volcanism to have already been happening in the Late Cretaceous, as assumed by some older, not entirely satisfactorily documented measurements, it must still be proved by other methods. The importance of the new results of revising and additional dating which were obtained between 2011 and 2012 is the fact that noticeable differences have been uncovered. The Oligo-Miocene age of the other neovolcanites of the Bohemian Massif is considered to be a symptom of the tectonic activity in the area of the Eger Graben. However, the above- mentioned results cannot be explained as a consequence of that process. This led to the conclusion that the pre-Oligo-Miocene volcanic events should be labelled products of "pre-rifting"-volcanism. However, this is a terminological solution only, which must be followed by answers to questions related to the genesis of studied intrusions and their different fabric composition.

Old age was confirmed with certain variations in samples of polzenites / mikromelilitolites (variety: vesecite) from the type locality of Vesec near Světlá pod Ještědem. The range of mean values reaches ca. 10Ma (68.4 to 58.6) there. Some older data do not, however, fulfil today's requirements for accuracy of determination. A similar range was also observed in samples of the olivine-melilitic nephelinite forming the Great Devil's wall, a dyke an as yet unproven spatial connection with the above mentioned dyke of vesecite. The range of mean values is ca. 12 Ma (70 to 58.3). A somewhat higher range was detected in the samples taken from the sill of polzenite called Osečná-intrusions from the depths of about 200 m; the values were published by Ulrych et al. (2008). The range of mean values reaches here ca. 11 Ma (67.4 to 55.9). A low value (58.6 Ma) in a sample from the Vesec locality results from the low content of potassium. However, a considerable difference of age (ca. 6.5 Ma) between the samples taken from the edge and the central part of the Great Devil's Wall dyke is conditioned by the low value (59.88 million years) from the middle part, where low argon has been established. What remains so far unexplained is the discrepancy between the assumed age of the Great Devil's Wall (ca. 60-65 Ma) and the age of the revised samples taken from this dyke approximately 5 and 10 km southwest (ca. 30 million years): the former is approximately twice as old as the latter. Both samples show distinctly lower values of potassium and argon.

Pécskay (2012) states in relation to this discrepancy: "A related problem arises from possible excess "argon "contamination. Due to the present of some "excess argon", the K/Ar age will be older than the real geological age." While large part of the Osečná-intrusions contains K_2O values roughly between 2 and 2.8 wt%., the content of this component decreases in the adjacent nephelinites to about 1.5% by weight. This section gives the impression of an anomaly that does not entirely correspond to the old age of the minerals.

A similar discrepancy also came to light in the Zeughausgang ultramafic dyke, which is located on the right-hand side of the Elbe valley near the Czech-Saxonian border. Pfeiffer (1994) assesses the age at 71.3 Ma, but revise measurement (Pécskay 2012, sampling Büchner & Tietz) led to a significantly lower age of 32.15 ± 1.31 Ma. The effect of alterations cannot be excluded; however it cannot be proved, either, because of nonexistent older documentation.

Finally there is a third important source of inconsistent data. Polzenites and nephelinites contain considerable amount of xenolithes, which during the preparation of samples for chemical analyses distort the fabric composition of the samples. These are often Upper Cretaceous sandstones, however, in the Vesec locality small bodies of fine-grained igneous rocks of the diorite type from deep underground were identified, which are probably of Variscian age. The comparison of the discussed high mean values of the age of ultramafic rocks with similarly high values of the Bohemian Massif and its northern foreland suggests an association between this early stage of volcanism and the tectonic structures of the Elbe-Trench. What remains unexplained is the discrepancy between the assumed paleogenous age of volcanism and a younger (Neogene) tectonic activity in the areas of the Lusatia-Fault Zone. The considered mean values of the age represent processes that occur with the highest probability in the measured data. This does not mean that higher or lower values cannot be taken into account. Indeed, in the $\pm\sigma_t$ (standard deviation) interval, 66% of all investigated data is located. This leads to the conclusion that it is acceptable to try to find in the obtained data a set of numbers that are common to the highest possible amount of measurements. Two such sets can actually be found. The first one is older and more concentrated (the variations between the individual values in it are smaller). Its mean value is 65.6 Ma. The second one is broader and its mean value is 60.3 Ma. Thus they could represent two periods of volcanic activity, and the interval between them is reduced to approximately 5 Ma.

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Ultramafic pre-rift volcanism of the Osečná Complex, northern Bohemia

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The easternmost part of the Cenozoic Volcanic Province of western and central Europe includes rare occurrences of Late Cretaceous to Paleocene (68 to 59 Ma) ultramafic melilitic and melilite-bearing rocks concentrated in the Osečná Complex and associated Devil's Dyke swarm. These rock suites, related to the initial stage of rifting of the Bohemian Massif, occur in the outer parts of the Ohře/Eger Rift zone. Here, in the Ploučnice River area, a group of clinopyroxene-free melilitic rocks of **polzenites** was defined by K.H. Scheumann in 1913.

The **Osečná Complex** is a lopolith-like subvolcanic intrusion (sill), composed mainly of olivine melilitolite with melilitolite pegmatoids, ijolites and glimmerites, with marginal facies and numerous apophyses of olivine micromelilitolite composition, accompanied by dykes of polzenites (the Vesec, Modlibohov and Luhov types of Scheumann) of lamprophyre, i.e. volatile-rich, character (Ulrych et al. 2008 and citations therein). The central part of the intrusion is composed of **olivine melilitolite** (melilite + olivine + spinel ± phlogopite, nepheline, and rare monticellite, titanian andradite and perovskite). This is a medium-grained porphyritic rock with certain attributes of lamprophyres. Phenocrysts of olivine and melilite are present in fine-grained groundmass. The central part also contains rare dykes and pods of evolved coarse-grained rocks of unusual compositions: melilitolite pegmatoids and ijolites; glimmerites concentrate along their contacts with the parental olivine melilitolite intrusion and apophyses thereof. **Melilitolite pegmatoids** (melilite + phlogopite + garnet + spinel ± nepheline, apatite) form irregular pods and dykes. Other minerals include phlogopite, apatite, perovskite, calzirtite and titanian andradite. **Ijolite** (nepheline + clinopyroxene ± melilite, calcite, phlogopite, garnet), which forms rare dykes, is a medium-grained rock with a high carbonate content. **Glimmerite** (phlogopite + garnet ± olivine, melilite, spinel) occurs as irregular pods, which gradually merge into the parent olivine melilitolite, and as rims on pegmatoid and ijolite dykes. Phlogopite-garnet symplectites are common in these rocks. Spinel, perovskite, apatite and rare rasvumite KFe_2S_3 occur as minor phases. The chilled margins of the intrusion and numerous centrally moderately inclined (max. 35°) apophyses are composed of **olivine micromelilitolite.** The rock is of lamprophyric character similar to polzenites of the Vesec type, with microphenocrysts of olivine with monticellite rims set in a groundmass rich in phlogopite. The other steeply dipping dykes up to 2 m thick associated with the intrusion are composed of the classical **ultramafic lamprophyre – polzenite** (melilite + olivine + phlogopite + spinel ± monticellite, clinopyroxene, nepheline, sodalite/hauyne, calcite, perovskite, apatite). Polzenites of the **Vesec type** are porphyritic, with phenocrysts being represented by olivine with thick monticellite rims set in groundmass with poikilitic phlogopite and abundant perovskite. The rocks pass from the **Modlibohov type** with minor clinopyroxene content to the clinopyroxene "polzenite" (alnöite) of the **Luhov type** with a substantial content of porphyritic clinopyroxene (max. 20 vol.%). The Modlibohov type is rich in phlogopite (groundmass, rarely phenocrysts) and calcite. The Luhov type is ever richer in calcite and contains a substantial proportion of sodalite/hauyne.

The NNE–SSW-trending **Devil's Dyke swarm** consists predominantly **of melilite-bearing olivine nephelinite to olivine melilitite** (olivine + clinopyroxene + nepheline/melilite). The dykes, up to 3 m in thickness are subvertical. The microphenocrysts are olivine and clinopyroxene, while the fine-grained holocrystalline groundmass consists of nepheline, melilite, olivine, clinopyroxene, phlogopite, spinel and perovskite.

The melilitic and melilite-bearing rocks of the Ploučnice River area show Mg# between 68 and 75. Polzenites of the Vesec type and olivine micromelilitolites have Mg# values up to 77 and fall within the mafic cumulates and ultramafic lamprophyres. The contents of compatible elements (Cr, Ni, Co, Sc) lie above the lower limits for undifferentiated primary melts of mantle origin. Mantle xenoliths are also present in all these rocks. Glimmerite to mica clinopyroxenite xenoliths in polzenites are representatives of metasomatized upper mantle.

The melilitic and melilite-bearing rocks are characterized by low contents of SiO_2, Al_2O_3 and total alkalis but high CaO, MgO, P_2O_5, CO_2 and strongly incompatible trace elements including LREE. Nevertheless, the contents of compatible elements are also high. Similar geochemical signatures are displayed by intraplate melilitic volcanic rocks from Hegau, Urach, the Rhine Graben and the Canary Islands while those from Tubuai, French Polynesia are depleted. High initial ε_{Nd} values of +3.2 to +5.2 accompanied by variable $^{87}Sr/^{86}Sr$ ratios of ~0.7033 to ~0.7049 are interpreted as evidence for melting of a heterogeneous veined metasomatically enriched mantle. A portion of a depleted mantle source was overprinted by carbonate-rich fluids with enriched Sr isotopic composition. Mantle metasomatism was probably related to carbonatitic magmatism associated with incipient Neoidic rifting of the Bohemian Massif lithosphere.

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Karl Hermann Scheumann, a geologist and petrologist in the area of the Czech-German border

In 2013, one hundred years will have elapsed since the introduction of the term "polzenites" for ultramafic volcanic rocks.

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In 1913 Karl Hermann Scheumann, a graduate of the University of Leipzig, published the results of his doctoral thesis, in which he described occurrences of ultramafic, mostly melilite-bearing dyke rocks. Such rocks had been known only sporadically until that time. These dykes were found in the area between Český Dub and Stráž pod Ralskem in northern Bohemia. Scheumann suggested the collective name "polzenites" for them (based on the German name of the river Ploučnice: die Polzen). He recognized their considerable mineral and chemical variability, and opted for different types varieties with name according to the major sites. The Vesec Type contains monticellite and lacks clinopyroxene, the Modlibov Type, lacks both clinopyroxene and monticellite and the Luhov Type with clinopyroxene and nepheline approaches melilite-bearing olivine nephelinite. Apart from this group of rocks, for which the international subcommittee for the nomenclature of igneous rocks has recently recommended the names melilitite and melilitolite, Scheumann also identified another rare rock type which was rich in amphibole and phlogopite phenocrysts and called it wesselite. Scheumann's results have served the geologists working in this field for decades. Even his terminology is still used. But a hundred years after Scheumann's research, the type localities near the villages of Vesec/Světlá pod Ještědem, Modlibohov (German Modlibov) near Český Dub, Luhov (German Luh) near Stráž pod Ralskem and Veselí (German Wesseln) near Zákupy, were to be found only with difficulties. After considerable effort, we managed to locate them and to open them for studies using up to date methods not available to Scheumann in the early 20th century. Although a systematic revision has not been finished yet, the current results represent a significant extension of knowledge, especially on the composition of the rocks discussed and on the structural-geological features of the ultrabasic volcanic rocks in northern Bohemia. Publication of the results pursues the aim to find points comparable with similar studies worldwide and accelerate the exchange of views on issues of research methodology, the genesis of rocks and the possibilities of protection of the most important objects.

Scheumann was born on February 25th 1881 in Metz, Lothringen, now in north-eastern France. He spent his youth in Dresden, where he attended the Art Academy thanks to his talent for drawing. Later, he decided to study natural sciences at the University of Leipzig. He applied his artistic talents in scientific research. He managed to render his observations of geological formations in nature, his ideas about tectonics and space position of bodies, diagrams as well as microscopic structures in masterfully graphical and artistic drawings. At the initiative of his professor R. Reinisch he visited the region of the upper Ploučnice River in 1907 for the first time. He mapped the outcrops of Upper Cretaceous sediments there, but focused mainly on the research of basic and ultrabasic volcanic rocks of the polzenite-trachydolerite-phonolite series (including olivine nephelinite of the Devil's Walls). He returned there a few more times in the next three years, completed his field work in 1910, and spent the next two years on laboratory research. The results of his study were summarized in the dissertation "Petrographische Untersuchungen an Gesteinen des Polzengebietes in Nord-Böhmen" which he defended in facing the committee which included Professor F. Zirkel and Professor F. Rinne. His dissertation was published in 1913 in Abhandlungen der Sächsischen Gesellschaft der Wissenschaften and gained international acclaim soon. During World War I, Scheumann served as an infantryman. His promising career in science was thus interrupted for years 1915–1918. After his return he continued his studies, being mainly inspired by the Bowen's study of alnöites of the Cadieux region. He assigned the polzenites from the upper Ploučnice to alkali-lamprophyric dyke rocks and compared them with the mineralogically similar rocks from Alnö, Isle de Cadieux, further with melilitic basalts of Swabian Alps and finally with bergalites from Kaiserstuhl, which had previously been described by Soelner. In an extended study published in 1922 he concluded that the initial alkali-basaltic magma of polzenites assimilated limestones completely, which enabled late-magmatic crystallization of monticellite and calcite. In the following years he devoted himself already to other petrographic problems, collaborated with many distinguished scholars and prepared many young petrographers for scientific careers. He was habilitated in 1924 and was appointed to teach petrography at the University of Gießen, where, however, he worked only briefly. He was called to the University of Berlin as early in 1926, and gained a leading position at the Department of Petrography at the University of Leipzig in 1928. Practically nothing is known of his fate in the World War II. Only a few scientific publications from that time suggest that he was able to devote himself to those topics which had previously interested him. After the war he contributed significantly to the rebuilding of the destroyed University of Bonn, where he was forced to relocate under the pressure of political changes in eastern zone (GDR). He was honoured many times for the results of his scientific efforts. He died shortly after his eightieth birthday in 1964.

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More melilitites in the Saxonian Vogtland, Germany

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Melilite-bearing igneous rocks are well known from the Upper Ploučnice River area in northern Bohemia such as the Osečná Complex and associated Devil's Dyke swarm (e.g., Scheumann 1913, 1922, Ulrych et al. 2008). However, melilite-bearing rocks are also present at the western end of the Ohře (Eger) Rift in western Bohemia (Ulrych et al. 1999) and in the Saxonian Vogtland (e.g. Abratis et al. 2009).

The small volcanic field of the SW Saxonian Vogtland is located northwest of the Cheb Basin and shows numerous volcanic plugs, dikes and diatremes of Cenozoic age. The outcropping igneous rocks – olivine melilitites, melilite bearing and melilite free olivine nephelinites, melanephelinites and a few tephrites – are strongly silica undersaturated and characterized by the appropriate mineralogy showing abundant nepheline and melilite as the silica-depleted substitutes for feldspars and pyroxenes, respectively. Other mineral phases are perovskite, haüyne/nosean, phlogopite/biotite and apatite besides diopsidic and aegirine-augitic pyroxene, forsteritic olivine and titanian magnetite. Most minerals indicate that the rocks are generated from melts which were highly enriched in incompatible elements and volatiles. Mineralogy and geochemistry suggest that melting took place at rather deep levels >80 km and very low degrees of melting within a strongly metasomatized, CO_2-rich mantle. Ponding of melts at the mantle-crust boundary is evidenced by the occurrence of green-core pyroxenes in some of the rocks. Rapid ascent of the mantle melts through

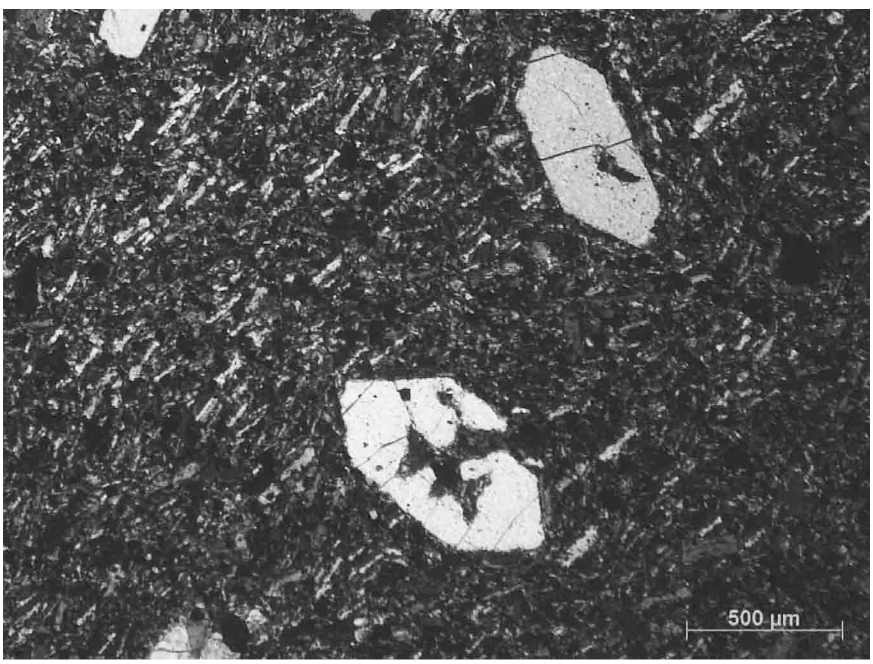

Fig. 1. Thin section micrograph of an olivine melilitite from Bösenbrunn (Vogtland, Saxony). Note the euhedral olivines and grayish melilite laths. Observation under crossed polarized light.

the crust is suggested by the association with the deep fault systems characterizing the region and by the presence of mantle-derived xenocrysts in the volcanics. Secondary minerals such as zeolites, analcite, apophyllite and some of the carbonate document late and post-magmatic hydrothermal activity within an area which is still affected by intense intracrustal magmatic fluid migration as indicated by abundant mofettes and frequent earthquake swarms within the Vogtland and western Bohemia.

Besides the known occurrences at Landesgemeinder Tal near Klingenthal we recently found olivine melilitites at two new locations near Oelsnitz, at Bösenbrunn and Burkhardtsgrün. Melilitites at these outcrops are astonishingly unaltered and have earlier been mapped erroneously as feldspar basalts. The geochemistry of the olivine melilitites shows strong enrichment of incompatible trace elements with low Zr/Nb and La/Nb ratios resembling HIMU basalts. ^{40}Ar/^{39}Ar age dating of the igneous rocks gave plateau ages of 24.95 ± 0.3, 24.38 ±0.11 and 24.87 ±0.47 Ma.

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Tectonic framework of ultramafic and associated dyke rocks in northern Bohemia

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According to the K-Ar dating the ultramafic volcanic rocks in North Bohemia had originated in the period before the tectonic activity in the Ohře(Eger)-Graben (Rift), which is associated with volcanism in the České středohoří Mountains and Doupovské hory Mountains. The studied ultramafite products are therefore called «prerifting-volcanism». Their formation was preceded by unspecified vertical tectonic movements (uplift in the Czech Upper Cretaceous Basin) in the final stage of the Mesozoic, which is probably associated with the regression of the sea in the Bohemian Massif in Santonian. Efforts to assess these phenomena related to volcanism according to their present character encounter a serious obstacle in the fact that these phenomena (e.g. significant uplift of the tectonic block of Stráž, in which the ultramafic volcanic rocks are located, or the movements in the Lusatia Fault zone that the main area of ultramafic rocks encircles in the northeast) are generally identified as belonging to a significantly later age. It can be added to the hitherto ideas about the nature of the process of deformations in the Lusatia Fault zone (it is generally regarded as a reverse fault, i.e. push up of the metamorphed and crystalline Ještědský hřbet massif from northeast to southwest over the Upper Cretaceous cover) that the partial dip of the major tectonic faults to the NE can be interpreted in a different way. Upper Cretaceous strata underwent a considerable change of their position - their northern part was in some sections uplifted several hundred meters. If we accept that the Lusatia Fault was created before this uplift, it is possible to reconstruct the original position in such way that the whole strata are transposed into the original (i.e. more or less horizontal) position. The Lusatia Fault, which is today inclined, would be in this way «turned» into a vertical position, so that the idea of reverse fault would not be necessary; it could be replaced by a vertical movement, whose result was only later transformed into an apparent reverse fault.

There is another phenomenon which is connected with the uplift of the Block of Stráž, one which follows from the results of geophysical measurements (Sedlák et al. 2007). The cited authors deduced the geological structures of the upper part of the Earth's crust up to the depth of 10 km from gravity values in the cross section of the territory in the NW-SE direction and assigned such density of rocks to the main units that the sum of their effects corresponds to the measured gravity. This enables the calculation of the vertical (gravitational) stress components σz at any point of the cross section. The quantification of these values shows that the mentioned stress in a depth of 10 km on the border of two types of profiles changing rapidly: the south-eastern part without granite massif shows σz values around 250-270 MPa, while the north-western part with the granite massif shows the values which are approximately 10 MPa lower. This non-equilibrium state can only be temporary - a rock mass exerts an effort to reach a balance, which can be achieved e.g. uplifting the granite block. In this sense we are talking here about an isostatic process, which has certainly not been completely finished until today. Nevertheless, this could be recognized as the cause of the uplifting of the Block of Stráž. As a result, in the horizontal direction there has been activated tensional stress which destroyed the mechanical continuity of the sedimentary formations (Permian-Carboniferous, Upper Cretaceous) which had not been consolidated very much yet. The tensional stress thus created so the preconditions («path») for the rising of the melt up to the original surface. In this sense one can interpret the subsidence of the Tlustecký block as having occurred at a time when the stability of the forming arches was destroyed.

It is necessary to extend the considered effects of the non-equilibrium state which is induced by different values of the vertical stress components onto other spatial components and support them by mathematically suitable instrumentation. First of all it is necessary to point out the fact that the ability of the rock mass to transfer the vertical component into the two horizontal directions is difficult to quantify. This ability varies with the depth, and in its final stage when the massif enters a viscous state, all three spatial components are roughly of the same size (which is similar to the hydrostatic state in liquids). Because of this variability, it is appropriate to replace Poisson's parameter, which is usually used in this context by what we designated as parameter λ (= $\sigma_{x,y}$ / ρ_z). Especially in the transition stage a significant role is played by deformations which are induced by an external stress - their size is a function of time t. The deformational process of this type is characterized by the parameter $\acute{\varepsilon}$ (strain rate, Dehnungsrate) which expresses the changes of relative deformations ($\varepsilon = \Delta H/H_0$) in time. Its size and the changes are reflected in the speed of the deformation process. The consequence of this for the unsteadied state is that the mass of rock gradually mobilizes the reactive force (marked here ζ) until an equilibrium between the two systems of forces ($\sigma_{x, y, z} = \zeta_{x, y, z}$) is reached; only then does the deformation stop. Here we have the chance to upgrade the existing mechanical theory which is based on the concept of continuum by a modification which is useful for the tectonic analysis. Reactive forces can only be mobilized at the "internal surface" of the "grained" mass, i.e. at the contacts between the grains. The size and geometry of the internal surface of the grained (dispersioned and crystalline) systems can be at least approximately determined and thus the development of reactive forces can be shown and quantified. Generally speaking, the sum of all contacts has the shape of a triaxial ellipsoid on which the external stress components partially decompose into tangential τ_n components, causing a displacement and thus changes of position of grains, and normal ν_n components (here instead of σ_n, because this is not the resultant vector of major stress components $\sigma_{1,2,3,}$ which in transition stage, i.e. quasiviskos, successively lose the significance); the component ν prevents the displacement. During this process the size and geometry of the internal surface keep changing until a point is reached at the ability of this area to offer mechanical resistance is exhausted. The consequence of the ever increasing external stress is the destruction of the grains and, under optimal conditions, the recrystallization of the mineral matter which has succumbed to the stress at the contact areas between grains. If there is space for this mass in the pores, it crystallizes there and fills the pores. The parameter for such changes is the increasing density ρ of the rocks. The remaining material is removed out of the system and crystallizes in some other free space. The intensity of this phenomenon is significantly influenced by the temperature T and its temporal and spatial change (dT/dt, dT/dx,dy,dz). This process can be described by a system of functions with the following variables: geometric parameters: x, y, z, H_0, H, general physics parameters: t, T and mechanical parameters $\sigma_{x, y, z}$, $\zeta_{x, y, z}$, τ_n, ν_n, λ, ε, $\acute{\varepsilon}$ for.

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A project of new protected areas with ultramafic and associated dyke rocks in northern Bohemia

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In the Czech massif ultramafic volcanic rocks (polzenites / melilitolites) occur in a large continuous area exclusively in northern Bohemia roughly between the village of Světlá pod Ještědem and the town of Stráž pod Ralskem. They represent a rare case of extreme developmental stage of magmatic formations. The places where they appear on the surface offer a unique opportunity to study units from depths which are unreachable by other means. Therefore such units rightly deserve inclusion among other highly valuede European geotopes. Their occurrence and formation are coupled with those of dykes of nephelinites, of which the most famous is the Great Devil's Wall – a National Natural Monument - between Český Dub and Osečná.

Currently, three projects are being prepared with the aim to protect the most important objects, to acquaint the wider public with them and facilitate their research so that both local and foreign researchers can be involved in them. They are:

- The extension of the National Natural Monument of the Great Devil's Wall,
- The establishment of a Geopark covering typical volcanic formations and
- The establishment of nature trails designed as part of the European volcanological trail which is currently under preparation.

The extension of the National Natural Monument the Great Devil's Wall

An approximately 1.2 km long portion of the Great Devil's Wall between Český Dub and Osečná has been protected since 1964 as an important geological object. In 1992 this section was declared a National Natural Monument. The remaining more than 10 kms are not yet protected in spite of the importance of both the volcanic rocks encountered there and the landscape value of this unit;last but not least, the Great Devil's Wall's historical importance should secure it inclusion among those natural phenomena that are protected by law. The authors have therefore prepared a proposal for the extension of the existing protected area and submitted it to the Ministry of Environment of the Czech Republic for assessment (Paluska & Veselý 2011). According to the ministry staff it will be possible in the foreseeable future to further extend the protected area to include an approximately 2 km long portion of the wall in the south-west direction, so that the new protected area will include a section between the Smržov and Kotel villages in the northeast and the valley of the Zábrdka river near Dolánky in the southwest.

The authors base their proposal on the following reasoning (this is a selection of the major aspects): the high age and the still unresolved discrepancies in the dating of volcanic rocks, their partly extreme basicity and its variability, the intensely discussed question of the origin of the melt, the extraordinary range of this dyke (or possibly the dyke zone) and the wide variety of textural and structural characteristics and their importance for understanding the rheological motion of the melt.

The establishment of the "Volcanites of the Devil's Walls" Geopark

The impetus for the project came from the meetings at the Ministry of Environment of the CR and the Geological Survey of the CR between 2011 and 2012. It turned out that many valuable localities are not thoroughly documented, nor are their conversation or protection envisaged. The extent of these mostly small-scale units is considerable. The most significant objects belonging to the volcanic rocks category are:

The volcanic rocks of the "Zone of Devil's Walls", the volcanic areas of polzenites / melilitolites including the dyke Osečná-intrusions and the volcanics of tephrites, basanites, picritic basaltes, trachytes and phonolites and pyroclastic materials. Apart from the volcanic, valuable objects of Upper Cretaceous formations, quaternary sediments and tectonic structures are located in the area.

The establishment of a volcanological educational trail

The most important sites will be interconnected by an educational trail whose central theme of "volcanic formations" will be gradually extended to include other objects whose significance for geology, natural sciences and/or history is high. This trail will be progressively extended to other volcanic formations in Bohemia and Moravia. Ultimately, it will be connected to the European volcanological trail which is under preparation.

References:

• *Paluska A. & Veselý P. (2011): Velká Čertova zeď. Národní přírodní památka evropského významu (Great Devil's Wall. National Natural Monument of European importance). – DIAMO, state enterprise [unpublished].*

Excursion guides

Field trip 1:

Upper Cretaceous/Paleogene ultramafic volcanism in the Osečná and the Ploučnice area (North Bohemia)

Antonín Paluska, Vladislav Rapprich, Pavel Veselý & Jaromír Ulrych

Field trip 2:

Księginki quarry in Lubań – nephelinite with two suites of mantle xenoliths

Jacek Puziewicz & Magdalena Matusiak-Małek

Field trip 3:

Volcanology of the Lusatian Volcanic Field – New insights in old well-known

Olaf Tietz, Jörg Büchner, Peter Suhr & Kurt Goth

Field trip 1: Ultramafic volcanic rocks in the Osečná – Upper Ploučnice river region in North Bohemia

Antonín Paluska[1], Pavel Veselý[2], Vladislav Rapprich[3] (geology), Jaromír Ulrych[4] (geochemistry, petrology)

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1. Introduction

1.1 Ultramafic volcanic rocks in the Osečná – Upper Ploučnice River region – geology

Despite extensive research in the area of the ultramafic rocks in North Bohemia, and namely in the last four decades, new surprising and often contradictory knowledge have been obtained by revisional investigations. Their interpretation goes beyond the scope of this guide. However, the authors deem it necessary to point out the most doubtful aspects and enable participants of the excursion to evaluate the visited objects on the background of the current scientific results, so far only a part of them has been published until now.

1.1.1 Brief overview of the knowledge developement

The outcrops of ultramafic volcanic dykes in the headwaters of the Ploučnice River in the area between the towns Osečná, Český Dub, Světlá pod Ještědem, Stráž pod Ralskem and Mimoň (see Fig. 1) had been known since the late 18th century. Franz Ambros Reuss described in 1797 the **Great Devil's Wall** dyke, rising in that time up to 10 m above the surface of surrounding Upper Cretaceous sandstones. Between 1822 and 1849 Maximilian Franz Xaver Zippe investigated the locality near Vesec and collected here first samples. Later Jan Krejčí (1869), Emanuel Bořický (1874 and 1876), Alfred Wilhelm Stelzner (1882) and Franz Wurm (1883 and 1884) visited some of the outcrops and described them. Based on their records it was possible to reconstruct the original shape of the later destroyed so-called Devil's Gate (Fig. 2). But only the systematic regional research and documentation of the fabric composition of the rocks, which have been published by **Karl Hermann Schumann** (Fig. 3) in 1913 and 1922, revealed the existence of different types of ultramafic rocks, for which the author suggested until now used names "**polzenite**" (according to the German name of the river Ploučnice: die Polzen) with varieties "vesecite", "modlibovite" and "luhite" and outside this group still "wesselite" (more details about the scientific work of K. H. Scheumann in northern Bohemia see Paluska et al., 2013a).

In late 60's of the 20th century a uranium ore deposit was discovered in the wider area of Stráž pod Ralskem. The uranium ore is located mainly in the Upper Cretaceous (Cenomanian) sediments in depths of ca. 200 m. Exploration wells discovered also volcanic rocks, of which the most important is a large sill southeast of the village Osečná roughly between the depths of 100 and 200 m. For this unit, which has been at first described by Joseph Rutšek (1979), Jaromir Ulrych, Edvin Pivec and others used the name"**Osečná-intrusions**". These authors examined the petrographic and chemical composition of ultramafic rocks of Osečná-intrusion and identified beside polzenites/melilitolites also other rare rock-types like pegmatoide, ijolite glimmerite (phlogopitite) and camptonite. From this period comes the first K/Ar-dating, which revealed high age of the local rocks (roughly between 55 and 80 million years).

The results of those studies have been presented in numerous publications (starting with Ulrych et al., 1988, and the last one is Ulrych et al., 2008) and linked on the previous research of Shrbený & Macháček (1974) and Kopecký (1987-1988). In the last three years the authors started the revision research. The following text relies on the results of this investigation, which is conceived as a basis for the extension of the existing protected area of **National natural monument Devil's Wall** and for the establishment of proposed **Geopark Devil's Walls**.

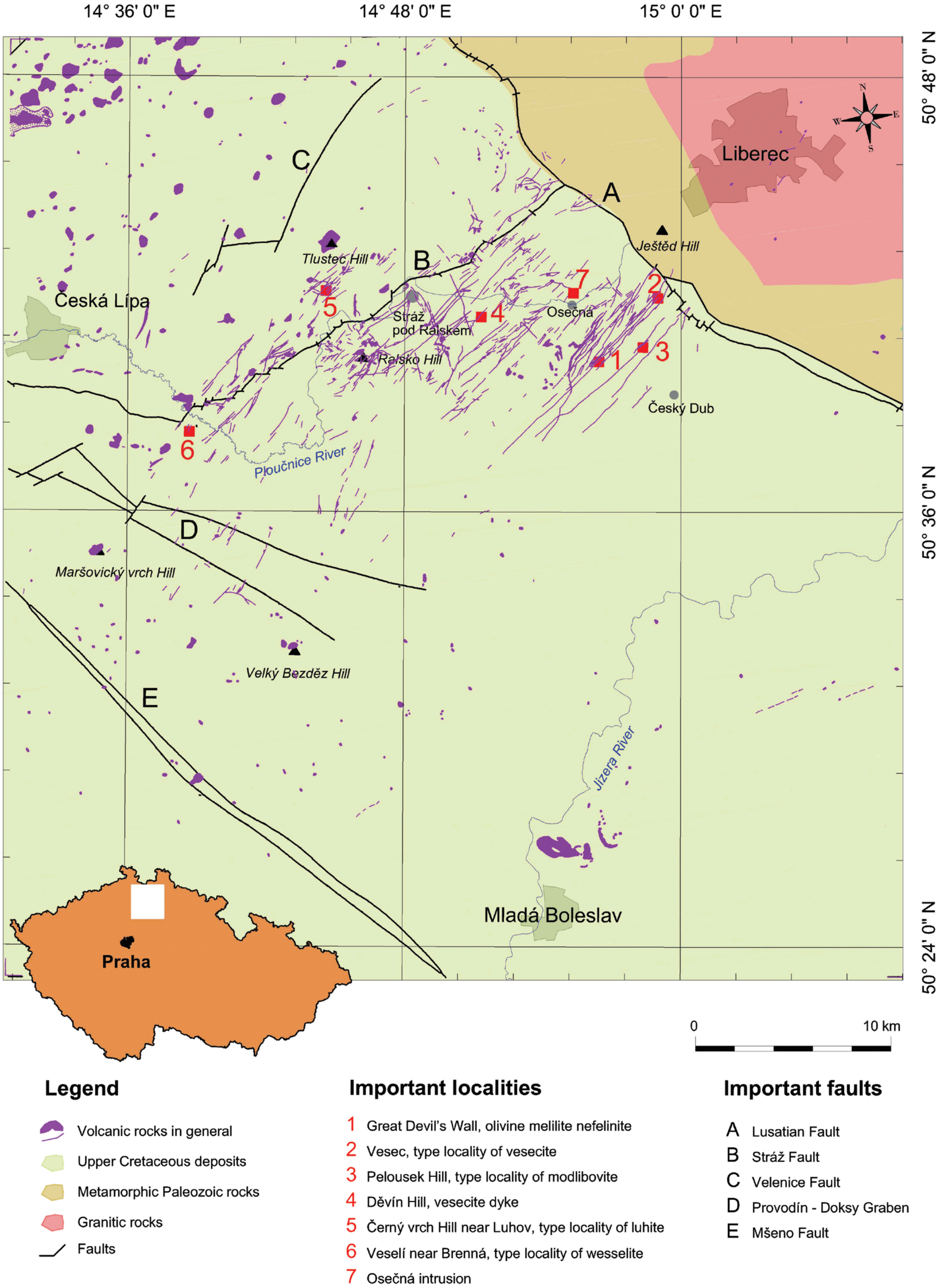

Fig. 1. The simplified geological map of the Ploučnice river region in North Bohemia showing the area of ultramafic dykes occurrences and selected important localities – the number 1, 2 and 7 are the excursion stops.

Fig. 2. *The reconstruction of the destroyed Devil's Gate in the Great Devil's Wall. The gate was created by break of the wall probably before 1300 (according to the finding of the Zittau bracteates treasure from 1300) and had been used until the end of 18th. century. Before 1879 the arch broke down and the remaining rock had been taken away. The reconstruction based on a drawing of the gate, which was published by Franz Wurm 1884 and on its description published by Franz Ambros Reuss 1797.*

Fig. 3. Karl Hermann SCHEUMANN seventy years old. According to O'Daniel, H. (1951): Zum 70. Geburtstag Karl Hermann Scheumanns.- Neues Jahrbuch für Mineralogie, Abhandlungen, 82: V-VI, Stuttgart

1.1.2 Geological units, structural and fabric characteristics of the region

The NE-SW trending dyke system reaches some 30 km total length (Fig. 2). The uniform trend gives the impression of structural uniformity, but it is in several aspects (in some cases only apparently) inconsistent. Its regional border is unambiguous only in the Northeast, where the dykes are superimposed in the immediate vicinity of the **Lusatian Fault zone** and break through the Upper Cretaceous cover in south-westerly direction almost to Maršovický hřbet ridge, which consists of metamorphosed Palaeozoic bedrock. Sometimes it has been suggested that similar volcanic rocks occur sporadically in metamorphic Massif of Ještěd Hill, i.e. in Northeast of Lusatia Fault. This cannot be ruled out so far but there are not reliably evidences.

Only at a distance of ca. 8 km NE in the area of Liberec appear minor dykes of ultramafic rocks, but their total length in this site does not exceed of about 8 km. The definition of border limiting of the region with ultramafic rocks in other sites remains unclear. It can be only noted that the width of the dyke zone reaches ca. 10 km. The largest of these dykes are located in the **Stráž tectonic block**, where the base of Upper Cretaceous strata lies mostly above the metamorphosed Palaeozoic rocks roughly between 30 (to the southwest) and 350 (to SE) m above sea level. The adjacent tectonic bloc to NW located in the area between Stráž pod Ralskem and Mimoň subsided some 600 m compared to its surroundings. Both of these blocks are separated by a Stráž Fault, its direction is almost identical to the main dyke trend.

The system of dykes (especially with nephelinite composition) can be well identified in present surface, which is levelled down about 200–300 m below the original surface of Upper Cretaceous cover in time after the regression of the Santonian Sea. Southeast of Osečná a sill intrusion was discovered by drilling works in the 70's of the 20th century, which is named as **Osečná-intrusion** (Fig. 4). It is located in the SE at a depth of ca. 250 m and towards the NW gradually rises and loses its thickness. After approximately 3 km it occurs near the surface and has there the form of the finger-like small dykes (Fig. 5).

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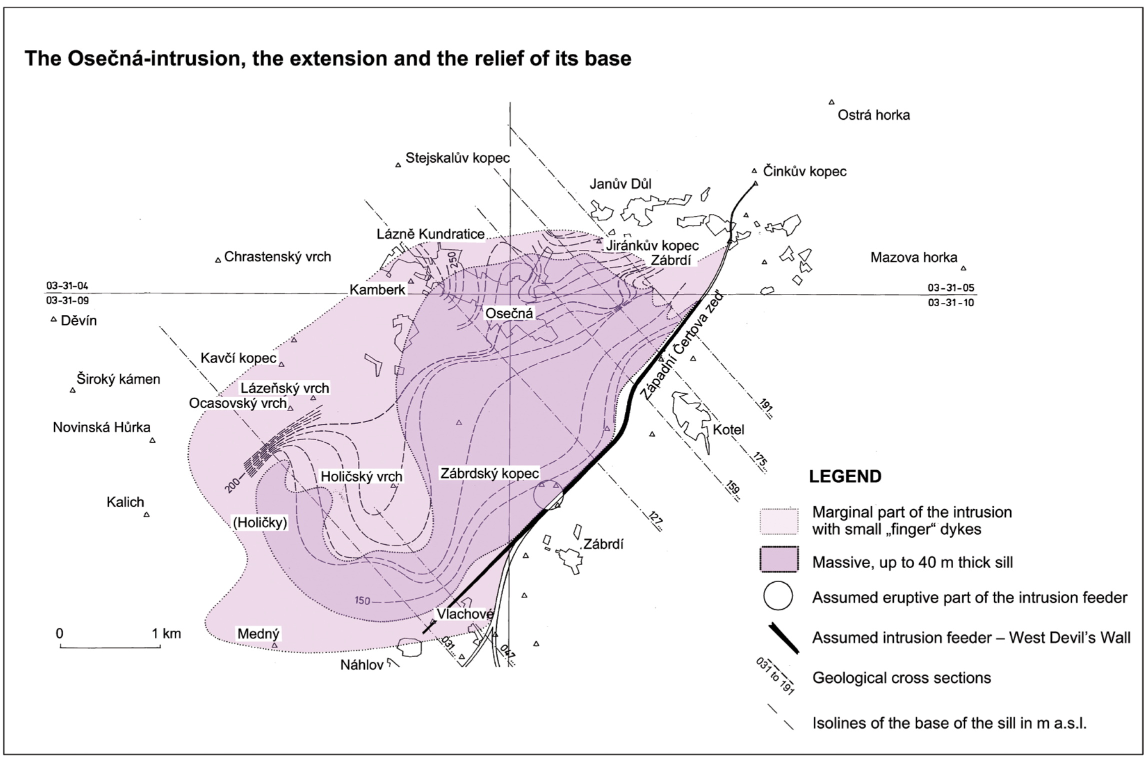

Fig. 4. The Osečná-intrusion, the extension and the relief of its base.

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Geological cross section of the Devil's Wall zone and Osečná-intrusion area

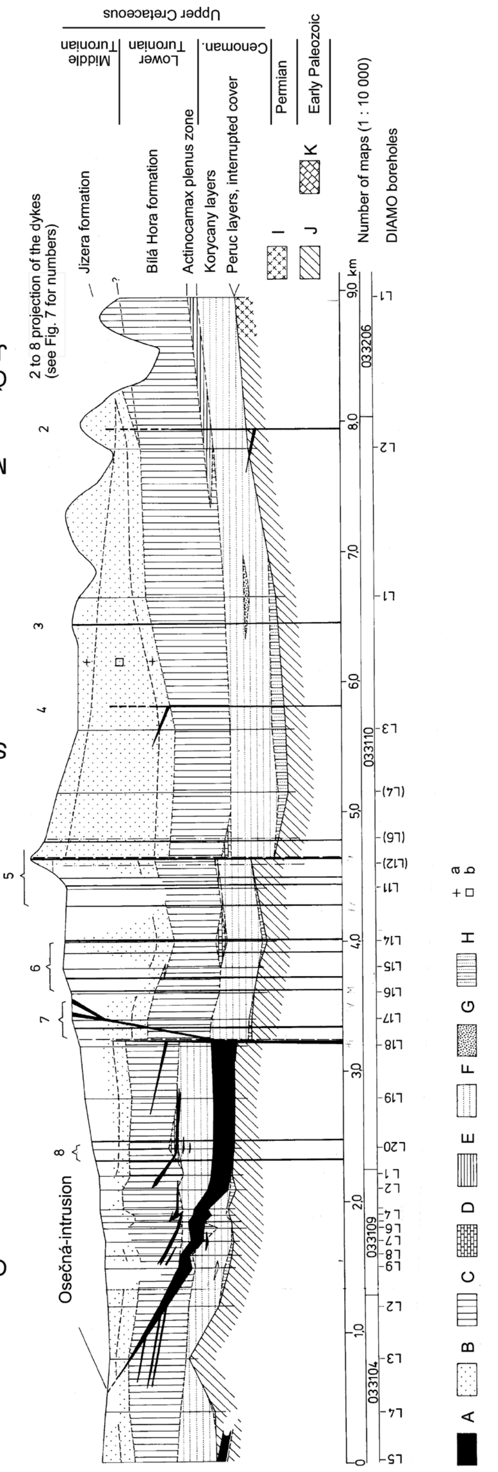

Fig. 5. Geological cross section of the Devil's Wall zone and Osečná-intrusion area. A – Ultramafic dyke rocks. Upper cretaceous deposits: B – Medium-grained sandstone, a - calcareous, b - quartz. C – Siltstone. D – Muddy limestone. E – Claystone. F – Fine-grained sandstone. G – Conglomerate. H – Alternation of the terrestrial deposits of different grain size. I – Permian silicic volcanic rocks. J – Paleozoic (Silurian ?), phylites. K – Quarzites. 2 to 8 projection of the dykes (see Fig. 7 for numbers).

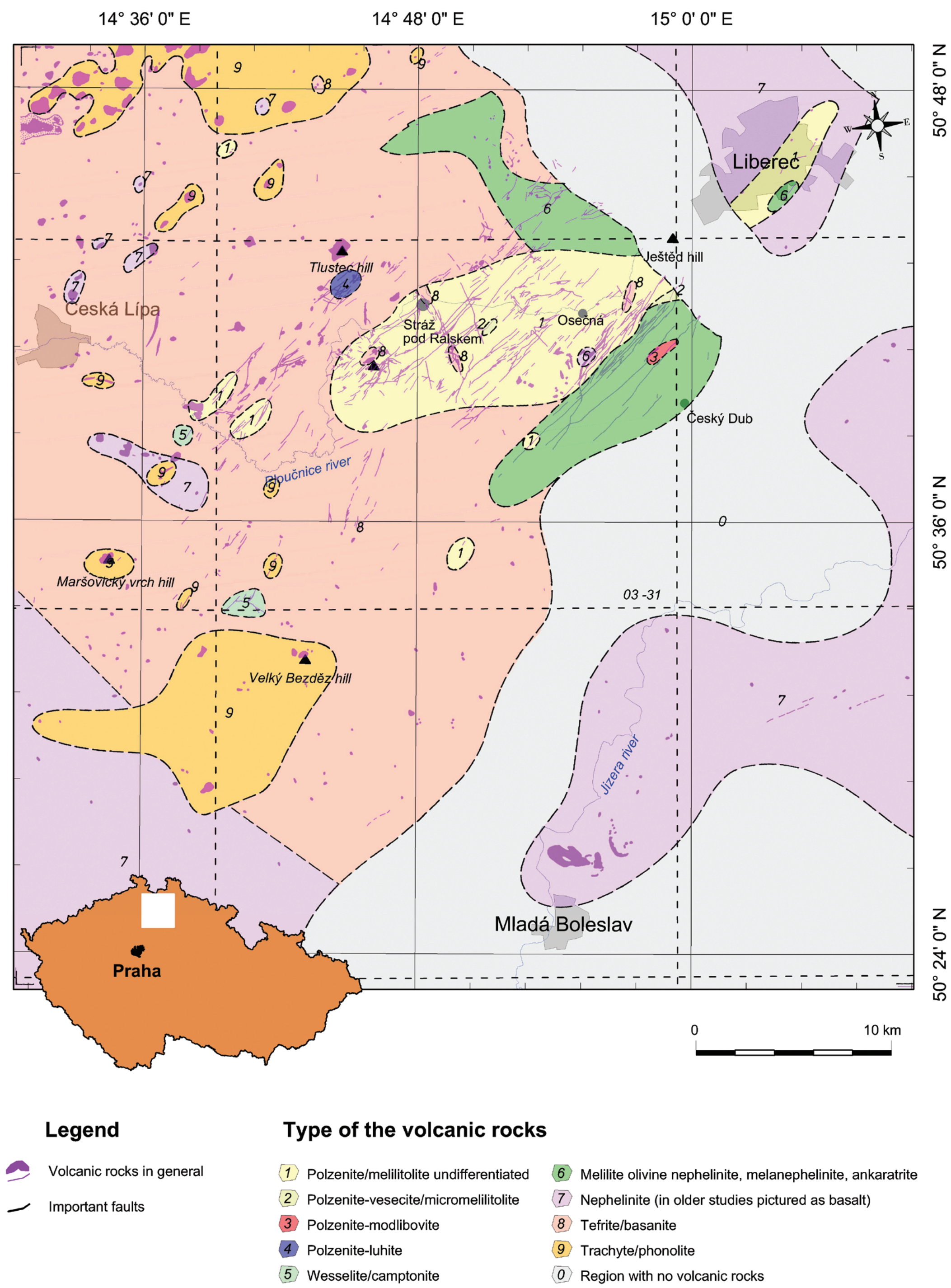

Fig. 6. The extent of the volcanic rocks in the area of interest and their petrography. 1 – Polzenite/melilitolite undifferentiated. 2. Polzenite-vesecite/ micromelilitolite. 3 – Polzenite-modlibovite. 4 – Polzenite-luhite. 5 – Wesselite/camptonite. 6 – Melilite olivine nephelinite, melanephelinite, ankaratrite. 7 – Nephelinite (in older studies pictured as basalt). 8 – Tefrite/basanite. 9 – Trachyte/phonolite. 0 – Region with no volcanic rocks.

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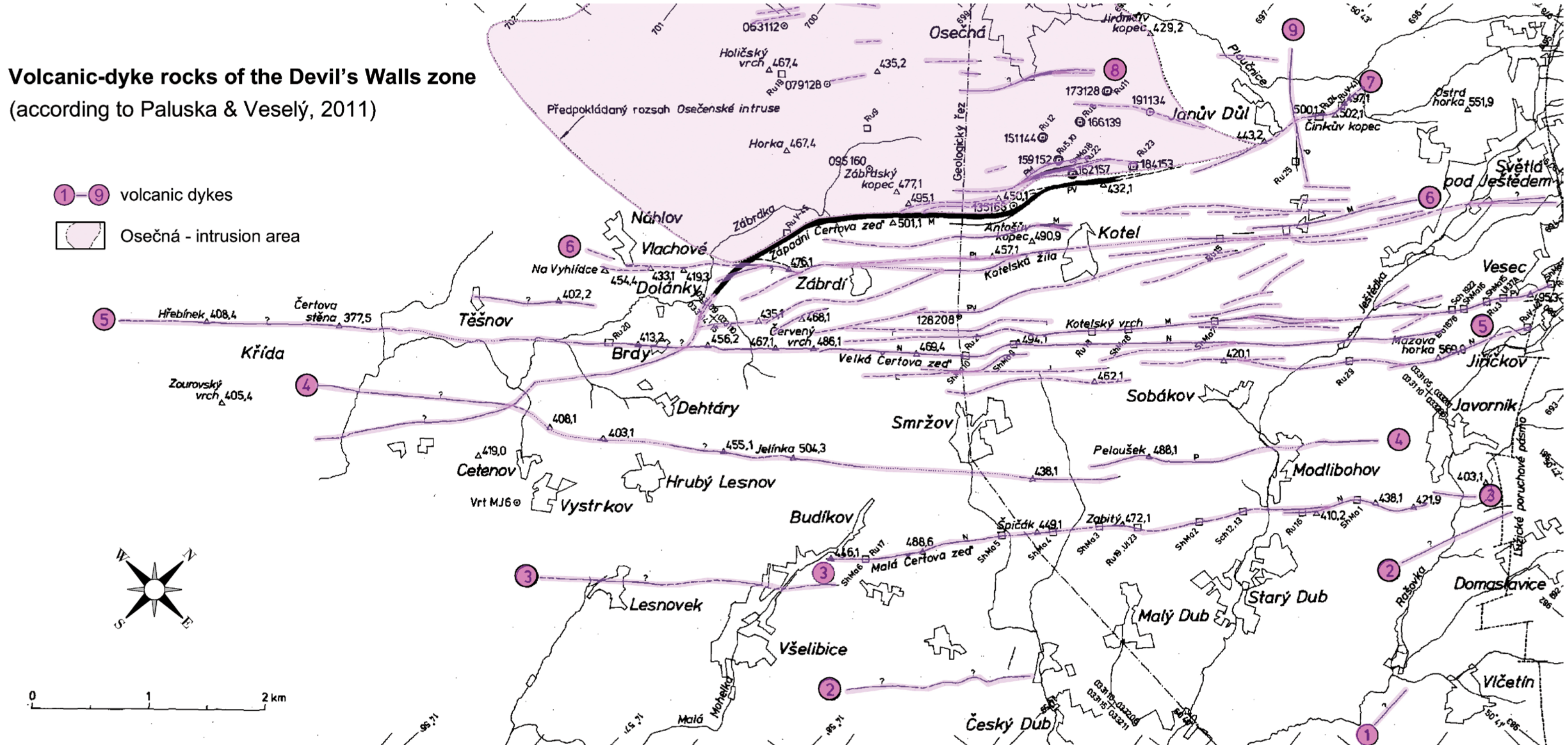

Fig. 7. Volcanic-dyke rocks of the Devil's Walls zone (according to Paluska & Veselý, 2011). 1 – The dyke of Vlčetín. 2 – The dyke between Domoslavice and Javorník. 3 – The Little Devil's Wall. 4 – The dyke between Modlibohov and Cetenov. 5 – A group of parallel dykes between Vesec and Hřebínek with the Great Devil's Wall. 6 – The dykes between Světlá pod Ještědem and Doláňky/Vlachové with Kotelská dyke in the central part. 7 – The West Devil's Wall between Janův Důl and Zábrdí. 8 – Small dykes east of Osečná. 9 – The NW-SE trending dyke of Janův Důl.

Inconsistencies of the dyke system are manifested primarily in a different mineral composition of volcanic rocks. The largest proportion of surface is occupied by rocks classified by various authors as **polzenite/melilitolite** (Fig. 6), i.e. these do not contain clinopyroxene. These dykes are adjacent to the SE of **melilite olivine nephelinite** (melanephelinite, ankaratrite), which formed the Devil's Wall zone (Fig. 7). A similar type of rock also occurs north of the area of polzenites. The remaining area is dominated by tephrites and basanites. Spatial distribution of occurrences of vesecite, modlibovite, luhite is very limited. Wesselite, a type of camptonite, is present SW of studied area.

Heterogeneity of rocks is further reflected in the content of main chemical components, mainly SiO_2 and CaO. While the SiO_2 content in the polzenite is decreasing below 30 wt.% and CaO content is increasing up to 25 wt%., in southwest the SiO_2 is increasing up to 40-45 wt.% and CaO is decreasing to ca. 10 wt.%.

Incongruous image provide the results of **K/Ar-dating** of the volcanic rocks. In the present time there are 37 mid-values of the age between **54 and 82 Ma** (Paluska et al., 2013c). First revision measurements at different places of the dykes, however, in part led also to significantly lower values (about 30 Ma). A doubts raise especially from unusual variations in the content of the ^{40}Ar in the investigated samples, which according to Pécskay (2012) leaves to suspect possible contamination due to post-magmatic processes.

1.1.3 Petrographic and chemical composition

Petrographic and chemical characteristics of the rocks are significantly notable for the fact that only a small part of the formerly analysed samples can be reliably localised. This applies in particular samples taken from the Osečná-intrusions, which generally lack data on the borehole number and depth. Assuming considerable petrographic variability, this lack only can be prevented by investigation of large data amounts.

Another difficulty stems from terminological inconsistency. Even in 1987, Le Maitre et al. kept Scheumann's expression polzenite as acceptable. In this sense, these rocks are classified in a numerous publications. In 2002, however, the cited authors the name of polzenite rejected and replaced it with expressions melilitite, respectively melilitolite. Their definition is based on quantitative content of melilite, clinopyroxene and olivine in the rock. But it is a requirement that proved on the basis of previous research to be unrealizable, and from a methodological point of view, in the future can not lead to satisfactory results (for critical aspects see Paluska & Büchner, 2013).

Decisive to identify **polzenite** according to Scheumann is **absence of clinopyroxene** and in **vesecite** the **presence of monticellite**, which is **absent in modlibovite**. Schumann's analyses were qualitative, maybe semi-quantitative. Quantitative determination of minerals in thin sections, i.e. the plane projection of the investigated texture, did Rutšek in 80's of the 20th century (e.g. Ulrych et al., 2008). He described his results as % of volume. These is, however, inconsistent and make it impossible to use the results for the mineralogical characterization of the rocks. The content of minerals related to the plane projection is namely much higher than that content related to the volume (Paluska & Büchner, 2013). We mentioned Rutšek's results (Fig. 8) therefore, to show at least framework proportions of mineral content in the investigated rocks.

Among all polzenites, the best documented is the **vesecite type**. Whereas the earliest analyses of Bořický (1867) relate to the locality of **Vesec** near Světlá pod Ještědem, Scheumann, which name vesecite introduced, studied the outcrop on the **Děvín Hill** near Hamr na Jezeře. Modern comparative study of these two sites does not exist. Important finding is that both outcrops are of a very limited area.

Modlibovite type is a very problematic variety of polzenite. Scheumann described its type locality as a hill near of **Modlibohov** (in German Modlibov) north of Český Dub. Currently we know, that it is the **Pelousek Hill**, but there are actually no natural outcrops of volcanic rock available. Scheumann collected surface samples, which we can identified as considerable heterogeneous. Last year an old pit was uncovered in about 5 m thick fault zone with irregular, mostly just cm to dm thick, steeply tilted veins of coarse grained crystalline calcite, which alternates with layers of tectonically deformed cretaceous sandstone. According to the magnetic measurement the volcanic rock occurs in the slope of the Pelousek hill in a very small area.

Also regional limited is the Scheumann's type locality of the third variety of polzenite: **luhite type** at the **Černý vrch Hill** near of **Luhov** west of Stráž pod Ralskem. There is no natural outcrop. The position of volcanic dykes could be approximately identified by ground magnetic survey only. The currently analysed samples were collected on the surface.

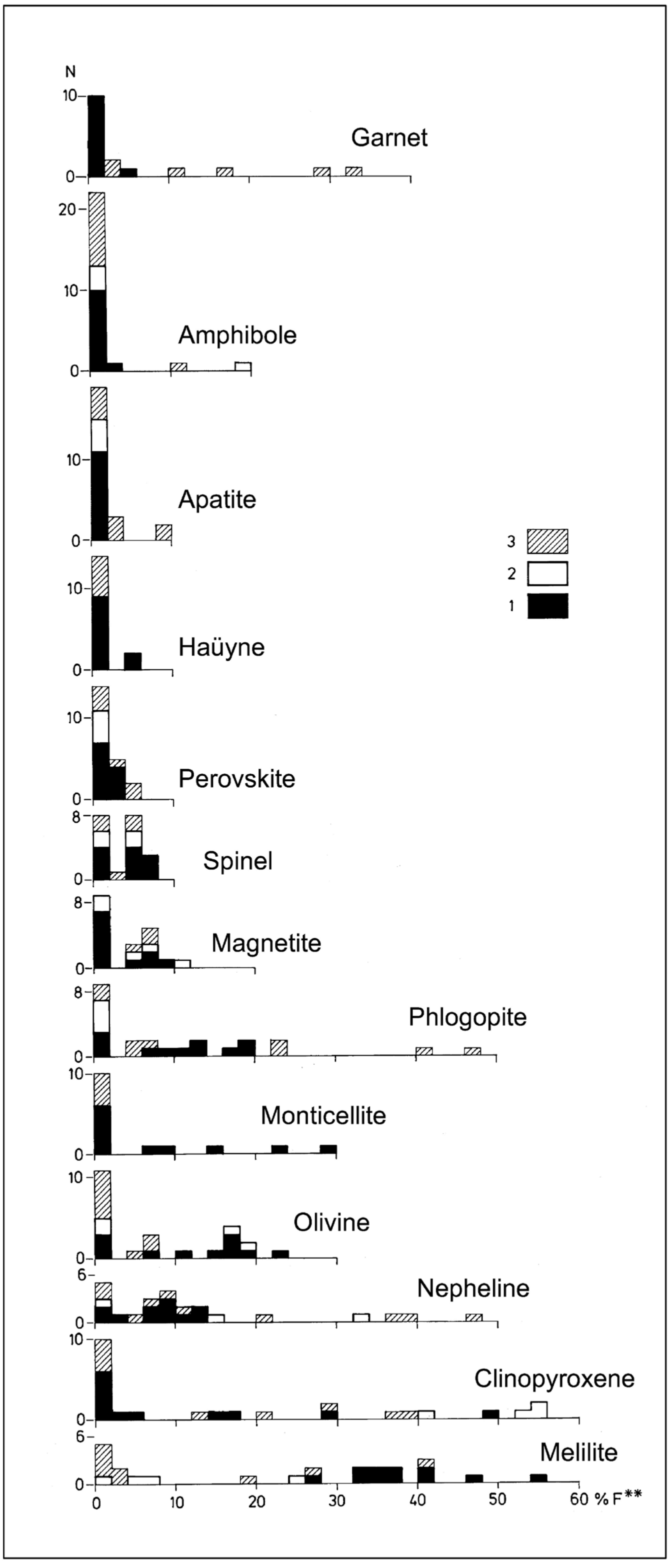

Fig. 8. The frequency diagrams of the main mineral components. 1 – Polzenite/melilitolite. 2 – Nephelinite. 3 – Other rock-types (pegmatoide, phlogopitite, ijolite, basanite).

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To summarize the current knowledge about the group of polzenites, as formulated by Ulrych, one has to lean in a large extent on Scheumann's researches:

The term polzenite applies to olivine-rich, clinopyroxene-free (rarely with minor Ti-Al-rich clinopyroxene) ultramafic alkaline **melilite dyke** rocks. **Polzenites** are characterized by the association: **melilite** + **olivine + zoned spinels ± monticellite, phlogopite, calcite, nepheline, hauyne, clinopyroxene, perovskite, apatite.** Three types of polzenite have been distinguished by Scheumann (1913), one of them overlapping with definition of alnöite by Rosenbusch and the group is completed with bergalite described from Kaiserstuhl. Definition of each rock type is described below.

- **Vesecite or Vesec type** characterized by the presence of monticellite rims of olivine, poikilitic phlogopite and abundant perovskite
- **Modlibovite or Modlibovite type** with minor amounts of clinopyroxene, rich in calcite and phlogopite (both in groundmass and as rare phenocrysts)
- **Luhite or Luhov type** with characteristic presence of clinopyroxene and calcite (resembling alnöite, Rosenbusch, 1887)
- **Alnöite** ultramafic melilitic lamprophyre from Alnö Island, Sweden, nepheline-free rocks with clinopyroxene, phlogopite and olivine phenocrysts (Rosenbusch, 1887)
- **Bergalite (**Söllner, 1913) ultramafic melilitic lamprophyre from Oberberge, Kaiserstuhl, olivine-free polzenite – not present in N Bohemia.

Probably the most reliably documented is the outcrop of **melilite olivine nephelinite Great Devil's Wall**. Older and newer samples were collected mainly from outcrops at the Devil's chair in the middle part of the National natural monument. One of the very important new findings is a significant **tabular jointing** of the volcanic rocks (Fig. 9 and 10), which can be explained as a result of the transition from viscous "creep" melt during the penetration into a crack in the sandstone to the mechanical deformation during its solidification. Also significant is the preferred **orientation of minerals** in the direction of the axis of the dyke, respectively of the contact between volcanic rocks and sandstone.

Fig 9. Subhorizontal crack in the Great Devil's Wall near Devil's Head.

Fig. 10. **The fold-like deformation of the plate jointing** of the Great Devil's Wall.

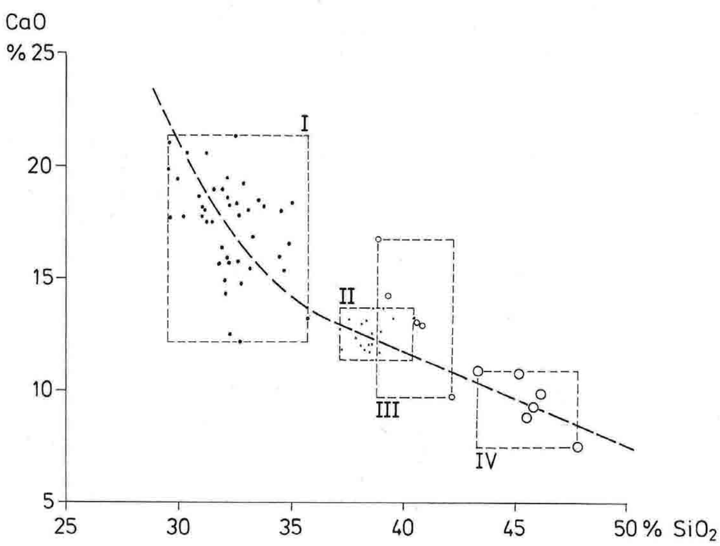

Fig. 11. The non linear dependence of the two main components (SiO_2 and CaO) in the ultramafic and the associated rocks. I – Polzenite/melilitolite, micromelilitolite (vesecite), modlibovite, luhite in ne-sw-dykes and in the Osečná-intrusion. II – Nephelinite of the Great Devil's Wall. III – Tephrite, basanite and volcanic rocks with xenolits and phenocrysts of amphibole (West Devil's Wall). IV – Basanite, phonotephrite, phonolite/trachyte, picrobasalt and volcanic rocks in the NW-SE trending-dykes. Dashed line (here called "trend-line") is marking the function of regression by using modal values.

In connection with the chemical composition of the north Bohemian ultramafic rocks, it should be noted the limited informative value of its presentation in a highly simplified TAS-diagram, originally intended for another type of rocks. Limitations of the content of component SiO_2 on the field above 35 wt.% does not take into account that ultramafites often contain only 30 wt. % of this component. TAS-diagram is further based on the contents of components Na_2O+K_2O, which are in the ultramafites subordinate, while the other major components of CaO and MgO are not taken into account. Their meaning is obvious from the **function CaO = f (SiO_2)** (Fig. 11), including all the volcanic rocks in the studied area. Somewhat simplified nonlinear regression function is based on the most frequent value of individual files. Other major chemical components also exhibit **nonlinear dependence on SiO_2** (Fig. 12), from which one can derive a characteristic stages taking place during the development of chemical compositions of magmatic melt (Paluska & Büchner, 2013).

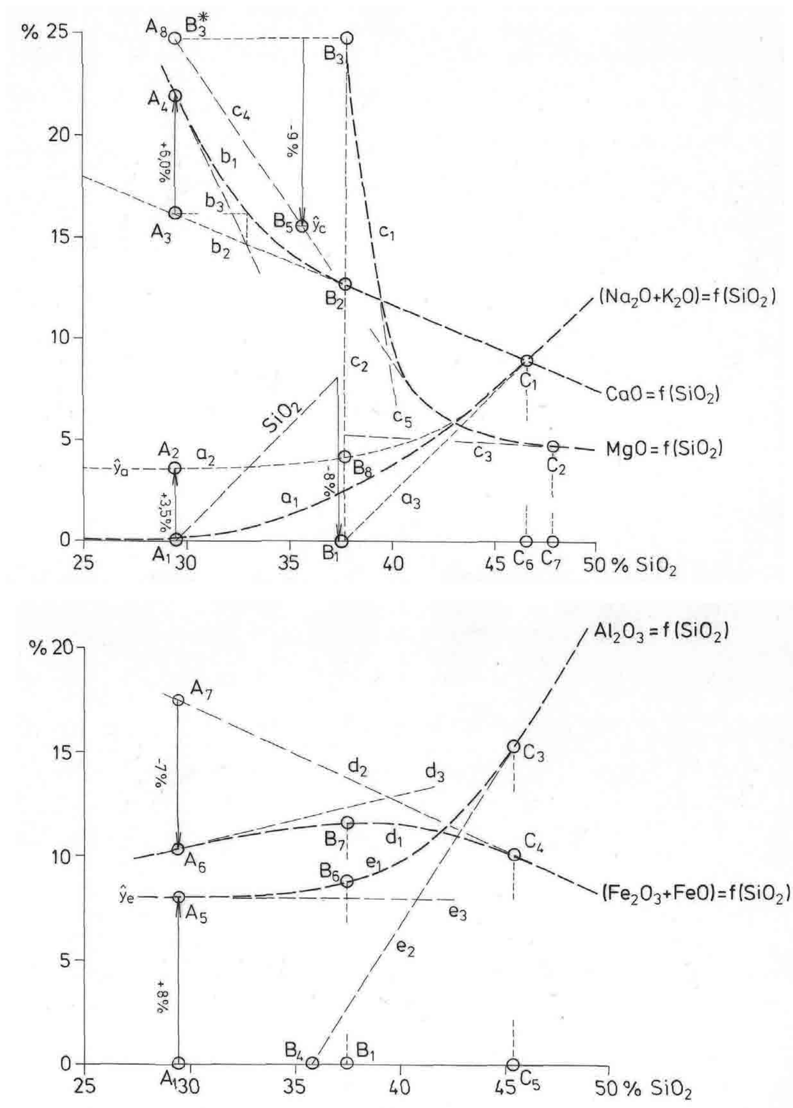

Fig. 12. The non linear functions (trend-lines) of the main chemical components in the ultramafic and associated rocks. The SiO_2 content is an independent variable (according to Paluska & Büchner, 2013). A, B, C – characteristic stages of the development of the melt chemistry. a, b, c – different variants of the regression functions.

1.1.4 The age

High ages about **54 to 80 (mean values) Ma** were analysed on rocks from the area 5 x 10 km southeast of Osečná by K/Ar-method since late 70's of the 20th century. Polzenite and marginal nephelinite predominate among dykes in this area. Revision measurements brought in the last year light on discrepancies in comparison with older measurements, so for instance the Great Devil's Wall was dated formerly to ca. **60–70 Ma**, but its continuation to SW has been dated to ca. **30 Ma**. Where the earlier measurements were confirmed, revealed a significant, yet unexplained variation in the content of the isotope ^{40}Ar (Paluska et al., 2013c). Heterogeneous distribution of the measured values is shown in Fig. 13 and its relationship to other areas of the neovolkanites in the Bohemian Massif is shown in Fig. 14.

Influence of more or less syngenetic metasomatic alteration or post-magmatic changes cannot be ruled out. However, more particularly investigations are necessary to explain the conflicting results. Pécskay (2012) assumes that it could be a consequence of secondary contamination of the volcanic rock with enriching of ^{40}Ar isotopes. This suspicion is gaining credibility because the high age cannot reconcile the tectonic evolution of the area, which activity was in Neogene, i.e. until much later as the mentioned age of ca. 54–80 Ma.

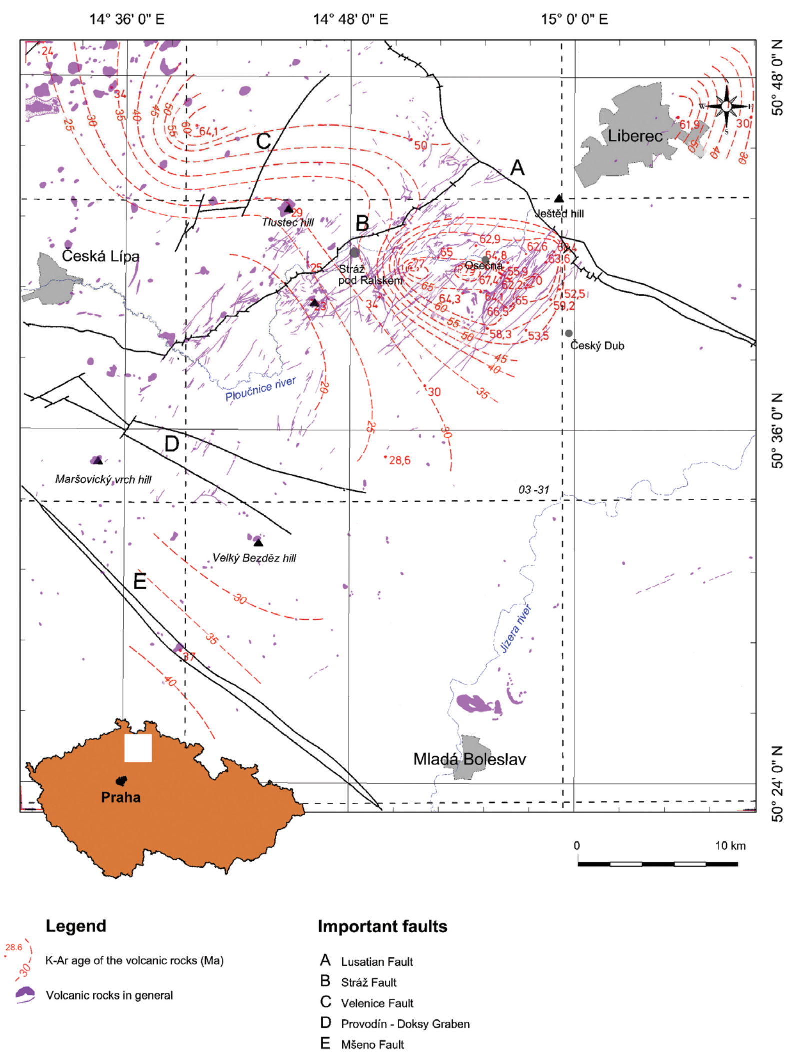

Fig. 13. The overview map of the K/Ar dating results of the volcanic rocks in North Bohemia – mean values (according to Paluska et al., 2013c).

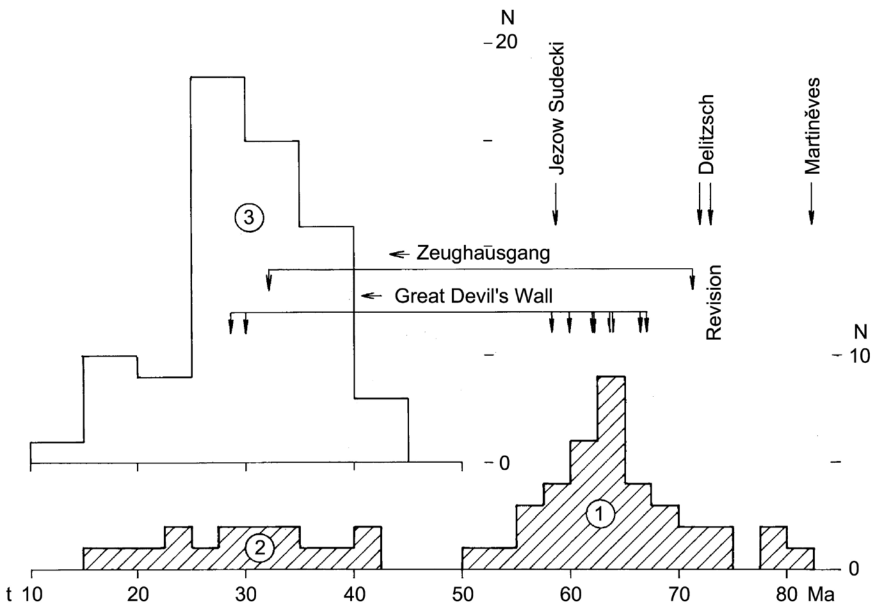

Fig. 14. The frequency diagram of the K/Ar-datings (mean values) of the ultramafic rocks compared with the other volcanic rocks of the Bohemian Massif (according to Paluska et al., 2013). 1 – Ultramafic rocks in the investigation area. 2 – Tephrite/basanite and phonolite of the younger volcanic phases. 3 – Values from the Bohemian Massif outside the investigation area. Three high values of the age from Czech Republic (Martiněves), Silesia (Jeżow Sudecki) and Saxony (Delitzsch) and the results of revision dating from the south part of the Great Devil's Wall and Zeughausgang are connected.

1.2 The tectonic framework

The discrepancy between the high age of the North Bohemian ultramafites and the much younger tectonic development in Neogene led to the conclusion that there is probably a very early volcanic phase in the area of Ploučnice river headwaters, for which was coined the name **pre-rift-volcanism**. In this concept the emphasis is given on the tectonic movements in the Eger Graben - a subsiding structure of SW-NE direction near of Krušné hory Mts. For its follow-up to the NE in the Zittau Basin there is in Bohemian Massif even not tectonic evidence (faults). The volcanism of Zittau Basin however, belongs to the regional volcanic unit, including many others volcanic centre in the Eger Graben as Doupovské hory Mts. and České středohoří Mts.

For the missing part of the Eger Graben north of the Elbe valley is considered the intensive subsided **tectonic Tlustec block**, bounded on the southeast edge by **Stráž Fault**. The direction of this fault (NE-SW) is remarkably consistent with the direction of the North Bohemian ultramafite dykes. Here, however, we encounter a discrepancy between the mainly Paleogene to Late Upper Cretaceous age of the ultramafic dykes and the Neogene age of the mentioned tectonic fault. It is necessary in this context to point out the considerable vertical movements both on the Stráž Fault (600 m), and on the most significant tectonic structure of these region, the **Lusatian Fault zone** (about 1000 m) (see Paluska, 2013).

1.3 Protection of important geological objects

Approximately 1 km long section of the **Great Devil's Wall** between villages Smržov near Český Dub and Kotel near Osečná is protected since 1948 as a rare natural phenomenon, and in 1993 was declared as **National natural monument**. Visitors of that object obtain all important information's from the boards (Fig. 15) located in strategic places. In 2011, Paluska & Veselý proposed extension of the existing protected area (Paluska & Veselý, 2011) and acquaint with them Czech specialists (Paluska & Veselý, 2010). The Ministry of Environment of the Czech Republic accepted this proposal.

To protect other important geological objects, which are not included in the upcoming project yet, recommended the Ministry to prepare a proposal for the establishment of the **Geopark Devil's Wall** (see also Paluska et al., 2013d), its proposed extent is shown in Fig. 16.

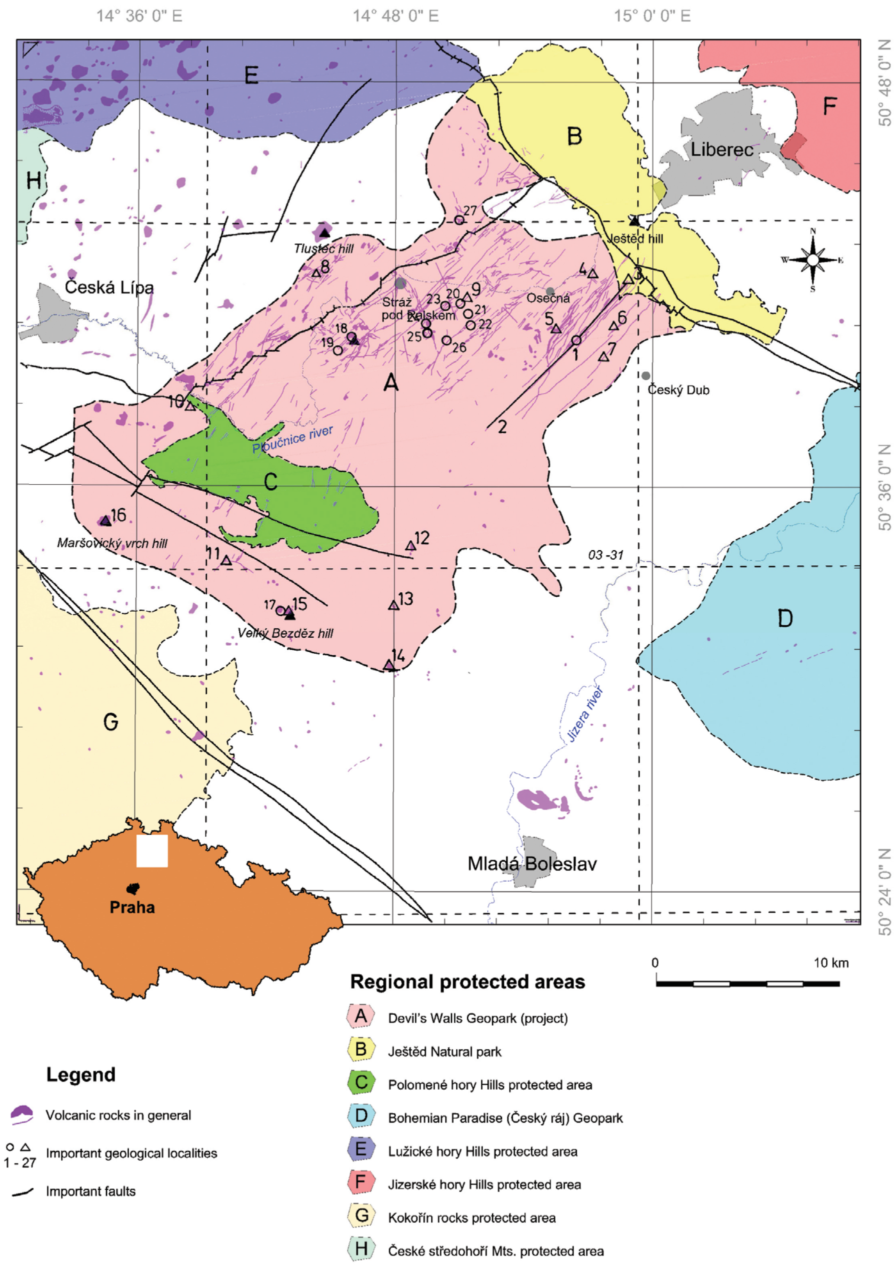

Fig 15. Overview map of the proposed Devil's Walls Geopark – according to Paluska et al. (2013). Important geological localities: 1 – Devil's Wall National natural monument, present state. 2 – Proposed extension of the currently protected area. 3 – Type locality of vesecite / micromelilitolite near Vesec/Světlá pod Ještědem. 4 – Činkův kopec Hill near Janův Důl/Osečná, outcrop of tephrite/basanite. 5 – Zábrdský kopec Hill near Zábrdí,

outcrop of pyroclastic rocks in the West Devil's Wall. 6 – Type locality of modlibovit, the Pelousek Hill near Modlibohov. 7 – Rasova rokle gorge, Little Devil's Wall. 8 – Type locality of luhit, Černý kopec Hill near Luhov (Stráž pod Ralskem. 9 – The Děvín Hill near Hamr na Jezeře, outcrop of vesecite / micromelilitolite. 10 – Type locality of wesselite, Veselí near Brenná/Zákupy. 11 – The Střelniční žíla dyke near Doksy, outcrop of camptonite. 12 – The Jezovská horka Hill near Kuřívody, outcrop of pyrocklastic rocks. 13 – The Lysá hora Hill between Kuřívody a Bělá pod Bezdězem, outcrop of pyroclastic rocks. 14 – The Šibeniční vrch Hill near Bělá pod Bezdězem, outcrop of pyroclastic rocks.15 – The Velký Bezděz Hill, a phonolitic laccolith with small basaltic bodies. 16 – The Maršovický vrch Hill near Chlum, outcrop of phonolit.
Present protected objects of biologic or scenic importance. 17 – The Malý Bezděz Hill. 18 – The Ralsko Hill. 19 – The Vranovské skály rocks. 20 – The Hamerský Špičák Hill. 21 – The Široký kámen Hill. 22 – The sandstone feature Skalí divadlo (rocky theatre). 23 – The Černý rybník pond. 24 – The Malý Jelení vrch Hill. 25 – The Velký Jelení vrch Hill. 26 – The Stohánek Hill. 27 – The Stříbrník Hill.

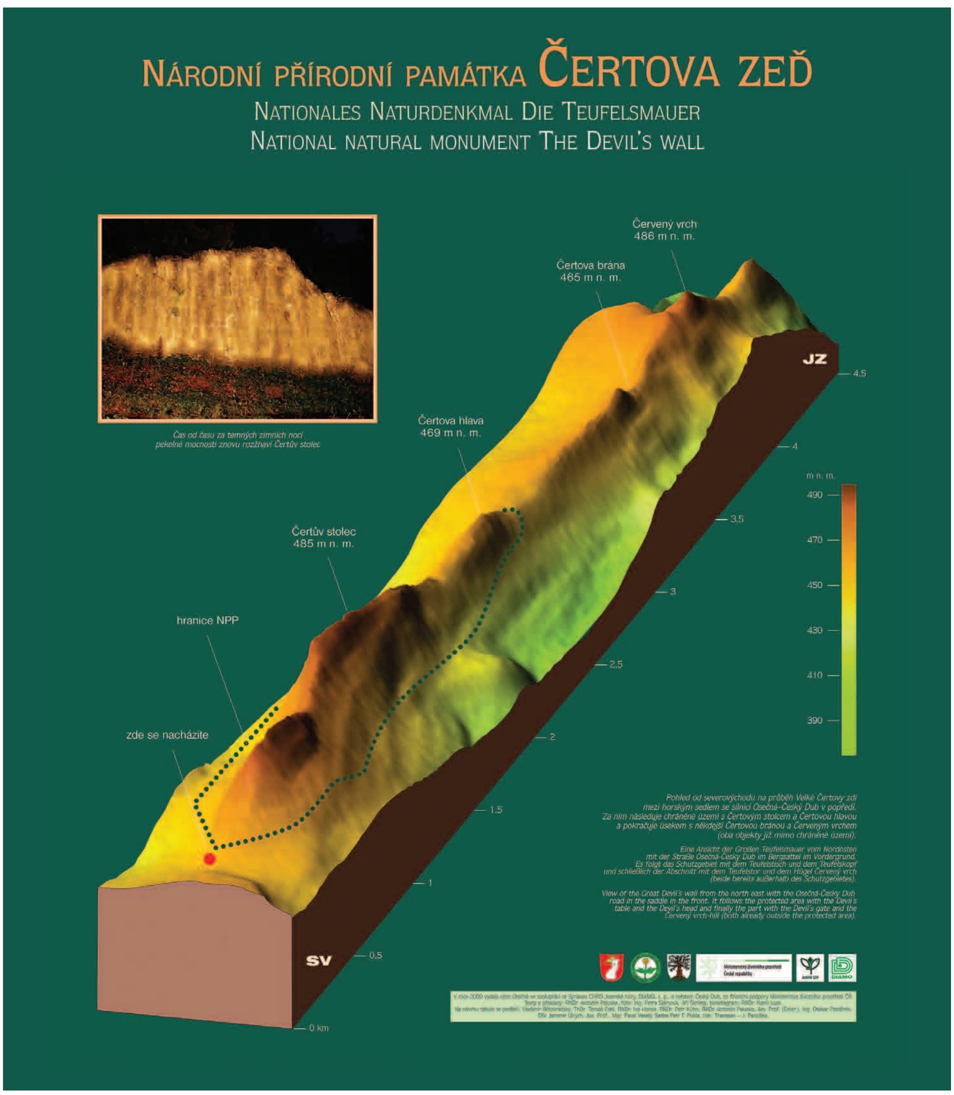

Fig. 16. The Devil's Wall, National natural monument. An information panel.

2. The excursion program

The excursion is focused on three major volcanic features (see Fig. 1):

- The outcrop of **olivine melilite nephelinite** at the **Great Devil's Wall** southeast of Osečná, between the villages Smržov and Kotel (locality 1 at the Fig. 1).

- The outcrop of **polzenite-vesecite at the type locality near the village of Vesec** south of the village of Světlá pod Ještědem (locality 2 at the Fig. 1).

- A visit of selected **drill-cores** from the **Osečná intrusion** (locality 7 at the Fig. 1); the drill-cores will be exposed in the building of the DIAMO state enterprise in Stráž pod Ralskem.

Time schedule of excursions does not allow to visit other significant sites, which are therefore mentioned only briefly (for details see Paluska et al., 2013b):

Locality 3 – Pelousek Hill near Modlibohov, Český Dub, type locality of modlibovite.

Locality 4 – Děvín Hill, Hamr na Jezeře, outcrop of vesecite/mikromelilitolite.

Locality 5 – Černý vrch Hill near Luhov, Stráž pod Ralskem, type locality of luhite.

Locality 6 – Veselí village near Brenná, Zákupy, type locality of wesselite.

2.1 Stop 1:
Great Devil's Wall between Osečná and Český Dub (geological map see Fig. 17)

Outcrops of volcanic rock 700 m W of Smržov, WNW of Český Dub.
The dyke belongs to the Devil's Wall swarm of approximately 20 NE–SW striking dykes of prevailing olivine melilite nephelinite composition.

REGIONAL GEOLOGY. Up to 4 km wide dyke swarm penetrating the Upper Cretaceous sediments known as the **Devil's Walls** is genetically associated with the Osečná Complex. The swarm comprises the Little Devil's Wall (5 km in length), Great Devil's Wall (12 km), Western Devil's Wall or Pöhlberggang (5.5 km), the Kotel dyke etc. Nearly all dykes strike NE–SW, transverse to the Lusatian Fault. In many cases, en-echelon arrangement can be observed.

The Devil's Walls dyke swarm approximately coincides with the western limit of the Permo- Carboniferous Mnichovo Hradiště Basin buried beneath the Cretaceous sediments. Boreholes SE of the dyke swarm recorded Permian volcanic rocks and sediments of the basin filling. In contrast, Cretaceous sediments NW of the dyke swarm are mostly underlain by Upper Proterozoic to Lower Paleozoic phyllites with local isolated occurrences of Permian rocks. At the present erosion surface, the dykes are hosted by Late Cretaceous sediments of the Bohemian Cretaceous Basin, namely the calcareous and quartzose sandstones of the Jizera Formation (Middle Turonian).

A relict of the **Great Devil's Wall** after excavation, known as Devil's chair, is an outcrop of olivine melilite nephelinite dyke ca. 2 m thick and 5 m high. No outcrops of the host rock (calcareous sandstone) have been preserved.

ROCK DESCRIPTION. The mineral composition of the Devil's Wall dyke swarm rocks varies from prevailing **melilite-bearing olivine nephelinite to olivine nephelinite** (olivine melanephelinite *sensu* Le Bas 1989, also ankaratrite) and rare olivine melilitite. The rock is microporphyritic with holocrystalline fine-grained groundmass and the following mineral paragenesis: **clinopyroxene > olivine phenocrysts in matrix (clinopyroxene, olivine, nepheline, melilite ± zoned spinels, phlogopite, rare perovskite, apatite, carbonates)** (see Fig. 18 for thin section).

According to earlier descriptions the rock consisted of horizontal columnar jointing. The major axis of the columns was oriented perpendicular to the dyke axis. Currently, this type of structure cannot be seen anywhere. The rock is mostly disintegrated into irregular fragments. In some parts of the exposed dyke, a strongly oriented platy jointing can be observed creating features resembling folds. The dyke is about 2 m thick and consists of two marginal areas formed through contact with the surrounding sandstone, and a central part of a slightly different mineralogical composition (lower content of melilite). These three parts are separated by well recognized vertical discontinuities (Fig. 19).

GEOCHEMISTRY. Olivine is homogeneous with $Fo_{88\text{-}89}$, clinopyroxene is mostly sector zoned with Ti-fassaite forming the prismatic sector and the matrix pyroxene and Ti-salite in the pyramidal sector. Nepheline belongs to the high-temperature types (> 500°C) *sensu* Hamilton (1961). Melilite is rich in Mg and Fe.

Phlogopite is represented by a rare Ti-rich variety (TiO_2 up to 8 wt.%). Spinel is zoned with a core formed by (Mg,Fe)-Al-chromite and a rim of Ti-magnetite composition (Ulrych et a1., 1991b). According to criteria of Frey et al. (1978), Mg# value (79), high contents of compatible elements as Cr, Ni, Co, Sc and newly found small angular harzburgite xenoliths (o1 >> opx) suggest undifferentiated primitive character of the mantle-derived magma forming the Devil's Walls.

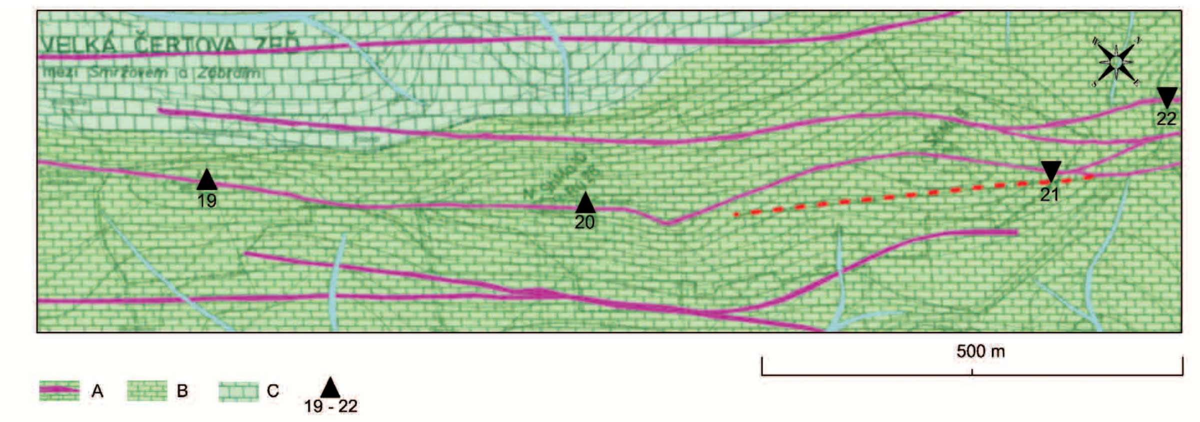

Fig. 17. Geological map of the National natural monument Devil's Wall. Nr. 19 to 22 – Important outcrops: 19 – Devil's head. 20 – Devil's chair. 21 and 22 – Excavation graben. A – The volcanic dykes. Upper cretaceous deposits (Middle Turonian): B – Fine-grained calcareous sandstone. C – Quartz sandstone.

Fig. 18. The overview thin section of the melilite olivine nephelinite from the Great Devil's Wall. 25.3 x 18 mm.

FT.1

Fig. 19. Jointing of the dyke in the cross-section of the Great Devil's Wall dividing the dyke body in three vertical parts.

FT.1

The high K/Rb (316) and low Rb/Sr (0.04) ratios as well as the low contents of incompatible elements as Rb, Sr, Ba, La, U, Nb, Zr compared to polzenites reflect a primitive character of parental magma of the Devil's Walls dykes and a low degree of partial melting of the mantle source. The primitive mantle-normalized trace-element composition displays a typical OIB signature with an enrichment of strongly incompatible element contents including Nb, characteristic of all melilitic rocks of the Osečná Complex. The chondrite-normalized REE pattern shows the lowest REE (260 ppm) contents and La_N/Yb_N ratios (29) of all rocks forming the Osečná Complex (Pivec et al., 1998).

The $^{87}Sr/^{86}Sr$ isotope ratios of (0.70326 to 0.70342) and $^{143}Nd/^{144}Nd$ ratio (0.512811 to 0.512820) indicated the parental magma of the melilite-bearing olivine nephelinite of Devil's Walls (51 to 63 Ma – Shrbený & Vokurka, 1985, newly 59.2 to 63.6 Ma – Ulrych et al., 2008) together with other melilitic rocks of the Osečná Complex, may be derived from a mantle reservoir close to HIMU-like OIB. The isotopic compositions of these rocks suggest melting of a heterogeneous veined mantle source. It may result from carbonate metasomatism related to carbonatitic magmatism during incipient rifting of the lithosphere.

Stop 2:
Vesec near Světlá pod Ještědem, 5 km NNW of Český Dub (geological map see Fig. 20)

A natural wall formed by a polzenite dyke. The type locality of the Vesec type of polzenite according to Scheumann (1913) is located closed to the Lusatian Fault.

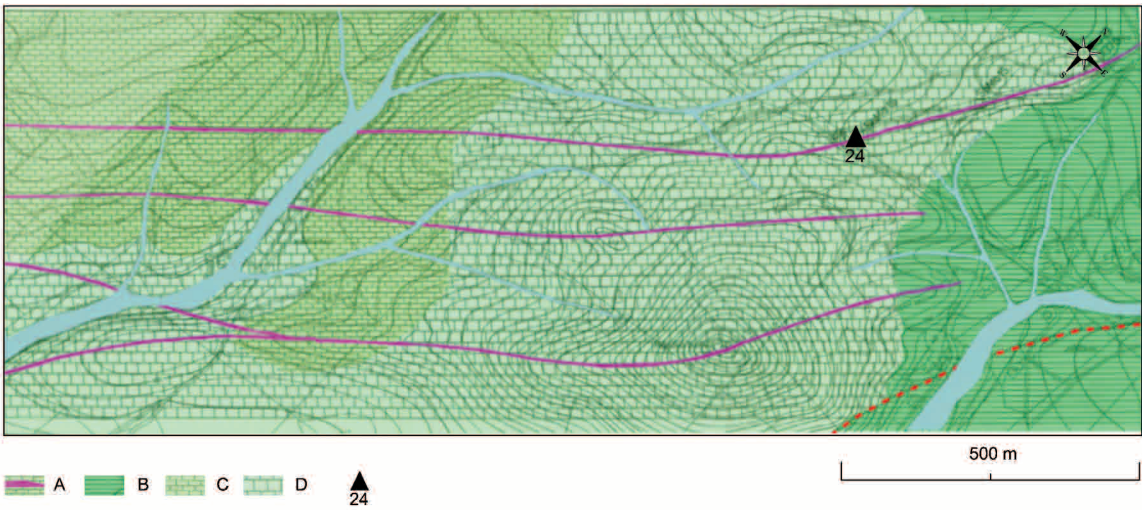

Fig. 20. Geological map of the vesecite type locality near Vesec village and the surrounding area. Nr. 24 – Important outcrop of vesecite. A – The volcanic dykes. Upper cretaceous deposits, Lower Turonian: B – Siltstone. Middle Turonian: C – Fine-grained calcareous sandstone. D – Quartz sandstone.

REGIONAL GEOLOGY. The locality is situated within a gently dipping block of Upper Cretaceous sediments (quartzose and calcareous sandstones). The NW–SE-striking Rovensko Fault and Lusatian Fault, ca. 1 km to the N of the locality, show an uplift of northern blocks. Bedding planes were dragged and dip approximately 40° south.

The slope of the Lusatian Fault varies from place to place. In the nearby village of Křižany boreholes helped to identify a dipping of about 35° to the north which is, however, practically vertical a few hundred meters away. An uplift of the northern Paleozoic metamorphic rocks of up to 1000 m can be assumed at the Lusatian Fault. The youngest movements can be dated to Late Miocene.

ROCK DESCRIPTION. Scheumann (1913) originally defined polzenite of the Vesec type as a clinopyroxene-free melilitic lamprophyric dyke rock with monticellite rims of olivine and nepheline in groundmass in contrast to the nepheline-free melilitic rocks with clinopyroxene called alnöite (Rosenbusch, 1887) from Sweden. However, mineral as well as chemical composition of **polzenite** dykes of the **Vesec type** (according to Scheumann, 1913) is practically identical with “chilled margins” and finger-like apophyses of olivine micromelilitolite of the olivine melilitolite central intrusion of the Osečná Complex, also with respect to elevated contents of probably primary carbonates (Ulrych et al., 1988).

The rock exhibits boulder like disintegration with characteristic warty surface as a typical surface structure of all polzenites in contrast to smooth one of olivine melilitites and nephelinites, and strong hydrothermal alteration (chloritization, serpentinization). **Polzenite of the Vesec type** and **olivine micromelilitolite** display microporphyritic texture with fine-grained matrix revealing a typical trachytic texture and the following mineral paragenesis: **olivine phenocrysts** rimmed by thick **monticellite enclosed in matrix of olivine, phlogopite, melilite, nepheline ± calcite,** zoned **perovskite** and **spinel, apatite** (thin section see Fig. 21)**.**

The samples of vesecite show often a typical warty surface (Fig. 22) due to a different resistance of about 1 cm large part of the rock against weathering. For samples of melilitolite from the locality Hill Pelousek near Modlibohov achieve durable parts up to ca. 5 cm and give the surface of tuberous character (Fig. 23).

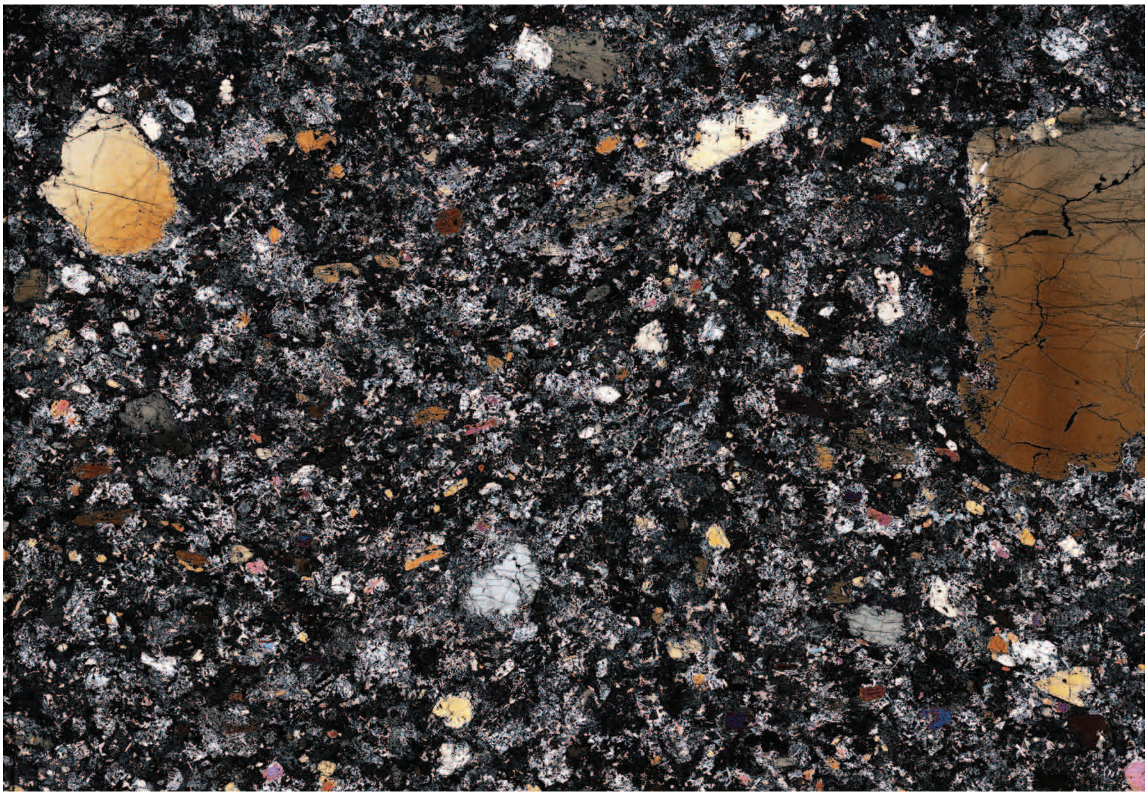

Fig. 21. The overview thin section of the vesecite from the type locality Vesec near Světlá pod Ještědem. 34 x 23 mm.

GEOCHEMISTRY. Hopper phenocrysts of Mg-rich olivine Fo_{88-90} are homoaxially rimmed by monticellite rich in Fe (7–9 mol.% of kirchsteinite component) and REE content. Melilite is rich in Al. Phlogopite occurs in two generations. The cores are formed by high-magnesium phlogopite (mg = 0.90), low in both TiO_2 (0.7 wt.%) and BaO (1.4 wt.%), whereas the rims are composed of low-magnesium phlogopite (mg = 0.84–0.87) with high TiO_2 (6.8 wt.%) and BaO (7.2 wt.%) contents. Nepheline crystallized at temperatures lower than 500 °C. Calcite belongs to the primary crystallized phases ($\sigma^{13}C$ = +4.7 ‰ PDB and $\sigma^{18}O$ = +15.5 ‰ SMOW). The core of trizonal spinel corresponds to (Mg,Fe)-Al-chromite, the intermediate zone has pleonast composition and the rim is formed by Ti-Al magnetite. The pleonast zone was often leached and an atoll texture was formed similar to that (together with trizonal development of spinels) described from mica kimberlites (Ulrych et al., 1991).

Polzenite of the Vesec type and olivine micromelilitolite of the marginal facies of the Osečná olivine melilitolite intrusion represent the most primitive lamprophyric rocks with high Mg# (77), and low Rb/Sr ratio (0.04) in the whole melilitic rock series of the Osečná Complex. Higher K/Rb ratio (195) is probably associated with additional gains of some rare incompatible elements during the late-magmatic stage proved in the Osečná Complex (Ulrych et al., 1988). Nevertheless, the olivine micromelilitolite "chilled margin" of the olivine melilitolite intrusion shows even more primitive composition with very high K/Rb, lower Rb/Sr and La_N/Yb_N ratios. High contents of compatible elements as Cr, Ni, Co, Sc and very high contents of incompatible elements as Rb, Sr, Ba, Nb, U, Zr presented as primitive mantle-normalized data agree with the above interpretations.

The chondrite-normalized REE pattern (total REE contents up to ~630 ppm!) displays the highest concentrations of all primitive rocks of the Osečná Complex (Pivec et al., 1998, Ulrych et al., 2011). The $^{87}Sr/^{86}Sr$ isotope ratios of ca. 0.7033 to 0.7049 and $^{143}Nd/^{144}Nd$ of 0.512716 to 0.512820 indicate that primary melts were derived from a mantle reservoir similar to HIMU-like OIB (Wilson et a1., 1995b and PIVEC et a1., 1998). Polzenites of the Vesec type show the oldest ages (77–62 Ma – Pivec et al., 1998) of the pre-rift stage of young volcanism in the Bohemian Massif. The K-Ar data of polzenite – vesecite from the Vesec locality show ages of 65 Ma (Kopecký, 1987–1988) and 68.4 Ma (Ulrych et al., 2008).

Fig. 22. Typical "warts"-habitus of a weathered vesecite sample from the locality Vesec.

Fig. 23. Rare "tuber"-habitus of a weathered modlibovite sample from the locality Pelousek Hill near Modlibohov.

Stop 3:
Osečná-intrusion - study of drill-cores in a storage facility of the DIAMO state enterprise in Stráž pod Ralskem (structural map see Fig. 4, cross section Fig. 5).

Central part of subsurface sill of olivine melilitolite, 8 km ESE of Český Dub. The locality shows olivine melilitolite affected by late-magmatic hydrothermal fluids producing metasomatic derivatives as melilitolite pegmatoids, ijolites and glimmerites. The marginal part and numerous apophyses of the olivine melilitolite sill are developed as chilled margins of the olivine micromelilitolite type.

They are very similar in minerall and chemical compositions to the melilite lamprophyres – polzenites of Vesec type.

REGIONAL GEOLOGY. The Osečná-intrusion is emplaced within the tectonic block of Stráž. It is assumed that this sill has been fed through the so-called Western Devil's Wall dyke, which consists of intensively weathered polzenites. For that reason, surface outcrops of this dyke are sporadic and qualitatively very bad for investigations. The bowl shape, the areal extension, the considerable thickness (up to 40 m), the internal structure and mineral composition of the Osečná-intrusions are unique in the region – as other volcanic forms are mostly sub-vertical dykes of small thickness and a small extent. The composition of the intrusion is deduced from a few samples from drill-cores; continuously analysed profiles do not exist. The considerable variability of the dyke in the vertical profile is reflected in the course of logging curves; individual anomalies have not yet, however, been reliably assigned to a corresponding petrographic, mineralogical and chemical composition of the rock.

LOCAL GEOLOGY. The Osečná intrusion is a lopolith-like sill which spreads over an area of 12.5 km^2 and has an apparent thickness of 20 to 40 m. It does not crop out on the surface but was documented at a shallow depth of several tens to about two hundred metres in numerous boreholes during uranium exploration in 1980'. The magma intruded into Cenomanian and Lower Turonian siliciclastic sediments of the Bohemian Cretaceous Basin.

The results of well logging measurement in a borehole near the Holičky village (Fig. 24) show the significant heterogeneity of the sill in vertical profile. Unfortunately the mineral or chemical reason of these variations had not been analysed until now. An example of a sharp transition between different rock types in a drilling core in another borehole is shown in Fig. 25.

ROCK DESCRIPTION. The central part of the intrusion is composed of **olivine melilitolite (melilite + olivine + spinel ± phlogopite ± nepheline ± calcite ± monticellite ± perovskite ± apatite).** This is a medium-grained porphyritic rock with phenocrysts of olivine and melilite set in a groundmass with ophitic to poikiloophitic texture. Olivine may have a rim of monticellite. Melilite is frequently altered and occurs both in phenocrysts and together with nepheline in groundmass. Phlogopite and titanian andradite are late magmatic minerals, which poikilitically enclose all older minerals. Isometric perovskite grains and needles of apatite are also characteristic minerals of the late magmatic stage. Two types of spinel are present – aluminous chromite and titanian magnetite.

The central part also contains rare dykes and pods of the evolved coarse-grained rocks of uncommon compositions (Ulrych et al., 1988; Pivec et al., 1998): melilitolite pegmatoids and ijolites; glimmerites (phlogopitites) are concentrated along their contacts with the parental olivine melilitolite intrusion and in apophyses thereof. **Melilitolite pegmatoids (melilite + phlogopite + garnet + spinel ± nepheline ± perovskite ± apatite)** form irregular pods and dykes. Altered melilite and nepheline predominate in volume. The other minerals include phlogopite, apatite, perovskite, calzirtite and titanian andradite (rich in Ti and Zr), which form symplectites with phlogopite.

Ijolite (nepheline + clinopyroxene + calcite ± phlogopite ± garnet), which forms rare dykes, is a medium-grained rock with a high carbonate content (up to 10 vol.%). Calcite and nepheline fill spaces between Na-rich diopside and altered (pseudomorphed) melilite. Phlogopite, titanian andradite and titanian magnetite are common accessory minerals.

Glimmerite (phlogopite + garnet ± olivine ± melilite ± spinel ± perovskite ± apatite) occurs i) as irregular pods, which gradually merge into the parent olivine melilitolite, and ii) as rims on the pegmatoid and ijolite dykes. The rock is medium-grained. It consists mainly of phlogopite (40 to 70 vol. %) and titaniferous andradite (30 vol. %). Relics of olivine and melilite are present in subordinate amounts. Phlogopite-garnet symplectites are common in these rocks. Spinel, perovskite and apatite occur as minor phases. The K-rich sulphide rasvumite (KFe_2S_3) was rarely identified.

The chilled margins of the intrusion and some other dykes consist of **olivine micromelilitolite. Phenocrysts** of **olivine** with **homoaxial monticellite rims** are set in the **groundmass** with trachytoid texture. The groundmass consists of **melilite** and **nepheline** ± **carbonate** ± **zoned spinels** together with **poikilitic phlogopite. Perovskite,** and **apatite** are **accessory minerals.**

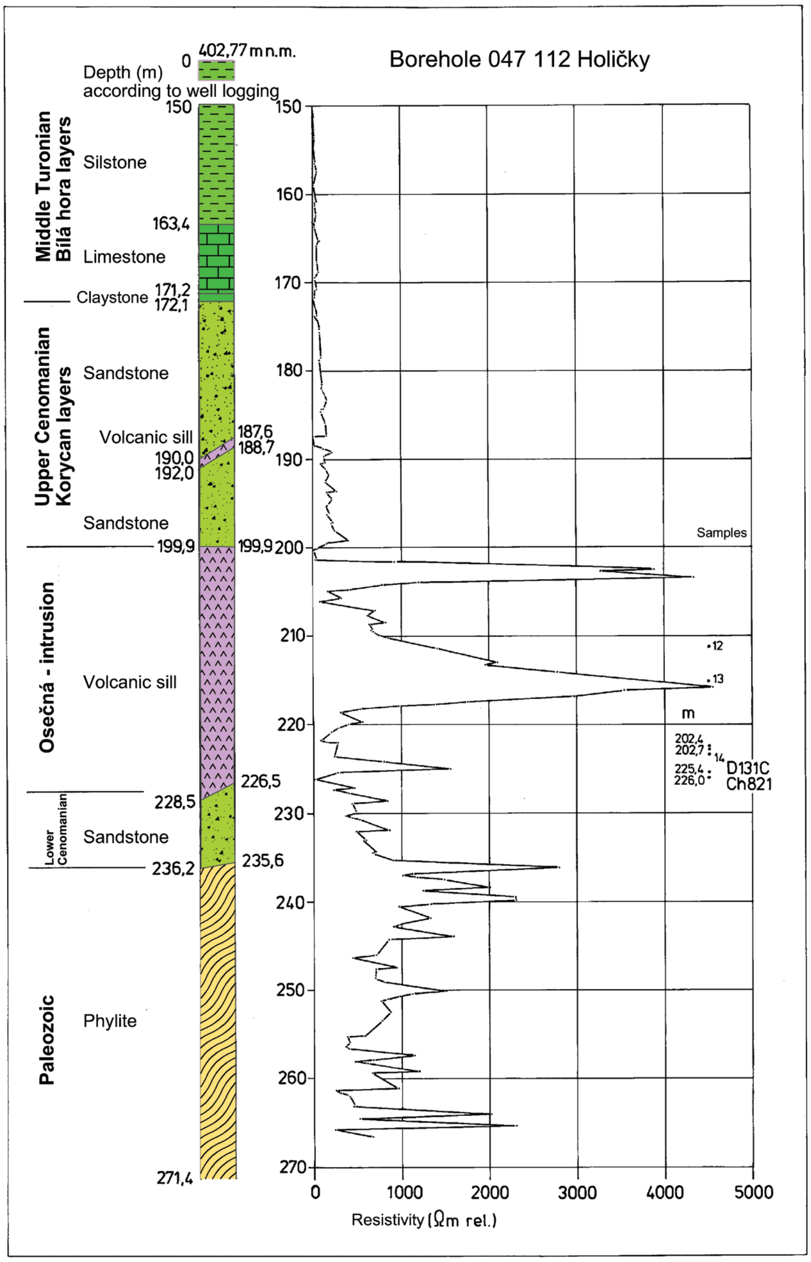

Fig. 24. Well logging in the borehole 047 112, locality Holičky.

GEOCHEMISTRY. In the Total Alkali Silica diagram (Le Maitre, Ed., 2002) melilitolite pegmatoids, ijolites and glimmerites plot in the foidite field together with parental **olivine melilitolite**. The **melilitolite pegmatoids** have very low SiO_2 (~ 30 wt.%) but high CaO (~25 wt.%), P_2O_5 (3–4 wt.%), Sr (up to 9000 ppm) and Ba (~2500 ppm). All the Ba is hosted by phlogopite (containing 6000–20000 ppm Ba) whereas Sr is mainly present in melilite (850–1300 ppm Sr). These rocks also have a relatively high Mg# (~65) and P_2O_5/TiO_2 ratio (~2). Very rare **ijolites** are high in Na_2O (>7%) and Zr (~1250 ppm). Compositions of the **glimmerites** typically fall within the same range as the olivine melilitolites.

Fig. 25. The drilling core from the borehole 063 160, the dept 224 m, with an intersion of the olivine melilite (light part) in a flogopitized olivine melilitolite (dark part) in the Osečná-intrusion. 22 x 9 cm.

Mantle-normalized incompatible trace element plots for the melilitic rocks of the Osečná Complex and the Devil's Walls dyke swarm show that they are enriched in strongly incompatible elements including Nb. They resemble melilitic rocks from other continental settings including Germany and France (Wilson et al., 1995, Alibert et al., 1983). The melilitic rocks of the Devil's Walls dyke swarm have similar geochemical characteristics as those of melilitic rocks of the Osečná Complex, although the concentrations of incompatible elements tend to be lower.

The melilitic rocks are strongly enriched in light REE (LREE) and have high La_N/Lu_N ratios (Pivec et al., 1998; Ulrych et al., 2008). The highest concentrations of LREE are in the olivine micromelilitolite and olivine melilitolite, and the lowest in the melilite-bearing olivine nephelinite of Devil's Walls dykes. Polzenite and (olivine micromelilitolite) have typically higher La_N/Yb_N ratios than the melilite olivine nephelinites, although the differences of chemical composition among the rocks are subtle. The LREE abundances of these rocks are significantly higher than those of average OIB (Sun and McDonough, 1989).

Melilitolite pegmatoids and ijolites have low MgO contents (<10 wt.%) and display characteristics of highly fractionated magmatic products with additional metasomatic contribution. They have low Ni and Cr contents indicating that they have experienced fractionation of mafic minerals. However, the melilitolite pegmatoids, ijolites and glimmerites have the shapes of the incompatible element patterns as well as Sr and Nd isotopic compositions overlapping with those of the more primitive magmas. This suggests that these evolved rocks are related to the primitive melilitic rocks in part through fractional crystallization and that fractionation occurred without any significant contamination by the surrounding crust. Minerals that would fractionate from primitive magmas include olivine, clinopyroxene, nepheline and melilite. However, additional transformation of these rocks by the metasomatic processes accompanied by crystallisation of phlogopite, garnet, second generations of nepheline and melilite, calcite, apatite, fluorite, calzirtite, wolastonite, pectolite, rasvumite is necessary to generate their unusual composition.

The data support the model that the chemical composition of the melilitic rocks, including the low SiO_2, Al_2O_3 and total alkalis contents accompanied by high CaO, MgO, (Ca+Na+K)/Al and CO_2, are primary features of the parent melts (Wilson et al., 1995, Di Battistini et al., 2001, Keshav & Gudfinnsson, 2004). The parent magma was probably derived from a heterogeneous carbonate- and phlogopite-bearing garnet lherzolite that was metasomatically enriched in strongly incompatible trace elements just prior to melting so that the mantle did not have time to develop an extensive Nd isotopic heterogeneity.

K-Ar ages (Ulrych et al., 2008) show that a magmatic event took place in the range of 68–59 Ma and that both the Osečná intrusion and the Devil's Walls dykes swarm are coeval. These data demonstrate a narrower range in comparison to the ages (79–51 Ma) compiled by Pivec et al. (1998) for melilitic rocks of northern Bohemia.

High initial ε_{Nd} values of +3.2 to +5.2 accompanied by variable $^{87}Sr/^{86}Sr$ ratios of ~0.7033 to ~0.7049 are interpreted as evidence for melting of a heterogeneous veined mantle. A portion of a depleted mantle source was overprinted by carbonate-rich fluids with enriched Sr isotopic composition. Mantle metasomatism was probably related to carbonatitic magmatism associated with incipient rifting of the BM lithosphere.

Melilitic magmas were probably generated by adiabatic decompression melting of the mantle, which might have been triggered by lithospheric extension (Wilson et al., 1995) associated with asthenospheric upwelling. They are probably the results of the incipient melting of the most fusible parts of the mantle (Dunworth & Wilson, 1998).

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Field trip 2: Księginki quarry in Lubań – nephelinite with two suites of mantle xenoliths

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The nephelinite quarry in Księginki (now part of Lubań) is one of the most mantle xenolith rich localities in SW Poland. The quarry is active since 1905, now it belongs to the EUROVIA company. Due to intense mining in last 20 years the pit is of impressive size. The mining was temporarily stopped in April 2012 because of lowered demand for stone on the local market, however it is kept dry and still offers the possibility to find attractive pieces of lithospheric mantle.

The nephelinite belongs to the numerous volcanic rock occurrences located in the NE prolongation of the Ohře Rift in Poland (Fig. 1). It is located in the Lubań – Frydlant "volcanic complex" (that concentration of lava occurrences was termed "volcanic field" by Matusiak-Małek et al. 2010).The age of nephelinite is estimated stratigraphically to be Miocene. Three nephelinite lava flows (locally with transitions to basanite) are interbedded with pyroclastic rocks (Kozłowski & Parachoniak1960). The pit visited during the field trip represents probably the deep part of a lava lake or the volcano feeder.

The nephelinite (description after Puziewicz et al. 2011) consists of nepheline-clinopyroxene groundmass embedding phenocrysts of clinopyroxene and olivine (Fig. 2a). The groundmass contains also smaller amounts of magnetite-ulvöspinel solid solution and traces of apatite, as well as post-magmatic analcime and feldspar (An_{14-18}, Or_{12-18}). The nepheline composition $Na_{3.0}(K_{0.4}Ca_{0.15})Al_{3.6}Si_{4.3}O_{16}$ is constant. Clinopyroxene has the composition of subsilicic titanian diopside, its grains usually do not exceed 50 µm. The smallest ones (<20 µm) are chemically variable, supposedly because they crystallized at final stages of lava solidification and did not achieved chemical equilibrium with the surrounding. The phenocrysts of clinopyroxene are up to few millimetres. They consist of diopsidic core surrounded by oscillatory zoned mantle and outer rim of composition corresponding to the groundmass grains (Fig. 2b). Olivine phenocrysts (from few hundreds of micrometres up to few millimetres) contain from 86 % of forsterite in cores to 79 % in rims.

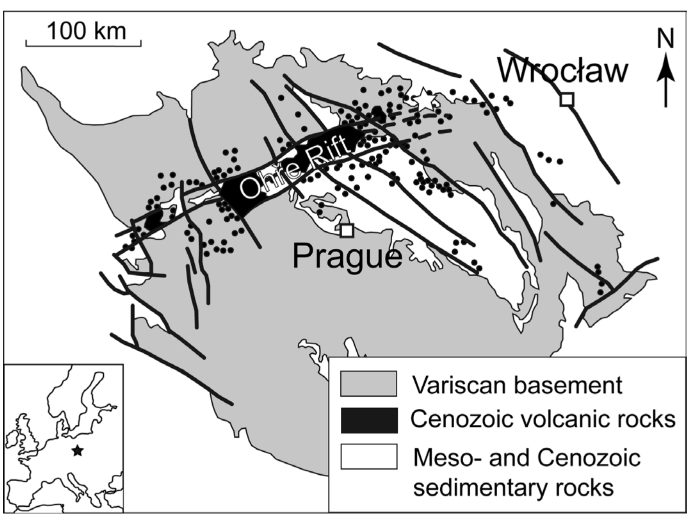

Fig. 1. Location of the Księginki quarry (asterisk) relative to the Ohře Rift.

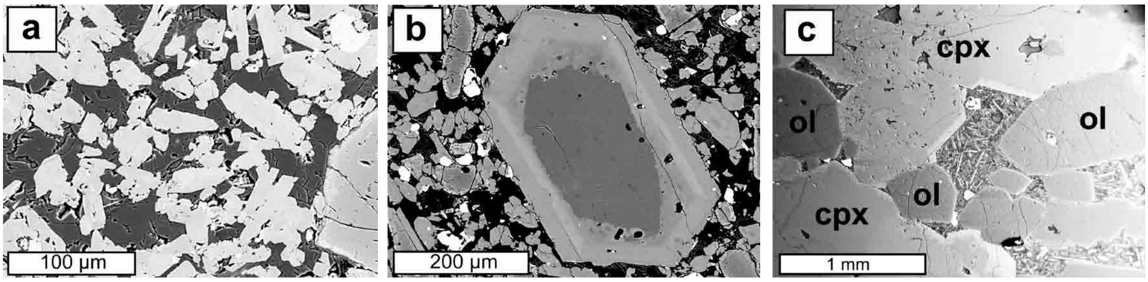

Fig. 2. The textures of nephelinite and wehrlite cumulate (back-scattered electron images). A – the nephelinite groundmass consisting of clinopyroxene(bright gray) and nepheline (dark gray); B – zoning of the small clinopyroxene phenocryst; C – wehrlitic cumulate belonging to the pyroxenite suite; the volcanic-texture intercumulus shows that the rock was entrained in the erupting lava before complete crystallization.

Xenoliths of mantle origin are common in the Księginki quarry (for detailed description see Puziewicz et al. 2011; the data below come from this study). Their sizes range from few centimetres to few decimetres; the xenoliths up to 1 meter in diameter occur sporadically. The xenoliths form two suites: the pyroxenitic one and the peridotitic one. Bot suites exhibit thermal homogenization, with temperatures of equilibration 1060 – 1120 ºC (cpx-opx algorithm of Brey & Köhler 1990). Olivine clinopyroxenites (no primary orthopyroxene) form the pyroxenite suite; sparse wehrlite or websterite xenoliths also belong to this suite. They form the veins in mantle peridotites, the cumulate textures are common (Fig. 2c). Olivine (Fo_{83-85}) contains < 1000 ppm of Ca. Clinopyroxene occurring in olivine clinopyroxenites is low-calcic (0.72 – 0.82 atoms of Ca per formula unit, pfu in the following), aluminous (0.22 – 0.27 atoms of Al pfu), its Mg/(Mg+Fe) ratio (mg# in the following) ranges from 0.81 to 0.93. Its REE patterns are characterized by enrichment of MREE relative to HREE and inflection from Nd to La (Fig. 3).

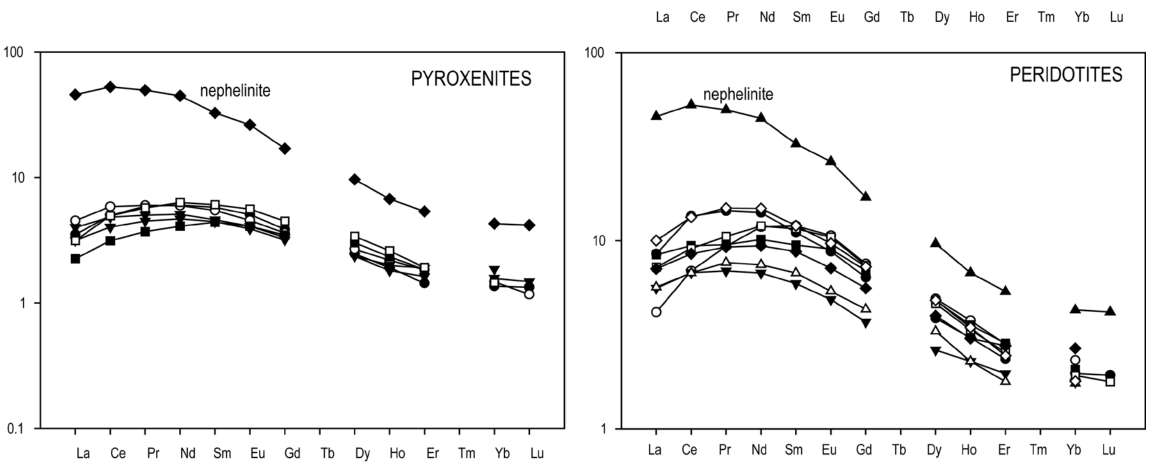

Fig. 3. Representative primitive-mantle normalised REE patterns of clinopyroxene from the peridotite and pyroxenite suites. The pattern of nephelinite shown for comparison.

The clinopyroxene megacrysts up to 10 cm in length occur in the Księginki nephelinite. Their chemical characteristic is similar to that of clinopyroxene occurring in the xenoliths of clinopyroxenite suite.

Harzburgites dominate in the peridotite suite. Their textures vary from protogranular to mylonitic. Typically the harzburgites consist of olivine (Fo_{89-92}) and orthopyroxene (mg# 0.89-0.93) plus small amounts of texturally later clinopyroxene of similar mg#. The REE patterns of clinopyroxene are identical to those of the pyroxenite suite (Fig. 3).

Spinel [Cr/(Cr+Al) 0.35-0.62] is rare. The harzburgites contain fine-grained mineral aggregates, consisting of various combinations olivine II, clinopyroxene II, spinel, titanian biotite, plagioclase and glass. The peridotites rich in these aggregates are enriched in clinopyroxene and contain no orthopyroxene, and the olivine composition is changed to Fo_{86-89}. Similar changes occur in harzburgites at the contact with clinopyroxenite veins.

Puziewicz et al. (2011) show that the mantle section sampled by the Księginki lavas was located at depth 35 – 50 km. At the time of volcanism the harzburgites were infiltrated by silicate melt of nephelinite composition. Pyroxenite cumulates crystallized from this melt in places, where the flow was channelized and stopped in periods of lower melt supply or due to channel geometry. The clinopyroxene megacrysts come from the pegmatitic crystal mushes entrained by the lava after periods of crystallization. The REE patterns of harzburgitic clinopyroxene were affected in places were the melt infiltration was pervasive; locally also the iron content in olivine and pyroxenes was also slightly increased, leading to the cryptic “Fe-metasomatism” of harzburgite. The xenoliths from Księginki sampled the lithospheric mantle at various stages of these processes and offer a snapshot of the effects of alkaline melt migrating through the sub-rift upper mantle.

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Field trip 3: Volcanology of the Lusatian Volcanic Field – New insights in old well-known

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1. Introduction

1.1 The Lusatian Volcanic Field – Boundary and geological setting

The Cenozoic volcanic rocks at the Lusatian Volcanic Field (LVF) are part of the Central European Volcanic Province and form a link between the volcanic fields of the Ohře rift zone in North Bohemia and the sub-province of Silesia in Poland (Tietz et al. 2011a). The LVF includes volcanic formations from Upper Lusatia (Oberlausitz- Germany, Łużyce Górne- Poland), Bohemian and Saxon Switzerland (České Švýcarsko- Czech Republic, Sächsische Schweiz- Germany), Lusatian Mountains (Lužické hory- Czech Republic) and the Zittau Mountains (Zittauer Gebirge- Germany). The Boundary of the LVF to the southwest is indistinct, because there are smooth transitions to the České středohoří Volcanic Field, the definition is performed analogous to Cajz et al. (1996). In contrast, the Jičín Volcanic Field as well as the Lower Silesia Volcanic Field is well separated from the LVF. North- and westward there are no volcanic structures known at the surface (Fig. 1).

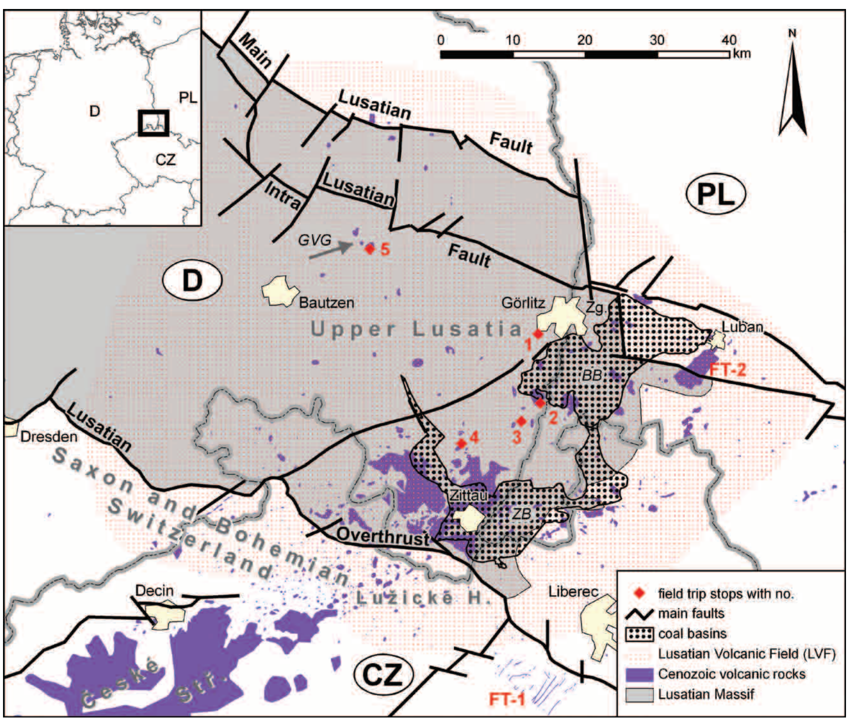

Fig. 1. Overview map of the Lusatian Volcanic Field (LVF) with the main geological units and landforms. BB – Berzdorf Basin, ZB – Zittau Basin, GVG – Guttau Volcano Group, Zg. – Zgorzelec, Lužické h. - Lužické hory, Ceské str. -Ceské středohoří, FT-1 – Field trip 1 (Osečná Complex), FT-2 – Field trip 2 (Lubań).

The LVF is located on various geological units (compare e.g. the overview of Kozdrój et al. 2001). The most northern and northeastern parts overlap Paleozoic anchimetamorphic sediments of the Kaczawa and Görlitz Synclinoriums and more to the south Cadomian granitoides and greywackes. The latter two basement units build up together the Lusatian Massif. The southern part of the LVF is situated at the northernmost margin of the North Bohemian Cretaceous Basin and the Elbe Zone. In both units the volcanic rocks overlie Upper Cretaceous sediments, mostly sand-, silt- and marl-stones. The Lusatian Overthrust cut this lowering basin and graben zone against the uplifted Lusatian Massif. Only the Cretaceous sandstones of the Zittau Mountains are actually uplifted, the result by tectonic inversion movement since 45 – 30 Ma. The basement of the southeastern margin of the LVF consists of metamorphic rocks of the Karkonosze-Jizera Block with a Proterozoic-lower Paleozoic age.

The puzzle of different basement slices is the result of the Variscian tectogenesis and consolidation before 325 Ma. Since about 100 Ma the Lusatian Massif and the Karkonosze-Jizera Block is uplifted as the western part of the West Sudetes block ("Lugicum" in older literature) – one of the low mountain range blocks of Central Europe. Great faults limited the block in the south (Lusatia Overthrust) and the north (Main Lusatian Fault, eastward in the Marginal Sudetic Fault continued). The vertical displacement of about 1000 – 3500 m took place after the Variscian orogenesis in the Permo-Carboniferous (320-260 Ma, Kozdrój et al. 2001) and since the Upper Cretaceous with a climax at 85-50 Ma (Lange et al. 2008, see also chapter 1.3).

1.2 Volcanic rocks – distribution, ages, petrography and "basaltic" zircons

The volcanic rocks are mainly concentrated along tectonic faults and around the tectonic Basins of Berzdorf and Zittau (Fig. 1). The largest extension and concentration of volcanic successions can be observed in the southern part of the LVF in the vicinity of Zittau. Outside of this area occur only isolated volcanites. The geological maps show about 700 localities.

The age of the volcanic rocks is mostly Lower and Upper Oligocene. The published data show a maximum range between 20 Ma (Alibert et al. 1987) and 70 Ma (Pfeiffer 1994, pp. 190). The climax of K-Ar isotopic ages range between 30 and 25 Ma (Pfeiffer et al. 1984, Kaiser & Pilot 1986, Suhr & Goth 2002) and of Ar/Ar ages between 35 and 27 Ma (unpublished date, see Büchner et al. 2013 and Fig. 2). One of the youngest ages was measured by K/Ar isotopic age method with 22 ± 2 Ma at a basaltic lava flow, intercalated in the basal part of the lignite seem complex in the Berzdorf Basin (Tietz & Czaja 2004). The biostratigraphic and lithostratigraphic sequences of the sedimentary profile support a reliable age determination and therefore an ongoing of the volcanic activity up to the lowest Miocene.

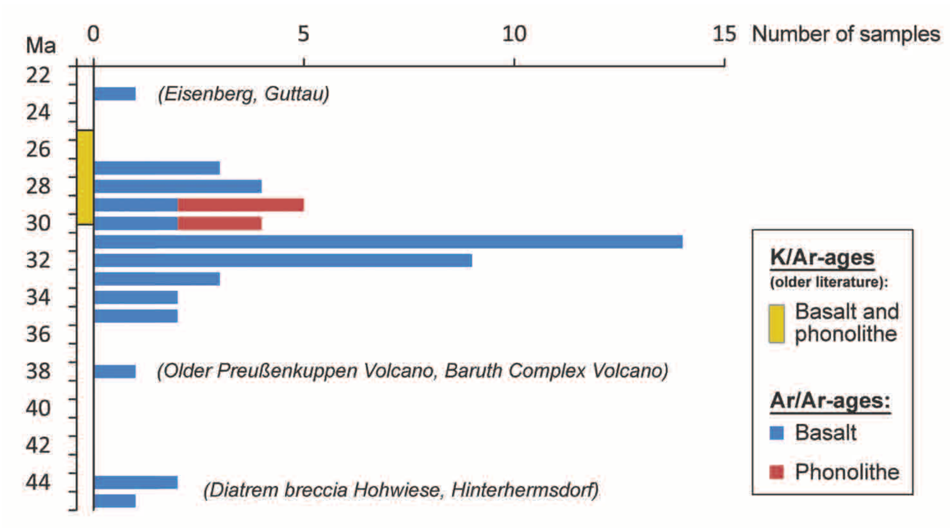

Fig. 2. Ar-Ar isotopic ages of alkaline volcanic rocks in the LVF, unpublished data from the geochronological labs TU Bergakademie Freiberg and GEOMAR Kiel. K-Ar ages according to Pfeiffer et al. (1984), Kaiser & Pilot (1986) and Suhr & Goth (2002).

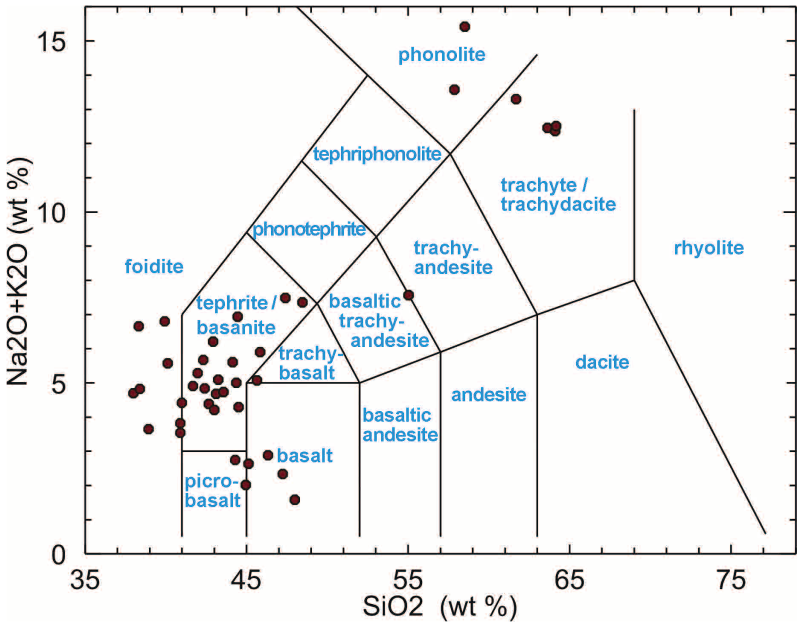

Fig. 3. TAS-diagram showing data of RFA analyses of volcanic rocks of the LVF (lab University Jena).

Fig. 4. Zircon megacrysts in gem stone quality derived from alkaline basaltic rock. Placer deposit in the Seufzergründel valley near Hinterhermsdorf, Saxon Switzerland. Crystal length 2-4 mm.

The volcanic rocks of the LVF are alkaline and bimodal (Fig. 3), which is typical for Cenozoic magmatism in Central Europe and generally for continental intraplate magmatism. Nephelinite, basanite, tephrite as well as phonolite and trachyte can be observed according to the TAS-classification. In contrast, alkali basalts are rare in the LVF; a prominent example is the castle hill Stolpen (Pfeiffer 1978). The complete alkaline suite could be observed in the central part of the LVF around the Zittau Basin and the Zittau Mountains (Büchner et al. 2011). Outside this centre the volcanic rocks are mostly nephelinite, basanite and tephrite. Ultramafic, melilite-bearing rocks occur additionally at marginal areas of the LVF in Saxon Switzerland Mountains (Zeughaus dike) and in Görlitz ("Pomologischer Garten") (Seifert et al. 2008a).

A special feature for the LVF is the occurrence of zircon megacrysts derived from alkaline volcanic rocks (Tietz et al. 2010). Such occurrences have been known for a long time, so in the Saxon Switzerland (Tietz 2003), but only from alluvial placer or weathering residuals (Fig. 4). The first worldwide proof for an alkaline volcanic origin of zircon succeeded at the Hofeberg quarry 10 km south of Görlitz in the LVF (Tietz & Büchner 2007). Other *in situ* evidences from zircon megacrysts in alkaline basaltic rocks were contemporaneously supplied by Italian geologists (Visonà et al. 2007) and by private mineral collectors in the Upper Palatine, Germany (Meier & Weiß 2007). Recently, zircon megacrysts are known in the LVF from 4 localities derived from alkaline basaltic rocks and from 3 localities derived from phonolitic rocks (Tietz et al. 2013). The zircon megacrysts derived from alkaline basaltic rocks have a mean size of 2 to 4 mm (min. 1 to max. 9 mm) and are of gem stone quality. Many crystals are intensively rounded, the result of a magmatic corrosion in the basaltic host melt. In contrast, the zircons from phonolithic rocks are smaller (0.2-0.8 mm) and mostly euhedral. The origin and the genesis of these zircon megacrysts derived from alkaline continental intraplate volcanic rocks are currently unknown and discussed controversially. Trace-element characteristics of Bohemian and Saxonian zircons indicate an alkali-silicatic parental melt, probably syenite, nepheline syenite or fenite (Seifert et al. 2008b, 2012) and preliminary Hf-isotopic analyses of *in situ* "basaltic" zircons implicate an origin from the lithospheric mantle (Tietz et al. 2010).

1.3 Volcanology and postvolcanic landscape evolution

The extensive erosion of the Cenozoic eruption products causes difficulties in reconstruction of the former volcanic edifices. But on the other hand these denudation processes give insights in the root zone of volcanoes, what is impossible by young or even active volcanoes.

The bimodal volcanism at the LVF is characterized through the end members of the magmatic evolution trend; therefore dominate nephelinite/basanite and phonolithe/trachyte. This different dominance is reflected by the volcanology and morphology of the volcanic remnants. The most frequent type at the LVF is the scoria cone type. These are relatively small basaltic volcanoes, from which only the hard "core" is obtained, as lava lake fillings, feeder dykes or lava flows. The name giving scoriae are mostly denudated in the LVF. This was the reason for many and persistent misinterpretations in the past and the common reconstruction of the Lusatian volcanoes as cryptodomes or lava domes. Today, we know only few localities with occurring scoriae remnants (Tietz & Büchner 2007, Tietz et al. 2011a+b, Büchner & Tietz 2012). These are mostly little deposits with welded scoria or localities protected beneath massive lava flows. The lava flow remnants from the scoria cone volcanoes occur today often isolated without a connection to an eruption centre. Typical is the occurrence as morphological relief inversion; the previous valley appears today as ridges or hills. In some cases remnants from top or basis breccias could observed.

Maars represent a rare volcanologic type in the LVF (Suhr & Goth 1996, see chapter 1.4). These consealed volcanic structures are only known from geophysical researches and bore holes (Lorenz et al. 2003). Phreatomagmatic eruptions are common for the initial stage of scoria cone volcanoes in the LVF. Because of the deep erosion level of the volcano edifies, we can observe often diatreme breccias in the root zone of the scoria cones. In some cases only this initial stage of volcanism is preserved (Tietz et al. 2011b). These initial phreatomagmatic structures are mostly developed in the sandstone areas in the Zittau Mountains and Saxon Switzerland. However, such volcanic diatreme breccias structures occur also in the granitic basement (Tietz et al. 2011a, Büchner & Tietz 2012 and unpublished data – see stop 4).

Only in the centre of the LVF lava domes or cryptodomes of phonolitic or trachytic rocks occur. In contrast to the České středohoří Volcanic Field in North Bohemia in the LVF mostly superficial successions are assumed. This assumption is proved by observations from vesiculated rocks (solidified phonolithic lava foam) on the top of phonolithic hills, phonolithic pumice clasts in a tephritic diatreme structure as well as the low erosion level in the Zittau Mountains with many phonolithic/trachytic deposits and the close position side by side of phonolithic/trachytic and superficial basaltic volcano remnants in the same level (Tietz et al. 2011b). We can distinguish in some cases monogenetic and polygenetic (complex) types by the phonolithic/trachytic lava domes.

Certain volcanicremnants mark the syneruptive land surface if detailed characteristics are known. Hence, the Cenozoic volcano remnants give a powerful tool for the reconstruction of the morphology of the landscape before about 30 Ma and give information about the post-volcanic landscape evolution. Two evaluated profiles in the LVF with 15 detailed investigated volcano remnants could give following preliminary results for the Lusatian Massif (Tietz et al. 2011b, Büchner & Tietz 2012, see Fig. 5): (1) the uplift and denudation rate is with 3-10 mm/ka very moderate, only a maximum of 50–90 m of the basement was eroded since the Upper Oligocene. In comparison, the apatite fission track ages show for the Lusatian Massif a well pronounced cooling and uplift event for the time between 85 and 50 Ma with an uplift value from 3.000-3.500 m and a denudation rate from 100 mm/ka (Lange et al. 2008). Furthermore, the uplift of the Lusatian Massif took place not en block, but rather along different internal micro blocks (Büchner & Tietz 2012). (2) The moderate uplift occurred especially intensive very late in Pleistocene time. Many arguments from the investigation of the volcano remnants, the Pleistocene sediments and the geomorphology suggest an intensive neotectonic movement at the turn of Elsterian to the Saalian Glacial Stage before about 300.000 years (Büchner & Tietz 2013).

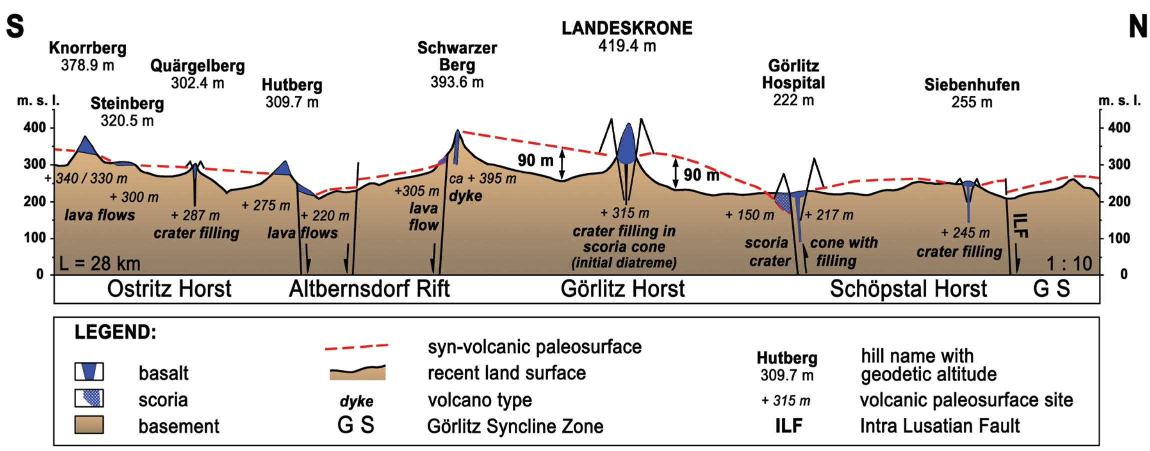

Fig. 5. N–S cross-section through the northeastern Lusatian Massif surrounding the Landeskrone Volcano with the reconstructed paleosurface at the time of volcanism, approximately 30–27 Ma ago (according to Büchner & Tietz 2012).

1.4. The Guttau Volcano Group – A multifarious volcanic unit at the northwestern margin of the LVF

The Guttau Volcano Group is, except of three small occurrences of volcanic rocks along the Lusatian Main Fault, the northernmost volcanic area connected with the Ohře/Eger rift (Fig. 1). It consists of five known structures: the volcanoes Schafberg und Eisenberg (former scoria cones with lava lakes) and the three maars Kleinsaubernitz, Baruth and Buchwalde (Fig. 6). Since the basalt hills have been known for a long time, the maars were discovered even recently by geophysical surveys and drillings (Suhr & Goth 1996, 1999). The basement rocks of the volcanic structures are Cadomian granodiorites and Upper Protorozoic greywackes, in the northern part Paleozoic slates and conglomerates (Lower Carboniferous). Above these units lies a blanket of soft Cenozoic sediments with intercalated lignite seams. In the Pleistocene the area was covered three times by continental ice shields. The erosion of the ice took away the vast bulk of the scoria and developed the tight parts of the lava lakes.

The Schafberg Volcano

The Schafberg and its surroundings is a complex volcano with a long mining tradition. Together with the Preußenkuppe and the Dubrauker Horken there were eight active basalt quarries between 1884 and 1999. Today the large quarry on the southern side of the Schafberg is protected as a technical monument.

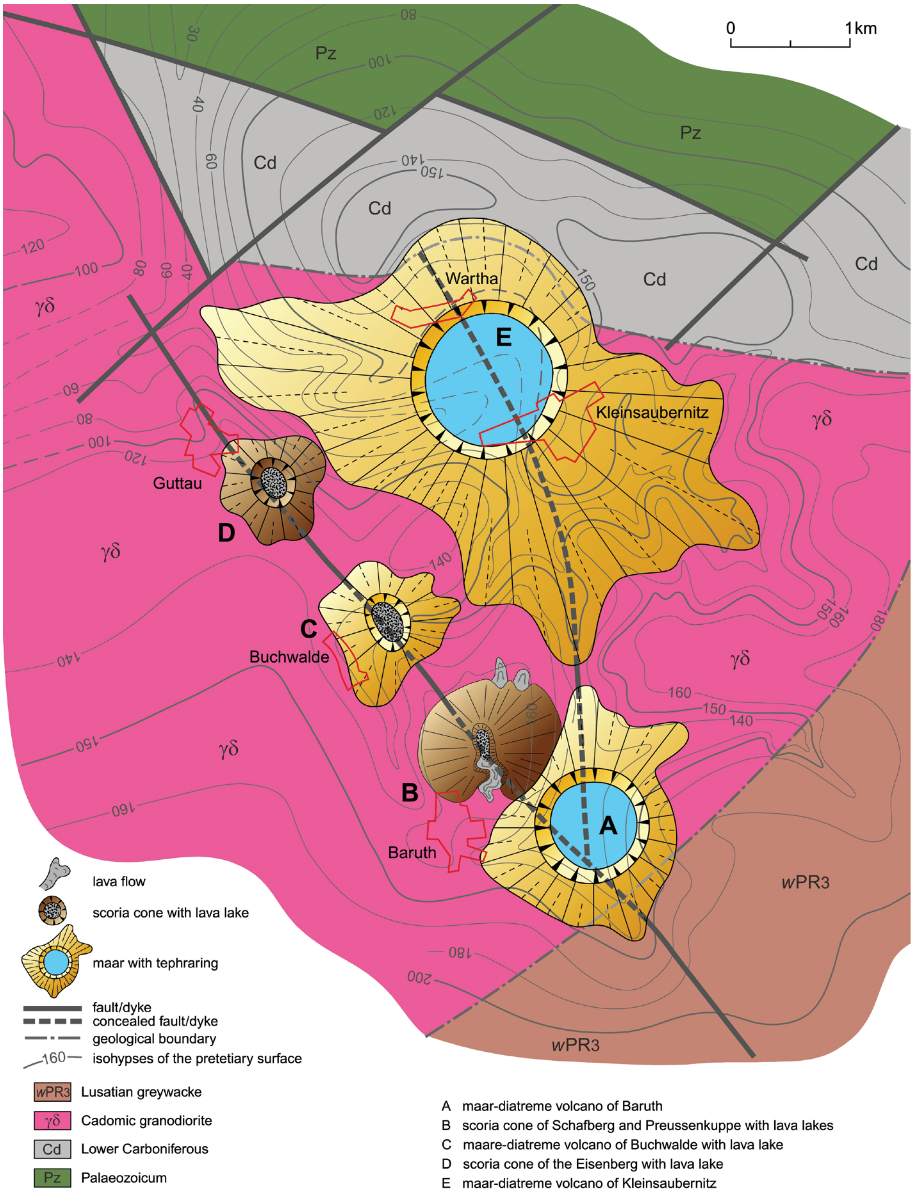

Fig. 6. Geological map of the Guttau Volcano Group.

Recent volcanological, petrographical and geochemical investigations (Tietz et al. 2011a) suggest a multistage development of this complex volcano as following (Fig. 7):

- ***Older Preußenkuppen Volcano***: nephelinitic lava flow at the western part of the Dubrauker Horken (Ar/Ar plateau ages of about: 33 Ma)
- ***Younger Preußenkuppen Volcano***: basanitic lava lake and the lava flow at the eastern part of the Dubrauker Horken (Ar/Ar plateau ages of about: 30 Ma)
- ***Schafberg Volcano***: basanitic lava lake and a lava flow to the south and west of the Schafberg hill (Ar/Ar plateau ages of about: 27 Ma)

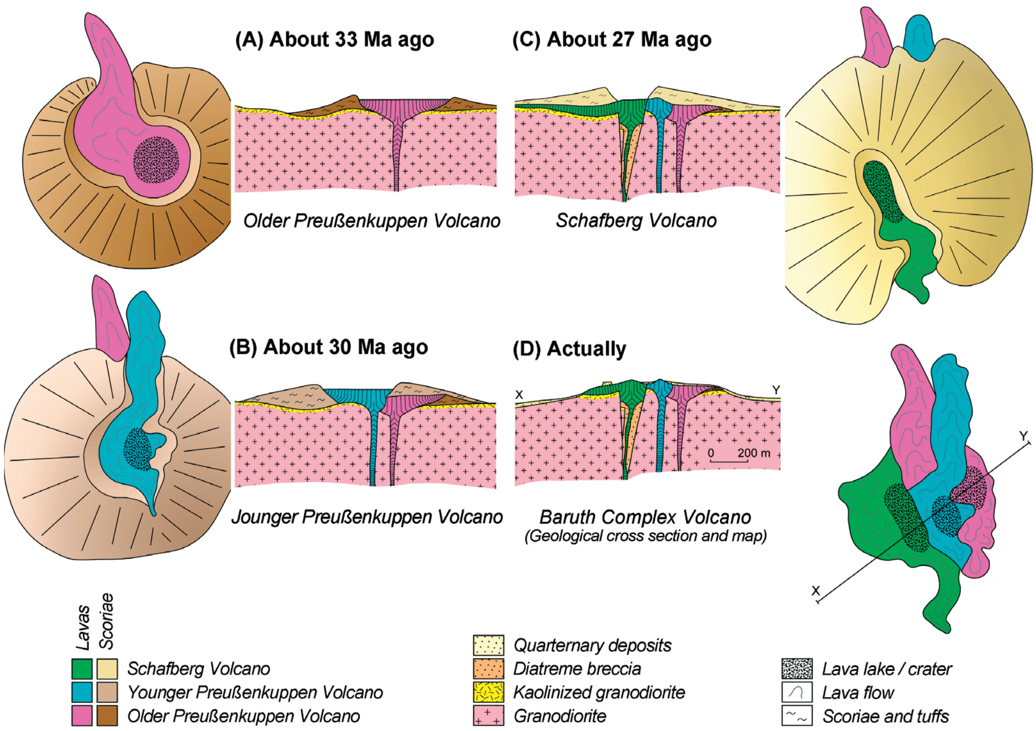

Fig. 7. Schematic sketch of the volcanic history of the Baruth complex volcano, adapted from Tietz et al. (2011a).

The remnants of these three volcanos represent scoria cones mutually overgrowing each other. Time gaps of some million years between the eruptions are confident. There are a lot of age determinations, which support the same time span (K/Ar age determinations by the lab of ATOMKI, Debrecen and Ar/Ar age determinations by TU BAF Freiberg and the labour of GEOMAR Kiel). The most recent volcano (Schafberg Volcano) showed a phreatomagmatic initial phase with simultaneous Strombolian eruptions. It evolved later into a scoria cone with increasing Strombolian-style eruptions. The scoria cones are almost completely degraded except for a remnant within a small outcrop. The entire volcanic complex shows an increasing of partial melting of the mantle. In the third volcanic phase (Schafberg Volcano) the fractionation of the melt intensifies during the ascent (Tietz et al. 2011a).

Beside the multistage development the impressive contact features between the kaolinitic weathered granodiorite basement and the hot lava are of interest. The resulting rocks are peperites documenting a strong influence of water during their formation. These peperites are preserved in the big Schafberg quarry.

The Eisenberg Volcano

As the Schafberg, the Eisenberg (Iron hill) is a remnant of a former scoria cone with a lava lake. The remains of the lava lake document just a single stage of the development. Some K/Ar ages scatter between 13.5 ±0.5 Ma (Puschkarev, St. Petersburg unpubl.) and 28.7 ±1.2 Ma (Pécskay, Debrecen pers. comm.). The higher age fits with the youngest eruption phase of the Schafberg volcano. Its associated magnetic anomaly has a value of <-1000 nT and indicates a strong inverse polarity of the basalt (Lindner et al. 2006). An old quarry shows thick steeply inclined basalt columns of the lava lake filling.

The Maar of Kleinsaubernitz

Due to its irregular bedding structures and the thick lignite seams the area around the village Kleinsaubernitz attracted attention already last century. During a regional gravimetric survey (Lindner 1963) a noticeable anomaly of -10 mGal was recognized and interpreted as a small variscian granite intrusion (Lindner & Brause 1967). A special survey was performed later on (Böhnert 1986) with only 100 m distances between the measure points. After interpolation, a nearly circular form of the anomaly with a diameter of 2 km was observed. In addition this gravity anomaly coincides with a strong magnetic anomaly.

In 1970 a borehole was drilled in the center of the gravity anomaly. The upper 200 m consisted of ± "normal" Lusatian Miocene sediments with some lignite seams. Underneath they found a more than 300 m thick sedimentary sequence, which was unknown before. Due to technical problems with the equipment the drilling was stopped at a depth of 528.5 m without reaching Pretertiary rocks.

A revision of this drill core by Suhr & Goth (1996) confirmed the earlier expressed assumption, that the structure Kleinsaubernitz is a fossil maar-diatreme volcano. The drill core starts with coarse breccias consisting mainly of the country rock (Lusatia Granodiorite, Lower Carboniferous slates and "Lydite-Chert-Conglomerate" (Kieselschiefer-Hornstein-Konglomerat). The matrix is made of tuffite with scarce lapilli and bombs of an altered mafic volcanic rock. After the eruptions this material slid from the rampart and the steep crater walls into the initial maar lake. Above the limnic sedimentation starts with thin layers of fine-grained oil shale between thick debris flow deposits and turbidites. During the lacustrine development the allochthonous clastic contribution (tubidites) decreases. An oil shale was deposited under quite calm conditions and resembles in many features the Messel Oil Shale (high content of organic components, thin lamination, accumulation of the coccal chlorophyte alga *Tetraedron minimum*, distinct siderite layers, content of diatoms, sponge needles, chrysophyte cysts etc.). After ca. 100 m of oil shale sedimentation, the content of diatom frusteles increases until almost pure diatomite is deposited. With this diatomite, which is also thinly laminated, the maar lake of Kleinsaubernitz was filled completely. The lake sediments yield macrofossils like fishes, insects and especially lots of plant remains (Walther 1999). The spore and pollen flora improves an Upper Oligocene age of the maar lake sediments (Goth et al. 2003). This age fits well to the youngest eruption of the Schafberg volcano.

The thick overlaying sequence of normal Miocene sediments with well connectable lignite seams allows an estimation of the post eruptive subsidence of the maar-diatreme structure Kleinsaubernitz (Suhr et al. 2006) by thickness comparison of equal stratigraphic units above and outside the structure. The total post-eruptive subsidence above the maar-diatreme sums up to more than 280 m for the last 27 Ma.

The recent surface above the maar-diatreme volcano of Kleinsaubernitz is coined by the subsurface - and open cast mining of lignite. The so called "Olba Lake" is not the result of the post eruptive subsidence but the relict of an open cast mine flooded in 1929.

The Maar of Baruth

A combined gravity-magnetic anomaly east of the village Baruth from the regional measurement was the reason for extensive geophysical surveys by scientists from the GGA Hannover (today LIAG) and the University of Leipzig (Prof. Jacobs). After the confirmation of these anomalies two research bore holes were drilled, one into the centre and one near the margin of the structure. The lowermost 11 m of the core of the research bore hole FB Bth 1/98 consist of huge blocks of granodiorite interstitially filled by tuffitic material. This is the so called "collapse breccia". The sequence represents the uppermost part of the diatreme filling. Directly above lie the first subaquatic deposited sediments of the former maar lake. Genetically these sediments are turbidites and debris flows, which are generated from the pyroclastics of the ring wall. The next sequence consists of about 7 m lapilli tuff with granodiorite xenoliths. Probably both components came from outside, may be from the simultaneously active Schafberg volcano. On top of this layer follow fine-grained lake sediments with partly pure diatomites. Very often, clastic material is deposited in between. During the lake sedimentation the debris flows turn more and more into turbidites. Distinct siderite layers are in certain sections quite common and indicate meromictic conditions in the Baruth maar lake. To the top of the sequence the amount on diatomites increases. At about 145 m depth phonolithic ash is intercalated, originated from the phonolithic volcanoes in the southern part of Upper Lusatia. The uppermost 30 m of the diatomite are excellently laminated and include just a few clastic layers. After an erosional discordance at 50 m depth clastic sediments of Middle Miocene age were deposited. A lignite seam of 2.5 m thickness follows and correlates with the 2nd Miocene seam horizon in the regional context. Above the seam bright Miocene clays and silts complete the pile. Only some decimeter of quaternary sediments finished the profile.

The second core (FB Bth 2/98) was drilled in the marginal facies. It shows complete different lake sediments as in the center. Coarse debris flows from blocks of granodiorite are mixed with organic rich sands. These granodiorite blocks are severely corroded because the water could simply circulate between them and altered the feldspars to clay minerals.

A detailed description of the two cores is given by Goth & Suhr 2005 and 2007. An Upper Oligocene age determination of the laminated maar sediments gives Hottenrott (2003) by palynological investigations from 3 samples.

The Maar of Buchwalde

The maar of Buchwalde is still today an enigmatic structure. The small but strong magnetic anomaly NE of the village Buchwalde (NW of Baruth) may be explained by basic volcanites below a slight cover of quaternary fluvial sediments. May be an initial maar explosion occurred. Then there was not enough water for further phreatomagmatic eruptions and the maar crater was filled with lava. This lava lake of "heavy" basalt prevents a gravimetrical anomaly as it is typical for maars. A shallow drill hole in the center of the magnetic anomaly hit at 14 m depth a highly altered basic volcanic rock, which explained the anomaly.

2. Excursion stops (positions see fig. 1)

Stop 1: The Landeskrone volcano – A large sized monogenetic scoria cone

Locality: basaltic hill on the southwest margin of the town Görlitz (summit 419.4 m a.s.l., foot of the hill about 275 m a.s.l.), visited outcrop: abandoned basalt quarry Ratssteinbruch on the northern slope of the Landeskrone Hill by 315 m a.s.l., 51.13108 N, 14.93190 E.

Geology: The Landeskrone Hill is a remnant of a monogenetic scoria cone. Today we find mainly the lava lake filling as dense nephelinite with more or less developed columns. This massive nephelinitic rock forms the steep slope part of the Landeskrone Hill above a gentle inclined slope of the granodioritic hill foot (Cadomian basement). For the nephelinite only unpublished isotopic age determinations with 34.0±2 Ma exist (K/Ar-method, labor Russian Academy of Science, St. Peterburg, Pushkarev 2000) and 32.39±0.085 Ma (Ar/Ar-method, labor TU Bergakademie Freiberg, personal communication Klaus Stanek, Freiberg). The columnar joints of nephelinite in the numerous exposed cliffs at the hill show almost a dip direction inclined outward the present hill. The inclination on the base of the nephelinite hill cone is with 40° flattest and increases up to 90°at the summit. Simultaneously the diameter of the columns rises up from 0.4 to 1.0 m. This feature indicates a cooling process as it could be observed in a lave lake. This assumption is supported by vesicle lava at the summit of the Landeskrone Hill interpreted as an upper part of the former lava lake and basaltic scoriae on the foot of the nephelinitic hill body. Actually, these scoriae are exposed in the visited outcrop (Ratssteinbruch, Fig. 8). The in situ scoriae are weakly weathered without bedding structures and could be interpreted as lapilli and bomb bearing scoria agglomerates of the scoria cone (wall or outer crater facies). The vesicles are round to flat in shape and appear in about 65 vol.% of the whole rock. All the described features allow, in combination with a geological mapping, a reconstruction of shape and size of the former scoria cone. Thus, the base of the crater should be shifted below the former surface. Only on this way can be explained the unusual large diameter of the lava lake by 500 m x 400 m at the level of the recent granodioritic basement (Fig. 9). The lowering and widening of the crater indicates a phreatomagmatic eruption after the scoria cone stage and before the final lava lake filling of the crater (Büchner & Tietz 2012, Fig. 10).

Geomorphology: The area of the Landeskrone Hill was run over two times from the Scandinavian ice glacier in the Pleistocene to the Elsterian-1 and -2 Glacial Stage (about 400.000 and 350.000 years before). The conservation of the lava lake with its total thickness implies, that the volcano edifice was uplifted after the Elsterian Glacial stages. Otherwise, more basaltic material from the Landeskrone Volcano would be denudated today. This assumption for neotectonic uplift is also supported by lacking of basaltic pebbles in glaciofluviatile sediments of Elsterian-2 Glacial Stage 5 km south-southeast from the Landeskrone Hill (Tietz & Büchner 2012).

Stop 2: Hofeberg Quarry – alkaline basaltic scoriae with *in situ* zircons of gem stone quality

Locality: abandoned basalt quarry at Hofeberg Hill near Leuba, about 10 km south of Görlitz, 650 m northwest Leuba church, southern quarry wall at the upper / western quarry (260 m a.s.l., 51.04744 N, 14.93234 E).

Geology: The southern wall profile of the upper (western) Hofeberg quarry shows a sequence from a lava lake filling (West) to a scoria cone in inner wall facies (middle to East). The open quarry area contained a probably massive lava flow, which had broken the scoria wall from West to East (Fig 11). This lava flow was the object of quarrying in the past. Possible, there were two lava flows one above the other, as showed in a canyon-like outcrop in the lower quarry more to the east. Unfortunately, the about two thirds of higher (western) quarry was filled with waste in the 1970s. Both lava flow units are characterized by vertical column jointing and top or basis breccias, exposed in the "canyon". The basaltic columns in the lava lake area show a periclinal structure. Petrographic and geochemical data indicate a basanitic composition of the lava. Three unpublished Ar/Ar age determinations range between 31 and 32 Ma (lab GEOMAR Kiel).

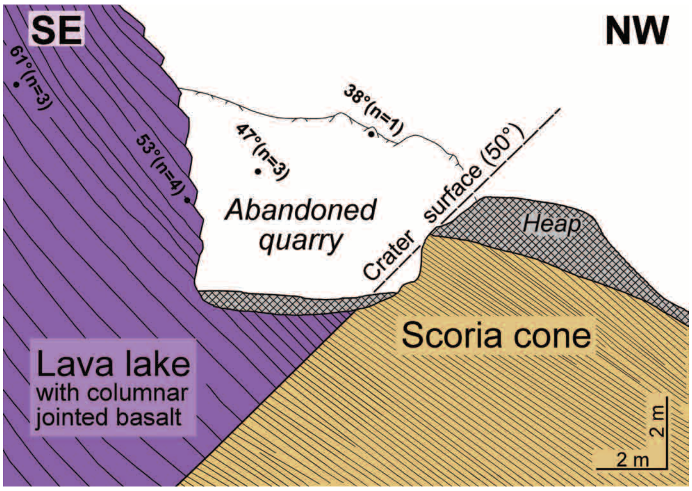

Fig. 8. Schematic cross-section of the abandoned quarry Ratssteinbruch on the northern slope of the Landeskrone Hill. Note the inclined basaltic columnar jointing in relation to the reconstructed crater surface (according to Büchner & Tietz 2012).

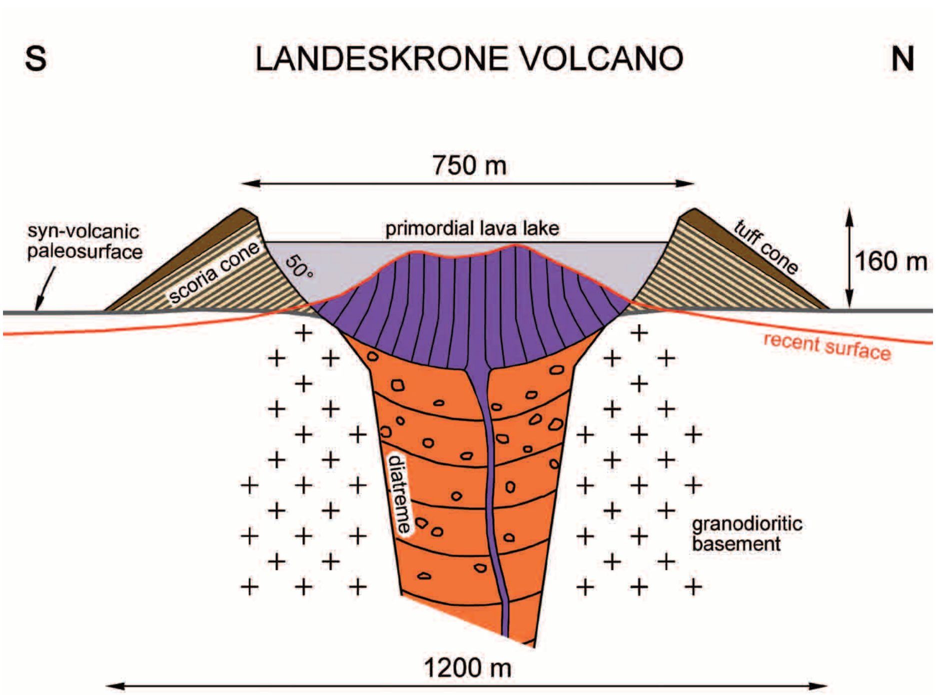

Fig. 9. Reconstructed cross-section of the Landeskrone Volcano. Note the virtual shifting of the scoria cone's baseline according to the syn-volcanic paleosurface. Possible hight of the cone edifice is shown, one-third higher than the thickness of the lava lake. Reconstruction according to the geological mapping and the dip data of the basaltic columnar jointing (according to Büchner & Tietz 2012).

The scoria profile in the upper quarry (south wall) is build by three, 2-3 m thick welded scoria beds and interposed massive lava sheets (Fig. 11). Both units incline flatly to the east. The welded scoria beds show intercalations of up to 0.2 m thick lava spatters. The scoria is laminated and characterized by a cellular structure; the 0.1-2.0 mm gas cavities are elliptic or completely flattened and the vesicles are arranged in garlands. All rocks contain some xenolithic fragments of granodiorite and quartz xenocrysts, as material derived from the country rock.

Mineralogy: The agglutinated scoria supplied *in situ* zircons from gem stone quality (Tietz & Büchner 2007, see Chapter 1.2 and Fig. 12). From all 3 scoria beds 39 zircons exist to this day collected directly from the wall, 34 isolated scoria pieces with zircon inclusions and 2282 prepared zircon crystals from 225 kg broken scoria sample material. In contrast, zircon crystals are lacking in the intercalated massive lava sheets. Here only two small zircon splinters in 40 kg rock samples have been found. The zircon content in the scoriae varies between 0.0 and 53 grams per ton scoria material (in average 19.0 g/t) or one kilogram scoria contains 0-124 zircon crystals (in average 27.6 crystals/kg). The zircon crystals have a mean size from 1 to 4 mm (max. 10 mm). Many crystals are more or less intensively rounded (73 %) and broken (21 %). The rounding is the result of a magmatic corrosion in the basaltic host rock and the sharp mineral splinters are probably the product of the quenching of the melt during the strombolian eruption. Only 6 % of zircon crystals have received the crystal shape and can be use for morphological determinations according to Pupin (1980). Thus, two zircon subpopulations can be distinguished. These are a main type with P-, D, and S-types and the side type with predominantly G1-type according to Pupin (1980). First preliminary mineralchemical investigations show no significant differences between both types. One U/Pb isotopic age determination at 4 zircon grains provided an age from 30.4 ±0.3 Ma (Büchner et al. 2011). The agreement with the host rock age (see above) could be an indication for the cogenetic origin of the gem stone quality zircons to the host rock melts (Tietz et al. 2013).

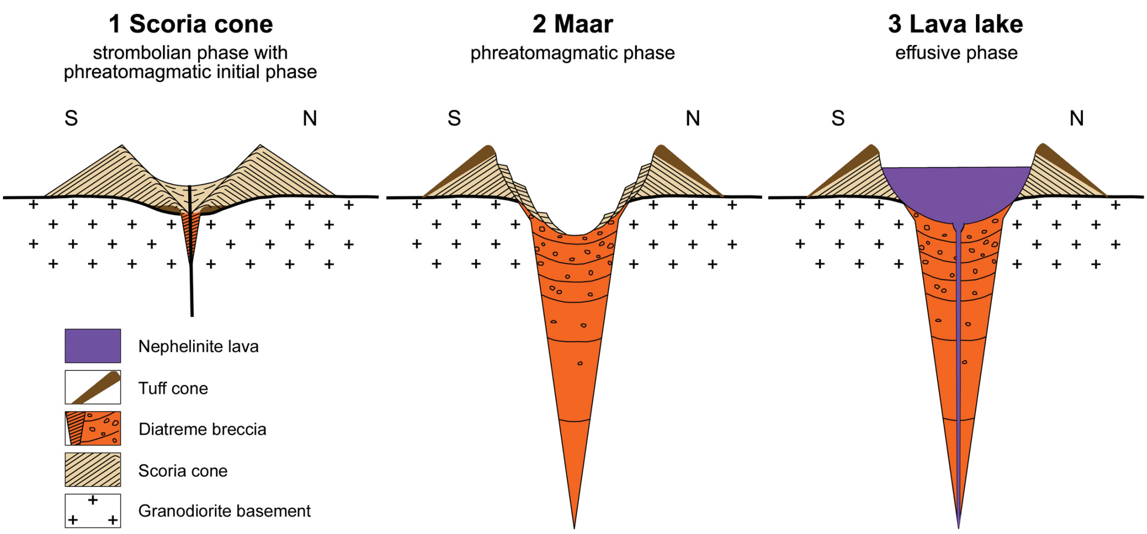

Fig. 10. Schematic view of the development of the Landeskrone Volcano (not to scale), deduced from the morphometric reconstruction. 1 — Strombolian eruptions created a scoria cone after an initial phreatomagmatic phase. 2 — A second intensive phreatomagmatic phase produced a maar-diatreme below the scoria cone. The scoria cone has been modified due to excavating the central part of the cone and sliding of the cone material into the enlarged crater. The crater slope became steeper and the scoria cone covered by a tuff cone. 3 — Final effusive phase produced a lava lake (according to Büchner & Tietz 2012).

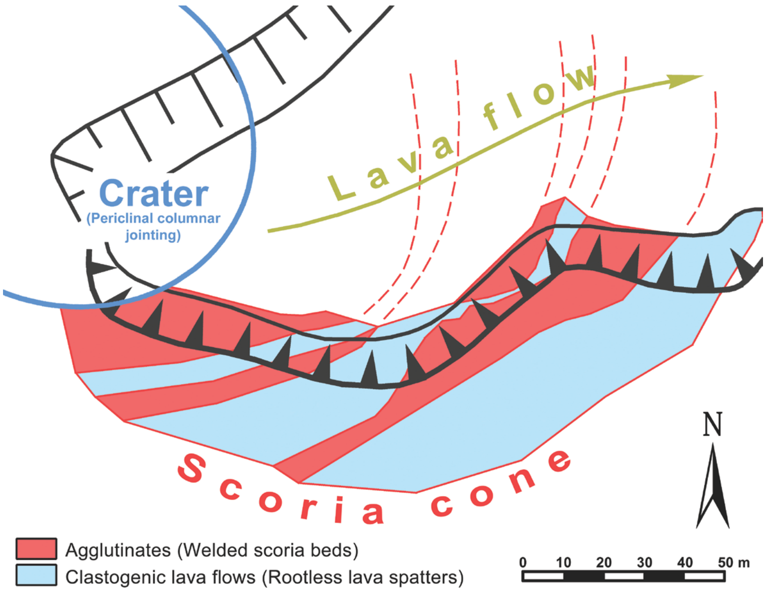

Fig. 11. Volcanological map of the western Hofeberg quarry near Leuba.

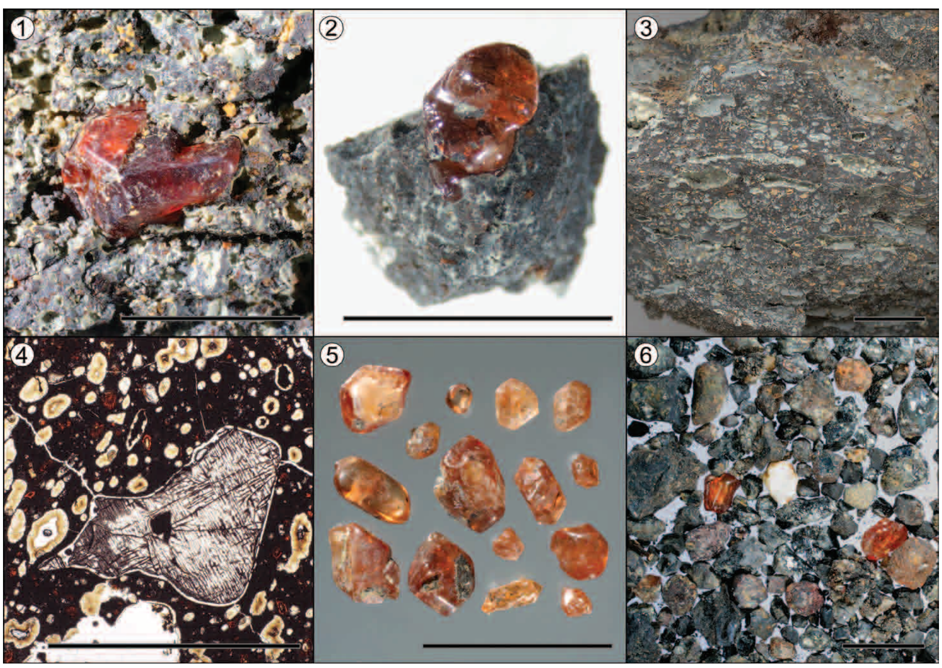

Fig. 12. Zircon megacryst in basanitic scoria from the Hofeberg Hill quarry. 1 + 2 – Insitu zircon crystals in scoriae. 3 – Hand specimen from a basanite scoria. 4 – Thin section from basanite scoria with a zircon crystal. Note the intensive roundshape by corrosion and the magmatic reaction rim. 5 – Zircon crystals with subhedral shape. 6 – Heavy mineral concentrate with two zircon crystals. Scale bars are 5 mm.

Stop 3: Steinberg quarry – a basanitic lava flow with mantle xenoliths and pyroclastic remnants

Locality: abandoned basalt quarry Stadtwaldbruch at Steinberg hill 2.5 km west of the town Ostritz (300 m a.s.l., 51.02065 N, 14.89875 E).

Geology: The quarry Stadtwaldbruch near Ostritz give a view inside a single basaltic lava flow. The lava flow remnant is 500 m long and 100 m wide and up to 20 m thick (Fig. 13). The location of the eruption center is unknown but is probably situated directly on the northeastern edge of the quarry. This is indicated by 1) the increased distribution and thickness of the basaltic flow, 2) the increased content of mantle xenoliths in the northeastern part of the lava flow and 3) the reduction of the diameter of basaltic columnar jointing from north (eruption center) to south (flow direction). The lava could be interpreted as an olivine-augite-basanite which is 30. 3 ±2 Ma old (K/Ar age, laboratory of Russian Academy of Science, St. Peterburg, Pushkarev 2000).

Donath (1929) and Grahmann & Ebert (1939) described a 2-4 m thick "conglomeratic tuff bed" between the basanitic lava sheet and the granodioritic basement (Fig. 14). The "conglomerate" comprises lapilli and abundant granodiorite fragments of variable size (up to cubic meters). Donath (1929) interpreted the red colored bed as explosive initial stage deposit of a volcano, whereas Grahmann & Ebert (1939) a lahar deposit assumed. Additionally, the lowest parts of the basanite as well as the "tuff" are weathered to brightly colored bentonite (Donath 1929, Schüller & Köhler 1953). Today, these soft rocks below the massive lava flow are rarely exposed. In small excavations were found breccias with clasts from pyroclastic rocks (scoriae), massive "basalts" and granodiorite. The interpretation of theses rocks is difficult. However, they seem to be originated from explosive eruptions of a volcano with phreatomagmatic and strombolian phases.

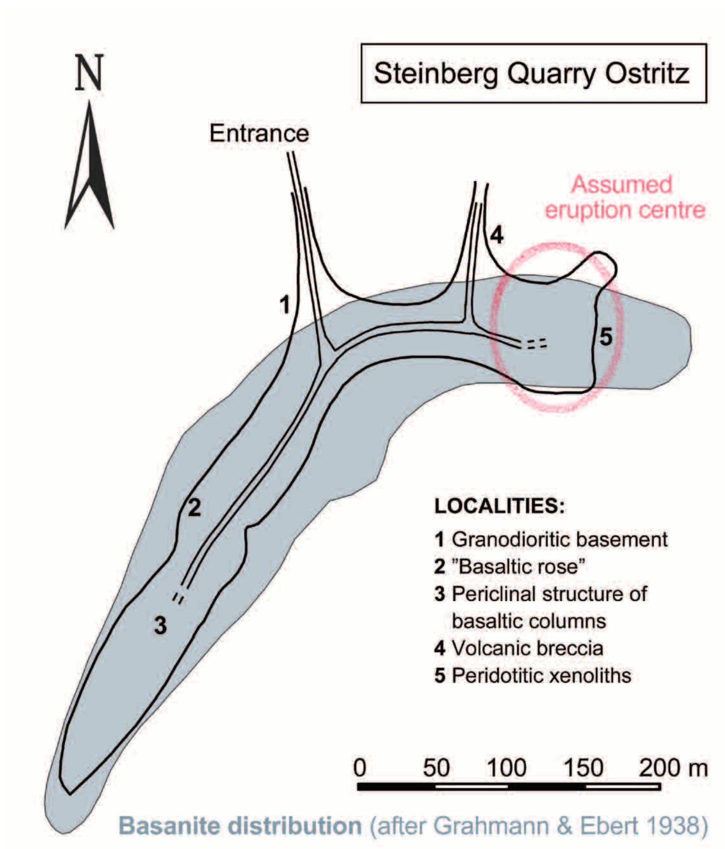

Fig. 13. Map of the Steinberg quarry near Ostritz with outcrops visited during the field trip and geological features (reworked after Schreiter 1957).

FT.3

The basanite contains locally numerous, small (< 8 cm in diameter) peridotitic xenoliths. The recent study (Kukuła et al., abstract volume "Basalt 2013"and unpublished data) shows three kinds of xenoliths. The first one represents peridotitic cumulate (olivine 72.7 – 77.5 % Fo, 0.02 – 0.11 wt. % NiO, orthopyroxene mg# 0.76 – 0.77, Al 0.15 – 0.20 a pfu and clinopyroxene mg# 0.77 – 0.85) with REE/trace element patterns demonstrating alkaline affinity). The two other xenolith groups are mantle harzburgites – partly strong depleted (olivine 91.2 – 91.4 % Fo, 0.39 – 0.45 wt.% NiO, orthopyroxene mg# 0.92, Al 0.06 – 0.08 a pfu and clinopyroxene mg# 0.93 – 0.95, with U-shaped REE patterns, and partly affected by metasomatic event which lowered slightly magnesium content of rock-forming phases and changed the REE patterns of clinopyroxene.

A special feature from Ostritz Steinberg are the "basalt roses", rosette like columnar jointing structures around silicified fossil tree trunks (see the cover image of this conference proceedings and Fig. 14). Today, we can only find one remnant of such "Ostritzer Basaltrose" with a light yellow altered palagonite core, but without fossil tree trunks, because the opalized wood was excavated by mineral collectors.

The lava flow from the Steinberg hill builds a morphological ridge in NNE-SSW direction, but originally, the lava flew in a flat valley incorporating fresh or waterlogged tree trunks. Cross sections show a periclinal structure of the basaltic columnar jointing in the southern part of the quarry which indicate 30°–40° inclined valley flanks. The Steinberg outcrop near Ostritz is a typical example for relief inversion in the Lusatian Volcanic Field.

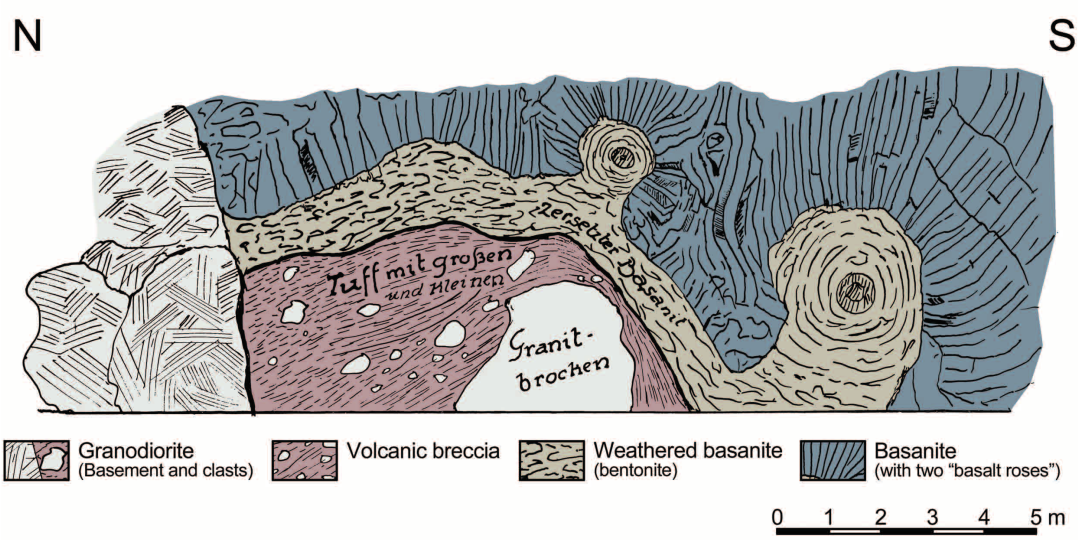

Fig. 14. Geological cross section at the northern margin of the Steinberg Quarry near Ostritz (according Donath 1929, location see in Fig. 13, Stop 4).

Stop 4: Eisberg quarry – insight in a volcano feeder zone

Locality: abandoned basalt quarry at Eisberg hill 0.7 km west of the village Großhennersdorf, 50 m east the road no B 175 (310 m a.s.l., 50.99181 N, 14.78232 E).

Geology: The quarry wall at the Eisberg hill exposes a complete profile from a volcano root zone to the granodioritic country rock (Fig. 15). The granodioritic frame is visible with fragmented structures like *in situ* breccias. The orthogonal joint system of the granodiorite and the inclusion of an aplitic dike are intensively disturbed. Additionally, juvenile basaltic clasts are incorporated in interspaces of the granodioritic rock breccia. The content of juvenile material increases towards to the volcano feeder from 0 % up to 90 % (Fig. 13).

FT.3

From the volcano remain two facies: (1) dense nephelinite rocks partly preserved in marginal dikes (feeder) and (2) a diatreme breccia (Fig. 16). The diatreme breccia is exposed in a great pillar in the eastern quarry wall. The breccias contain granodioritic fragments up to 25 cm size and much juvenile debris up to 70 cm diameter. Mostly, the juvenile debris consists of dense nephelinitic rocks, but also of scoria lapilli or bombs. The sandy-clayish matrix contains quartz crystals and a lot yellow colored palagonite. The texture of the volcanic breccia is clast supported.

The described cross section and a geological mapping implicate the following reconstruction of the volcanic processes (compare with Fig. 17): (A) An initial phreatomagmatic "basaltic" eruption opened a diatreme cone and fragmented the granodioritic host rock and incorporated juvenile basaltic clasts in granodioritic interspaces. (B) The high content of juvenile clast material in the diatreme breccias indicates a simultaneous change between strombolian and phreatomagmatic eruption styles and builds probably a scoria cone at the surface. This could also explain the occurrence of scoriaceous material in the granodioritic breccia. (C) In a final stage nephelinitic gas-poor magma intruded in the margin of the diatreme breccias (mainly mined in the quarry)., The superficial volcano edifice is completely eroded. Today only the volcano root zone is accessible.

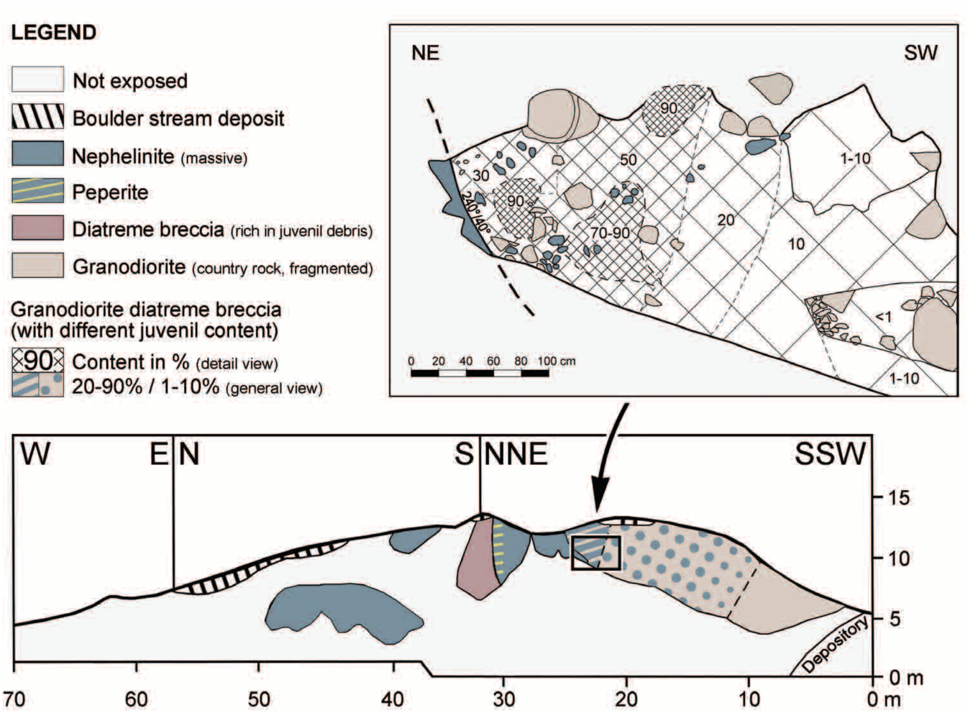

Fig. 15. Geological cross section of the southeastern wall of the Eisberg quarry near Großhennersdorf.

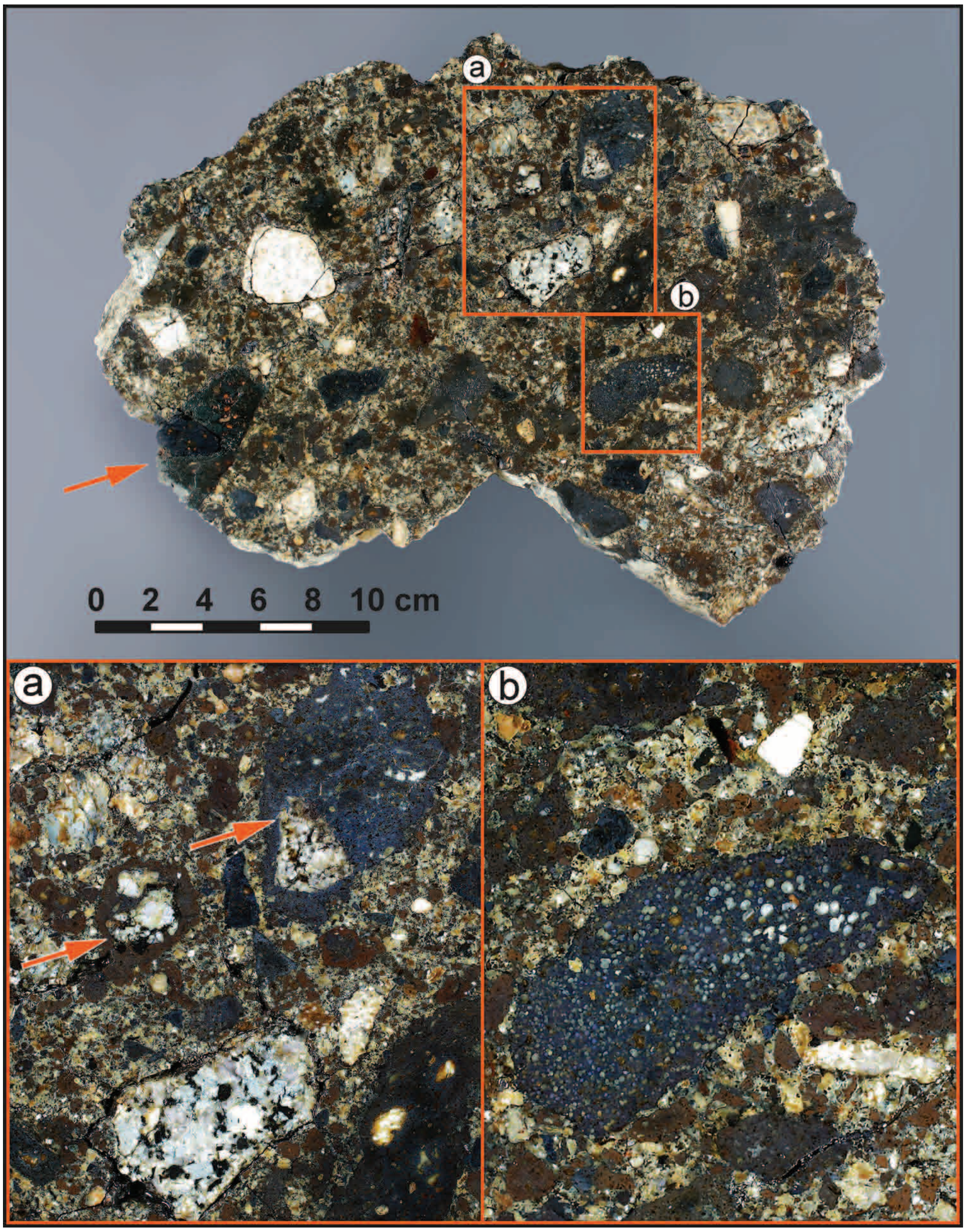

Fig. 16. Polished hand specimen of diatreme breccias from the Eisberg quarry near Großhennersdorf. Note the simultaneous occurrence of granodioritic and basaltic clasts. Some juvenile basaltic clasts are polyphasic lapilli (inset image a, arrows) or scoriae (see the inset image b).

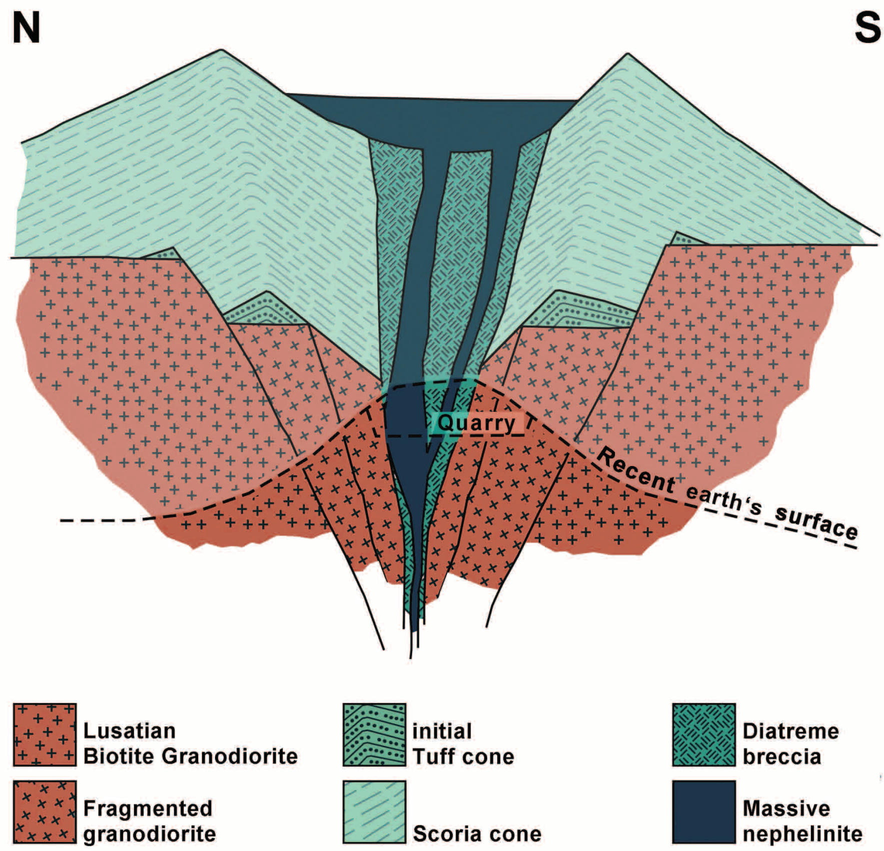

Fig. 17. Schematic reconstruction of the Eisberg Volcano (Tietz & Büchner 2009).

FT.3

Stop 5: Schafberg quarrys – a polygenetic complex volcano in the northwestern margin of the LVF

Locality: The two inactive basalt quarries from the company HWO Hartsteinwerke GmbH & Co. KG Ostsachsen lie 14 km northeast of Bautzen. The Schafberg hill (206.9 m a.s.l.) is today quarried by the new Schafberg quarry (up to 30 m deep, 51.23407 N, 14.59815 E). To the east the old Schafberg quarry is connected (51.23372 N, 14.59959 E), which is located on the southern slope of the Preußenkuppe hill (198.3 m a.s.l.).

The largest quarry at the hill is the "new Schafberg quarry" with the "old crasher factory", which is protected as a technical monument from 1930. In the quarry the boundary between a lava lake and a lava flow is exposed. In a lot of places peperitic contacts between the kaolinitic weathered granodiorite and the different basaltic rocks are visible (Fig.18). The geological map in figure 19 gives an overview about the three volcanoes from the Baruth Complex Volcano and figure 20 shows a geological cross section of the Schafberg quarries, whereas the polyphase development is illustrated in the sketches in figure 7.

Geology: The major part of the quarry consists of the basanitic lava lake of the Schafberg Volcano (about 27 Ma). The small basanitic columns show a periclinal structure around the whole quarry with a more or less steep dip (Fig. 21). The granodioritic host rock is visible as white windows in the quarry walls in several cases. T. The result of the phreatomagmatic initial eruption and the subsequent widening of the granodioritic country rock is 300 x 100 m sized crater. Isolated blocks from the Schafberg basanite show the simultaneous stages of phreatomagmatic and strombolian eruption styles of the Schafberg Volcano. These agglutinated breccias contain fragmented granodioritic material from the country rock and basanitic spatter.

The upper working level wall shows in the eastern part of the new Schafberg quarry the contact of the lava lake (about 27 Ma) with the marginal part of the lava flow from the Younger Preußenkuppen Volcano (about 30 Ma). The columnar jointing is significantly different and about twice as thick as the columnar jointing from the Schafberg lava lake. The centre of the Younger Preußenkuppen Volcano lava lake is outcropped with a periclinal structure of basaltic column jointing about 50 m eastward in the old Schafberg quarry. Here occurs a relatively large amount of small peridorite xenoliths in the basanite. The scoria cone of this eruption event is only preserved in the NE part of the upper level of the new Schafberg Quarry in a little outcrop as heavily weathered scoria agglomerate.

On top of the Preußenkuppe hill we have a good look northward to the two lava flows of the Dubrauker Horken (Fig. 22) and to the shallow depression of the Maar of Baruth in south-eastern direction. The western ridge of the Dubrauker Horken is formed by the nephelinite lava flow from the Older Preußenkuppen Volcano (about 33 Ma). The eastern ridge belongs to the Younger Preußenkuppen Volcano.

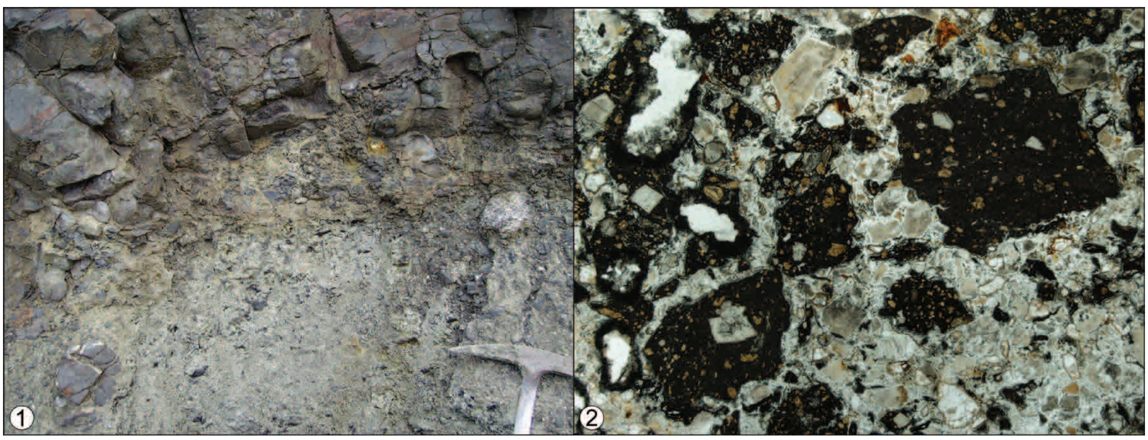

Fig. 18. Peperit from the New Schafberg Quarry near Baruth.
1 - In the surrounding of the contact between kaolinitic weathered granodiorit and the basanite.
2 - Thin section of the peperit, dark round clasts are basanite and light parts are quartz and feldspar of the disintegrated granodiorit. Image width 16 mm, plane-polarized (photo by Manuel Lapp, Freiberg).

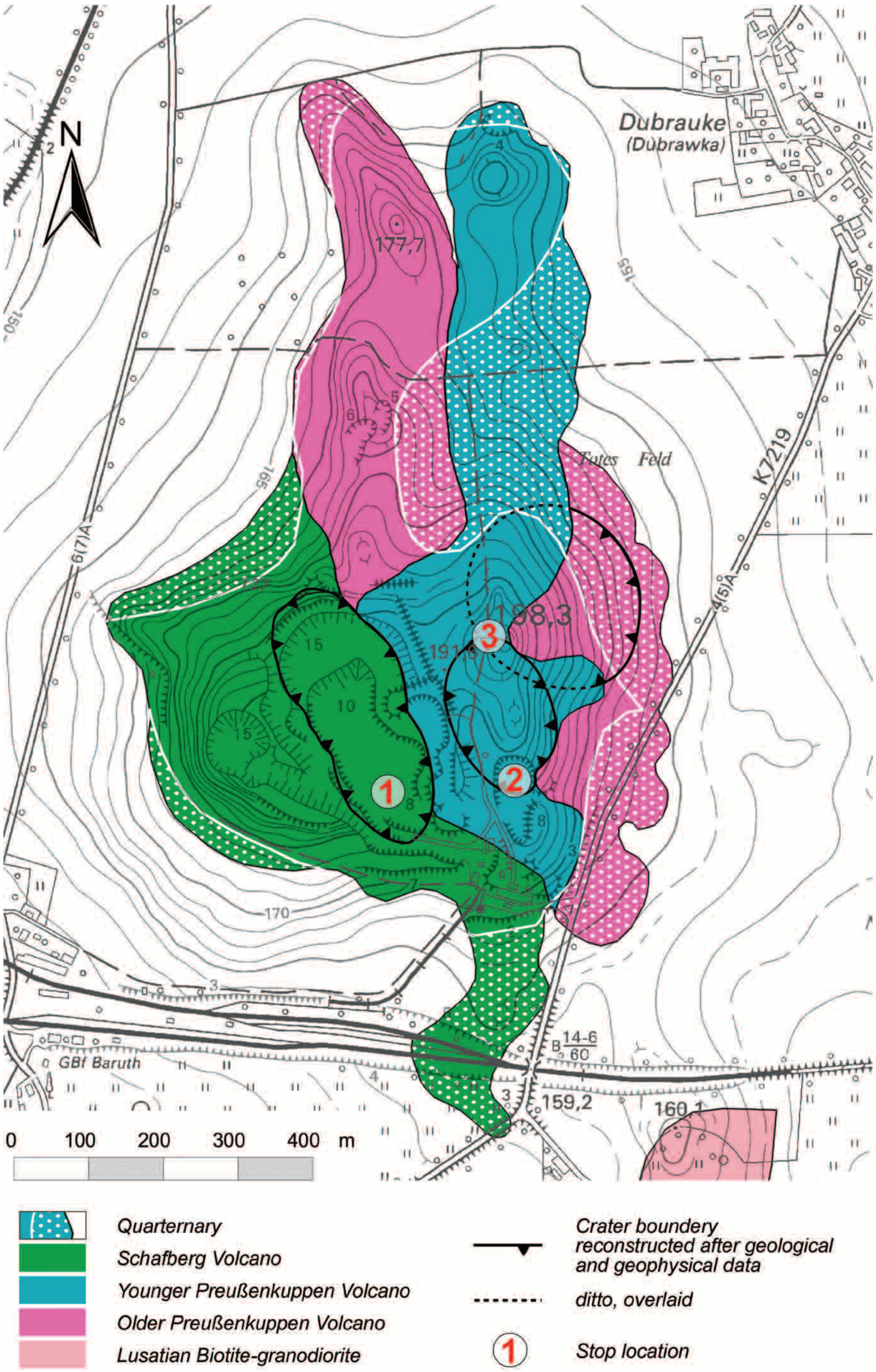

Fig. 19. Geological map of the Baruth Complex Volcano (Tietz et al. 2011a). Stop locations: 1 – New Schafberg Quarry, 2 – Old Schafberg Quarry, 3 – Preußenkuppe Hill.

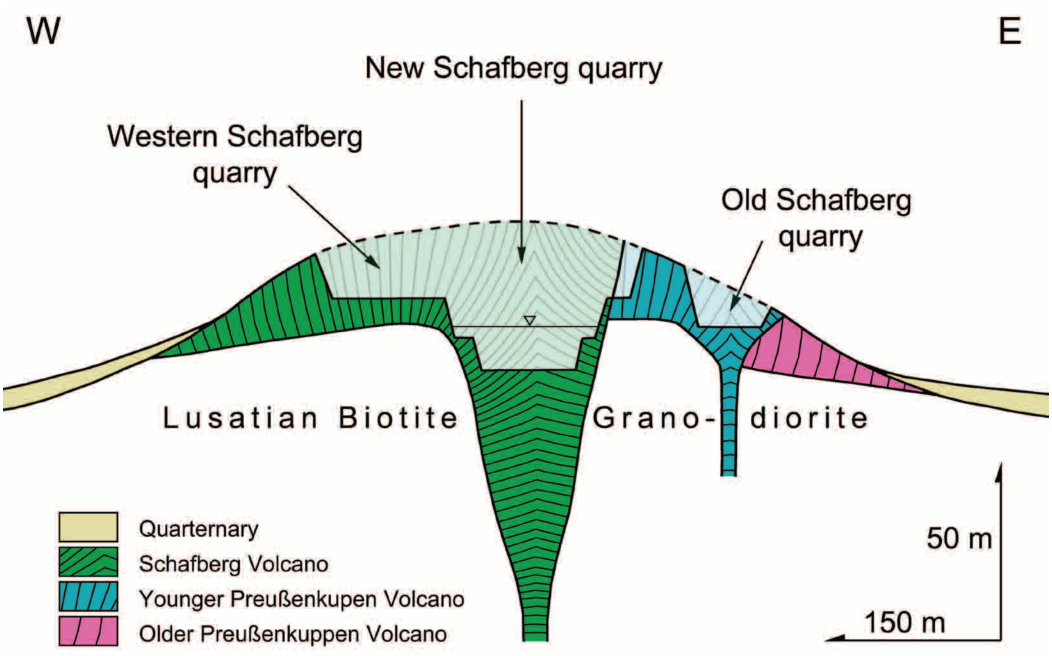

Fig. 20. Geological cross section of the New and Old Schafberg Quarry (according to Palme 1996, Tietz et al. 2011a).

Fig. 21. Deepest level of the quarry showing periclinal structure of columnar jointing – now under water (Picture: Peter Suhr, 1998).

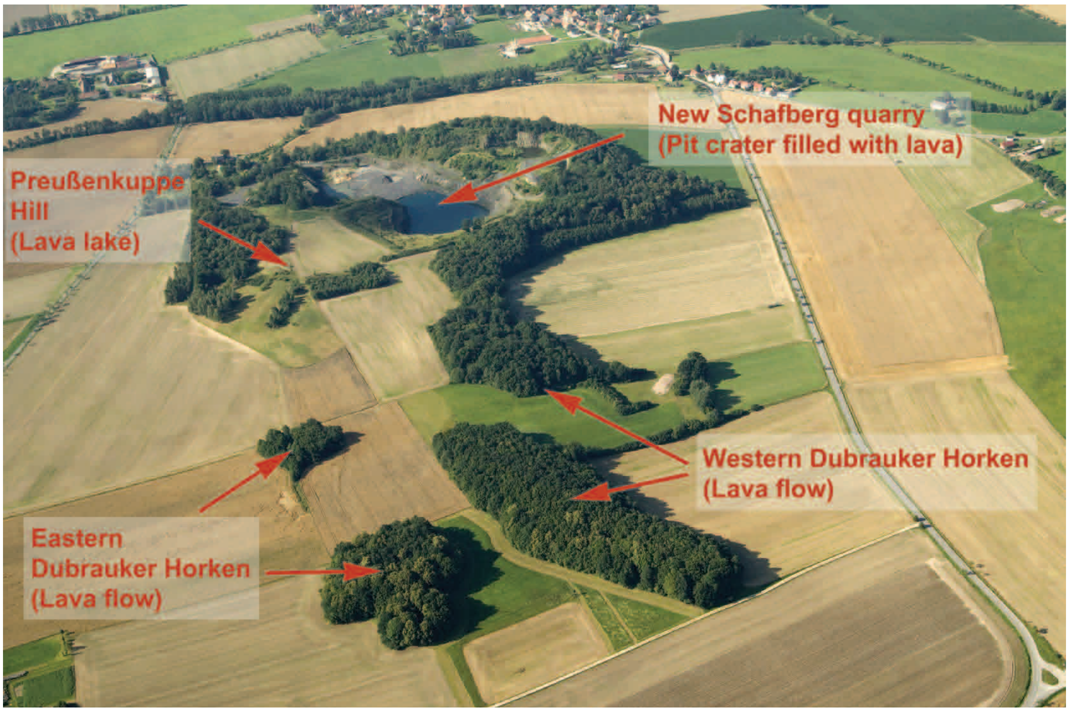

Fig. 22. Arial view of the Baruth Complex Volcano, looking north (Picture: www.topluftbilder.de from 2007/07/15; archive LfULG).

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