Maar-diatreme practical exercise

Energy available (E) for explosion is derived from the heat energy of a mass of magma that interacts with externally derived water:

$$E_{tot} = mc_p\Delta T$$

m = mass of magma, c_p = heat capacity of the magma, ΔT = change in temperature

Assume that the magma-water interaction is a type of molten fuel-coolant interaction (MFCI, which involves mixing of melt and water followed by explosive vaporization of the water). Efficiency of MFCI (i.e., how much of the magma's heat energy actually gets converted to mechanical energy) is estimated to be between 1-10%. For 1% efficiency, explosion energy $E = 0.01E_{tot}$. For 10% efficiency, $E = 0.1E_{tot}$.

Additional assumptions:

Heat capacity is $c_p = 1200$ J kg^{-1} K^{-1} for typical basalt

The drop in melt temperature during interaction $\Delta T = 1000\ K$

Density of basaltic magma can be approximated as $\rho_{mag} = 2900$ kg/m^3

Most intrusion volumes are 10^2-10^5 m^3 in diatremes, which we assume are appropriate analogs for the scale of magma bodies that might be involved in magma-water interaction during eruptive activity.

Scaled depth for optimal crater size is 0.004 m J$^{-1/3}$.

Scaled depth for confinement (or containment) is 0.008 m J$^{-1/3}$.

Remember that scaled depth $D_{sc} = d \cdot E^{-1/3}$

Questions

1) For observed intrusion volumes of basalt in diatremes (10^2-10^5 m^3) calculate the range of explosion energies where the conversion from thermal to mechanical energy is 1% and 10% efficient as is expected for MFCI.

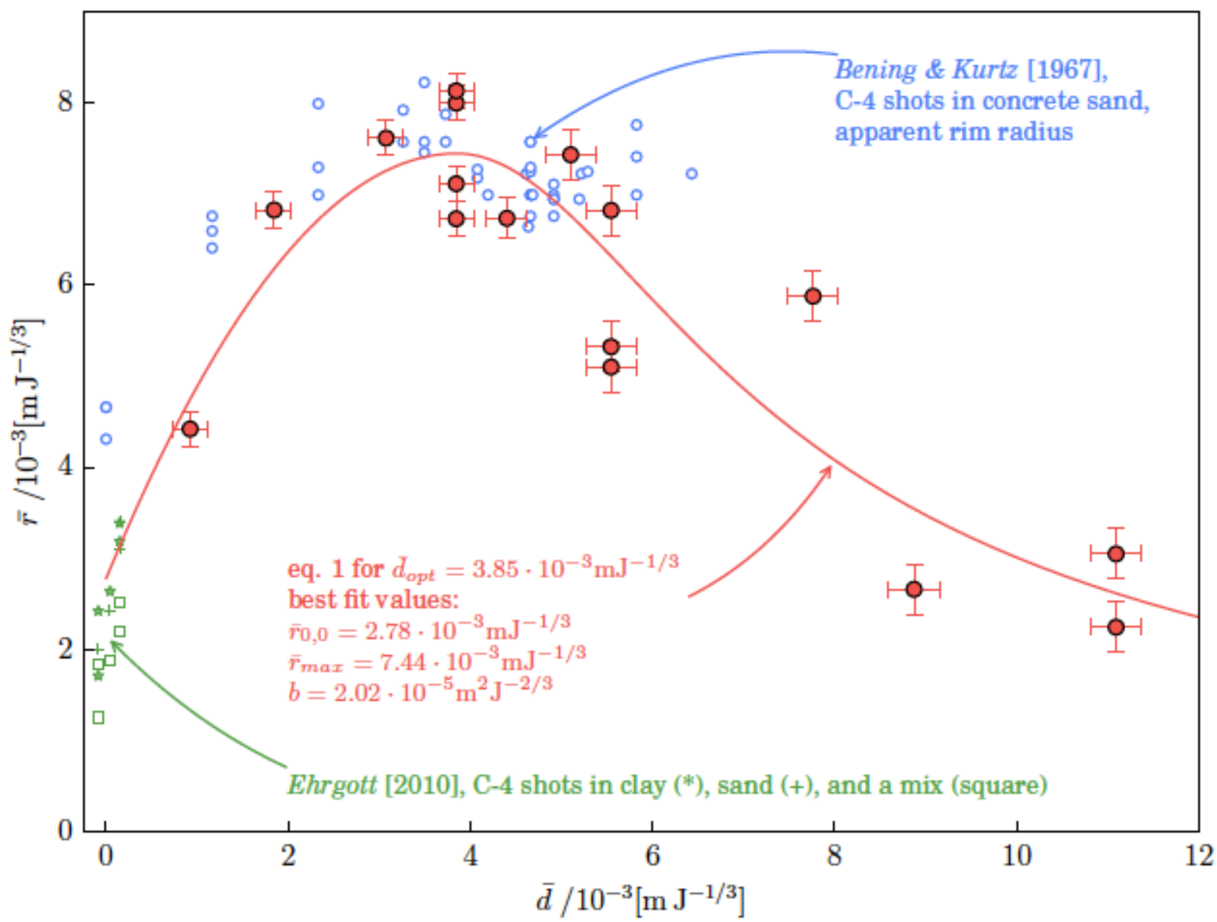
(Note: When asked to calculate size, it is in meters, and energy, it is in Joules. If the text says "scaled radius" or "scaled depth" then you need to divide the radius or depth by the cube-root of energy. Also be aware of going between radius and diameter in the below.)

2) Based on these energies estimate the depth range where the explosions would produce the largest crater (optimal scaled depth) and no ejecta (confinement depth). Produce a table that includes the energies estimated in problem 1 and the explosion depths by scaled depth.

3) If the optimal scaled depth explosions produce craters with scaled radius of 0.0075 m/J$^{1/3}$ calculate the radius of the crater that would be produced by an optimal scaled depth explosion under flat ground for the explosion energy range calculated in problem 1. Add these values to the table.

4) If natural maar craters are typically 600-800 m in diameter are the values calculated in problem 3 in similar? Explain how an eruption with multiple (10's to 1000's) of explosions (of the sizes calculated here) could produce crater sizes observed in nature?

5) Using the curve of scaled radius by scaled depth figure below from Sonder et al. 2015, discuss the following scenarios:



(Note: On this plot the values on the axes are to be multiplied by 10^{-3}. For example, the number 6 on the horizontal axis translates to 6×10^{-3} m·J$^{1/3}$.)

a) If a growing maar-diatreme crater was produced by an explosion of 10^{10} J at optimal scaled depth was followed by a deeper than optimal scaled depth (0.006 m/J$^{1/3}$) explosion of 10^{10} J would the crater increase in size?

b) If a growing maar-diatreme crater was produced by an explosion of 10^{10} J at optimal scaled depth and was followed by a deeper than optimal scaled depth (0.006 m/$J^{1/3}$) explosion of 10^{13} J would the crater increase in size?

c) Ignoring lateral migration and collapse of the crater rim, what is the smallest explosion energy at a deeper than optimal scaled depth (0.006 m/$J^{1/3}$) that is required to increase the crater diameter by more than 5 m (compared to the first crater in 5a)?

d) For explosions with similar sized reference footprints (crater diameter made by an explosion in undisturbed ground at optimal scaled depth) the distance of the epicenters of the reference footprints controls whether the final crater will be circular or elongate. When the epicenter occurs in both footprints the crater remains circular, if the footprints overlap but the epicenters do not fall within both footprints the crater will be elongate.

If a 200 m diameter crater is produced by a single explosion at an optimal scaled depth, what is the minimum distance for the epicenter for a second explosion of the same energy and scaled depth conditions to form an elongate crater?

e) If the second explosion had the same energy but occurred at a deeper scaled depth, and occurred at the distance calculated in 5d would the resulting *idealized* crater still be elongate (given the information provided above)? If the second explosion at the distance calculated in 5d occurred at optimal scaled depth conditions but had a larger energy (by an order of magnitude) would the crater still be elongate?

6) Considering the calculations above list the reasons that it is difficult to estimate explosion energy from the final crater shape of a maar. Also list additional factors that are not accounted for in the above.

Sources (see bibliography):

Büttner and Zimanowski 1998; Büttner et al. 2005; Sonder et al. 2015; Valentine et al. 2014; Wohletz 1986