**Questionnaires adopted in the Kolumbo elicitation**

**Supporting Material 2 to:**
**Kolumbo Volcano, Greece: expert elicitation findings supporting volcanic hazard and risk assessment**

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In this Supporting File we detail the questionnaires adopted in the first elicitation workshop held on Santorini, 9-12 May 2023, and in the second, follow-up elicitation workshop, held at INGV Pisa, Italy, 18-19 October 2023. To keep the original formulation of the target questions unaltered, the Central Volcano in this document is called "main cone" or "main crater".

## Santorini Workshop elicitation - Seed questions, Part I

1. From records in the Volcanoes of the World Catalogue (3rd Edition), from 1800 – 1810 on average there were 15 volcanoes per year reported as "erupting". What is the corresponding average yearly number for the decade 2000 - 2010?

| *5th %ile* | *50th %ile (Median)* | *95th %ile* | *Units* |
|---|---|---|---|
| | | | |

2. Up to and including Mt. St. Helens 1980 eruption, there had been about 52,000 fatalities from volcanic hazards in the 20th century; what percentage was attributed directly to gases (excluding pyroclastic flows)?

| *5th %ile* | *50th %ile (Median)* | *95th %ile* | *Units* |
|---|---|---|---|
| | | | |

3. Myojinsho shallow submarine volcano, Japan, had an explosive eruption sequence in 1952-53, and a further 12 minor episodes of unrest up to 1993. When it was surveyed in 1993, what was the angle of slope of the upper parts of its symmetrical cone?

| *5th %ile* | *50th %ile (Median)* | *95th %ile* | *Units* |
|---|---|---|---|
| | | | |

4. In the 100 years from 1910 – 2010, how many earthquakes with magnitudes M3.5+ were reported by the International Seismological Centre with epicentres within 30 km of Kulumbo volcano?

| *5th %ile* | *50th %ile (Median)* | *95th %ile* | *Units* |
|---|---|---|---|
| | | | |

5. From GPS measurements during the 1990-95 Unzen dome-building eruption, a Mogi model locates the magma pressure source at 11km depth. What horizontal radial distance was this model point from a vertical axis centred on the crater? (please state your distance estimate units e.g., m or km …)

| *5th %ile* | *50th %ile (Median)* | *95th %ile* | *Units* |
|---|---|---|---|
| | | | |

6. In a study modelling the magma dynamics and collapse mechanisms for four well-known historic caldera-forming events, one model input was the time duration of magma evacuation before the caldera block began to subside. This model parameter was based on data for Katmai 1912 eruption; what was the duration of magma evacuation before collapse started in that case? Please state your units of time, e.g., minutes; hours; days…

| *5th %ile* | *50th %ile (Median)* | *95th %ile* | *Units* |
|---|---|---|---|
| | | | |

7. The same study quoted the observed total downward surface displacement of the caldera block in the Pinatubo 1991 caldera-forming eruption. What was the reported block downward displacement, in metres?

| *5th %ile* | *50th %ile (Median)* | *95th %ile* | *Units* |
|---|---|---|---|
| | | | |

8. What <u>percentage</u> of documented volcanic tsunamis are attributed directly to submarine volcanic eruptions (as opposed to volcanic collapses, landslides, flows, lahars or earthquakes)?

| *5th %ile* | *50th %ile (Median)* | *95th %ile* | *Units* |
|---|---|---|---|
| | | | |

9. The Tambora 1815 eruption plume hit an estimated altitude of 44 km a.s.l; it was preceded by 3 years of eruptive activity. In this prior period -- before the paroxysmal event -- what was the highest estimated cloud height?

| *5th %ile* | *50th %ile (Median)* | *95th %ile* | *Units* |
|---|---|---|---|
| | | | |

10. Mount Unzen grew a dome with intermittent phreatomagmatic eruptions between 1990 - 95. GPS measurements of subsidence, from October 1991 to February 1994, were converted to an internal volume change by modelling. While lava was being discharged, what was the inferred internal volume change, expressed as a percentage of the discharged lava volume? (the inferred internal volume change might exceed 100% of the lava output volume)

| *5th %ile* | *50th %ile (Median)* | *95th %ile* | *Units* |
|---|---|---|---|
| | | | |

11. What is the typical measured $SO_2$ gas flux from Stromboli, in tonnes / day? We consider the "quiescent" $SO_2$ gas flux, i.e. by excluding the explosive emissions.

| *5th %ile* | *50th %ile (Median)* | *95th %ile* | *Units* |
|---|---|---|---|
| | | | |

12. In the January 2022 eruption of Hunga Tonga–Hunga Ha'apai submarine volcano in the South Pacific, what was the reported tsunami run-up height on Mango Island, 75 km ENE of HTHH?

| *5th %ile* | *50th %ile (Median)* | *95th %ile* | *Units* |
|---|---|---|---|
| | | | |

13. [EXCLUDED FOR AMBIGUITIES] In 1991, Pinatubo volcano ejected an estimated 17 ±~2 Mt of gas and ash; in 2018, Manaro Voui volcano on the island of Ambae, Vanuatu, injected 0.4 Mt $SO_2$ into the upper troposphere and stratosphere. Large volumes of gas and ash were ejected from HTHH in the 2022 eruption. What was the approximate measured $SO_2$ output, in tonnes?

| *5th %ile* | *50th %ile (Median)* | *95th %ile* | *Units* |
|---|---|---|---|
| | | | |

14. Kick'em Jenny is an active submarine volcano in the Eastern Caribbean island arc. Between 1938 and 2018, 14 episodes of T-phase were detected, emanating from the volcano. (T-phase comprises seismoacoustic tertiary waves that travel in a layer of minimal sound speed (SOFAR) in the oceanic water column; the detection of T-phase provides information on the timing and location of submarine volcanic activity). What percentage of the Kick'em Jenny T-phase episodes in those eight decades also produced visible signs of an eruption?

| $5^{th}$ %ile | $50^{th}$ %ile (Median) | $95^{th}$ %ile | Units |
|---|---|---|---|
| | | | |

15. NAME is the UK Met Office Lagrangian particle model which, for volcanic plumes, calculates ash and gas dispersion by tracking 'particles' through the modelled atmosphere. Particles move with the wind, with NAME applying a random component for the effects of atmospheric turbulence. For a source releasing $10^4$ kg/sec of $SO_2$ in a uniform wind field with constant windspeed 1 m/s at all heights, the model predicts a cloud width of 60 km at 50 km from the vent and, at 130 km distance, a width of 120 km. For the same model with windspeed 8 m/s, the cloud width is 13 km at 50 km distance; what is the modelled cloud width, in km, at 130 km distance?

| $5^{th}$ %ile | $50^{th}$ %ile (Median) | $95^{th}$ %ile | Units |
|---|---|---|---|
| | | | |

16. Tephra2 is an advection-diffusion tephra transport and sedimentation model, used to forecast accumulations of tephra across a region. One run (with typical Tephra2 model parameter values) modelled 20 x $10^6$ $m^3$ tephra erupting into a column 5 km high with wind speed profile 5 m/s constant from the surface to 5.5 km altitude. With a Gaussian grainsize distribution between phi = 6.64 (0.01mm) to 3.32 (10mm) and median grainsize phi = 1.66 (0.31 mm), Tephra2 predicted tephra loading of 110 kg/$m^2$ at 10km distance and 1.2 kg/$m^2$ at 50 km. For a finer ash size distribution, median phi = 4.15 (0.056mm), the model predicts 2.4 kg/$m^2$ at 50km distance. What was the predicted tephra loading 10 km distance (in kg/$m^2$)?

| $5^{th}$ %ile | $50^{th}$ %ile (Median) | $95^{th}$ %ile | Units |
|---|---|---|---|
| | | | |

17. Banks & Hoblitt (1996) measured pyroclastic flow deposit emplacement temperatures in the days and weeks after the 18 May 1980 Mt St Helens eruption. Six sites were measured in an area 5 to 6 km north of the crater. What was the average measured emplacement temperature for these samples, in °C?

| $5^{th}$ %ile | $50^{th}$ %ile (Median) | $95^{th}$ %ile | Units |
|---|---|---|---|
| | | | |

# Pisa Workshop elicitation - Seed questions, Part II

**Additional petrological/geochemistry seed items**

18. A study analysed near-liquidus residence times (NLRT) of phenocrysts from samples of a ~22 ka dacitic caldera-forming eruption of Santorini (Cape Riva eruption). Crystallisation occurred prior to eruption as melts ascended from ~10 – 16 km to 4 – 6 km. To calculate NLRT for the two stages, the authors used an experimentally-derived Mg diffusion coefficient and a two-stage model for equilibration. They calculated 'best estimate' lower (1st) stage NLRT residence times for rims in 14 plagioclase crystals in the dacite.

What was the median residence time, in years?

| **low end value (5th %ile)** | **median (50th %ile)** | **high end value (95th %ile)** |
|---|---|---|
| | | |

19. Trace element and isotope data for volcanic products of Kulumbo submarine volcano have been analysed with an electron microprobe, with 24 samples of biotite-bearing rhyolitic pumices yielding mean results: 73.6 wt.% $SiO_2$ and 4.18 wt.% $K_2O$.

What is the ratio of the standard deviations on these two sets of measurements, i.e. ratio = stdev{$SiO_2$} / stdev {$K_2O$}?

| **low end value (5th %ile)** | **median (50th %ile)** | **high end value (95th %ile)** |
|---|---|---|
| | | |

20. In a study of caldera-forming eruptions, data on published erupted magma geochemical compositions were compiled for each volcano using $SiO_2$ contents as a measure of differentiation, on the basis they show the largest variation over the igneous spectrum. Bulk-rock variation for each volcano was expressed as a 'filtered' range of values, between the 2.5th and 97.5th percentiles of the distribution for $SiO_2$ contents in weight percent. That is, values falling outside this range were censored by the authors before analysis, truncating the distributions in order to reduce sensitivity of their results to outliers. For Santorini volcano, 520 data values were available before filtering.

By how much did this tail truncation filtering reduce the spread of the original unfiltered range of $SiO_2$ contents, in wt% $SiO_2$?

| **low end value (5th %ile)** | **median (50th %ile)** | **high end value (95th %ile)** |
|---|---|---|
| | | |

## Santorini Workshop elicitation - Target questions, Part II

### *1650 eruption*

We start with questions related to the 1650 eruption and reconstruction key characteristics. Experts should familiarise themselves with relevant publications and presentations from our previous online meetings. We suggest that this is done before the meeting.

Q1. **Total volume (DRE) of the 1650 eruption (between 14 September and December)**.

***Q1. Concerning the 1650 eruption of Kulumbo, what do you judge its volume in km$^3$ (DRE)?***

***Please give your range of judgments for the low-end, median and high-end.***

| _____ | _____ | _____ |
|---|---|---|
| **Low (5$^{th}$)** | **Median (50$^{th}$)** | **High (95$^{th}$)** |

Q2. **The initial phase of 1650 eruption**.

***Q2a. What is the probability the initial magmatic eruption in 1650 was an extrusive phase?***

***Please give your range of judgments for the low-end, median and high-end probabilities of this happening, expressed as <u>percentage probabilities,</u> in range 0 – 100%.***

| _____ | _____ | _____ |
|---|---|---|
| ***Low (5$^{th}$)*** | ***Median (50$^{th}$)*** | ***High (95$^{th}$)*** |

***Q2b. What is the probability the initial magmatic eruption was an explosive phase?***

***Please give your range of judgments for the low-end, median and high-end probabilities of this happening, expressed as <u>percentage probabilities,</u> in range 0 – 100%.***

| _____ | _____ | _____ |
|---|---|---|
| ***Low (5$^{th}$)*** | ***Median (50$^{th}$)*** | ***High (95$^{th}$)*** |

NOTE: these two scenarios are exhaustive and mutually exclusive, thus your two median/central probabilities should sum approximately to 100%; in each scenario, your *Low* (5$^{th}$ percentile) and *High* probabilities (95$^{th}$ percentile) should express your uncertainty around the scenario Median (central) probability, and there is no requirement for these two outer marker quantiles to sum to 100% over the two scenarios – they are independent scenario-specific uncertainties.

Q3. **Characteristics of paroxysmal explosive eruption of 29 September 1650**. These questions relate to understanding of this eruption given the fragmentary and incomplete evidence. Note that some of the parameters in the questions below are related to one another and so these relations should be taken into account in responding.

***Q3a. Give your judgement of the likely duration of the paroxysmal explosive eruption, in hours.***

***Please give your range of judgments for the low-end, median and high-end values.***

| _____ | _____ | _____ |
|---|---|---|
| ***Low (5$^{th}$)*** | ***Median (50$^{th}$)*** | ***High (95$^{th}$)*** |

***Q3b. Give your judgement of the explosive eruption volume (DRE) of magma erupted in the paroxysmal explosive eruption, in km$^3$.***

***Please give your range of judgments for the low-end, median and high-end values.***

| _____ | _____ | _____ |
|---|---|---|
| ***Low (5$^{th}$)*** | ***Median (50$^{th}$)*** | ***High (95$^{th}$)*** |

***Q3c. Give your estimate of the mean discharge rate of magma in the paroxysmal explosive eruption, in m$^3$/s (assuming a density of 2400 kg/m$^3$).***

***Please give your range of judgments for the low-end, median and high-end values.***

| _____ | _____ | _____ |
|---|---|---|
| ***Low (5$^{th}$)*** | ***Median (50$^{th}$)*** | ***High (95$^{th}$)*** |

***Q3d. Give your estimate of the peak column height in this eruption, in kilometres. <u>Note that the height requested is the plume top.</u>***

***Please give your range of judgments for the low-end, median and high-end values.***

| _____ | _____ | _____ |
|---|---|---|
| ***Low (5$^{th}$)*** | ***Median (50$^{th}$)*** | ***High (95$^{th}$)*** |

***Q3e. Give your estimate of the mean column height during the paroxysmal eruption, in kilometres. <u>Note that the height requested is the plume top.</u>***

***Please give your range of judgments for the low-end, median and high-end values.***

| | | |
|---|---|---|
| _____ | _____ | _____ |
| ***Low ($5^{th}$)*** | ***Median ($50^{th}$)*** | ***High ($95^{th}$)*** |

***Q3f. Give your estimate of the mass fraction of sea water in the initial erupted mixture.***

***Please give your range of judgments for the low-end, median and high-end values.***

| | | |
|---|---|---|
| _____ | _____ | _____ |
| ***Low ($5^{th}$)*** | ***Median ($50^{th}$)*** | ***High ($95^{th}$)*** |

***Q3g. Give your estimate of the probability that pyroclastic density currents with run-out > 1 km were generated during the paroxysmal explosive eruption expressed as percentage probability values.***

***Please give your range of judgments for the low-end, median and high-end values.***

| | | |
|---|---|---|
| _____ | _____ | _____ |
| ***Low ($5^{th}$)*** | ***Median ($50^{th}$)*** | ***High ($95^{th}$)*** |

Q4. **Characteristics of gas emission events**. Many deaths occurred in the NE Thera region on 30th September 1650. Here these deaths are attributed to a volcanic gas cloud containing $H_2S$. $CO_2$ is also a hazardous gas and might an important hazard.

***Q4a. Concerning the gas poisoning of 30th September, what do you judge the $H_2S$ and $CO_2$ concentration to have been in the source eruption fluid in ppm ($H_2S$) and weight percentage ($CO_2$)?***

***Please give your range of judgments for the low-end, median and high-end.***

| | | |
|---|---|---|
| _____ | _____ | _____*($H_2S$)* |
| ***Low (5th)*** | ***Median (50th)*** | ***High (95th)*** |
| _____ | _____ | _____*($CO_2$)* |
| ***Low (5th)*** | ***Median (50th)*** | ***High (95th)*** |

**Q4b. Concerning the gas poisoning of 30th September, what do you judge the typical $H_2S$ concentration[1] of the gas cloud to have been when is reached NE Thera in ppm?**

**Please give your range of judgments for the low-end, median and high-end.**

| | | |
|---|---|---|
| _____ | _____ | _____ |
| **Low (5th)** | **Median (50th)** | **High (95th)** |

[1] The concentration of $H_2S$ will vary within a turbulent cloud. We are interested in the exposure of people to $H_2S$ so here the typical concentration of $H_2S$ near the ground for the duration of exposure to the cloud. Since concentration in detail will vary with time and the location of the individual typical here means an averaged concentration for the exposed population. The uncertainty here will include aleatory uncertainty related to the actual variation of concentration and epistemic uncertainty related to the source concentration.

## Future eruptions of Kulumbo and its associated volcanic field

Q5. **The location of the next eruption of Kulumbo volcanic field.** The Kulumbo volcano is part of a wider field of volcanic cones along a NE-SW lineament. The cones appear to be monogenetic but this might be a debating point.

***Q5a. What is the probability the next magmatic eruption of the Kulumbo volcanic field will vent in the existing main crater?***

***Please give your range of judgments for the low-end, median and high-end probabilities of this happening, expressed as <u>percentages</u> in range 0 – 100%.***

| _____ | _____ | _____ |
|---|---|---|
| ***Low (5$^{th}$)*** | ***Median (50$^{th}$)*** | ***High (95$^{th}$)*** |

***Q5b. What is the probability the next magmatic eruption will vent from within the area of the existing seamounts NE of the main edifice?***

***Please give your range of judgments for the low-end, median and high-end probabilities of this happening, expressed as <u>percentages</u> in range 0 – 100%.***

| _____ | _____ | _____ |
|---|---|---|
| ***Low (5$^{th}$)*** | ***Median (50$^{th}$)*** | ***High (95$^{th}$)*** |

***Q5c. What is the probability the next magmatic eruption will vent from a new vent outside of the volcanic field and thus extend the area of the Kulumbo volcanic field?***

***Please give your range of judgments for the low-end, median and high-end probabilities of this happening, expressed as <u>percentages</u> in range 0 – 100%.***

| _____ | _____ | _____ |
|---|---|---|
| ***Low (5$^{th}$)*** | ***Median (50$^{th}$)*** | ***High (95$^{th}$)*** |

NOTE: as these three scenarios are exhaustive and mutually exclusive, your three median/central probabilities should sum approximately to 100%; note, however, in each scenario your *Low* and *High* probabilities serve to express your uncertainty on the scenario Median (central) probability, and there is no requirement for these quantiles to sum to 100% or anything else over the four scenarios – they are independent scenario-specific uncertainty intervals about the median.

Q6. **Magma composition of the next eruption within the Kulumbo field**.

***Q6. What do you judge to be the probability that the next eruption within the Kulumbo volcanic field will have the following dominant compositions (a) rhyolite and/or rhyodacite; (b) andesite and/or dacite; (c) basalt?***

***Please give your range of judgments for the low-end, median and high-end. The central (median) value of the three answers should sum to 100%.***

| | | |
|---|---|---|
| _____ | _____ | _____ **(rhy)** |
| **Low (5th)** | **Median (50th)** | **High (95th)** |
| _____ | _____ | _____**(and/dac)** |
| **Low (5th)** | **Median (50th)** | **High (95th)** |
| _____ | _____ | _____**(basalt)** |
| **Low (5th)** | **Median (50th)** | **High (95th)** |

Q7. **Volume (DRE) of the next eruption** within the Kulumbo volcanic field and **volume of existing shallow magma chamber** based on your understanding of geophysical and petrological observations.

***Q7a. Given the location of the next eruption is in the main crater of the cone associated with the 1650 eruption, what do you judge its DRE volume, in $km^3$***

***Please give your range of judgments for the low-end, median and high-end.***

| | | |
|---|---|---|
| _____ | _____ | _____ |
| ***Low (5th)*** | ***Median (50th)*** | ***High (95th)*** |

***Q7b. Given the location of the next eruption is within the Kulumbo field but is not located at the 1650 cone, what do you judge its DRE volume, in $km^3$.***

***Please give your range of judgments for the low-end, median and high-end.***

| | | |
|---|---|---|
| _____ | _____ | _____ |
| **Low (5th)** | **Median (50th)** | **High (95th)** |

***Q7c. What is the current volume of eruptible magma in the shallow chamber identified by geophysical imaging?***

**Please give your range of judgments for the low-end, median and high-end DRE volume estimates, in $km^3$.**

| Low ($5^{th}$) | Median ($50^{th}$) | High ($95^{th}$) |
|---|---|---|
| _____ | _____ | _____ |

For planning purposes, it may be helpful for decision-makers to know what likelihood volcanologists judge for the next eruption occurring within the next 30 years.

Q8. **Likelihood of an eruption within the Kulumbo volcanic field in the next 30 years**. Note that here we are not specifying that the next eruption need be like 1650 in terms of magnitude or eruption characteristics. The likelihood of an eruption like 1650 occurring in the next 30 years can be calculated using the results from Q9.

***Q8. What is the probability of an eruption within the volcanic field in the next 30 years?***

***Please give your range of judgments for the low-end, median and high-end, expressed as a percentage probability in range 0 – 100%.***

| Low ($5^{th}$) | Median ($50^{th}$) | High ($95^{th}$) |
|---|---|---|
| _____ | _____ | _____ |

NOTE: you can use decimal values to express small (or large) probabilities. For example, if you judge there is only a 1 – in – 5000 chance in the next 30 years, this would be expressed as 0.02% in the elicitation response, and so on.

Q9. **Volume of the next eruption if located in the Main Cone and within the next 30 years**. If there is a new eruption of Kulumbo volcano located in the Main Cone, what is the likelihood this eruption will have volume similar to 1650 or an order of magnitude smaller or greater. To be specific "similar' here means within a factor of 3 (half an order of magnitude) of the 1650 eruption.

***Q9a. The probability of a next eruption from the Main Cone within the next 30 years will have a volume SIMILAR to 1650, within an order of magnitude?***

***Please give your range of judgments for the low-end, median and high-end probabilities of this happening, expressed as <u>percentages</u> in range 0 – 100%.***

| _____ | _____ | _____ |
|---|---|---|
| ***Low ($5^{th}$)*** | ***Median ($50^{th}$)*** | ***High ($95^{th}$)*** |

***Q9b. The probability of a first new eruption in the next 30 years will have a much smaller volume than 1650, say 10x SMALLER than 1650 or less?***

***Please give your range of judgments for the low-end, median and high-end probabilities of this happening, expressed as <u>percentages</u> in range 0 – 100%.***

| _____ | _____ | _____ |
|---|---|---|
| ***Low ($5^{th}$)*** | ***Median ($50^{th}$)*** | ***High ($95^{th}$)*** |

***Q9c. The probability of a first new eruption in the next 30 years will have a much greater volume than 1650, say 10x GREATER than 1650 or more?***

***Please give your range of judgments for the low-end, median and high-end probabilities of this happening, expressed as <u>percentages</u> in range 0 – 100%.***

| _____ | _____ | _____ |
|---|---|---|
| ***Low ($5^{th}$)*** | ***Median ($50^{th}$)*** | ***High ($95^{th}$)*** |

NOTE: as these three alternative order-of-magnitude scenarios are exhaustive and mutually exclusive, your four median/central probabilities should sum approximately to 100%; note, however, in each scenario your *Low* and *High* probabilities serve to express your uncertainty on the scenario Median (central) probability, and there is no requirement for these quantiles to sum to 100% or anything else over the three scenarios – they are independent scenario-specific uncertainty intervals about the median.

So called false alarms can be a major problem. The next question asks about your probability judgement that the next episode of major unrest does not lead to an eruption. The question will need some discussion within the group of what phenomena would constitute major unrest for Kulumbo volcano.

Q10. **Probability of unrest in next 30 years BUT no eruption occurs**.

***Q10. If the next episode at Kulumbo volcano in the next 30 years is a major unrest crisis, what is the probability it will not be followed by a magmatic eruption within six months?***

***Please give your range of judgments for the low-end, median and high-end, expressed as a percentage probability in range 0 – 100%.***

| _____ | _____ | _____ |
|---|---|---|
| **Low (5th)** | **Median (50th)** | **High (95th)** |

**Q11. Duration of precursory unrest and duration of next eruption if within the next 30 years.** These questions address how much warning might be expected prior to a future eruption from unrest and how long the eruption might last. Both are important for preparation and mitigation planning. In this question there is no constraint on when this eruption might happen.

***Q11a. How long in days would precursory and recognisable unrest last prior to onset of an eruption?***

***Please give your range of judgments for the low-end, median and high-end.***

| _____ | _____ | _____ |
|---|---|---|
| ***Low (5th)*** | ***Median (50th)*** | ***High (95th)*** |

**Q11b How long would the next eruption last in days?**

**Please give your range of judgments for the low-end, median and high-end.**

| _____ | _____ | _____ |
|---|---|---|
| **Low (5th)** | **Median (50th)** | **High (95th)** |

Q12. **Initial phase of future eruption of Kulumbo volcano located in Main Cone.**

***Q12a. If an eruption occurs in the next 30 years, what is the probability the initial magmatic phase of the next eruption from Kulumbo Main Crater will be effusive?***

***Please give your range of judgments for the low-end, median and high-end probabilities of this happening, expressed as percentage probabilities in range 0 – 100%.***

| _____ | _____ | _____ |
|---|---|---|
| ***Low ($5^{th}$)*** | ***Median ($50^{th}$)*** | ***High ($95^{th}$)*** |

***Q12b. If an eruption occurs in the next 30 years, what is the probability the initial magmatic phase of the next eruption from Kulumbo Main Crater will be explosive?***

***Please give your range of judgments for the low-end, median and high-end probabilities of this happening, expressed as percentage probabilities in range 0 – 100%.***

| _____ | _____ | _____ |
|---|---|---|
| ***Low ($5^{th}$)*** | ***Median ($50^{th}$)*** | ***High ($95^{th}$)*** |

NOTE: for Q12 a,b median/central probabilities should sum approximately to 100%.

Q13. **Time of submarine pumice cone building**. Up to now, we mostly consider that the explosive submarine pumice cone building activity started at 14/09/1650 and lasted up to 26/09/1650, when the first subaerial explosive events were observed and the first pumice mass outcropped over the sea level. This time interval might be different in a future eruption because the initial topography is different and other factors, such as magma flux, might affect the time interval. The question is for an eruption occurring within the next 30 years.

***Q13. In the next eruption if explosive submarine pumice cone building activity begins (and is promptly detected) AND subsequently a pumice outcrop breaks sea surface, how long might this take, in days.***

***Please give your range of judgments for the low-end, median and high-end elapsed time, expressed in days.***

| _____ | _____ | _____ |
|---|---|---|
| **Low (5th)** | **Median (50th)** | **High (95th)** |

Q14. **Tsunami Hazard.**

***Q14a. If the next eruption of Kulumbo is located in the Main Crater and occurs within the next 30 years, producing explosions, what is the probability that at least one major tsunami[2] occurs during the eruption?***

***Please give your range of judgments for the low-end, median and high-end probabilities of this happening, expressed as <u>percentages</u> in range 0 – 100%.***

| _____ | _____ | _____ |
|---|---|---|
| ***Low (5th)*** | ***Median (50th)*** | ***High (95th)*** |

***Q14b. If the next eruption of Kulumbo is located outside of the Main Crater but in the Kulumbo volcanic field and occurs within the next 30 years, what is the probability that at least one major tsunami occurs during the eruption?***

***Please give your range of judgments for the low-end, median and high-end probabilities of this happening, expressed as <u>percentages</u> in range 0 – 100%.***

| _____ | _____ | _____ |
|---|---|---|
| ***Low (5th)*** | ***Median (50th)*** | ***High (95th)*** |

[2] Here a major tsunami is defined as one that has a 1 metre or greater wave height on the NE Coast of Thera.

***Q14c. If the next eruption of Kulumbo located in the Main Crater occurs within the next 30 years, producing explosions, what is the probability that a major tsunami will be generated during a paroxysmal explosive eruption?***

***Please give your range of judgments for the low-end, median and high-end probabilities of this happening, expressed as <u>percentages</u> in range 0 – 100%.***

| _____ | _____ | _____ |
|---|---|---|
| ***Low ($5^{th}$)*** | ***Median ($50^{th}$)*** | ***High ($95^{th}$)*** |

***Q14d. If the next eruption from Kulumbo is located in the Main Crater and occurs within the next 30 years, what is the probability that at least one ≥1 m, ≥5 m and ≥10 m wave will reach the NE coast of Santorini?***

***Please give your range of judgments for the low-end, median and high-end probabilities of this happening, expressed as <u>percentages</u> in range 0 – 100%.***

| _____ | _____ | _____ |
|---|---|---|
| **Low ($5^{th}$)** | **Median ($50^{th}$)** | **High ($95^{th}$) (≥ 1 m)** |
| _____ | _____ | _____ |
| **Low ($5^{th}$)** | **Median ($50^{th}$)** | **High ($95^{th}$) (≥ 5m)** |
| _____ | _____ | _____ |
| **Low ($5^{th}$)** | **Median ($50^{th}$)** | **High ($95^{th}$) (≥ 10 m)** |

NOTE: these scenarios involve two different conditional probabilities and the only logical condition is: Q14d (≥ 10 m) < Q14d (≥ 5m) < Q14d (≥ 1 m).

Q15. **Ash and Pyroclastic Density Current (PDC) hazards**. We now consider various eruptive phenomena and eruption related hazards in the next eruption, assuming it occurs in the next 30 years.

***Q15a. If there is a paroxysmal eruption in the next eruption from Kulumbo Main Cone within the next 30 years, what is the probability it will generate a high eruption column that reaches the upper troposphere or stratosphere, i.e approximately 20 km a.s.l. (with reference to the plume top)?***

***Please give your range of judgments for the low-end, median and high-end probabilities of this happening, expressed as <u>percentages</u> in range 0 – 100%.***

| _____ | _____ | _____ |
|---|---|---|
| ***Low ($5^{th}$)*** | ***Median ($50^{th}$)*** | ***High ($95^{th}$)*** |

***Q15b. What would be the mean height (plume top) of the eruption column, given this paroxysmal eruption?***

***Please give your range of judgments for the low-end, median and high-end probabilities of this happening, expressed as <u>km</u>.***

| _____ | _____ | _____ |
|---|---|---|
| ***Low ($5^{th}$)*** | ***Median ($50^{th}$)*** | ***High ($95^{th}$)*** |

***Q15c. What would be the duration of the paroxysmal phase of this future eruption?***

***Please give your range of judgments for the low-end, median and high-end elapsed time, expressed in hours.***

| _____ | _____ | _____ |
|---|---|---|
| ***Low ($5^{th}$)*** | ***Median ($50^{th}$)*** | ***High ($95^{th}$)*** |

***Q15d. If there is a paroxysmal eruption from the Kulumbo volcanic field, what is the probability that at least one pyroclastic density currents with run-out > 1 km is formed?***

***Please give your range of judgments for the low-end, median and high-end probabilities of this happening, expressed as <u>percentages</u> in range 0 – 100%.***

| _____ | _____ | _____ |
|---|---|---|
| ***Low ($5^{th}$)*** | ***Median ($50^{th}$)*** | ***High ($95^{th}$)*** |

***Q15e. If such a pyroclastic density current forms, what is the probability of run-out of > 3, >7 and >15 km?***

***Please give your range of judgments for the low-end, median and high-end probabilities of this happening, expressed as <u>percentages</u> in range 0 – 100%. Three sets of answers are required in the order >3, >7, and >15 km.***

| | | |
|---|---|---|
| _____ | _____ | _____ *(>3 km)* |
| *Low ($5^{th}$)* | *Median ($50^{th}$)* | *High ($95^{th}$)* |
| _____ | _____ | _____ *(>7 km)* |
| *Low ($5^{th}$)* | *Median ($50^{th}$)* | *High ($95^{th}$)* |
| _____ | _____ | _____*(>15 km)* |
| *Low ($5^{th}$)* | *Median ($50^{th}$)* | *High ($95^{th}$)* |

Q16. **Gas hazard.** Death related to lethal concentrations of volcanic gas are suspected in 1650, so the following questions address this hazard for the next eruption of Kulumbo volcano from the Main Cone.

***Q16a.What is the probability that the next eruption of Kulumbo volcano occurring in the next 30 years involves generation of a density current largely composed of volcanic gas and entrained air?***

***Please give your range of judgments for the low-end, median and high-end probabilities of this happening, expressed as <u>percentages</u> in range 0 – 100%.***

| | | |
|---|---|---|
| _____ | _____ | _____ |
| *Low ($5^{th}$)* | *Median ($50^{th}$)* | *High ($95^{th}$)* |

***Q16b. If such a gas density current forms, what do you judge to be the initial $H_2S$ concentration (ppm) and the $CO_2$ concentration (weight percent) in the erupted mixture?***

**Please give your range of judgments for the low-end, median and high-end.**

| | | |
|---|---|---|
| _____ | _____ | _____ *($H_2S$)* |
| *Low ($5^{th}$)* | *Median ($50^{th}$)* | *High ($95^{th}$)* |
| _____ | _____ | _____ *($CO_2$)* |
| *Low ($5^{th}$)* | *Median ($50^{th}$)* | *High ($95^{th}$)* |

**Q16c. If such a gas density current forms what is the probability that the gas density current will reach >3, >7 and >15 km distance from the vent to the west?**

**Please give your range of judgments for the low-end, median and high-end probabilities of this happening, expressed as <u>percentages</u> in range 0 – 100%.**

| | | |
|---|---|---|
| _____ | _____ | _____*(>3 km)* |
| ***Low (5th)*** | ***Median (50th)*** | ***High (95th)*** |
| _____ | _____ | _____ *(>7 km)* |
| ***Low (5th)*** | ***Median (50th)*** | ***High (95th)*** |
| _____ | _____ | _____ *(>15 km)* |
| ***Low (5th)*** | ***Median (50th)*** | ***High (95th)*** |

**Q16d. If such a gas density current reaches the NE Coast of Thera, what do you judge to be the typical $H_2S$ concentration (ppm) and the $CO_2$ concentration (weight percent) in the erupted mixture?**

**Please give your range of judgments for the low-end, median and high-end.**

| | | |
|---|---|---|
| _____ | _____ | _____ *($H_2S$)* |
| ***Low (5th)*** | ***Median (50th)*** | ***High (95th)*** |
| _____ | _____ | _____ *($CO_2$)* |
| ***Low (5th)*** | ***Median (50th)*** | ***High (95th)*** |

***Q16e.*** **How long will the discharge of volcanic gas to supply the gas density current last in hours?**

**Please give your range of judgments for the low-end, median and high-end values.**

| | | |
|---|---|---|
| _____ | _____ | _____ |
| **Low (5th)** | **Median (50th)** | **High (95th)** |

Q17. **$CO_2$ hazard.** $CO_2$ is a prominent gas in the fumaroles within Kulumbo Crater and concentrations of dissolved $CO_2$ are developing within the water column. This $CO_2$ can be released if $CO_2$-rich water from deep comes to the surface likely due to some disturbance. Concentrated $CO_2$ flows can be lethal as exemplified by the release at Lake Nyos in Cameroon.

Contemporaneous earthquakes could occur by coincidence.

***Q17a. What is the probability that a $CO_2$ release could occur in association with the next eruption of Kulumbo in the next 30 years?***

***Please give your range of judgments for the low-end, median and high-end probabilities of this happening, expressed as <u>percentages</u> in range 0 – 100%.***

| _____ | _____ | _____ |
|---|---|---|
| ***Low ($5^{th}$)*** | ***Median ($50^{th}$)*** | ***High ($95^{th}$)*** |

***Q17b. What is the probability that a $CO_2$ release could occur in association with a period of volcanic unrest but no consequent eruption of Kulumbo in the next 30 years?***

***Please give your range of judgments for the low-end, median and high-end probabilities of this happening, expressed as <u>percentages</u> in range 0 – 100%.***

| _____ | _____ | _____ |
|---|---|---|
| ***Low ($5^{th}$)*** | ***Median ($50^{th}$)*** | ***High ($95^{th}$)*** |

***Q17c. What is the probability that a $CO_2$ release occurs unrelated to either a period of volcanic unrest or an eruption in the next 30 years?***

***Please give your range of judgments for the low-end, median and high-end probabilities of this happening, expressed as <u>percentages</u> in range 0 – 100%.***

| _____ | _____ | _____ |
|---|---|---|
| ***Low ($5^{th}$)*** | ***Median ($50^{th}$)*** | ***High ($95^{th}$)*** |

***Q17d. If there is a release of $CO_2$ what is the volume in $m^3$ of the release assuming Standard Temperature and Pressure?***

***Please give your range of judgments for the low-end, median and high-end probabilities of this happening, expressed as <u>percentages</u> in range 0 – 100%.***

| _____ | _____ | _____ |
|---|---|---|
| ***Low ($5^{th}$)*** | ***Median ($50^{th}$)*** | ***High ($95^{th}$)*** |

***Q17e. If there is a release of $CO_2$ over what time scale would it be released?***

***Please give your range of judgments for the low-end, median and high-end probabilities of this happening, expressed as <u>hours</u> in range 0 – 100%.***

| _____ | _____ | _____ |
|---|---|---|
| ***Low ($5^{th}$)*** | ***Median ($50^{th}$)*** | ***High ($95^{th}$)*** |

## Pisa Workshop elicitation - Target questions, Part II

### *1650 eruption*

Q3. **Characteristics of paroxysmal explosive eruption of 29 September 1650**. The following question relates to understanding of this eruption given the fragmentary and incomplete evidence.

Q3g. Give your estimate of the probability that pyroclastic density currents with run-out > 1 km were generated during the paroxysmal explosive eruption expressed as percentage probability values.
*Re-Elicited*

| **low end value (5th %ile)** | **median (50th %ile)** | **high end value (95th %ile)** |
|---|---|---|
| | | |

Q4. **Characteristics of gas emission events**. Many deaths occurred in the NE Thera region on 30th September 1650. Here these deaths are attributed to a volcanic gas cloud containing $H_2S$. $CO_2$ is also a hazardous gas and might an important hazard.
Conversion factor: 1wt% = $10^4$ ppm

Q4a3. Concerning the gas poisoning of 30th September, what do you judge the $SO_2$ concentration to have been in the source eruption fluid in weight percentage?
*NEW*

| **low end value (5th %ile)** | **median (50th %ile)** | **high end value (95th %ile)** |
|---|---|---|
| | | |

Q4b2 Concerning the gas poisoning of 30th September what do you judge the typical $SO_2$ concentration of the gas cloud to have been when is reached NE Thera in ppm?
*NEW*

| **low end value (5th %ile)** | **median (50th %ile)** | **high end value (95th %ile)** |
|---|---|---|
| | | |

## *Future eruptions of Kulumbo and its associated volcanic field*

Q5. **The location of the next eruption of Kulumbo volcanic field.** The Kulumbo volcano is part of a wider field of volcanic cones along a NE-SW lineament. The cones appear to be monogenetic but this might be a debating point.

Q5a. What is the probability the next magmatic eruption of the Kulumbo volcanic field will vent in the existing main crater?
*Re-Elicited*

| **low end value (5th %ile)** | **median (50th %ile)** | **high end value (95th %ile)** |
|---|---|---|
| | | |

Q5b. What is the probability the next magmatic eruption will vent from within the area of the existing seamounts NE of the main edifice?
*Re-Elicited*

| **low end value (5th %ile)** | **median (50th %ile)** | **high end value (95th %ile)** |
|---|---|---|
| | | |

Q5c. What is the probability the next magmatic eruption will vent from a new vent outside of the volcanic field and thus extend the area of the Kulumbo volcanic field?
*Re-Elicited*

| **low end value (5th %ile)** | **median (50th %ile)** | **high end value (95th %ile)** |
|---|---|---|
| | | |

Q6. **Magma composition of the next eruption within the Kulumbo field**.

Q6a. What do you judge to be the probability that the next eruption within the Kulumbo volcanic field will have a dominant rhyolite and/or rhyodacite composition?
*Re-Elicited*

| **low end value (5th %ile)** | **median (50th %ile)** | **high end value (95th %ile)** |
|---|---|---|
| | | |

Q6b. What do you judge to be the probability that the next eruption within the Kulumbo volcanic field will have a dominant andesite and/or dacite composition?
*Re-Elicited*

| **low end value (5th %ile)** | **median (50th %ile)** | **high end value (95th %ile)** |
|---|---|---|
| | | |

Q6c. What do you judge to be the probability that the next eruption within the Kulumbo volcanic field will have a dominant basalt composition?
*Re-Elicited*

| **low end value (5th %ile)** | **median (50th %ile)** | **high end value (95th %ile)** |
|---|---|---|
| | | |

Q7. **Volume (DRE) of the next eruption** within the Kulumbo volcanic field and **volume of existing shallow magma chamber** based on your understanding of geophysical and petrological observations.

Q7b. Given the location of the next eruption is within the Kulumbo field but is not located at the 1650 cone, what do you judge its DRE volume, in $km^3$?
*Re-Elicited*

| **low end value (5th %ile)** | **median (50th %ile)** | **high end value (95th %ile)** |
|---|---|---|
| | | |

Q8. **Likelihood of an eruption within the Kulumbo volcanic field in the next 30 years**. Note that here we are not specifying that the next eruption need be like 1650 in terms of magnitude or eruption characteristics. The likelihood of an eruption like 1650 occurring in the next 30 years can be calculated using the results from Q5.

Q8a. What is the likely time interval between now and next eruption from Kulumbo main cone?
*NEW*

| **low end value (5th %ile)** | **median (50th %ile)** | **high end value (95th %ile)** |
|---|---|---|
| | | |

Q14. **Tsunami Hazard.**

Q14b. If the next eruption of Kulumbo is located outside of the Main Crater but in the Kulumbo volcanic field and occurs within the next 30 years, what is the probability that at least one major tsunami occurs during the eruption?
Please give your range of judgments for the low-end, median and high-end probabilities of this happening, expressed as percentages in range 0 – 100%.
*Re-Elicited*

| **low end value (5th %ile)** | **median (50th %ile)** | **high end value (95th %ile)** |
|---|---|---|
| | | |

Q15. **Ash and Pyroclastic Density Current (PDC) hazards**. We now consider various eruptive phenomena and eruption related hazards in the next eruption, assuming it occurs in the next 30 years.

Q15d. If there is a paroxysmal eruption from the Kulumbo volcanic field, what is the probability that at least one pyroclastic density currents with run-out > 1 km is formed?
Please give your range of judgments for the low-end, median and high-end probabilities of this happening, expressed as percentages in range 0 – 100%.
*Re-Elicited*

| **low end value (5th %ile)** | **median (50th %ile)** | **high end value (95th %ile)** |
|---|---|---|
| | | |

Q15e1. If such a pyroclastic density current forms, what is the probability of run-out of > 3 km?
Please give your range of judgments for the low-end, median and high-end probabilities of this happening, expressed as percentages in range 0 – 100%.
*Re-Elicited*

| **low end value (5th %ile)** | **median (50th %ile)** | **high end value (95th %ile)** |
|---|---|---|
| | | |

Q15e2. If such a pyroclastic density current forms, what is the probability of run-out of >7 km?
Please give your range of judgments for the low-end, median and high-end probabilities of this happening, expressed as percentages in range 0 – 100%.
*Re-Elicited*

| **low end value (5th %ile)** | **median (50th %ile)** | **high end value (95th %ile)** |
|---|---|---|
| | | |

Q15e3. If such a pyroclastic density current forms, what is the probability of run-out of >15 km?
Please give your range of judgments for the low-end, median and high-end probabilities of this happening, expressed as percentages in range 0 – 100%.
*Re-Elicited*

| **low end value (5th %ile)** | **median (50th %ile)** | **high end value (95th %ile)** |
|---|---|---|
| | | |

Q16. **Gas hazard.** Death related to lethal concentrations of volcanic gas are suspected in 1650, so the following questions address this hazard for the next eruption of Kulumbo volcano from the Main Cone.

Q16b3. If such a gas density current forms, what do you judge to be the initial SO2 concentration (weight percent) in the erupted mixture?
*NEW*

**low end value (5th %ile)** **median (50th %ile)** **high end value (95th %ile)**

Q16c1. If such a gas density current forms what is the probability that the gas density current will reach > 3 km distance from the vent to the Southwest?
*Re-Elicited*

**low end value (5th %ile)** **median (50th %ile)** **high end value (95th %ile)**

Q16c2 If such a gas density current forms what is the probability that the gas density current will reach > 7 km distance from the vent to the Southwest?
*Re-Elicited*

**low end value (5th %ile)** **median (50th %ile)** **high end value (95th %ile)**

Q16c3 If such a gas density current forms what is the probability that the gas density current will reach > 15 km distance from the vent to the Southwest?
*Re-Elicited*

**low end value (5th %ile)** **median (50th %ile)** **high end value (95th %ile)**

Q16d3 If such a gas density current reaches the NE Coast of Thera, what do you judge to be the typical SO2 concentration (ppm) in the erupted mixture?
*NEW*

**low end value (5th %ile)** **median (50th %ile)** **high end value (95th %ile)**