CSQ-52 Summary

Question	Knowledge Advancement Objectives	Observables	Measurement Requirements	Tools & Models	Policies / Benefits
How can we help predict a volcanic event through the detection of thermal transient phenomena, gas emissionis and surface deformation evidences	A) Ability to estimate the changing magma supply volume and depth beneath volcanos via the changing in shape of the volcano and Expansion or contraction of the summit region	• Surface deformation vertical and horizontal • Surface velocity • Surface topography	• < 10 mm • < 1 cm/year • <50 cm horizontal • < 1m vertical	Insar techniques GNSS networks High resolution visible images	Emergency planning and volcanic eruption forecast Climate effects of large volcanic eruptions
	B) Assessment of surface vertical deformation extent and atmospheric contamination, and composition and temperature of volcanic products following volcanic eruption	• Surface Deformation • Atmospheric composition at different distances from the volcano (columnar content and vertical distribution) • Surface topography	• <10mm • <100m resolution • 200 km observed area • hourly to daily sampling • <50 cm horizontal • <1 m vertical	Optical and IR sensors to measure optical depth, ash content, particle size	
	C) Measurement of the composition and quantity of the gas emitted prior to and during an eruption as well as the composition of any ash.	• Volcano degassing plume composition • Aerosols • Volcano eruptive plume composition	• Every 2-3 days pre-eruptive • (ppmTBD) • Hourly during eruption	Measure columnar content and flux of gas species emitted by volcanoes (CO_2, SO_2, H_2S, KCL) and H_2O Develop suitable atmospheric Radiative transfer models	
	D) Inference of changes at shallow depths as magma reaches the uppermost plumbing system prior to an eruption	• Ground Surface Temperature • Lava Lake Temperature	• <0.5 K • < 3 K • Weekly to daily		

	E) Capturing transient behaviour in an ongoing eruption to model the vent-scale processes	• Volcano Surface structure / composition imagery	High temporal repeat (hours to days)		
	F) Routinely monitor the of Earth's entire active land volcano inventory (pre-, syn-, and post eruption) surface deformation and products of Earth's entire active land volcano inventory.	• Surface deformation Composition of emissions	time scale of days to weeks.	Photogrammetric Techniques Structure from motion techniques	

CSQ-52 Narrative

Volcanic unrest is a complex multi-hazard phenomenon of volcanism. Although it is fair to assume that probably all volcanic eruptions are preceded by some form of unrest, the cause and effect relationship between subsurface processes and resulting unrest signals (geophysical or geochemical data recorded at the ground surface, phenomenological observations) is unclear and surrounded by uncertainty (e.g., Wright and Pierson 1992). Unrest may, or may not lead to eruption in the short-term (days to months). If an eruption were to ensure it may involve the eruption of magma or may be non-magmatic and mainly driven by expanding steam and hot water (hydrothermal fluids). These conundrums contribute significant uncertainty to short-term hazard assessment and forecasting of volcanic activity and have profound impact on the management of unrest crises (e.g., Marzocchi and Woo 2007).

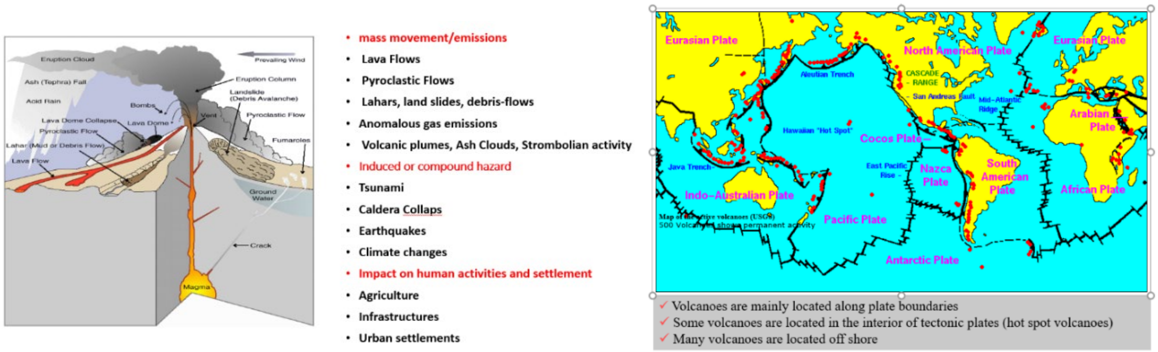

Figure 34: Volcano processes and distribution

While institutional and individual decision-making in response to this unrest should promote the efficient and effective mitigation or management of risk, informed decision-making is fundamentally dependent on the early and reliable identification of changes in the subsurface dynamics of a volcano and their "correct" assessment as precursors to an impending eruption. However, uncertainties in identifying the causative processes of unrest impact significantly on the ability to "correctly" forecast the short-term evolution of unrest.

The interaction between hydrological and volcanic systems is an important element in volcanic unrest. Changes in hydrological behaviour, such as water table elevation, spring discharge, temperature and chemistry, at an active volcano can provide early indications of changes in volcanic activity. Hydrological interactions can also alter and augment the existing volcanic hazard. Chemical and physical interactions between host rocks and different fluid types can modify fluid degassing pathways, generating dynamic pressure distributions within a volcanic edifice

A magmatic hydrothermal system is composed of three main elements: a host rock (or reservoir), which contains a circulating fluid, set in motion by an igneous heat source. While the difference in relief between stratovolcanoes and calderas can lead to contrasting hydrological systems, secondary processes (e.g. hydrothermal system perturbation, meteorological forcing) modify primary signals from deeper-seated magmatic processes.

Gas and aerosol emissions

Volcanic gases are one of the main tools used to monitor changes in the activity of volcanoes and forecast their eruption. This approach is rooted in the strong pressure dependence of the solubility of volatiles (mainly H_2O, CO_2, SO_2, H_2S, Cl) in silicate melts. Accordingly, magma ascent toward the surface is associated with the exsolution of volatiles initially dissolved in the melt, a process designated as "magma degassing". The different volatiles have contrasted solubilities in silicate melts and, therefore, are expected to react differently to decompression. This forms the basis for using volcanic gas ratios to infer magma ascent and depth of gas segregation in volcanic conduits. For example, the sudden increase of gas CO_2/SO_2

ratio has been used as an indication for deep magma recharge at Stromboli (Aiuppa et al. 2010). At Soufriere Hills volcano (Montserrat), a correlation has been noted between gas HCl/SO2 and the level of shallow activity as marked by the rate of lava extrusion and dome growth (Christopher et al. 2010; Edmonds et al. 2010).

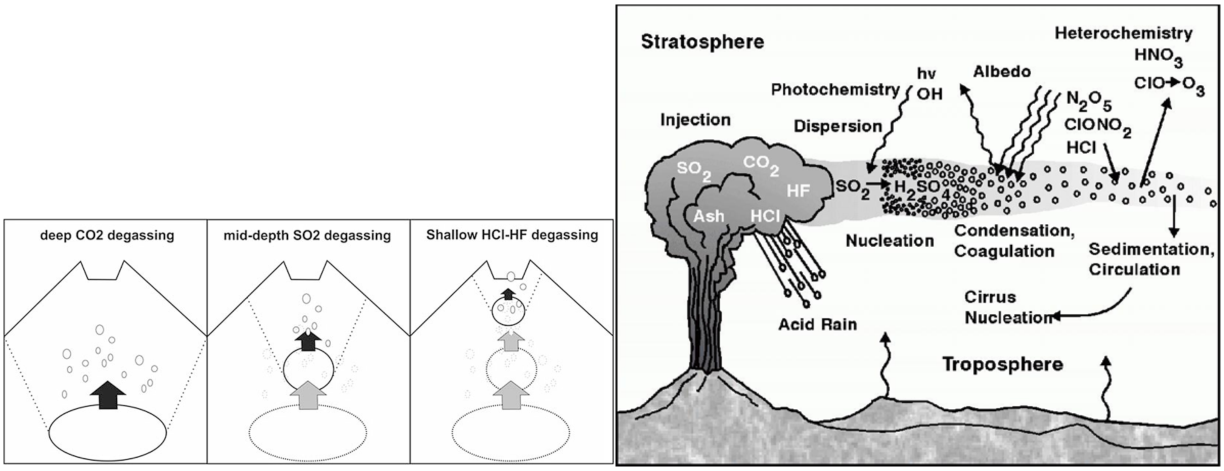

Figure 35: Volcano gas and aerosol emissions

Which gas species are released, how much and when? When a magma starts to degas, by any of the above processes, the less soluble species is released first (i.e. at higher confining pressure in the magma chamber). The order in solubility of indicative magmatic gas species is CO2 < SO2 < HCl < HF; the order of release when a magma progressively degasses is “CO2-first till HF-last”

Temperature characteristics

Some volcanoes have thermal features such as smoking vents, geysers, hot springs, lava flows or lava domes. Surface temperature changes at these thermal features sometimes occur before a volcanic eruption. Recognition of these “thermal anomalies” can be useful in predicting changes in activity.

- Steam, or vapor-dominated features such as gas vents, fumaroles, and mud pots range in temperature from boiling up to several hundred degrees (about 400 °C or 750 °F).
- Water-dominated features include geysers, hot springs/pools, crater lakes, elevated sea surface temperature (e.g., from underwater or island volcanic activity), and even melting ice (e.g., sub-glacial volcanoes). These range in temperature from freezing to boiling.
- Lava-dominated features include lava lakes, lava flows, lava domes, and pyroclastic flows, and can reach temperatures up to about 1200 °C (2200 °F).

Deformation monitoring in volcanic areas

Volcanic eruptions are often preceded by small changes in the shape of the volcano. Such volcanic deformation may be measured using precise surveying techniques and analysed to better understand volcanic processes. Complicating the matter is the fact that deformation events (e.g., inflation or deflation) may result from magmatic, non-magmatic or mixed/hybrid sources. Using spatial and temporal patterns in volcanic deformation data and mathematical models it is possible to infer the location and strength of the subsurface driving mechanism.

Detectable changes in volcano shape, gas emissions, and thermal output prior to a new eruption event occur over time scales ranging from months to minutes. The relevant length scales are 10 m to 200 km for surface and plume measurements, with most shape changes occurring over length scales greater than 1km.

The necessary vertical precision (1-10 mm) and the temporal frequency need to be adjusted to match the activity of a particular volcano.

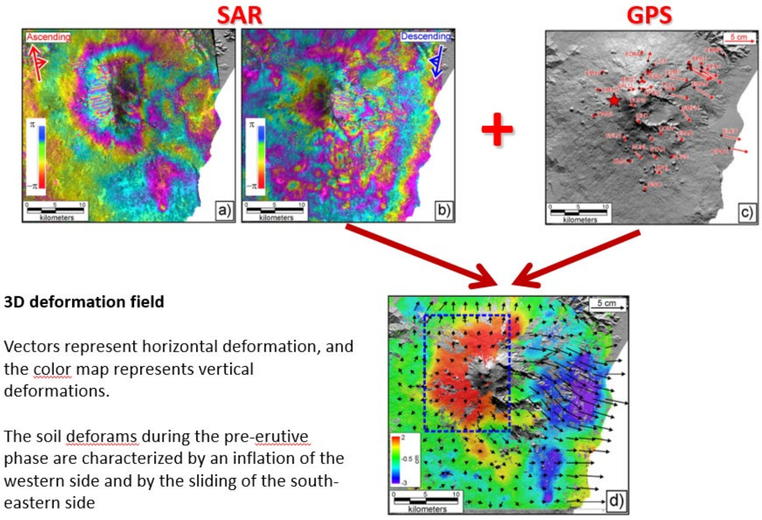

Figure 36: Volcanic monitoring of the pre-eruptive phase of Mt Etna (INGV)