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PART VI:

SUMMARY AND CONCLUSIONS

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Despite the existence of important limitations, experimental, and theoretical/numerical modelling have represented a significant advance in the understanding of caldera collapse processes. In combination with traditional field studies, the development of experimental and theoretical models has allowed us to determine the causes and mechanisms that control caldera collapse. They provide a clear idea on how and when caldera collapse will occur and on how the resulting structure will look like.

The combination of field studies with experimental and theoretical/numerical and modelling allows us to identify and quantify the main controlling factors on the formation of collapse calderas. These include magma chamber size and shape, magma chamber depth, host rock rheology, previous history of deformation, topography, regional tectonics, temperature field around the magma chamber, and magma composition and rheology. In the same way, the critical role of the magma chamber shape, roof aspect ratio, and volume fraction of erupted magma on the resulting caldera structure has also been determined using experimental and theoretical modelling. It has also been possible to prove that fractures and faults controlling caldera subsidence may nucleate both at surface and at depth and that conditions for caldera collapse may be achieved in magma chambers subjected to both overpressure and underpressure.

The review of collapse caldera field studies has been indispensable for comparing the performed observations with the results obtained by analogue and numerical modelling. Additionally, the generation of the collapse caldera database is a first attempt to establish a link between scientific groups working on collapse calderas and to initiate data processing and information exchange in order to improve the general knowledge on concerning collapse caldera structures. Moreover, throughout the analysis of the information included in the database we have inferred the existence of two clear collapse caldera end-members. The definition of these two end-members has been one of the mainstays for the final genetic classification.

Besides, results obtained by the experimental models on collapse calderas have allowed us to study qualitatively and semi-quantitatively the structural evolution of a collapse process and to suggest which factors play a more relevant role. We have verified that caldera collapse formation is influenced by multiple aspects like regional tectonics, system geometry, magma and host rock properties, pre-existing structural discontinuities, deformation history, etc. We have already mentioned (see sections III.2.3 and III.3.7) that differences among the existing analogue models lie on the applied experimental devices, the host rock analogue materials (dry quartz sand, flour, etc.) and the magma chamber analogue (water or air-filled balloons, silicone reservoirs, etc.). In section III.3.4.3, we have offered three types of semi-quantitative analyses performed with the results from the analogue models: 1) the measurement of the erupted magma chamber volume fraction $\boldsymbol{f}$ required to achieve each step of the collapse process (and the dependency $\boldsymbol{f}(\mathbf{R})$) (see section III.3.4.3.7), 2) the estimation of the structural subsidence pattern (see section III.3.4.3.8), and 3) the study of the influence of the roof aspect ratio in the dimensions of the collapsed zones at surface (see section III.3.4.3.9). The quantification of these aspects is of particular interest for volcanic hazard assessment. For example, to determine the size of the collapse at surface and the subsidence pattern, crucial parameters when evaluating the volcanic risk in an area with susceptible caldera-forming eruptions.

As we have seen in previous sections (see section II.3.7.2) an important contribution to the study of collapse calderas comes from the comparison with mining subsidence and scaled experimental models of subsidence, as they provide a useful analogue for caldera collapse. Results obtained by that kind of models and in previous or our own analogue models are quite similar, specially for what concerns to the geometry of the resulting depressions and the distribution of the bounding faults (see sections II.2.2, III.3.4 and III.3.5). Experimental models reveal that the apparent diversity of caldera morphologies and collapse mechanisms that can be deduced from field studies may result just from the effect of different magma chamber geometries and magma chamber roof aspect ratios, or may simply correspond to different stages of a single collapse process. Therefore, classifications on collapse calderas based on the morphology of the resulting depressions or the inferred collapse mechanism should be revised, as they could just result or correspond to an artefact due to different degree of exposure of natural examples (see section V1.2).

Finally, numerical modes may allow us to quantify some of the parameters involved in the collapse process, to define the theoretical conditions for ring fault initiation and to describe the pressure evolution of the volcanic system during the caldera-forming event. Moreover, reproducing numerically some of the analogue models we have establish general similarities and discrepancies between both methodologies and some of the restrictions implicit in both modelling types. Additionally, we have seen that it is possible to apply the results of numerical models coming from other disciplines not directly related to volcanological studies in order to obtain more information about the collapse caldera process. One of the most important results of the described numerical results is the conclusion that from a theoretical/numerical point of view, collapse calderas can be classified in two main groups depending on whether the collapse process is initiated by overpressure inside the magma chamber or by underpressure.

Combining the end-members defined with field evidences and those inferred from theoretical/numerical models together with results obtained with analogue models, it is possible to establish a genetic classification for collapse calderas. In short, we distinguish between "Cordilleran type" and "Composite volcano type" calderas. Calderas related to the first group correspond to commonly rhyolitic or dacitic, large plate/piston or trap-door calderas formed from a sill-like overpressurized magma chamber in the presence of a regional extensive stress field and a large scale doming or underplating. In general, there are neither evidences about a possible pre-caldera edifice nor indices of eruptive phases previous to the formation of the caldera. These calderas tend to occur in areas of thick or thin continental crust and occasionally, in evolved transitional thick crust, and they are uniquely associated with C-type subduction zones and areas of continental rifting. By contrast, "Composite volcano type" calderas occur at the culmination of a long eruptive cycle in composite volcanoes. They take place at the summit of a long-lived volcanic edifice, which has undergone various periods of magma chamber inflation and deflation and different eruptions. The caldera-forming eruption begins with overpressure inside the chamber that triggers, once overcome the tensile strength of the host rock, magma injection into the host rock and finally, an eruption. Calderas included in this group tend to be smaller and not too voluminous. Although, the most common associated deposits are felsic calc-alkaline, it is also possible to find mafic calc-alkaline or alkaline samples.

We have demonstrated that future works should combine different types of information and not be restricted to results obtained with one methodology. Separately, each of the data sources: field evidences, analogue models and numerical models, carry several implicit restrictions. In some cases, these can be only detected when combining the results obtained with the different methodologies. The final aim of this work has been to making clear that in order to better understand the dynamic processes at caldera volcanoes, cross boundary interaction across all disciplines of Earth Sciences is needed. Only then can the benefit of individual techniques for providing answers to the most striking questions on caldera volcanism be assessed.