'Express' geological mapping of potential targets during reconnaissance surveys in volcanic terrains: an example from Almería, Spain

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To the mappers (an endangered species) and to those who are new to the noble and old art of mapping

Some words before we start: *Tempus fugit* (*"time flies"*) said the Romans, and this is true also in the modern world. A geologist in the field is expensive, particularly if he or she is working in a remote corner of the world. So the shorter the field work is the better, especially for junior exploration companies, with budgets not as splendid as those of the major ones. Thus, if we talk about mapping, knowing what to do in the field can be of paramount importance, particularly in volcanic geologic settings, which unfortunately are not usually a priority of BSc degrees in geology. From the economic geology viewpoint this is ludicrous, because many valuable hydrothermal ore deposits, including the gold-silver epithermal ores are specifically related to volcanic rocks. Besides, what happens with the teaching on volcanic hazards? This might be irrelevant if you live in Arkansas (*USA*), but what about the Andean countries? Or near to the Cascade volcanoes (*northern California, Oregon, Washington and southern BC*)? In this regard, the mapping of volcanic rocks from past eruptions may offer some helpful insights onto what the future volcanic activity may bring.

Unlike stratigraphic sequences of sedimentary rocks, volcanic sequences, particularly in the case of pyroclastic units (*explosive volcanism*), tend to have less continuity, and one volcanic eruption can give rise to several overlapping volcanic units. Of course, we refer here to small volume volcanic eruptions (*lasting days or a few weeks*), with discrete episodes of ignimbrite formation on the slopes of the volcanic cone, and abundant fall deposits (*bombs, lapilli, ash*). An example of this volcanism is the Unzen volcano in Japan (*Fig. 1*), where tragically a pyroclastic flow associated with the 1991 eruption killed the famous French volcanologists Katia and Maurice Krafft. In this regard, predicting what will specifically occur during an eruption is not (*unfortunately*) an exact science.

Pyroclastic flow formed during an eruption of the Unzen volcano. Image[1].

From the viewpoint of mapping, these eruptions (*Fig.1*) give rise to a geology that can vary drastically on the surface in a few hundred meters (*or even less*), whereas vertical variations in the stratigraphic column can occur at the scale of meters and even centimeters. On the other extreme, the huge Plinian eruptions generate ash columns exceeding 10 km in altitude and pyroclastic flows that can extend for long distances, all associated with large volcanic calderas with a diameter that can exceed 10 km (*e.g. the Valles type*). Ash fall deposits from these giant eruptions can extend for thousands of kilometers (*e.g. the Toba eruption, some 70,000 years BP*).

The chronological difference between overlapping volcanic units can sometimes be as small as days or even hours, so to separate eruptive episodes apply the principle of caution. On the other hand, it is also true that two volcanic units can be separated by a much longer period of time that may span thousands of years. Complicated? Yes indeed, but if it were easy then you wouldn't need a university degree in geology to map volcanic areas, would you? Anyway, don't worry in excess, it sounds worse than it really is.

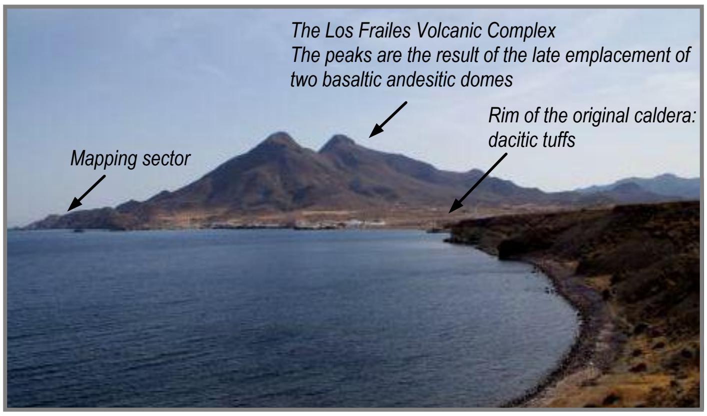


Fig. 2: The Los Frailes Volcanic Complex (looking SW): a counterintuitive caldera. Image[2].

Express mapping: The following is an example of 'express mapping' of a sector in the Los Frailes Volcanic Complex (*Miocene*) (*Fig.2*), in the flank of a 'counterintuitive caldera type volcanic edifice', along the coast between San José and Los Escullos (*Níjar township*) (*see Oyarzun et al. 2018*). The mapping was done around a quarry (*Los Frailes Este*) where zeolites and special clays were mined from a hydrothermally altered outcrop of ignimbrites (*Fig. 3*). Even if the mapping area is small (*1000 x 500 m*) the sector hosts extensively faulted volcanic units representing different volcanic episodes within a challenging landscape including a cliff and a hilly mountain flank (*see Appendix*). This reconnaissance mapping was performed in one day (*04.25.06*) by two geologists.

Fig. 3: View to the SW of Los Frailes Este Quarry (Cala Tomate).

Tips for a mapping task like this one: It is important to check well the area because some key stratigraphic relationships may be visible only in a few small sectors, but attention, you don't have to step on every single square meter of the study area. Save time being smart, choosing these sites that appear to be crucial to understand the local geology, for example, where stratigraphic relationships are crystal clear. Binoculars (*the so called 'Swiss hammer'*) can help a lot reducing walking times. Some important outcrops may be partially hidden by colluvial sediments, so don't underestimate apparently unimportant gullies. Regarding faults and block tilting: if you find fiamees (*flames*) in ignimbrites and they are 'inclined' then the block may have been tilted. Why? Because fiamees are horizontal in origin; they form by compaction of the pyroclastic material under its own weight (*remember, the $\vec{g}$ vector is vertical*). In this case the fiamees inclination will serve as a proxy to measure the tilting.

Be a 'lumper'; 'splitters' may end up with a wonderful and detailed draft map which however took 'more than a month' to be completed in the field. Remember, "time is money". Don't use fancy rock classifications that require the use of a microscope (*you don't have one in the field, do you?*) or a chemical lab (*you don't have either a Star Trek's Tricorder*). In this regard, a TAS diagram will be as useful in the field as a Ferrari sports car in a hilly mapping area in the middle of the jungle. Try instead simple schemes based on minerals easy to identify such as quartz and feldspars (*see Oyarzun et al. 2018*). The hand lens (*10x*) will prove to be your best friend. Don't be shy (*mapping is for bold* *people*), draw the contacts on your topographic map and name the rocks. Even if you are wrong with the name of a rock (*not a terrible mistake, you may rectify later*), the contact relationships will remain. Finally, a GPS Garmin 60 (*or equivalent*) will be perfect to draw: 1) the UTM coordinates (*the chosen system in mineral exploration and mining*), and 2) to geolocate your rock samples.

Last words: return from the field with a reasonably good draft of the local geology. This can be later 'polished' at the office to finally give rise to the geological reconnaissance map that is needed (*see Appendix*). If you don't have a map you have nothing. Rock sampling without the support of a geological map may prove to be a useless and expensive exercise.

To know more about the area:

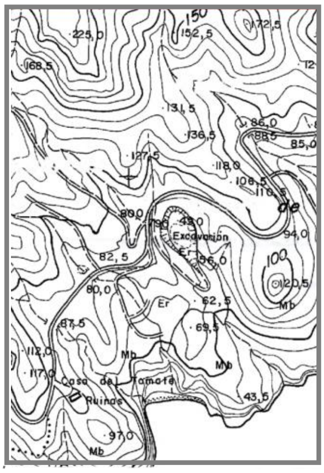
R. Oyarzun, J.A. López García & E. Crespo (2018) The Cabo the Gata Miocene volcanics and the gold mining district of Rodalquilar – SE Spain: a field & teaching guide. Some insights into the geology, ore deposits, mining, and environmental issues. Aula2puntonet – GEMM, https://aulados.net/GEMM/Libros_Manuales/index_libros.html

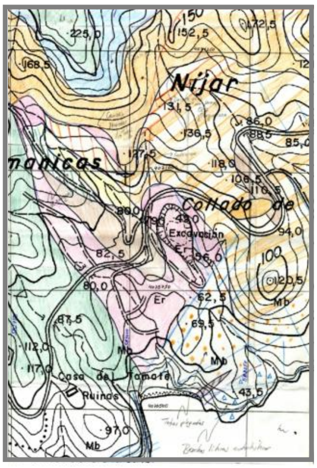
Image sources:

1. http://volcano.oregonstate.edu/book/export/html/367
2. http://www.ruraliberica.com/fotos/foto.asp?Id=5447

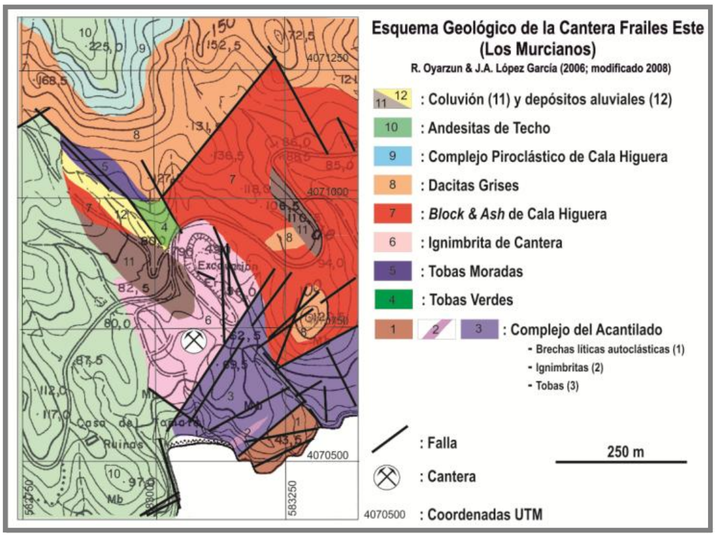
Appendix

From the blank map to the field draft and from there ..





To the final map



Informal units:

1-3: Cliff Complex (1: autoclastic lithic breccias, 2: ignimbrites, 3: tuffs); 4: Green tuffs; 5: Purple tuffs; 6: Quarry ignimbrite; 7: Block and Ash deposit of Cala Higuera; 8: Grey dacites; 9: Pyroclastic Complex of Cala Higuera; 10: Upper andesites; 11-12: Colluvial and alluvial deposits.

Cantera: Quarry
Falla: Fault