Teaching field geology in SE Spain: an alternative approach

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The Department of Crystallography and Mineralogy (Complutense University, Madrid) carries out every year a field geology course in San José – Rodalquilar (Almería, SE Spain. The region of Almería offers a unique opportunity for the teaching of field geology because of the variety of contrasted geologic scenarios: 1) Alpine metamorphic complexes; 2) Miocene sedimentary basins; 3) Miocene volcanic rocks including world-class pyroclastic deposits of almost every possible type; 4) epithermal gold and industrial minerals deposits; and 5) a second-to-none large fault zone (Carboneras Fault Zone, Serrata de Níjar). However, what makes different our field geology course is the fact that the students, in teams of 3 to 4 members, simulate a professional survey. Given that most students will end up working for companies, it is important that they receive some practical training before they leave the university.

Le Département de cristallographie et de minéralogie de l'Université de Madrid effectue chaque année une sortie/cours de géologie sur le terrain dans le secteur de San José – Rodalquilar (région d'Almeria, au Sud-est de l'Espagne). Cette région offre l'occasion unique d'un enseignement de géologie de terrain en raison de la diversité des contextes géologiques, très contrastés : 1) les formations métamorphiques complexes des Alpes, 2) les bassins sédimentaires miocènes, 3) les roches éruptives du Miocène comprenant tous les types de dépôts pyroclastiques répertoriés, 4) l'or de type épithermal et les dépôts de minéraux industriels, 5) une zone de failles majeures (zone faillée de Carboneras, Dentelle de Nijar). Cependant, ce qui fait l'originalité de ce cours de géologie est que les étudiants, par groupe de 3 ou 4, accomplissent un travail équivalent à une étude professionnelle. En considérant que la plupart des étudiants vont travailler au sein de compagnies, il est important qu'ils reçoivent une formation pratique avant de quitter l'université.

El Departamento de Cristalografía y Mineralogía de la Universidad Complutense de Madrid realiza anualmente un curso de geología de campo en San José – Rodalquilar (Almería, Sureste de España). La región de Almería ofrece una oportunidad única para la enseñanza de la geología de campo ya que en ella encontramos una gran variedad de escenarios geológicos: 1) complejos alpinos; 2) cuencas sedimentarias del Mioceno; 3) rocas volcánicas del Mioceno con extraordinarios ejemplos de diferentes tipos de depósitos piroclásticos; 4) yacimientos epitermales de oro, yacimientos de bentonitas, alunita, y zeolitas; y 5) una gran zona de falla (Zona de Falla de Carboneras, Serrata de Níjar). Sin embargo, lo que hace diferente nuestro curso de campo es el hecho de que los alumnos, en equipos de 3 o 4 miembros, simulan estar realizando un trabajo profesional. Dado que la mayor parte de los alumnos acabará trabajando para alguna empresa, nos parece importante que reciban alguna formación práctica antes de que acaben la carrera.

"Education should include knowledge of what to do with it …" (Anonymous)

The province of Almería in southeast Spain offers a unique opportunity for the teaching of field geology because within a relatively small area, one may find a variety of contrasted geologic scenarios: Alpine metamorphic complexes of Palaeozoic to Triassic age, Miocene sedimentary basins, a Miocene volcanic block comprising a whole calc-alkaline suite with andesites, dacites and rhyolites, superb pyroclastic deposits of almost every possible type, epithermal gold and industrial minerals deposits (bentonites, zeolites, alunite), and a second-to-none fault zone running ENE-WSW (Carboneras fault zone) (Fig. 1). The Department of Crystallography & Mineralogy (Faculty of Geological Sciences, Complutense University; Madrid) has been running a field geology course in this realm for seven years. We conduct a regional survey followed by detailed mapping of specific zones. So far, nice mapping within a beautiful geological scenario; however, what makes these activities different is the fact that the students, in teams of 3 to 4 , simulate a field survey for either an exploration (Kondor Mining Co.) or an Environmental company (Terra Green GmbH), both fictitious companies (Fig. 2).

The training takes place within the hilly semi-arid environment of the Cabo de Gata - Níjar Natural Park. The small coastal town of San José (Fig. 1) has hotels and a youth hostel, as well as a couple of small supermarkets from where food and water for the daily work can be bought. The town also has restaurants, pizzerias, pubs, and a small but nice beach and marina. Almería is one of the last relatively large and relatively unspoilt stretches of the Spanish Mediterranean. Together with Sorbas, a few kilometres inland, this is surely the driest region of Europe with barely 150 mm of rain a year. Unsurprisingly, trees are thin on the ground, being restricted to

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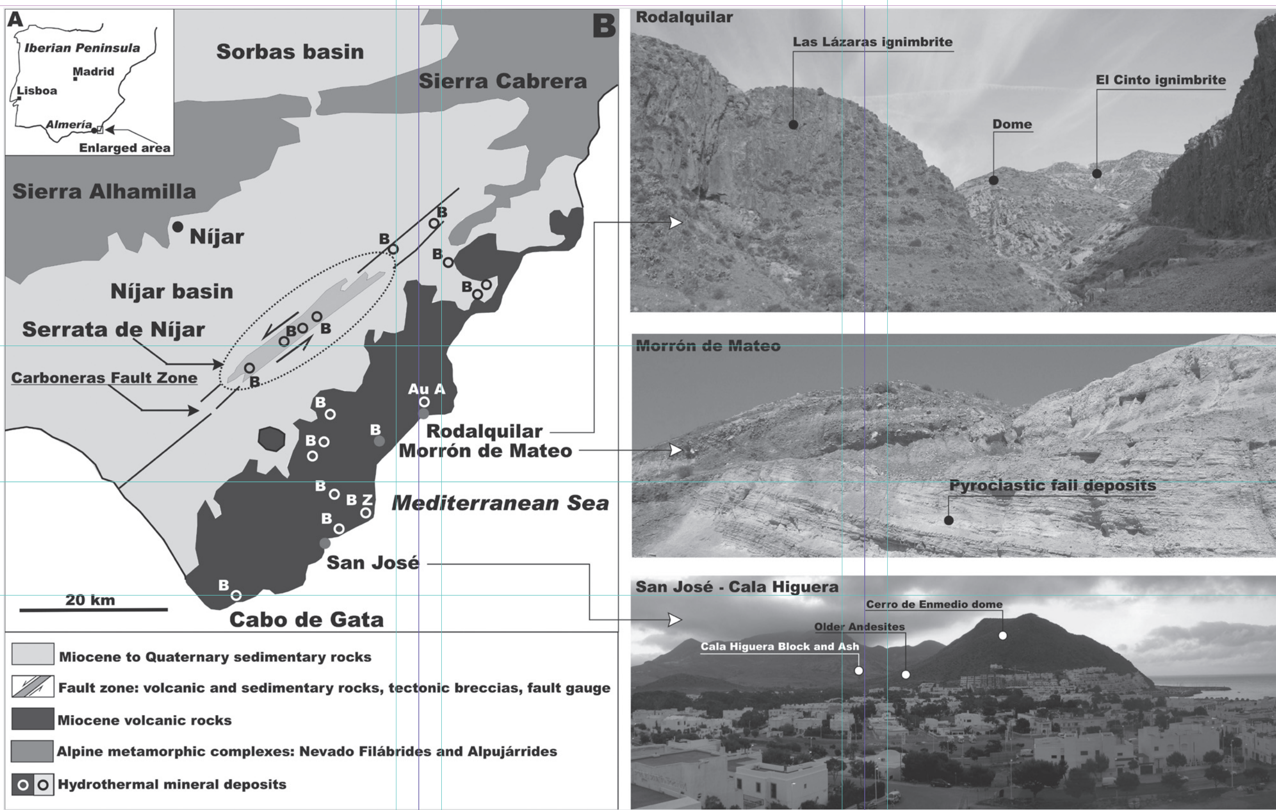

Figure 1. A: Location of the study zone within the Iberian Peninsula. B: Simplified scheme depicting the major geological units of the region and mineral deposits (A: alunite; Au: gold; B: bentonite, Z: zeolite). On the right: images from the study zones

ramblas and irrigated areas. The cabo de Gata – Níjar Natural Park is home to some 1,000 species of vascular plants, around 12% of the total figure for Iberia, the vast majority of which is xerophytic and halophytic. Particularly characteristic is the fan dwarf palm (palmito) the only native palm in Europe (Iberia Nature, 2007).

Geological setting and field activities

The study region is characterized by the following geological units (from north to south) (Fig. 1): the Miocene Sorbas basin, the Alhamilla Sierrra with Alpine metamorphic complexes; the Níjar basin, the Serrata de Níjar (carboneras) fault zone, and the Cabo de Gata volcanic block. The older rocks are those of two of the most important Alpine complexes of southern Spain: Alpujárrides and Nevado Filábrides. These units were intensively folded during late Oligocene - Early Miocene, and later underwent extensional collapse through major detachment systems in Middle - Late Miocene time (e.g., Doblas and Oyarzun, 1989; Platt and Vissers, 1989). The latter episode was accompanied by important calc-alkaline volcanism (andesites, dacites, rhyolites) and sedimentation within evaporitic sedimentary basins. The volcanic block is NE-SW oriented and comprises (from south to north) (Arribas, 1993): andesites ('Old Andesites'), ignimbrites, breccias, and the domes, ignimbrites dacites to andesites from the Los Frailes Volcanic Complex (Middle Miocene); ignimbrite facies (El Cinto and Las Lázaras), fall deposits, and domes of Tortonian age: the Rodalquilar caldera, with strong alteration (hydrothermal and supergene) and epithermal gold-alunite mineralization (Oyarzun *et al*., 1995; Arribas, 1992). Subsequent large (40+ km) ENE-WSW sinistral wrench faulting during uppermost Miocene (Carboneras Fault Zone: CFZ) (Huibregtse *et al*., 1998; Keller *et al*., 1997) gave rise to the formation of one of the most remarkable morphological features of the Níjar - San José sector, the so-called Serrata de Níjar, a compressive duplex characterized by large-scale pervasive deformation of the Miocene sedimentary and volcanic units. Thus, the Serrata de Níjar can be regarded as an uplifted tectonic block formed within a transpression zone developed along the CFZ. From the structural viewpoint the Serrata de Níjar duplex is characterized by a dominance of P- over the more relatively common R-type shears (Keller *et al*., 1997) (P and R nomenclature after Passchier and Trouw, 1998). The sedimentary units (limestone and gypsum beds) were intensively folded, whereas the volcanic rocks were either tectonically brecciated or transformed into massive zones of fault gouge (García Romero *et al*., 2006). The fault gouge consists of cm- to m-scale bands of a very fine clay-rich matrix with mm- to cm-scale clasts (Keller *et al*., 1997).

The students first have an introduction to the regional geology and gather data for a cross section that comprises from NW to SE: the Alpujárrides Complex near to the town of Níjar, the Serrata de Níjar fault zone, and the volcanic block. After this helicopter-view work is completed, the teams are distributed within three main field zones labelled as (from north to south): Kondor 1, 2 and 3. This local geology part of the work (at the detailed scales of 1: 2,500 and 1: 5,000) takes place at the Rodalquilar volcanic caldera (Kondor 1), the Morrón the Mateo - Presillas Bajas sedimentary and pyroclastic outcrops (Kondor 2), and the Cala Higuera zone (Kondor 3) along the border of the Los Frailes volcanic complex (Fig. 1). Each lecturer specifically supervises one or two teams in the Kondor 1-3 zones (Fig. 1).

The reasons for two fictitious companies

Given that most students will end up working for companies (only a minority will follow a university research career), it is important that they receive some practical training before they leave the university. Although every single company that hires geologists has its own methods and procedures, we can teach some basic skills that may be useful later. Thus, we combine the teaching of field mapping with the building up of a professional attitude towards the time invested in the field activities. The writing of a report for a company (with a specific style) is another of the priorities of this field course. These are matters that are seldom dealt with during the teaching of geology. To simulate a professional scenario, we created two companies, and in order to provide a more cosmopolitan environment, we decided that both fictitious companies should be foreign. Thus, the Kondor Mining Co. became a South African company founded in 1895 that runs initial gold mining operations in the Witwatersrand. We tell the students that at present the Kondor Mining Co. is an important, global mining company running exploration programmes for gold and base metals around the world. On the other hand, Terra Green GmbH is a German company founded in 1988 that works on environmental impact evaluations and land reclamation in abandoned mining sites, operating on a European scale.

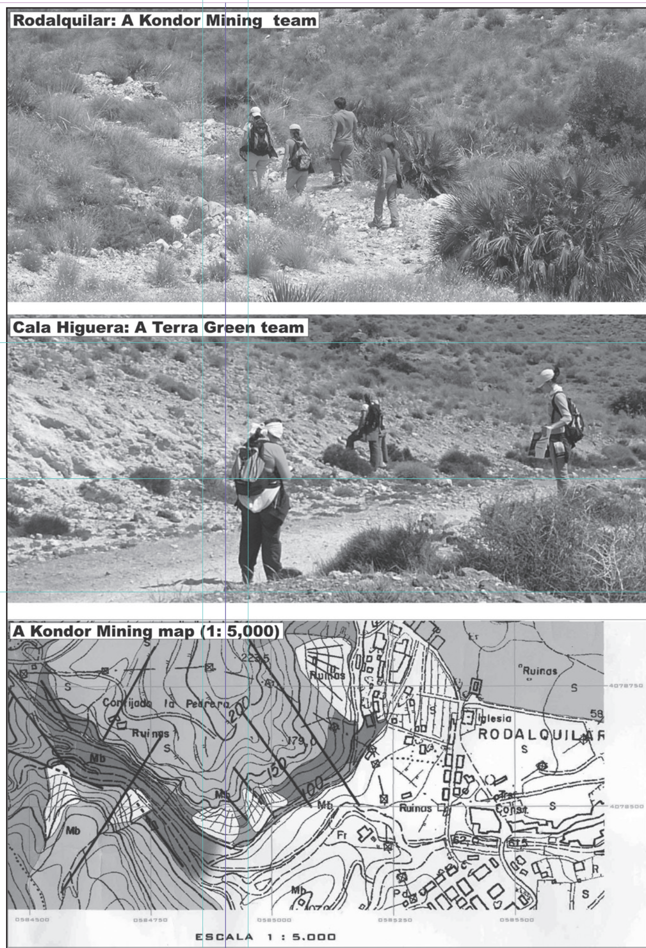

Figure 2. Kondor Mining and Terra Green teams working in Rodalquilar and Cala Higuera respectively (June, 2007). Below, segment of a geological map of Rodalquilar made in June 2005 by a Kondor Mining Co. team (M. Alcázar Torralba, V. Blanco Alonso, E. Delgado Ventura and E. Domínguez Cuesta)

On team building

> ***"Modern society and culture continues to become more fluid and dynamic. Factors contributing to this include the communications revolution, the global market and the ever-increasing specialization and division of labor. The net effect is that individuals are now required to work with many different groups of people in their professional as well as personal lives. Joining a new group and immediately being expected to get along with them is somewhat unnatural. People have developed methods to help people adapt to the new requirements. All kinds of companies face the same difficulties. As yet there is no generally agreed solution to the problem - it may not even be possible given the thousands of years of cultural evolution that brought us to our present behavior patterns" (Wikipedia, 2007)***

Geology, for whatever reason, favours individualism. Although there is nothing (basically) wrong with this, in society we seldom work as lone wolves but as wolf packs in which cooperation is needed and prized. In this respect, if we want to prepare students for the real world, team building must be an essential part of the training. Thus, the final report must be written by a team of 3 to 4 students, that may or may not agree on either the style of the report, or worse, the conclusions. This is an essential part of the exercise, because success or failure will much depend on cooperation. We nevertheless control individual achievement by means of an initial test on the geology, economic geology, and environmental setting of the study zone, and the quality of each field notebook. Preparation for the initial test is gained from the Internet by means of a specific web page that contains vital geologic and environmental information for the field activities: *http://www.ucm.es/info/crismine/San_Jose_web/index.htm*. The page includes (among others) the following documents: a virtual trip through the zone, an introduction to rock types, a global picture of the volcanism, the environmental setting, and a document on how to write the report. The students also receive a DVD that includes the contents of the web page plus geologic videoclips (recorded by the lecturers), orthophotos, and maps of soils and vegetation.

On the importance of a report

> ***"From the day you walk into university until the day you leave, there are many reports you'll have to write. As a student, these reports might be the bane of your life - but the truth is, you'll have to write them no matter where you go. From a simple work assessment report to the high-flying technical write-up, reports are a common form of workplace communication. You may have to write a report to a 'client' or an assessing manager. Report writing is an essential skill for professionals; master it now and writing reports won't have to be a pain" (UNSW, 2007)***

The above paragraph summarizes our views regarding this important part of the work. The report that the students must produce includes a series of items.
General, for all teams:

- 0. Cover: indicating title and authors. 1. Index: indicating chapters and pages.

2. Abstract: brief and informative, 300 words. 3. Introduction: 3.1 Aims, 3.2 Location and access to the zone, 3.3 Climate and physiography, 3.4 methods. 4. Regional geological setting: 4.1 Main geological units, 4.2 Tectonic and structural setting. 5. Local geology (assigned zone): 5.1 Description of volcanic, sub-volcanic and sedimentary units, 5.2 Stratigraphic column, 5.3 Structure.

Those who choose the Kondor Mining option:

- 6A. Economic geology: 6.1 History of mining activities in the zone, 6.2 Mineralization types, 6.3 Geology of the ore bodies, 6.4. Alteration (hydrothermal and/or supergene), 6.5. Potential environmental impacts.

Those who choose the Terra Green option:

- 6B. Environmental impact derived from mining activities: 6.1 History of mining activities in the zone, 6.2 Environmental mineralogy, 6.3 Location and characterization of abandoned mineral dumps, 6.4 Potential impacts on the local vegetation, 6.5 Solution proposals, 6.6. Other impacts (visual, water and soil contamination), 6.7 Conservation of vegetation.

General, for all teams:

- 7. Conclusions, including recommendations, 8. References.

The students have three weeks to write the report and during this time they are closely monitored. They bring drafts that are corrected by the team of lecturers until a minimum standard of quality is reached. Apart from the text and figures the report must include a regional cross section, a map of the assigned zone, and a local stratigraphic column and cross section. No important errors are allowed to be present in the last four items.

Final remarks

This is a fieldwork experience that has worked remarkably well along the years. Every year brings new ideas that become incorporated in the following season. For example, given the importance of the flora and vegetation of the zone, a botanist was added to the team in June 2007. This lecturer taught the students subjects such as conservation and geobotany. We must bear in mind that one of the most peculiar Mediterranean areas is that of the SE of the Iberian Península, where the semi-arid climate controls the occurrence of shrublands as natural potential vegetation. This vegetation is constituted by a floristic combination unique to Europe. In this thorny shrubland, phytogeographic elements, whose origins can be traced to the lower Cretaceous, grow together, such as Maytenus europaeus (harto) and Ziziphus lotus (azufaifo). Also, there are Cainozoic elements such as Fagonia cretica or Lycium intrincatum (cambrón), and xerophytic elements such as Periploca laevigata (cornical) related to the arid phases of the Messinian. Geobotanically, we found intimate spatial relationships between plants and rocks, for example that of Genista umbellata with dacites from a block and ash complex in Cala Higuera. The important thing regarding this is that the students were able to see this relationship and trace it throughout the outcrops in Cala Higuera.

Although it is not our intention to teach others how to run a field geology course, we nevertheless believe that sharing this experience may help to improve teaching in times in which environmental issues are becoming progressively important. Geologists have a lot to say on these matters, and it is up to us to incorporate and combine geology and environmental mapping. Besides, we insist on the importance of team building and report writing as essential chapters in the education of students. Finally, although sedimentary, plutonic, and metamorphic rocks can be found almost everywhere in the EU, volcanic outcrops are rather scarce, and if we ask for a combination of volcanic rocks, mineralizing processes and environmental issues, Almería is the only answer.

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