4 Granite Landforms in Galicia

Juan Ramón Vidal-Romaní, Marcos Vaqueiro, and Jorge Sanjurjo

Abstract

Galicia, in the NW of the Iberian Peninsula, is dominated by igneous rocks, mostly granitoids intruded during the Variscan orogeny. These granitoids can be grouped into four types: post- and syn-tectonic tonalite granites, and post- and syn-tectonic leucogranites. Granite landforms in Galicia have been largely controlled by endogenous features defined during their intrusion. Subsequently, tectonics associated with the Alpine orogeny between the Eocene and the beginning of the Late Miocene resulted in a dense network of faults and fractures. These structures delimit a heterogeneous mosaic of blocks in many cases formed by granite rocks, which were affected by differential tectonic movements during the Palaeogene, controlling the development of mountain ranges and depressions. However, the final subaerial exposure of the granite bedrock is mainly related to a wide range of erosion processes since Palaeogene times. In spite of the limited extent of the granitic outcrops in Galicia, they display a broad variety of landforms.

Keywords

Inselbergs • Pseudobedding • Polygonal cracking • Sheet structure • Tafone • Granite caves • Speleothems

4.1 Introduction

The development of the landscape in Galicia started around 200 million years ago (Mesozoic), significantly later than the formation of the rocks (granite, slates and schist predominantly) on which it is developed, dating back to the Palaeozoic (542–299 Myr) (Johnston and Gutiérrez-Alonso 2010) (Fig. 4.1). During the Mesozoic, the Pangea mega-continent split into several tectonic plates, one of them including the Galicia region. Consequently, most of the morphological features observable at the present time formed during the Cenozoic (De Vicente and Vegas 2009; Martín-González 2009).

Since the time the Galician territories emerged, they have been affected by erosion mainly related to fluvial, marine and glacial processes. During the Mesozoic, the rivers in Galicia began to flow towards the Atlantic coast carving the valleys that millions of years later became one of the most characteristic geomorphic features of its Atlantic coast; the "rías" (lower reaches of fluvial valleys submerged by the sea) (Viveen et al. 2013). Nevertheless, the most important landmark in the landscape evolution of Galicia dates back to the Palaeogene (65–34 Myr), when the Iberian Peninsula was defined as a small plate between two converging tectonic plates: the Eurasian Plate and the African Plate. The continental collision led to a dense fracturing and the

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F. Gutiérrez and M. Gutiérrez (eds.), *Landscapes and Landforms of Spain*, World Geomorphological Landscapes,
DOI: 10.1007/978-94-017-8628-7_4, © Springer Science+Business Media Dordrecht 2014

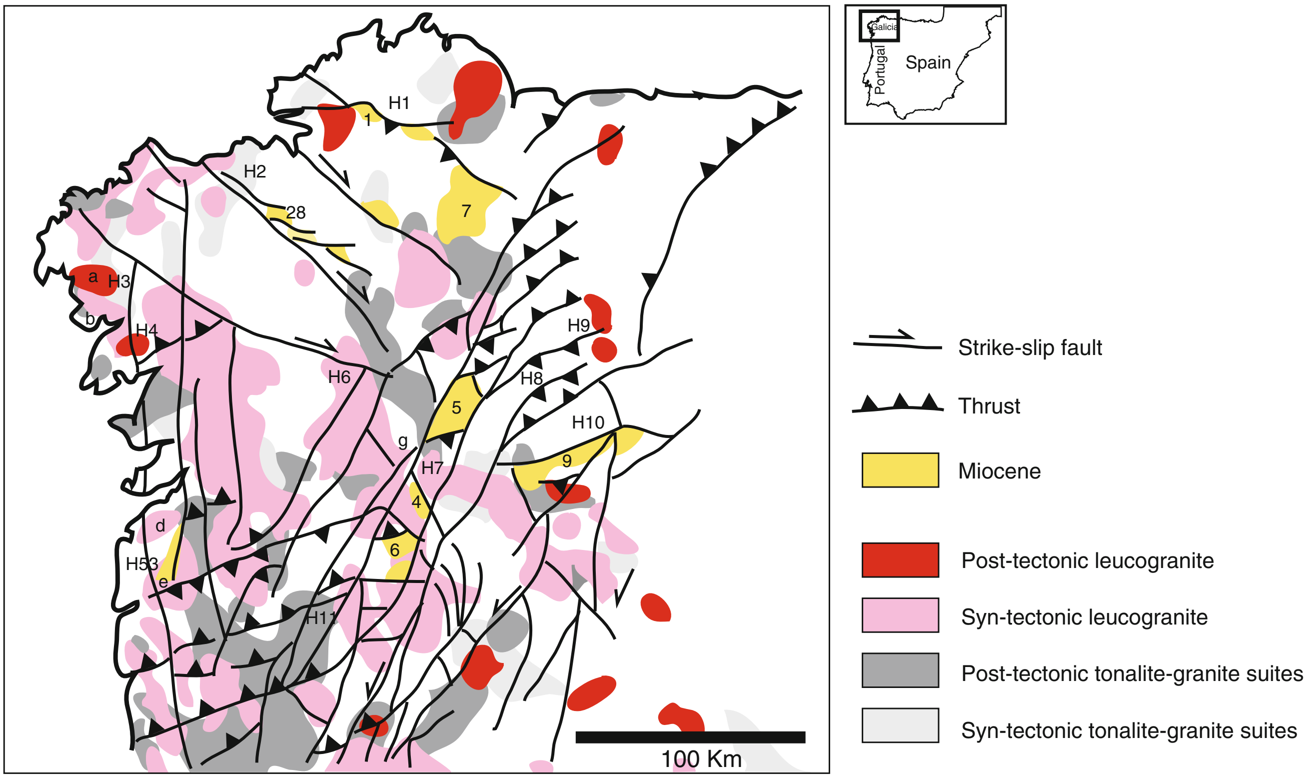

Fig. 4.1 Distribution of the main granitoid groups and Tertiary faults in NW Spain. Cenozoic Basins: (*1*) As Pontes, (*2*) Meirama, (*3*) Budiño, (*4*) Maceda, (*5*) Monforte, (*6*) Xinzo, (*7*) Villalba-Abadín, (*8*) Boimorto and (*9*) El Bierzo. (*H*) Horsts: (*1*) Xistral, (*2*) Xalo, (*3*) Pindo, (*4*) Barbanza, (*5*) Galiñeiro, (*6*) Faro, (*7*) Manzaneda, (*8*) Courel, (*9*) Ancares, (*10*) Trevinca and (*11*) Peneda Gêrez. Block caves: (*a*) Pindo, (*b*) Louro, (*c*) Barbanza, (*d*) Folón, (*e*) Trapa, (*f*) Albarellos, (*g*) Adeghas [modified from De Vicente and Vegas (2009), Johnston and Gutiérrez-Alonso (2010)]

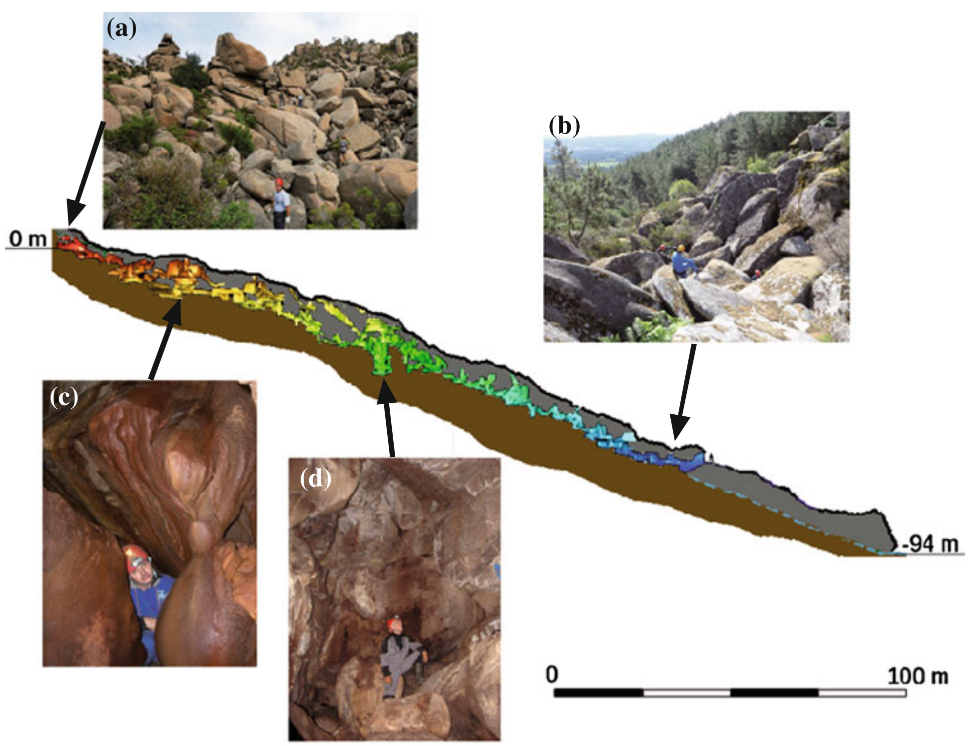

Fig. 4.2 Longitudinal profile of the granitic cave of A Trapa (Tui, Galicia, Spain). Colours from *red* to *blue* indicate the zonation of the cave from drier to wetter parts. **a** and **b** Big blocks on the surface, **c** Pigotite speleothem 3 kyr old in A Trapa Cave, **d** View of one of the chambers in a granitic cave

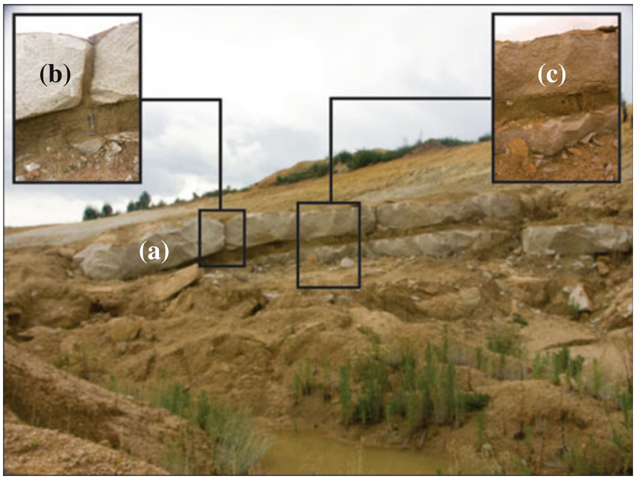

Fig. 4.3 Top of granite dome with sheet structure (Oleiros, Salvaterra de Miño). **a** Detail of boudinage. **b** and **c** Shearing with dense foliation

definition of blocks affected by differential tectonic movements throughout the Tertiary (Fig. 4.1). Tectonic activity produced the mountain ranges of Galicia, which correspond to the uplifted blocks and are largely underlain by granitoids (O Pindo, Barbanza, O Galiñeiro, Manzaneda-Invernadoiro, Os Ancares, Gêrez-Xurés, Peneda, etc.). A secondary effect of this uplifting process was the generation of important accumulations of blocks in the bottom of the depressions by slope movement processes, which currently form spectacular block streams (Fig. 4.2a, b). These are the most recent granite features, of particularly high interest when associated with pseudokarstic systems including speleothems. These caves host troglodyte sites from the Epipalaeolithic to the Middle Ages (Vidal-Romaní and Vaqueiro 2007) (Fig. 4.2c).

Finally, the mountain ranges uplifted during the Tertiary favoured the development of small glaciers above 1,000 m a.s.l., during the Quaternary (2.58 Ma–15 ka). In the numerous glaciated areas of Galicia underlain by granitoids (Os Ancares, Manzaneda, Peneda Gêrez-Xurés, etc.) (Vidal-Romaní et al. 1990), Pleistocene erosional glacial features are superimposed on the previous granite landforms.

4.2 Granite Landforms

When dealing with granite terrains, geomorphologists tend to describe landforms without paying much attention to their genesis. It is the case of the so-called pseudobedding (Twidale 1982) that has been frequently considered as an exogenic feature. However, their analysis strongly suggests that they are related to tectonic shear bands (Fig. 4.3a–c). In granite rocks, the discontinuities of intrusive endogenous origin are generally the main factor that controls the surface morphology. The dilemma of considering a granitic landform endogenous or exogenous is especially outstanding in Galicia, given its complex geological history. Granite landforms are classified into three major groups: megaforms, mesoforms and microforms (Twidale and Vidal-Romaní 2005). Megaforms are those whose minimum dimensions are at least 100 m; mesoforms range between 1 and 100 m; and microforms are typically smaller than 1 m.

4.3 Megaforms. Bornhardts or Rock Domes, Castle Rocks, Nubbins and Tors

Generally, megaforms correspond to the different types of residual hills (Twidale 1982). In Galicia, the most frequent types are bornhardts or rock domes of large dimensions. The geometry of these landforms has been defined by the primary intrusive structure of the granitic rock, without significant modifications after their exposure by erosion of the country rocks in which they intruded. In Galicia, these landforms lack flared or overhanging walls or the characteristic counter-slopes in the pediments surrounding them. Most cases cited coincide with coastal areas characterized by an intense dissection during the Cenozoic. Thus, they can be considered as recent landforms. In Galicia, they have been named as “moa” (molar) because of their rounded and sticking out morphology. Probably, the best-developed example is O Pindo, a mountain group described by Nonn (1966) as a complex inselberg (Fig. 4.4). The O Pindo was formed by two successive intrusions, the first one of leucogranites and the next one of post-tectonic tonalites.

The other types of residual hills like castle rocks, nubbins and tors, of smaller dimensions than the previous type, are also frequent in Galicia. Castle rocks are convex reliefs controlled by systems of sub-vertical discontinuities which are called “castelos” in Galicia (Fig. 4.5a). Nubbins, considered by some authors as the initial stages of exposure of the rock domes (Twidale 1982), are common landforms. They are found in all types of granites, mainly inland, but they also occur as granite rocks emerging from the sea. Finally, tors are associated with all types of granites and are found in very different geomorphic contexts, including coastal areas and inland sectors with periglacial conditions.

4.4 Microforms

Microforms are features with maximum dimensions lower than 1 m. There are discrepancies when assigning an exogenous or endogenous origin to these forms.

Fig. 4.4 Panoramic view of the granite inselberg in the O Pindo Massif

4.4.1 Linear Concave Forms (Rills, Grooves, Flutings, Clefts, Runnels and Gutters)

The prototype corresponds to channel-shaped features that concentrate run-off over rock surfaces. Rills, runnels and gutters develop on horizontal or gently sloping surfaces, whereas grooves and flutings correspond to similar features associated with more inclined surfaces (Fig. 4.5b). In Galicia, these types of microforms are particularly frequent in coastal areas and sometimes connected with gnammas (weathering pits) (Fig. 4.5d).

4.4.2 Rounded Convex Forms (Gnammas, Pits, Pans, Vasques)

The gnammas, designated with the local name pía, are almost ubiquitous in the Galician granite landscape. Two genetic types of gnammas have been proposed. One of subaerial or epigenic origin, in which the accumulation of surface water on a concavity leads to the formation of a hollow by physical and/or chemical weathering (Fig. 4.5d). Other gnammas have a more complex genesis related to the concentration of stresses in particular points of the granite massif during the emplacement of the intrusion and, therefore, can be considered as endogenous features (Vidal-Romaní 1985).

4.4.3 Tafoni (Cavernous Weathering)

Tafone (plural tafoni) is a Corsican word meaning perforation or window. The geomorphological term refers to a shallow cavern or hollow. It was first described by Casiano de Prado in 1864 from the Sierra de Guadarrama, central Spain, later by Reusch in 1883 from Corsica, and by Hult in 1888 in Galicia, NW Spain (see Twidale and Vidal-Romaní 2005). However, the most well-known citation is the one by Penck in 1894 from Corsica (see Klaer 1956). Tafoni are especially well developed in granite outcrops where the rock is compartmentalized into blocks by sheet-type fracture systems. The clusters of closely spaced alveoles developed on the inner walls of tafoni are designated by many authors as honeycomb weathering (Fig. 4.5c). At a local scale, the distribution of tafoni is puzzling, with some blocks hollowed, and others, immediately adjacent and apparently identical, intact (Twidale and Vidal-Romaní 2005). In Galicia, tafoni are a very well-developed morphological feature. They show an unusually high spatial frequency and are typically associated with the zones of most active morphological evolution. Some authors interpret tafoni as features of subaerial origin (Klaer 1956; Migon 2006), whereas others propose that their formation is initiated in the subsurface (Vidal-Romaní 1985; Twidale and Vidal-Romaní 2005; Roqué et al. 2012).

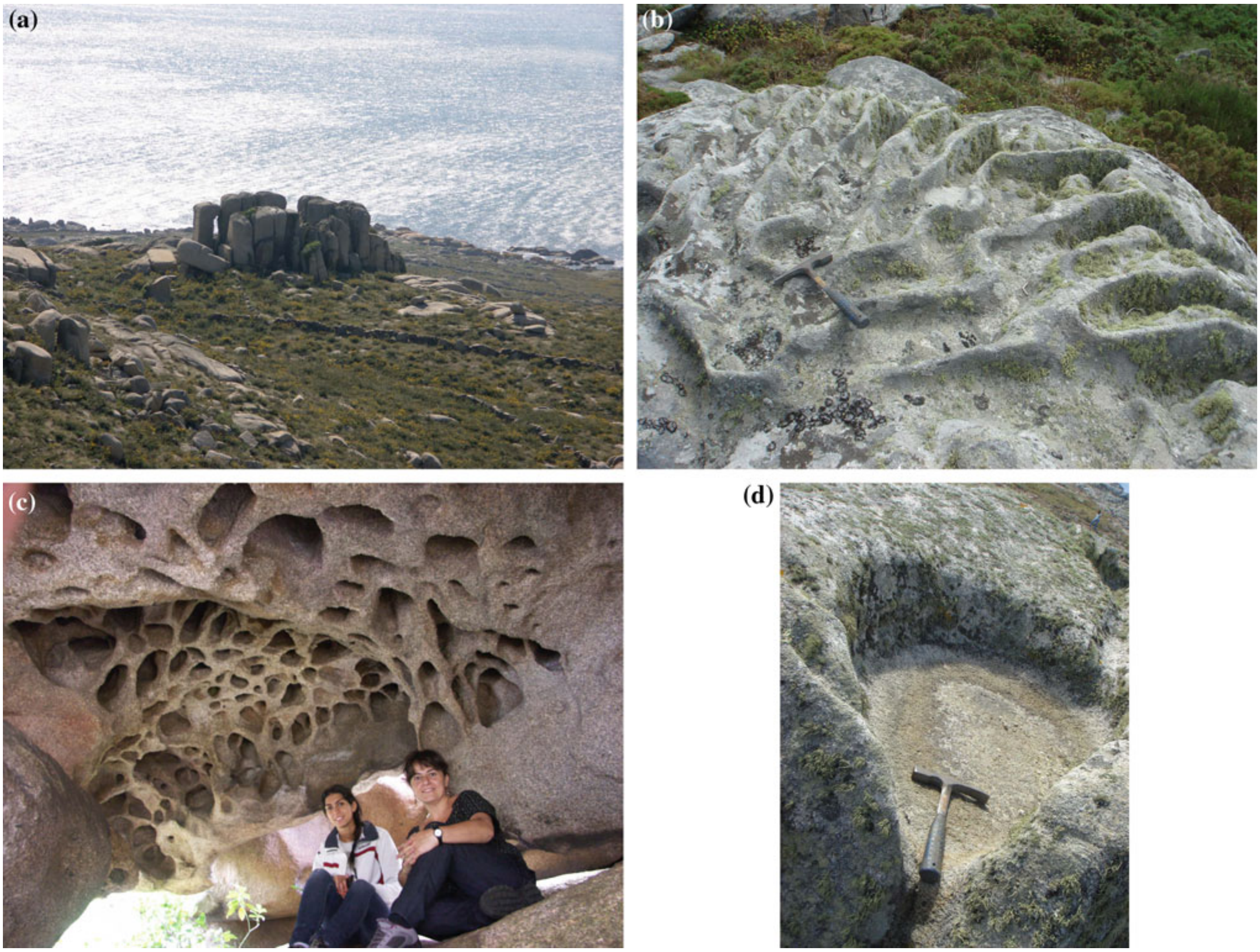

Fig. 4.5 Different types of granite landforms from Galicia. **a** Castle rock at Quilmas, Coruña. **b** Incised rills at Roncudo, Corme, Coruña. **c** Tafone with honeycomb development at Ézaro, Coruña. **d** Gnamma showing lichen colonization at Corme, Coruña

Fig. 4.6 Concordant valley controlled by sheet fractures with a synclinal structure in the northern sector of the granitic massif of O Pindo. Note the sheet fractures dipping towards the valley axis

4.4.4 Sheet Structure, Pseudobedding, Boudinage and Polygonal Cracking in Granites: A Continuum Sequence of a Strain Process

In granites with a well-developed deformation by shearing, weathering is preferentially controlled by foliation planes, resulting in a pseudostratified granite. The discontinuous layers may be up to one metre thick (sheet structure) and are typically a few centimetres thick (pseudobedding) (Figs. 4.3a–c, 4.6). In some cases, closely spaced foliation produces thin partings some millimetres thick (Twidale and Vidal-Romaní 1994, 2005; Migon 2006). An intermediate type is the granite boudinage (Vidal-Romaní 2008), in which thin foliation bands alternate with thick ones, forming granite boudins (Fig. 4.3a–c). The dip of these foliation surfaces can vary considerably from sub-vertical to sub-horizontal. These microforms are very abundant in Galicia.

4.4.5 Polygonal Cracking

It corresponds to a shallow network of cracks perpendicular to the sheet structure that produces a mosaic of fragments and is genetically related to boudinage (Ramsay and Huber 1987; Twidale and Vidal-Romaní 2005) in both sedimentary rocks and granites. Some authors attribute them to cracking due to thermal expansion related to insolation or to the accumulation of Fe–Mn-oxides and carbonates (Klaer 1956; Twidale 1982; Migon 2006). However, in the cases studied in Galicia, they are due to shearing caused by regional stress fields (Ramsay and Huber 1987; Plotnikov 1994; Twidale and Vidal-Romaní 2005) as shown by their alternation with the shearing planes of the granite and the frequent infill of the polygonal cracking by quartz or pegmatite injections of clear endogenous origin (Vidal-Romaní 2008).

4.4.6 Caves Associated with Rock Fall Accumulations and Associated Speleothems

In areas with intense fracturing and accumulations of large boulders related to slope instability, kilometre-size caves may be found (Vidal-Romaní and Vaqueiro 2007) (Fig. 4.2a–d). In these settings, generally with high gradient, underground waters may have a high erosive capability, resulting in the formation of potholes (Fig. 4.2d). When run-off infiltration is slow, the sedimentation of hydrosuspensions (slurry) of grains of quartz, feldspar and mica, or the growth of authigenic minerals in the cave at room temperature prevail. They are called speleothems due to their morphology and sedimentary environment (Twidale and Vidal-Romaní 2005). So far, opal-A, evansite, struvite, pigotite, allophane, haematite, goethite, and nanocrystals of halite, gypsum, plumboaragonite and calcite have been reported (Vidal-Romaní et al. 2010) (Fig. 4.2c).

4.5 Conclusions

The first problem to understand the genesis of rocky landforms developed on granitic rocks is to determine to which extent they are controlled by exogenous, endogenous or both features. In Galicia, the granite landscape has a strong endogenous inheritance due to the complex tectonic history of the region, including intrusion phases during the Late Palaeozoic and brittle fracturing in the Palaeogene. None of these stages must be excluded to fully understand the true origin of the granitic geomorphology of Galicia.

Acknowledgments We thank Ana Martelli for the English translation of the chapter.

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