7 Cordilleran granitoids in convergent continental margins (lower, plutonic levels)

7.1. Introduction

This Chapter is a review of the deeper, plutonic levels of convergent continental margins, the shallow levels of which (volcanics and sediments deposited at the surface or in shallow subsurface) have been covered in the previous Chapter 6 ("Andean-type margins"). The term "Cordilleran Granitoids" is here used in an informal way. Cordilleran granitoids are best developed, you guess it!, in the North American Cordillera, especially in the Canadian and NW USA portion where the mountain system has not been much affected by the post-orogenic extension. The term "Cordilleran" is commonly used in the literature for the North American orogenic system and comparable terrains elsewhere, especially for those with dominantly subduction-related granitoids emplaced into continental crustal basement (Pitcher, 1982, coined the term "andinotype" for this granitoid variety). Here the term serves mainly as a brief chapter heading for the deeper-seated form of magmatism in convergent continental margins.

We are fortunate that this crustal segment has an excellent, recent, comprehensive descriptive literature under three single covers, in the following volumes of the Decade of North American Geology series: Plafker and Berg, eds. (1994) for Alaska; Gabrielse and Yorath, eds. (1992) for the Canadian Cordillera; Burchfiel et al., eds. (1992) for the United States’ Cordillera. The size of these volumes is proportional to the geologic and metallogenic complexity to be expected in this setting, a fact not apparent from the “telegraphic” selection of topics provided in this chapter. Cordilleran granitoids and the almost exclusively hydrothermal deposits in this setting have the largest complement of “giants” of all divisions treated here.

As with other chapters, this is not a sharply delineated entity. The difference between the contents in this and Chapters 5, 6, 8 9 and 12, especially, is more quantitative than qualitative and it is a matter of emphasis. In respect to Chapter 6, this chapter focuses on what is below the predominantly young, near-surface and undisturbed Andean volcanics. In relation to Chapter 8, the typical granitoids and their ores, treated here, are related to subduction under convergent continental margins as in the Peruvian Andes (Pitcher et al., 1985). The typical ore metal here is Cu. In Chapter 8 the typical granitoids are related to orogeny and the typical metals there are Sn and U. Mo, W, Zn, Pb, Au and Ag are common in both settings. In practice, however, the Andean-type continental margins incorporate all genetic varieties of granitoids that overlap and mingle in a collage of rock groupings collected over the span of 500 m.y. or more. Despite the frequent departures from the “model” and the existence of local irregularities, there is a repetitive overall trend across the Cordilleran-type systems where the granitoids and associated ores become more mature, fractionated, and potassic away from the ocean and towards the continental interior.

There is another point that requires clarification: the meaning and role of orogeny and orogen. Orogeny is a timed upheaval that deform, reposition and metamorphose rocks and that produces structural complexes called orogens; the American Cordillera is one such orogen. At the introductory level as in textbooks and university courses, as well as in specialist studies focused on processes acting in a restricted time interval, it is quite possible to treat separately the rocks and ores related to ocean spreading, subduction, collision and extension. The island arc (Chapter 5) and Andean-type margins (Chapter 6) focus on rocks/ores created, for the first time, during the existence and as a part of the respective (mega)domain. An orogeny later created a new geological entity (orogen) that incorporates components formed earlier in one of the above mentioned settings. Orogeny modified (deformed, metamorphosed) the earlier rocks and also created brand new “orogenic” rocks and ores that had not been there before. So Andean-style continental margins can be the same thing as Cordilleran orogens, depending on premise.

In the study of granitoids and associated ores it is customary to distinguish pre-orogenic, syn-orogenic (orogenic), post-orogenic and anorogenic granitoids, all of which can be found in the same orogen (e.g. the Cordilleran orogen), sometimes even within a single composite batholith (e.g. the Sierra Nevada Batholith). Most pre-orogenic
granitoids are also synvolcanic, formed both in island arcs and Andean/Cordilleran-type margins simultaneously with coeval volcanics at the surface, although the volcanics need not be preserved. In this chapter the emphasis is on the latter. In the “real world”, however, there is no sharp boundary between the subduction-influenced (mostly synvolcanic, but many magmas did not reach the surface) and orogenic granitoids. This genetic overlap is well illustrated by the great Sierra Nevada Batholith in California. The bulk of this Jurassic-Cretaceous composite intrusion is composed of metaluminous phases (granodiorite is dominant) presently attributed to subduction-related melting. There, as well as farther east of the main magmatic arc in Arizona, also occur peraluminous granites formed by intractrustal melting as a consequence of crustal compression and thickening under a thermal blanket of overthrust sheets (Miller et al., 1992). The crustal silicic melts rose and intruded the metamorphics in the batholith roof. The melting, although attributed to the thermal energy from mantle, was contemporaneous with or shortly postdated the peak of orogeny. This process is thus identical with formation of anatectic granites in the purely collisional orogens (Chapter 8).

Sometimes, in orogens with multiple accreted terranes as in British Columbia (Dawson et al., 1992) granitoids and ores are classified in respect to the time of amalgamation (docking) to an ancestral craton or an earlier superterrane, as pre-, syn- and post-accretionary.

**Cordilleran granitoid varieties and settings**

The granitoid varieties in orogens, based on presumed magma sources (I, S, S-I, M, A) are briefly reviewed in Section 8.1. Figure 7.1. shows diagrammatically the usual setting of granitoids in the various facies and structural divisions of a typical Cordilleran orogen. The visually recognizable (mappable) setting has a considerable influence on petrology, expected magma families, style and metallogeny of most granitoids, although some granitoids seem to be almost oblivious to the nature of the immediate wallrocks (e.g. the porphyry Cu–Mo related granitoids). There can be a considerable local heterogeneity in granitoid type, and related mineralization. Keith et al. (1991) noted that, in Nevada alone, “within any given mountain range as many as ten distinct mineral systems may be present in a limited geographic area”. In each setting, further variation is due to the relative timing (pre-, syn-, post-orogenic and anorogenic) and the level of granitoid emplacement (and exposure at the present erosional surface). The latter range from the highest level subvolcanic intrusions (emplaced ~0.3 to 1.5 km under the paleosurface) through the “porphyry” and epizonal granite levels (~1 to 5 km depths) to mesozonal (~5 to 15) and katazonal (15 km plus) granitoids (Buddington, 1959).

### 7.2. Metallogeny

Ore deposits related to granitoid plutonism form by far the greatest proportion of the giant metal accumulations (Laznicka, 1999). Of these, the porphyry Cu–Mo and the zonally arranged Pb–Zn veins and replacements demonstrably formed within the Andean/Cordilleran type of convergent margins are the strongest group but there is a controversy as to the setting of many of the hydrothermal Mo, Zn–Pb–Ag, Au, W and Sn giants affiliated to granitoids. Some are subduction-related, others formed during collision or crustal extension but as Cobbing (1990) and others have correctly stated, the granitoid-related metallogenesis is influenced mainly by the magma variety and the melt sources that could be identical in both subductive, collisional and extensional settings.

There is little doubt that the ultimate provenance of metals in ores changes from the predominant mantle/oceanic sources to the continental sources as the continental crust thickens in the cratonward direction and this results in a distinct zonality of preferentially accumulated metals across the continental margin and orogen, typically (from the ocean to the craton margin): Fe (Cr,Ni,Hg,Sb,Au) – Cu,Au (Zn,Ag,Au) – Cu,Mo (Zn,Pb,Ag,Au) – Mo,W – Sn,U (W,Mo,Bi,Be,Li). This zonality is best developed across the North American Cordillera and across the northern Chile-Bolivia transect in the Andes, but numerous local exceptions and reversals occur as a consequence of accretion of pre-subduction mineralized terranes, different timing, local environments, depths of emplacement, and other factors.

**Magmatic deposits**

Orthomagmatic ores, directly separated from magmas in the course of magmatic crystallization and fractionation, are uncommon, small and sometimes controversial in convergent margins. The only metallogene with some magmatic ore potential are the scattered occurrences of mafic and rarely ultramafic rocks, other than the ophiolite association. They are both pre-orogenic and syn-orogenic.