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Mafic magmatic enclaves and mafic rocks associated with some granitoids of the central Sierra Nevada batholith, California: nature, origin, and relations with the hosts

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Abstract

The calc-alkaline granitoids of the central Sierra Nevada batholith are associated with abundant mafic rocks. These include both country-rock xenoliths and mafic magmatic enclaves (MME) that commonly have fine-grained and, less commonly, cumulate textures. Scarce composite enclaves consist of either xenoliths enclosed in MME, or of MME enclosed in other MME with different grain size and texture. Enclaves are often enclosed in mafic aggregates and form meter-size polygenic swarms, mostly in the margins of normally zoned plutons. Enclaves may locally divert schlieren layering. Mafic dikes, which also occur in swarms, are undisturbed, composite, or largely hybridized. In central Sierra Nevada, with the exception of xenoliths that completely differ from the other rocks, host granitoids, mafic aggregates, MME, and some composite dikes exhibit a bulk compositional diversity and, at the same time, important mineralogical and geochemical (including isotopic) similarities. MME and host granitoids display distinct major and trace element compositions. However, strong correlations between MME–host granitoid pairs indicate interactions and parallel evolution of MME and enclosing granitoid in each pluton. Identical mafic mineral compositions and isotopic features are the result of these interactions and parallel evolution. Mafic dikes have broadly the same major and trace element compositions as the MME although variations are large between the different dikes that are at distinctly different stages of hybridization and digestion by the host granitoids. The composition of the granitoids and various mafic rocks reflects three distinct stages of hybridization that occurred, respectively, at depth, during ascent and emplacement, and after emplacement. The occurrence and succession of hybridization processes were tightly controlled by the physical properties of the magmas. The sequential thorough or partial mixing and mingling were commonly followed by differentiation and segregation processes. Unusual MME that contain abundant large crystals of hornblende resulted from disruption of early cumulates at depth, whereas those richer in large crystals of biotite were formed by disruption of late mafic aggregates or schlieren layerings at the level of emplacement. MME and host granitoids are considered cogenetic, because both are hybrid rocks that were produced by the mixing of the same two components in different proportions. The felsic component was produced by partial melting of preexisting crustal

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materials, whereas the dominant mafic component was probably derived from the upper mantle. However, in the lack of a clear mantle signature, the origin of the mafic component remains questionable.

Keywords: Mafic enclaves; Magma mixing; Calc-alkaline granitoids; Sierra Nevada batholith; California

1. Introduction

Mafic magmatic enclaves (MME) are common in calc-alkaline granitoids (Didier and Barbarin, 1991) and are abundant in most of the Cordilleran granitoids (e.g., Pitcher, 1983; Barbarin, 1999). They provide evidence of the role of mafic magmas in the initiation and evolution of calc-alkaline granitoid magmas and thus their origin is of fundamental significance in interpreting the history of batholiths.

Field and petrographic features of MME have been determined in detail by many investigators. The main references are an early paper of Phillips (1880), a descriptive survey of "autoliths" of the Sierra Nevada by Pabst (1928), comprehensive books on the subject by Didier (1973) and Didier and Barbarin (1991), which contain many examples and a review of the various characteristics of MME, and a discussion of microstructures by Vernon (1991). Geochemical and isotopic studies of MME (e.g., Fourcade and Allègre, 1981; Domenick et al., 1983; Tindle and Pearce, 1983; Reid et al., 1983; Noyes et al., 1983a; Barbarin et al., 1985; Kistler et al., 1986; Hill et al., 1988; Dorais et al., 1990; Dodge and Kistler, 1990) emphasize their significance to the genesis of granitoid magmas and their relations to associated mafic rocks.

MME are particularly abundant in the calc-alkaline granitoids of the Sierra Nevada batholith (Fig. 1) (e.g., Pabst, 1928; Bateman, 1992). They have been described in many plutons (Bateman and Nokleberg, 1978; Bateman and Chappell, 1979; Noyes et al., 1983a,b; Bateman, 1992) and represent the main topic of several other investigations (Pabst, 1928; Link, 1969; Reid et al., 1983; Domenick et al., 1983; Furman and Spera, 1985; Frost and Mahood, 1987; Dodge and Kistler, 1990; Dorais et al., 1990; Barbarin, 1991).

This report concerns the characteristics and origin of MME and associated mafic rocks such as mafic aggregates, schlieren layering, undisturbed or composite mafic dikes, mainly from selected plutons in the central Sierra Nevada batholith (Bateman, 1992). The localities described or mentioned in this report are identified in Fig. 1 and Table 1. Petrographic, modal, mineralogical, and chemical data on these rocks (Barbarin et al., 1989) and their host granitoids (Bateman et al., 1984a; Bateman, 1992), impose constraints to a general model for their origin and evolution.

2. The Sierra Nevada granitoids

The Sierra Nevada batholith represents a portion of the nearly-continuous chain of Circum-Pacific granitoids (Pitcher, 1983). Like the Coastal batholith of Peru (Pitcher et al., 1985), the Sierra Nevada batholith is an example of a batholith emplaced in a continental magmatic arc (references in Bateman, 1992). The plutonic rocks of the Sierra Nevada batholith range in composition from gabbro to granite. Tonalite, quartz diorite, granodiorite, and quartz monzonite are the most common types and hornblende is the characteristic mafic silicate. They form normally zoned plutons (e.g., Tuolumne Intrusive Suite: Bateman and Chappell, 1979) that commonly are associated in suites of various ages. In general, the plutons are rounded or elongated ~NE–SW, parallel to the long axis of the batholith (Bateman, 1992).

The axial part of the batholith consists of Cretaceous granitoid suites that progressively young eastward (from ~125 to ~88 Ma) (Stern et al., 1981; Chen and Moore, 1982). Jurassic plutons and suites (from 186 to 155 Ma) are exposed along both margins and, locally, in the interior of the batholith. A single Triassic suite is present in the east side of the batholith. The central part between 37°N and 38°N has been mapped at a scale of 1:62,500 (e.g., Bateman, 1992), and relations between the different plutons and suites are clearly defined (Fig. 1). Many plutons and suites have been studied in detail (Mount