STRUCTURAL AND STRATIGRAPHIC RELATIONS BETWEEN THE RIGID COASTAL BATHOLITH BLOCK AND THE HIGHLAND MOBILE BELT AND THEIR ASSOCIATION WITH MAGMATISM AND CALDERA FORMATION

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CENOZOIC GEOLOGIC FRAMEWORK AND EVOLUTION

Throughout Cenozoic time, the western part of the Andes of central Perú can be divided into a relatively rigid Coastal Batholith block (CBB) and a highland mobile belt (HMB) to the east (Fig. 1). The rigid CBB has experienced repeated episodes of uplift and erosion, repetitive tilting, small-scale high-angle faulting, and perhaps strike-slip movement. This is most readily shown by the virtually undeformed nature of ash-flow sheets deposited upon surfaces of erosion and aggradation developed on the CBB. In contrast, the pyroclastic units, volcaniclastic and sedimentary beds, and lavas of the HMB have been subject to repeated pulses of folding and local thrust faulting, uplift and erosion; high-angle faulting is minimal in some portions of the HMB. Markedly different degrees of erosion following each of the compressive pulses has resulted in unconformities that in various places reflect the removal of small to large portions of the Cenozoic section. Large-scale silicic ash-flow volcanism and less voluminous volcanism of intermediate to mafic composition was focused within (but not limited to) an active magmatic belt directly northeast of the Coastal batholith (Fig. 1, 2). Plutons underlying the calderas caused these areas to resist compressive folding, enlarging the CBB to the northeast. The existence and location of the a number of calderas have been identified by a combination of topographic wall morphology, the presence or absence, distribution, thickness relations, etc., of ash-flow sheets, and geologic features indicative of intracaldera tuff; many remain to be identified. Thick (1,200-1,500+ m) sections of intracaldera tuff typically possess very indistinct subhorizontal layering and not uncommonly no eutaxitic structure. Very large lithic blocks (Fig. 3), are an important diagnostic feature. Isotopic ages show that the eruption of large volumes of silicic pyroclastic material and the formation of collapse calderas took place in the Paleocene, middle and late Eocene, Oligocene, early Miocene and Pleistocene (e.g., Noble et al., 1979a; 1979b; 2005; McKee & Noble, 1982; unpub. data of the authors). These calderas are some of the northernmost recognized in the Andean chain. The number of ash-flow sheets and of recognized calderas indicated that large-scale pyroclastic volcanism extended for more than 2,000 km from Chile to well north of Lima. The recognition of thick intracaldera tuff prisms of probable Eocene age is an important new finding (Fig. 3). The intracaldera (cauldron) fills remain largely unfolded, showing that the underlying magma chambers have either behaved in a rigid manner so as to widen the CCB or perhaps in some cases were developed partially within the CBB domain.

Significant pyroclastic material undoubtedly bypassed the Pacific slope and Coastal plains and was deposited in the Pacific Ocean. Much of these tuffs probably moved down canyons cut or reincised at intervals along the Pacific slope (Noble et al., 2009a). Nature, abundance and distribution of deposited material and the local presence of fresh-water limestone, gypsum and black shale suggests that during at least some periods between phases of compressive depression the mobile belt was low relative to the CBB. Isotopic ages on units within the mobile belt place an upper limit of about 17.5 to 18 Ma on the Quechua I pulse of compressive deformation and push back the time of Incaic tectonism to at least 45 Ma. The work of Wise et al. (2008) on the Quechua II pulse in the Ayacucho intermontane basin strongly suggests that many or all of the compressional pulses were of very short duration. The Oligocene was a time of volcanic activity, although based on the relative abundance of age determinations this epoch probably was a time of reduced magmatism.

A NW-trending curvilinear topographic high about 80-km long within the mobile belt marks the northeastern margin of the Castrovirreyna Synclinorium (McKee & Noble, 1982). The highest portions of this ridge are generally formed by resistant lavas of mafic to intermediate composition of middle Eocene age; to the southwest the dips of younger overlying units progressively decrease. We suggest that the rigid behavior of this belt reflects the presence at depth of plutons related to the eruption of the Eocene volcanic rocks. The Chonta fault system (Wise & Noble, 2001) is situated directly to the northeast of the topographic high, which may have served to localized fault movement. Faults are conspicuously absent within the Castrovirreyna Synclinorium.

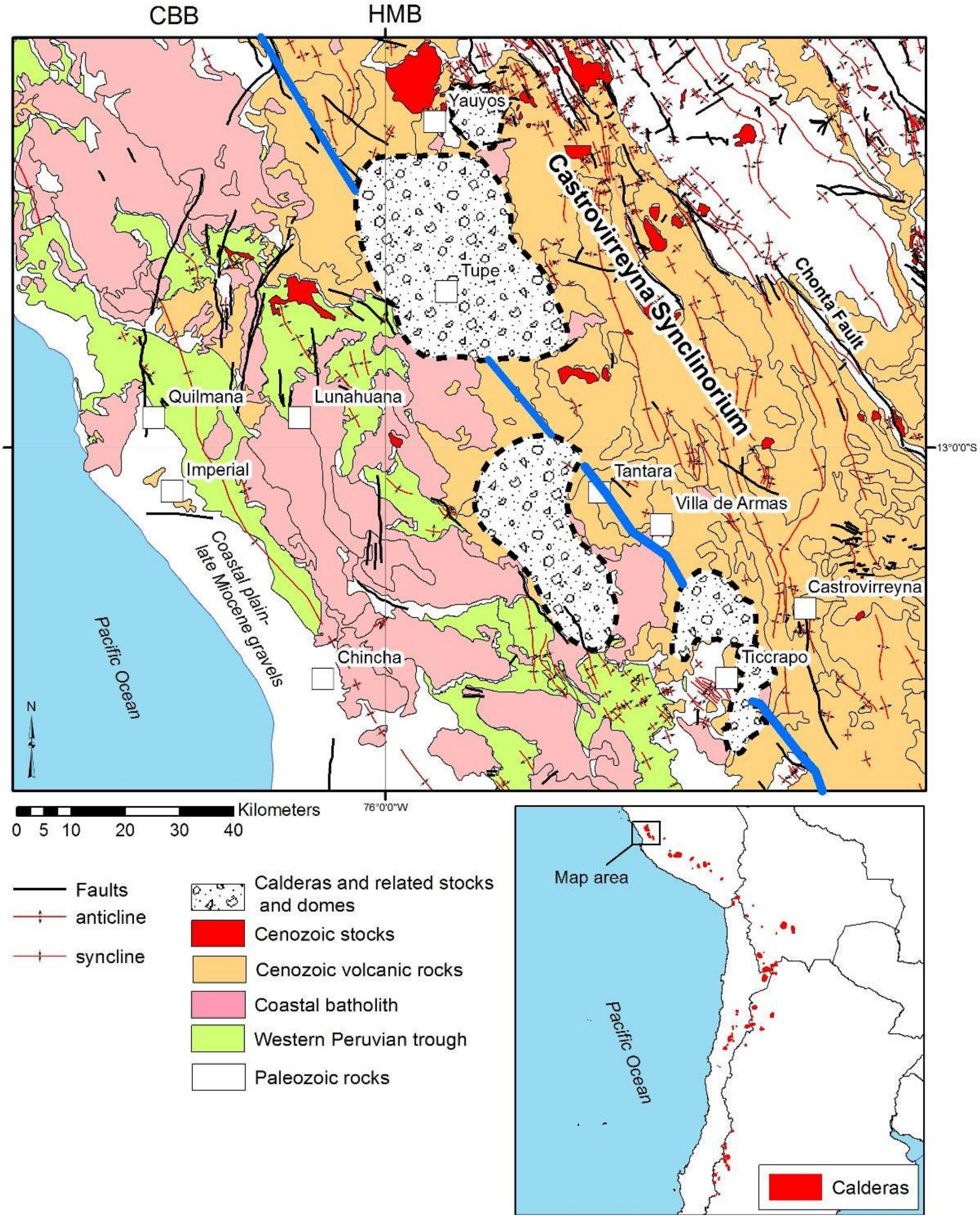

Figure 1. *Generalized map showing Coastal Batholith Block, as it existed at the end of the Mesozoic, and Highland Mobile Belt (separated by the blue line), Chonta fault, and locations referred to in text. The transition between the CBB and HMB in many places lies along the eastern edge of the Mesozoic batholith and may coincide with the east margin of the Western Peruvian trough. Elsewhere the eastern margin of the CBB has encroached upon the HMB through the formation of plutons both related and unrelated to caldera formation. Areas shown as calderas include those that are known or inferred with reasonable confidence to be underlain by intracaldera tuff fill; they do not necessarily indicate known or inferred total original extent of the collapse calderas.*

Figure 2. *Image of northeastern limb and margin of Castrovirreyna Synclinorium looking to the northwest. Road junction is at Chonta Pass. Topographically high dark vertically-dipping rocks SW and NE of Chonta Pass consist of resistant mafic to intermediate lavas of middle Eocene age. These lavas are overlain by volcanosedimentary strata, white partly-welded ash-flow tuffs and dark andesite lavas, all of middle Eocene age. Beds in upper left of image are Miocene. Vertically-dipping yellowish strata conformably beneath dark lavas are fluvial and lacustrine beds of Chonta member. Strands of Chonta fault separate Chonta member and overlying lavas from red beds of the Late Cretaceous Casapalca Formation to the northeast*.

Figure 3. *Part of very large lithic block (lower left) within intracaldera tuff.*

DEFORMATION NEAR THE CONTACTS OF THE HMB WITH THE CBB

Deformation of the well-layered volcanic and volcaniclastic beds of the HMB is, in general, most intense and irregular at contacts with the CBB and, to a lesser extent, along the northeastern margin of the Castrovirreyna synclinorium. An example of strong deformation can be readily seen along the road from Nazca to Puquio, where units of the Nazca Tuff are folded along the western flank of the valley of Río Acari directly east of the Pampa Galeras caldera (Fig. 4 top). Another is along the eastern margins of intracaldera tuff prisms of probable Eocene age in the general region of Ticrapo-Castrovirreyna-Huachos (Fig. 4 bottom). Vertical dips and local tight folding and thrusting are characteristic of rocks of the “Chonta fault”. The more intense deformation on both margins of the belt argues that folding was not produced by gravity sliding. Where calderas, cauldron subsidence blocks or plutons are covered by undeformed to slightly deformed younger volcanic/volcaniclastic strata, the transition into a mobile belt in some cases may be inferred from the onset of strong deformation in the overlying strata.

Likewise, consistent east-vergent folding towards the center of the thickest crust of the Andes is the exact opposite pattern from those of poorly supported inferred gravity-collapse models. Compressive deformation to transpressive conditions is evidenced by the presence of conjugate vein patterns at Morococha and Huachocolpa (Wise, 2010), and internally consistent with the direction of dike sets, which again are clearly features unrelated to a slumping process. Deformation of the HMB is best understood as a tectonic feature directly developed from plate convergence.

LONG-TERM EVOLUTION AND ORIGIN OF MOBILE BELTS

Although the Coastal Batholith of central Perú has undergone repeated brittle deformation since its emplacement (Wise, 2002), any aggregate shortening was minor compared to that suffered by the strata of the mobile belt. Moreover, the formation of collapse calderas, which are known to be underlain by plutons of considerable size, can solidify a portion of a mobile belt. It also appears that crystallized bodies of magma that fed eruptions of mafic to intermediate volcanic rocks can have the same effect. If so, many episodes of magmatism, presumably related to subduction, can progressively reduce the size of zones of mobility. A further question is the origin of mobile belts. Some undoubtedly reflect deposition of strata on unsolidified lithosphere. Others, however, may have been formed by extensional or transtensional rifting more or less parallel to the axis of an orogenic belt. Examples may be provided by some of the intermontane basins in Perú, for example the Miocene Ayacucho basin (Wise et al., 2008) that after filling underwent strong compressive deformation.

LATE MIOCENE AND PLIOCENE VOLCANISM

By late Miocene time the locus of magmatism had shifted inland. Tuffs were deposited in the central and eastern parts of the mobile belt (e.g., Ayacucho Tuff, Bosque de Piedras tuff, Junin). Only extremely distal portions of late Miocene ash-flow units are only very locally preserved on the Pacific slope or coastal plain (Noble et al., 2009b). The eruption of the Atunsulla Tuff and associated caldera collapse at the Nevado Portugueza volcanic center east of Ayacucho at about 2.4 Ma is the youngest important silicic pyroclastic event of the region (Noble & McKee, 1982).

Figure 4. *Images showing contacts between strongly deformed layered ash-flow tuffs of the HMB at the contact with extended portions of the rigid CBB. Top: Strongly folded early Miocene Nazca Tuff east of Pampa Galeras caldera (looking south) and Bottom: layered ash-flow tuff of the HMB (right) deformed against intracaldera tuff of probable Eocene age with faint subhorizontal structure (left; contact at UTM coordinates 460410E, 8522120S; view towards NNE).*

FUTURE STUDIES OF THE INTERFACE BETWEEN THE CBB AND HMB

The large number of different outflow sheets present in west-central Perú indicates a complicated eruptive history within the zone along the northeastern margin of the CBB. Preservation of both intracaldera and outflow-sheet tuffs and other units will be partial or fragmentary. Units will be partially or completely removed by caldera collapse, erosion and pluton emplacement and hidden by younger volcanic rocks. Further study of the eastern part of the CBB and the western part of the HMB is important. It will require detailed mapping following classic procedures of unit identification and tracing as well as correlation utilizing petrography, geochemistry and isotopic dating methods (e.g., Byers et al., 1968; Noble et al., 1984; Best et al., 1995).

ACKNOWLEDGEMENTS

Our work over the years would not have been possible without the ongoing interest and support for both exploration and research of Mr. Alberto Benavides de la Quintana and Minas Buenaventura. We also are greatly indebted to the many geologists and staff who have assisted us over many years.

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