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Carboniferous plutonism along the Eastern Peruvian Cordillera: Implications for the Late Paleozoic to Early Mesozoic Gondwanan tectonics

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Introduction

The Eastern Cordillera of northern Peru represents a major yet relatively unstudied part of the proto-Andean orogenic belt. Paleozoic to early Mesozoic batholiths that span its length exhibit profound and systematic variations in the chemistry and timing of emplacement from north to south (Mégard, 1978; Soler, 1991; Vidal et al., 1995, Jacay et al., 1999). As products of long-lived magmatic episodes, these plutonic belts mark loci of active lithospheric boundaries between the western Gondwana and variable Paleozoic crustal domains (terranes) during the final assembly and ultimate break-up of Pangea. Recognizing variations in their geochemical signature through time and space provides constraints on the composition of crustal members involved, their provenance and the nature of underlying mantle as well as the type of tectonism along the margin. Here, a preliminary geochemical characterization of plutonic rocks from the Mississippian-age Pataz Batholith is integrated with existing geochemical, geochronological and isotopic characterizations of the Peruvian landmass and a provisional geodynamic model for the Devonian-Triassic evolution of this section of the Gondwanan margin is proposed.

Pataz Intrusive Suite

Lithology and structure. The Pataz Batholith is a linear (60 km in length), composite intrusive complex emplaced sub-parallel to a NNW-trending fault zone associated with the upper Marañon River valley (Schreiber et al., 1990; Fig. 1). It is a part of an extensive belt of Mississippian age granitoids (347-329 Ma; Petersen, 1999) flanking the Eastern Peruvian Cordillera north of 11°S. Locally, the granitoids intrude pre-Cambrian schists and phyllites of the Marañon metamorphic complex, Cambro-Ordovician Vijus meta-volcanics and Ordovician meta-arenites of the Contaya Formation, and are themselves overlain by epicontinental molasses of the Ambo Gr. and the Mitu Gr. sandstones (Fig. 1). The plutonic rocks define a compositional spectrum from medium-to-coarse grained hornblende and pyroxene-bearing diorites through amphibole-rich tonalites into dominant biotite, hornblende granodiorites and minor granites. Fragmented dioritic dykes and mafic magma pulses intrude most of the granodioritic rocks and occur together with abundant micro-granular enclaves as well as partially fused xenoliths of the Marañon complex. Widespread textural evidence suggests coexistence and mingling of compositionally contrasting magmas and P-T conditions in the vicinity of those required for melting and assimilation of a significant amount of the local (upper crustal) lithologies. The Pataz granitoids and the Ordovician slates are hosts to orogenic-type Au lodes which postdate the main phase of batholith emplacement by ~15 Ma (Haeberlin, 2002).

Geochemistry and geochronology. Pataz plutonic rocks constitute a transitional metaluminous to mildly peraluminous (A/CNK ~ 0.8-1.2), calc-alkaline suite, lacking significant iron enrichment. A unimodal and wide compositional range of Pataz intrusives (49-78 wt. % SiO_2) is characteristic of I-type orogenic suites. The most evolved granodiorites and granites however, are corundum-normative with low Na_2O/K_2O ratios (<1.2) more akin to S-type intrusives, and display hypersolvus mineralogies characterized by the presence of single albitic feldspar, thus placing a maximum on the H_2O-saturated pressures of crystallization / melting below ~ 4.0 kb. Mantle-normalized trace element patterns reveal the classic subduction-related signature with high LILE/HFSE ratios (Fig. 2a). Chondrite-normalized REE patterns do not show significant HREE fractionation suggesting the absence of high-pressure residual mineralogy in the source and formation in a "normal-thickness", garnet-free crust. Mild Eu anomalies, lowering Sr contents and concave-up REE patterns of the Pataz diorite support a model involving fractionation of plagioclase, amphibole and pyroxene from a basaltic parent. Continuation of these trends with increasing SiO_2 content is compatible with derivation of the mesocratic granodiorites (62-66 wt. % SiO_2) by low-pressure crystal fractionation of a dioritic melt, but it fails short of accounting for highly variable Th, Nb, Sr, Ce and LILE concentrations found in majority of the most evolved plutonic rocks (Fig. 2a), features probably attributable to source-region variations and fractionation of minor LREE-bearing phases such as monazite, apatite and zircon from granitic melt. The timing of emplacement of Pataz granitoids is constrained by U/Pb ages obtained from granodioritic zircons (Vidal et al., 1995) and $^{40}Ar/^{39}Ar$ dating of monzogranitic biotite (Haeberlin et al., 2002) which cluster near ~ 329 and ~328 Ma b.p. respectively. The Pb isotope ratios from the residue fractions are homogeneous and comparable to the Pb province *III* ($^{206}Pb/^{204}Pb$ = 18.46-18.59; $^{207}Pb/^{204}Pb$ = 15.61-15.67; $^{208}Pb/^{204}Pb$ = 38.25-38.42) defined by Macfarlane et al. (1990). Sr isotope systematics across the compositional range of intrusive rocks from the Pataz Batholith further reveal extensive involvement of an old and highly radiogenic continental crust ($^{87}Sr/^{86}Sr$ = 0.708-0.709; Haeberlin et al., 2002).

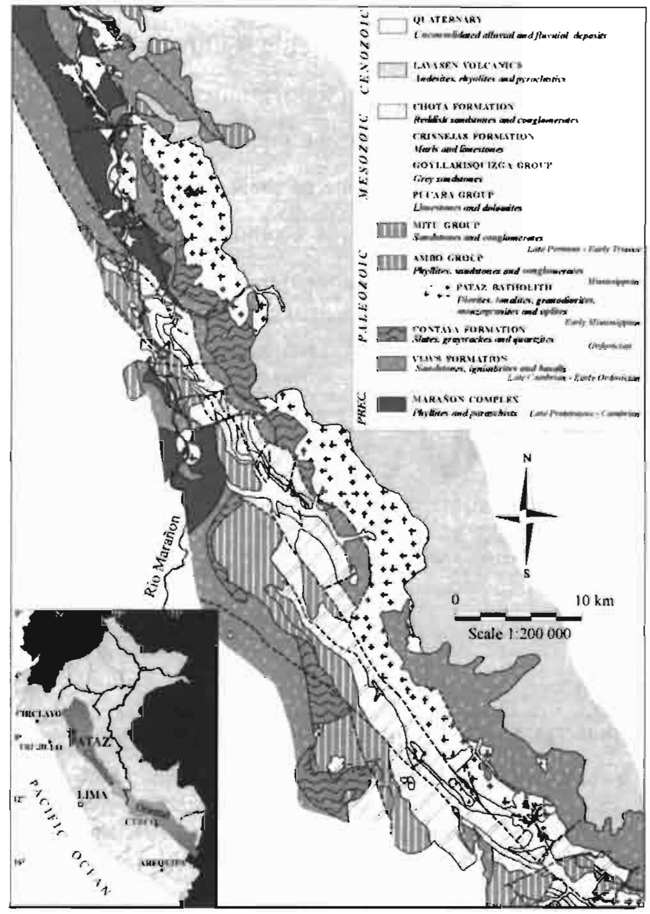

Figure 1. Simplified geological map of the Pataz Batholith including the major Paleozoic to Mesozoic litho-stratigraphic units of the northern Peruvian Cordillera Oriental.

Petrogenesis. Quantitative modelling of incompatible trace elements confirms previous estimates regarding the contribution of crustal melts to the mantle-derived magmas during petrogenesis of the Pataz complex (Macfarlane, 1999). In case of an average (metapelitic) upper crust, between 50 and 70 % of anatexis is required to achieve incompatible element concentrations observed in the Pataz granites (Fig. 2b). Such whole-sale crustal melting is unlikely and probably reserved only for the most evolved granodiorites and granites. On the other hand, an AFC (magma recharge) process which assumes differentiation of a basaltic andesite parent accompanied by assimilation of felsic wall rocks is capable of achieving Th/Rb ratios observed in most of the volumetrically dominant granodiorites after undergoing only 20% contamination. Similarly, a simple binary mixing model between dioritic and granitic melts is also capable of producing chemically intermediate intrusives (Fig. 2b). Regardless which one of these mechanisms was dominant, it is clear that the magmatism associated with the Pataz Batholith records a subduction mantle source that has been extensively modified by profound interactions with the upper continental crust.

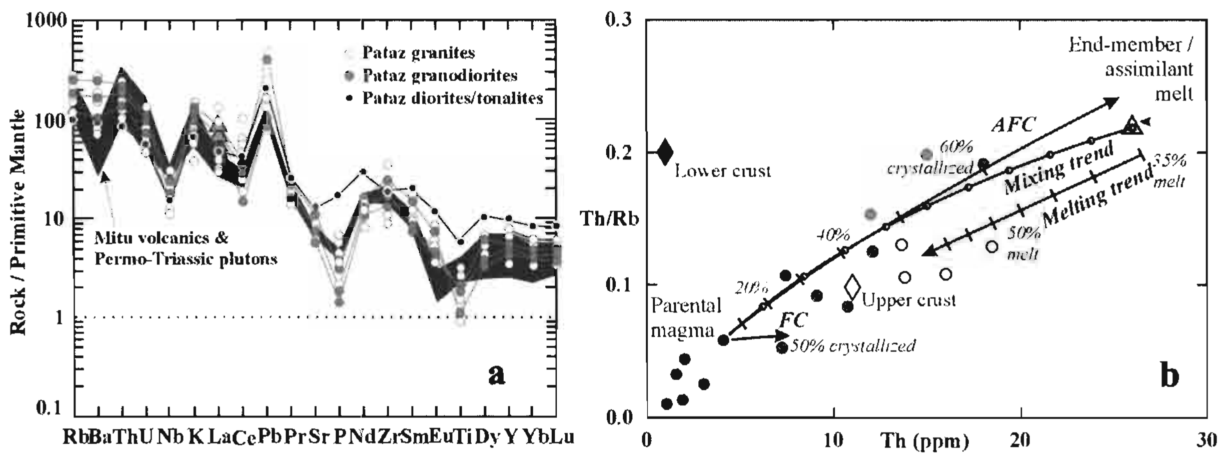

__Figure 2. a)__ Normalized extended REEs of the Pataz Batholith compared to the Permo-Triassic plutonic suites south of 11° S and the associated Mitu volcanism (black). __b)__ Incompatible trace-elements of the Pataz intrusives on a process-identification plot; $D_{Th\ (diorite)}$ *0.046,* $D_{Rb\ (diorite)}$ *0.104,* $D_{Th\ (granodiorite/granite)}$ *0.114,* $D_{Rb\ (granodiorite/granite)}$ *0.825 (D calculated from GERM database; http://earthref.org/GERM/index.html?main.htm).*

Carboniferous to Permo-Triassic plutonism of the Eastern Peruvian Cordillera – Tectonic Significance

A striking relationship exists between the two principal plutonic belts of eastern Peruvian Cordillera: (1) Mississippian to Pennsylvanian I-type metaluminous to peraluminous granitoids are restricted to the segment north of 11°S, and display calc-alkaline evolutionary trends with elevated LILE/HFSE ratios characteristic of continental subduction zones, whereas (2) Permian to Early Triassic S to A-type granitoids of the central and southern Peru, contemporaneously intruded with the Mitu-age basic alkaline volcanics, are characterized by restricted bimodal compositional range (51-55; 66-72 wt. % SiO_2), Fe enrichment, low LILE/HFSE values, Ba depletions relative to Th and Rb and higher Ga/Al ratios, all of which are associated with transitional to anorogenic (within-plate) granitoid suites. Combined Sr and Pb isotopic ratios of rocks from both intrusive provinces however, suggest large degrees of assimilation of the Proterozoic Amazonian basement suggesting their position proximal to the Gondwanan craton. Peculiarly, the Early Carboniferous calc-alkaline intrusives in Peru bound both the presumed northern segment of the Arequipa-Antofalla terrane, and the western margin of the Amazonian craton (Fig. 3). Such complementarity of subduction and rift-related plutonic belts in the eastern Peruvian Andes seems indicative of a major tectono-magmatic change that took place along this segment of the proto-Andean margin of Gondwana during the late Paleozoic.

Any self-consistent tectonic model for the Peruvian segment of the western Gondwanan margin during the Paleozoic-Mesozoic transition must take into account the following evidence: 1) apparent absence of the cratonic crust under most of the Western Peruvian Cordillera north of 13° S, 2) an episode of subduction-related plutonism restricted to the northern Eastern Cordillera of Peru during mid-to-late Mississippian that resumed 25

Ma later along the Chilean Frontal Cordillera (Mpodozis and Kay, 1992), 3) purely Gondwanan Pb isotopic signature of both the Carboniferous and Permo-Triassic plutonic rocks (Macfarlane, 1999); 4) a north-to-south transition from subduction-related I-type to the rift-associated S-to A-type plutons, and 5) a diachronous onset of the Permo-Triassic rift-related magmatism in the central and southern Peru with a younging-southward trend (Sempere et al., 2002). Based on the aforementioned geochemical and tectonic evidence, a geodynamic model is proposed in which an originally orthogonal eastward subduction of the Pacific crust below the western Gondwana during the Late Devonian to Early Carboniferous became strongly oblique towards south-east thus imposing a sinistral strike-slip stress regime on the Gondwanan margin and inducing a counter-clockwise rotation of the northern edge of the Arequipa terrane. The proposed change in strike of the subducting plate could have resulted in transport of a buoyant (plateau?) segment of oceanic crust which plugged the subduction zone and resulted in an ocean-ward trench migration coupled with subsequent back-arc extension. This scenario explains the "craton- free" basement underlying the Western Cordillera of northern Peru as well as termination of arc-related magmatism along the present-day northern Cordillera Oriental in Pennsylvanian followed by progressive strike-slip duplexing, development of transtenisonal ensialic basins and generation of the Permian rift-related magmas in the central Peru and subsequently further south during Triassic. We exclude the possibility of extending the Arequipa terrane north of its present isotopic borders during this period and reserve its removal from the Peruvian segment of the Gondwana margin for pre-Carboniferous times.

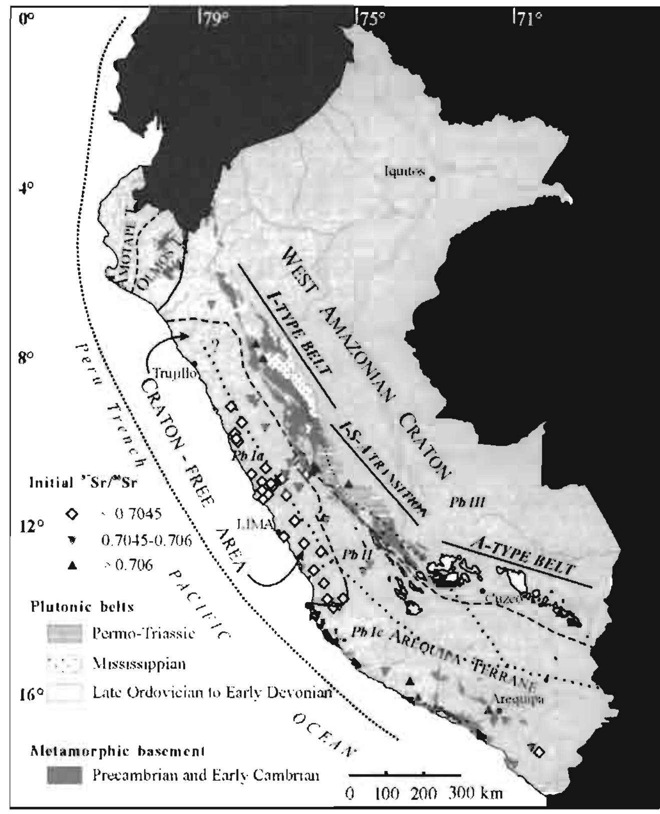

Figure 3. *Tectonic map of Peru with Macfarlane's (1990) Pb isotopic provinces and the initial $^{87/86}Sr$ values from Beckinsale et al. (1985) and Kontak et al. (1990). Modified after Haeberlin et al. (2002).*

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