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Geological Structure and Tectonic History of Bolivian Orocline

The Bolivian orocline results from the autoindentation of South America by part of its western margin in an area occupied by a thick, northwest-trending, initially 800 km wide, Paleozoic basin mostly filled with shales, which provided the main decollements used by the observed great-scale propagation of thin-skinned thrusting toward the craton. North and South of this Paleozoic basin, the shallower Precambrian basements acted as buttresses resisting somehow rigidly the advance of deformation, resulting in distinct, partly thick-skinned, tectonic styles.

Subduction of the Nazca plate below South America seems to have only been the motor of the continental margin deformation, of which the actual structural features were mainly determined by heterogeneities of the upper plate, probably influencing in return the geometry of the subducted one. However, major tectonic crises, resulting in apparent abrupt changes in the modalities of deformation and magmatism, were triggered by changes in convergence direction and/or velocity, since they nearly coincide in time. Present data obtained in the orocline allow us to locate the last two major events at 10–11 Ma and 26–28 Ma.

Phanerozoic basin reconstructions and structural mapping in the Bolivian orocline area (12°–24°S) have impelled the definition of fault-bounded tectonostratigraphic domains, clearly shortened and displaced in relation to each other during the Cenozoic Andean orogeny. These domains are quite distinct from the traditional physiographic units that have constantly grounded any geologic model of the Central Andes until now. We do not call them "terranes" because they all have been linked to one another at least since Upper Paleozoic times and are not exotic to South America.

To describe the orocline general structure, the tectonostratigraphic domains can be grouped in two major structural belts. South of 14°S, the very complex western belt began to be wedged beneath the Precambrian basement and/or Paleozoic cover of the eastern belt in Upper Oligocene times, thus triggering the eastward propagation of tectonic imbrication that has resulted during the Neogene in individualization of the four tectonostratigraphic domains now recognized in this belt. The characteristic asymmetry of the orocline is due to differential propagation of the deformation. In the Vilcabamba "hinge zone" and northwest-trending branch, propagation of thrusts has been relatively impeded by rapidly northeast-tapering of Paleozoic units, and/or Carboniferous to Traissic deformational and magmatic heterogeneities. This resulted in considerable tectonic wedging, backthrusting, and vertical piling-up, from which the Cordillera Real inherited some of the highest elevations in the Andes. The very subsident Northern Altiplano basin formed in response to the Cordillera Real "backthrust belt," and also to major strike-slip motions that deeply affected the whole Altiplano, in part probably reactivating ancient fault zones. In contrast, the north-south branch formed in the area of maximum thickness of flat-lying Paleozoic units, which led to easier propagation of shortening, wider thrust belts and lesser altitudes. Accommodation of deformation along the southwestern margin of the Paleozoic basin (21°–24°S) is expressed by common northeast-trending right-lateral strike-slip faulting. This compensates the limited thrust motion of the vilcabamba "hinge zone" and suggests a gross anticlockwise rotation of the eastern belt of the orocline, in good agreement with the published paleomagnetic data.

Timing of deformation in the orocline is approximated by dating the functioning of the associated foreland basins, which discontinuously shifted in time from west to east. Two of them, of Late Jurassic–Early Cretaceous and Upper Cretaceous–Paleocene ages, respectively, are known in the western belt, whereas the other two locate in the eastern belt, covering the Eocene–Middle Oligocene and Late Oligocene–Present time spans. The Eocene–Middle Oligocene foreland basin, which located in the Bolivian Altiplano and Cordillera Oriental, evolved during the 26–28 Ma tectonic crisis to become the Altiplanic intermontane basin, while eastward progression of thrusting built the present Cordillera Oriental and triggered the individualization of the easternmost foreland basin. Relative tectonic quiescence seems to have occurred during the 17–20 Ma interval in most part of Bolivia. Tectonism and magmatism, however, resumed at 15–17 Ma, notably increased during the 10–11 Ma crisis until ca. 6 Ma and have lingered on until now.

Crustal thickening occurs particularly below the Altiplano–Puna plateau. Its origin should be south in (1) the underthrusting of the western belt crust and deformed cover beneath the Precambrian basement and Paleozoic rocks of the eastern belt, and (2) probably complex duplexing of both brittle and ductile crusts of the eastern belt, which would be responsible for the crustal fusion evidenced in the easternmost, ore-bearing, Neogene magmatic belt.

The Bolivian orocline enlightens the processes that deform a continental margin submitted to subduction. Its main characteristics show that at all scales continental heterogeneities have imposed some important controls upon the actual three-dimensional structures. A model of indenters-and-buttresses tectonics is proposed to explain most of them, and the whole orocline is one large-scale example of it.

Conclusions reached between 12° and 24°S can be extended to the 6°–32°S interval. A detailed study of the geology of the orocline is to be presented in a forthcoming paper.

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Paleozoic Evolution of Central Andes (10–26°S)

The "Paleozoic" history of the present Central Andes (10–26°S) records the evolution of part of the western Gondwanaland active margin from Late Cambrian to Early Triassic Times. Most outcrop zones locate in what was then a northwest-trending back-arc basin (Andean Peru, Bolivia), and several areas (coastal Southern Peru, Northern Chile, northwestern Argen-:ina) show magmatic arc rocks or fore-arc deposits that also define a ·oughly northwest strike for the Paleozoic margin.

Important tensional episodes occurred in the Late Cambrian, \shgillian–Early Llandoverian, and Pennsylvanian. The main periods of ᵓaleozoic compressive deformation in the back-arc basin are Llandeilian–Caradocian ("Caledonian"), Late Famennian–Visean ("Hercynian"), ınd Middle to Late Permian ("Gondwanian").

The Paleozoic back-arc basin individualized in Late Cambrian times tarting from a rift, nearly perpendicular to the margin, that propagated nto the continent with a north-northeast trend. Its evolution led in Early)rdovician times to the formation of ophiolitic rocks in northwestern ırgentina. In southern Bolivia, tensional processes are only marked along ıe same north-northeast trend by numerous spilitic sills and dykes, the freuency of which decreases northwards. Approximately at 20°S, the basin xis progressively turns west to take a northwest trend and shows little syn-:dimentary magmatism from there on.

This development created a paleogeography somehow similar to the ıodern Gulf of California. Extension lasted till Llanvirnian times (maxi-.um areal transgression). During the Llandeilian–Caradocian period, the ›rth-northeast-striking ophiolite-floored "straits" cut in the Precam-·ian continental margin closed, triggering the functioning of the ›rthwest-trending Peru–Bolivian back-arc as a marine foreland basin, ʰere very thick shallow-water deposits (4000 m) are known for this time terval. Intense deformation in the "straights" area produced structures th cleavage and local metemorphism, dying out in a northeast direction, d the southwest edge of the continent was then intruded by numerous anitoids.

This "Caledonian" crisis was followed in Bolivia by an abrupt deepen-; of the back-arc basin in the Ashgillian–Early Llandoverian, as recorded deposition of euxinites and debris-flows sharply above the Caradocian ıllow-marine beds. Some clasts show evidence of contemporary glacia-n in an unknown area. From Late Llandoverian to Early Famennian, the :k-arc basin progressively filled under unconstrained conditions, show-onlap in a northeast direction.

ſhe Late Famennian–Visean tectonics partly coincide in time with a Late nennian–Tournaisian glaciation. Within the back-arc basin, the "Her-ıian" deformed area only occupies a northwest-trending belt clearly ated north of the "Caledonian" one. Deformation is maximum in Peru l decreases into Bolivian territory. Where more intense, it is mainly char-:rized by asymmetrical to recumbent folds with associated cleavage, picnt metamorphism and, very locally, medium, to high-grade meta-ɪphism and anatexis. Most structures are southwest-verging, which sug-s northeast-dipping tectonic wedging. Deformation is probably of ı-skinned type in Peru, laterally changes to thick-skinned type in west-Andean Bolivia, and dies out eastwards. Parts of the back-arc basin t on functioning during the orogeny, receiving the erosion products of uplifted areas, but emersion seems to have been general in the Namur-

he southwestern continental edge recorded a magmatic peak near the onia–Carboniferous boundary. Fore-arc turbiditic sediments were plexly deformed within accretionary wedges, suggesting a northeast-ing subduction. On the proto-Pacific margin, deformation lasted until ısylvanian times and may have been partly caused or complicated by ction of exotic terranes, such as the Mejillones terrane and possibly rs now located west of the present shoreline. Apparently as a result of :tion, the magmatic arc shifted to the west in the Late Pennsylvanian, ıumerous granitoids were emplaced.

ıe eastern part of the back-arc basin recorded, in a syntectonic setting, ea-level falls and mostly resedimented lowstand deposits linked to the lwana glaciations, until Latest Pennsylvanian when a climatic warm-ccurred. Transgressive carbonates deposited on both sides of the Late Pennsylvania–Early Permian magmatic arc. The back-arc marine basin, rich in warm-water fauna, was then bounded to the east (65°W) by eolian and fluvial sands.

The "Gondwanian" tectonic crises started in Mid-Permian times, only affecting an apparently narrow belt in Perus and westernmost Bolivia, geographically located within the "Hercynian" belt. As a consequence the depositional area rapidly migrated eastwards. Shallow-water chert-rich carbonates were mainly deposited until Early Triassic times, when the basin gradually emerged (siliceous stromatolites). During the Late Pennsylvanian–Permian period, the magmatic arc was the site of abundant volcanism and plutonism, and of locally thick lacustrine sedimentation.

Intensities of "Hercynian" and "Gondwanian" deformations in the back-arc basin both show a significant decrease from Peru into Bolivia, which points to a probable strong crustal difference between the two areas. Present lack of outcropping rocks older than Jurassic along the coast of Central Peru might be linked to it.

The Middle to Late Triassic general extension is considered to mark the beginning of the "Andean" evolution, which culminated with the building of the present Andes Cordillera. it must be stressed that the geometry of pre-Cenozoic basins and structures has been deeply modified during this orogeny. The "Andean" overprint on the Paleozoic geologic record thus makes somewhat difficult any precise understanding of the pre-Andean history of the western margin of Gondwanaland, at least at the present time.

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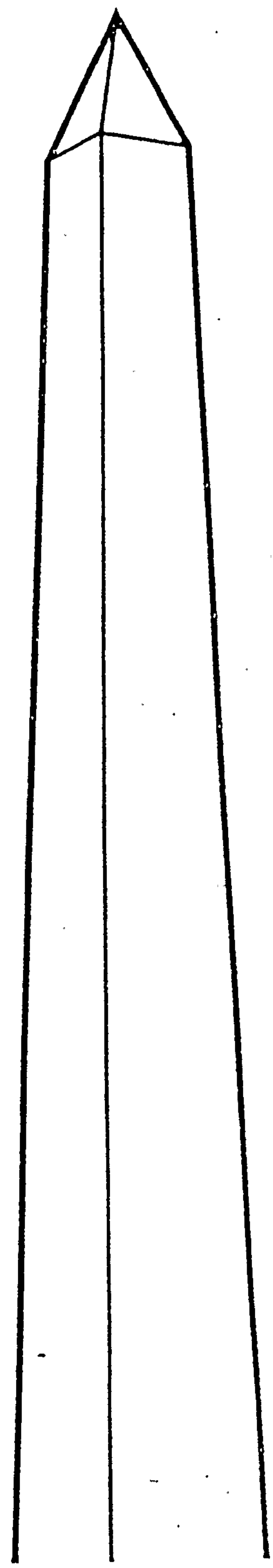

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