Abstract

Late Paleozoic Carbonates and Coeval Glacial Deposits in Bolivia: Correlations across a Significant Paleoclimatic Gradient

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Introduction

In Bolivia there are contrasting paleoclimates from west and north ("northwestern") to south in coeval Carboniferous depositional systems. In the northwest is the Pangean trend, and in the south is the Gondwanan trend. A Late Devonian glacially-derived rock assemblage is followed by warm water Pennsylvanian and Permian sequences in the Pangean trend. The southern Gondwanan succession consists of Late Devonian through Pennsylvanian cold water siliciclastics with glacially influenced deposition. Here Permian tilloids are also known, with large-scale, down-slope remobilization of siliciclastics and repetitive, thick mud/sand sequences of very different ages that confuse time-slice paleogeographic models. Whereas northwestern and southern Devonian through (limited) Mississippian strata share Gondwanan fauna and are comparable in overall character, a juxtaposition of facies and a sharp climatic gradient in western South America is established by the earliest Pennsylvanian. The Pangean trend in northwestern Bolivia and Perú continues with warm water Pennsylvanian and Permian carbonates, evaporites and mixed siliciclastics of a semi-arid, open seaway association (Copacabana Formation). This unit onlaps from the north, reaching central Bolivia by the Early Permian (early Cisuralian). Regionally the warm Pangean pattern continues into the younger and more restricted overlying Cirsuralian and younger Permian and Triassic rocks characterized by restricted marine deposits of both humid and arid association (including red beds).

What makes the Copacabana Formation so enigmatic is 1) its autochthonous succession over cold water, glacigene deposits of the Late Devonian and Mississippian (Figure 1), and 2) its apparent coeval deposition with Pennsylvanian (and Permian) glacial diamictites. Although the former can be attributed to paleolatitudinal shift, or "clockwise" rotation of Gondwana, what is not easily explained (and much discussed) is the autothonous continuity of northeastern and central Bolivian carbonate deposits of the northern Perú-Bolivia basin with southern Pennsylvanian and Permian glacigene deposits, which accumulated in the Chaco-Tarija basins. Given that these cold and warm water deposits were coeval in time this means there were severe climate gradients within Bolivia beginning in Pennsylvanian time.

Western Gondwana records steady progression from mid- (~50°S, Late Devonian) to lower latitudes (< 40°S) by Pennsylvanian time. Glacial deposits migrate away from the northwest. By Early Pennsylvanian (Bashkirian) time carbonates, evaporites and siliciclastics were deposited in NW Bolivia. In central Bolivia, Mississippian diamictites, undated Pennsylvanian siliciclastics, Copacabana lithofacies, and also carbonates of the Vitiacua Formation are vertically stacked at a few locations.

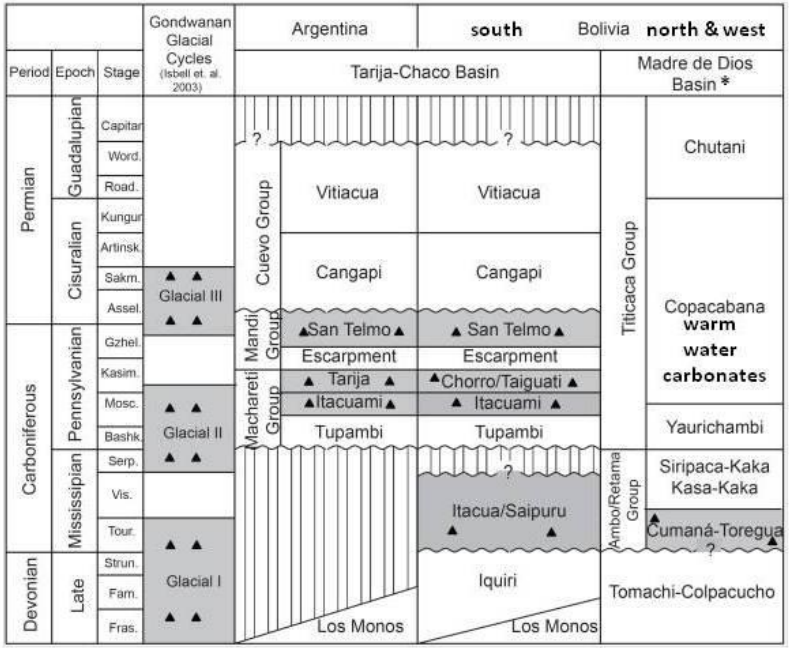

Figure 1. Late Paleozoic stratigraphy of Bolivia and Argentina. Formations containing glacial and/or glacially influenced rocks are shaded grey. Contrasts between Cumaná (glacial) and Copacabana (warm water carbonate) formations parallels the paleoclimatic shift from north to south in Pennsylvanian time.
(* The main Bolivia-Perú basin is represented by the Madre de Dios Basin, *sensu lato*).

Western and Northern Bolivia

The Pennsylvanian and Permian Copacabana Formation is a significant contrast with underlying units, which are Gondwanan glacial and peri-glacial deposits. The Copacabana Formation (and Titicaca Group) consist of diverse carbonates, compositionally immature (but texturally more mature) arkosic and lithic sandstones, shales, tuffs and evaporites, which have been dated by foraminifera, "west Texas" fusulinids, conodonts and palynomorphs. Remnant eolian sands and cross-bedded, fossiliferous marine sandstones with limestone lithoclasts were sourced from reworked semi-lithified Copacabana rocks during lowstands and transgressive flooding events. Many large and small scale cycles form warm water composite sequences in the central Andes. The Pangean 2nd-order transgressive sequence in the Perú-Bolivia Basin records inherited basement controls and ephemeral pericratonic seaways to the interior of a western landmass. Warm water marine transgression was from the north.

Copacabana sedimentation rates in Bolivia were relatively low (7-25 m/my) compared with the thicker and shale-rich formation in Perú. Stacked TST/HST systems tracts with significant hiatuses formed in open and restricted to semi-arid coastal and marine depositional systems. Twelve 3rd-order, 30 to 100 m sequences have paleosols developed on the marine limestone and extensive siliciclastic lowstand/transgressive shoreline facies above sequence boundaries. Thick accumulations of progradational carbonate characterize HSTs. More distal, subtidal ramp sequences have fossiliferous packstone/grainstone caps that do not reach subaerial exposure . These sequences are well-developed in the northern lowlands and Perú, as well as near Cochabamba (central Bolivia) in one of many seaway-connected depocenters). Small meter-scale shallowing-upward parasequences and internal autocyclic, icehouse facies mosaics make up the large Copacabana sequences. Overall accumulation patterns and sandstone/carbonate cyclicity are indicative of combined tectonic and high-amplitude, high-frequency glacio-eustatic depositional controls and sequence boundaries that serve as proxies for glaciations events elsewhere in Gondwana.

Southern Bolivia - Northern Argentina

Ice-proximal stratigraphy of the Late Devonian through Pennsylvanian Gondwana succession is complex in southern Bolivia and adjacent Argentina. Extreme lateral variability of both facies and thickness of the Pennsylvanian age Macharetí and Mandiyutí groups (and underlying units; Figure 1) reflects changes in tectonics and the growth and withdrawal of glaciers. Common deformation features, including synsedimentary slumps, folds, and faults and thick beds of climbing ripples throughout both the Macharetí and Mandiyutí groups indicate high sedimentation rates throughout deposition. Reconstructions of unit thicknesses and depositional environments across the region show a series of depocenters within the larger Tarija-Chaco Basin (smaller basins' depocenters within the late Paleozoic foreland) indicating a change in shelf geometry and primary tectonic stresses within the area during that time. Basin reconstructions from Devonian through Pennsylvanian time indicate basin inversion during the Late Devonian to Mississippian. Pennsylvanian basin reconstructions show a change in basin type from a simple foreland basin deepening to the north in the Devonian to a dissected back-arc basin in the Pennsylvanian with at least three depocenters or sub-basins.

Limited biostratigraphic markers in the Macharetí and Mandiyutí groups lead to numerous models for the depositional environments (continental to deep marine) and age of the these lithostratigraphic groups, making it difficult to develop a geodynamic model for the basin. Palynological work has refined the age of the Macharetí and Mandiyutí groups to Early Pennsylvanian with fewer geographically restricted or eroded Late Devonian and Late Mississippian units, confirming coeval deposition of carbonate (NW Bolivia) and glacial units in the south. Addionally, detailed correlation complexity (depending on age given to individual Macharetí and Mandiyutí formations), comes from an assumed connection of the basin to the north (as it was previously in the Devonian) feeding cold glacial sediments of the Macharetí and Mandiyutí groups north into shallow warm water carbonates of the Copacabana Formation thereby echoing a sharp climatic gradient. Nevertheless the stark contrast from the northwest to the south is evident.

Faceted and striated clasts within the diamictites confirm a glacial origin to several units within the Macharetí and Mandiyutí groups recording at least six major glacial ice advances. Glacial, cold climate influence slightly decreases to the north and through time in the Tarija-Chaco Basin, also reflecting the northward clockwise rotation of Gondwana throughout the late Paleozoic. Previously unrecognized paleosols have been described throughout the sandstones and even within the diamictites of both the Macharetí and Mandiyutí groups confirming that these units were deposited within a largely continental basin. However, brachiopods and marine incursions occurred during deposition. The shallow

marine systems and very limited gastropods have been described within the upper formations of both groups suggesting minor faunas correlate to more complete, fossiliferous marine sections to the south, in Argentina.

Conclusions

Late Devonian glacial beds throughout Bolivia are part of the cold-water Gondwanan trend. In northwestern Bolivia, a Pennsylvanian age Pangean, warm-water system overlies the cold water systems and shows transgression from the north, depositing the carbonates and evaporates (among other lithologies) of the Copacabana Formation within the Titicaca Group.

However, in southern Bolivia, the Gondwana trend continues into Pennsylvanian time. Faunal connections and shallow marine depositional environments in southern Bolivia suggest that these marine incursions came from the south and not from the north as previously thought.

Additional complexity comes from an assumed connection of the basin to the north (as it was previously in the Devonian) feeding cold glacial sediments of the Machareti and Mandiyuti groups into shallow warm water carbonates of the Copacabana Formation, thereby suggesting a sharp climatic gradient.