

Contributions to Late Paleozoic Paleoclimatology of South America: 1970-1979 *

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INTRODUCTION

Contributions to the Late Paleozoic paleoclimatology of South America in the period 1970-1979 involve mainly, though not exclusively, discussion of different aspects of lower Gondwana glaciation along the following lines:

a) Descriptions of glacial deposits features and facies, and their stratigraphic and geographic distribution;

b) Descriptions of fossil flora and fauna intercalated in the glacial sequence bearing on paleoclimatic interpretation and/or interpretation of facies and age of the Late Paleozoic glaciation;

c) Contributions to the regional distribution of glacial or supposedly glacial Late Paleozoic rocks;

d) Regional analysis of paleoclimatic important Late Paleozoic rock sequences relevant for general paleoenvironmental and paleogeographic interpretation;

e) Paleomagnetic analysis of the paleolatitudinal position of glacial bearing and other Late Paleozoic strata.

Though other information pertinent to the understanding of South American late Paleozoic paleoclimatology may appear in more general discussions of Gondwana climate or

geography (e.g., Frakes & Crowell, 1970; Crowell & Frakes, 1975; Bigarella, 1970; Creer, 1970, etc.), these will be excluded from the present review that intends to incorporate only the more geographically specific information.

For practical purposes discussion within each item will not strictly follow the chronological order, but will rather be organized according to the nature of the contributions dealt with. References to data for stratigraphic units other than the diamictite-bearing sequences will appear jointly.

a) IDENTIFICATION OF GLACIAL DEPOSITS AND FEATURES

Attempts to distinguish tillites from other diamictites of the Itararé Subgroup through the application of statistical techniques have been made by Landim (1970) and Landim & Barros (1972). Of the several parameters utilized (grain/matrix ratio, sand fraction mean roundness and sand fraction mean sphericity) the first seems the most discriminative. Recent research, however (Saad, 1977; Santos, 1979), demonstrates that tillites identified as such by the technique employed contain marine microfossils.

Subsurface lithologic sequences of the Itararé Subgroup have been analysed by the transition probability matrices technique (Landim, 1971). Results indicated a general cyclic type of deposition of the glacial sequence possibly associated with recurrent sedimentary processes in the glacial environment.

Additional evidence of glacial origin of the late Paleozoic diamictites of Mato Grosso

* Received July 15, 1980.

Under the sponsorship of the Conselho Nacional de Desenvolvimento Científico e Tecnológico, CNPq (Procs. 2222.0219/75 and 2222.0854/77) and the Academia Brasileira de Ciências. This paper is a contribution of the IGCP Project n. 42, Upper Paleozoic of South America. Presented at the Annual Meeting of the Working-Group of Prof. n. 42, São Paulo, November, 1979. Revised by Thomas R. Fairchild.

do Sul (Aquidauana Group) and São Paulo (Itararé Subgroup) have been derived from electron microscope observation of typical glacial textures on sand grains (Landim *et al.*, 1975).

Two extensive boulder pavements have been described intercalated within a single diamictite body in the northern Paraná Basin (Rocha-Campos *et al.*, 1976). A comparative study of the probable sense of ice-flow on the basis of measurements of striae on beveled faces of clasts of the two pavements and of the fabric of clasts at several levels within the diamictite yielded substantially different results, thus indicating the complexities that involve deductions of sense of glacier movement.

Rocha-Campos *et al.* (1977a) identified possible pseudomorphs or casts of ancient ice-wedges inside a diamictite of the Itararé Subgroup. The features suggest the occurrence of rigorous periglacial conditions (permafrost) in the northern Paraná Basin during the late Paleozoic.

Saad (1977) and Santos (1979) revised the stratigraphic distribution, characteristics and facies of Itararé Subgroup diamictites in the northern Paraná Basin. Lithostratigraphic correlation coupled with palynological analysis helped to understand the spatial distribution and gross correlation of the Itararé strata along about 500 km of the eastern outcrop band in the Paraná Basin. Santos (1979) used sedimentary models derived from studies on recent terrestrial and glacial marine sedimentation for the analysis of facies of diamictites of the Itararé. Ice-retreat and ice-contact features occur associated with diamictites and seem to be important elements for the understanding of patterns of late Paleozoic glacial sedimentation.

Reconstructions of the general glacial geography of southeastern South America have been attempted on the basis of analysis of facies, their spatial distribution and environmental significance (Landim, 1972; Landim & Fulfaro, 1972; Frakes & Crowell, 1972).

On the basis of trend-surface treatment of thickness data, Landim (1972) and Landim & Fulfaro (1972) defined both the thick and thin deposition of the Itararé strata in northern Paraná Basin. They also observed the coincidence of abundant tillite and thin stratigraphic sequences and tillite-poor sediments with relatively thick sections of the Itararé Subgroup. Frakes & Crowell (1972) interpreted the geographic position of postulated glacial lobes reaching the eastern Paraná Basin as coincident with the axes of depressions delineated by trend-surface analysis. Frakes & Crowell (1972) speculated that the eastern ice lobes may have originated in Africa except for the Uruguay lobe that might have constituted an isolated ice-center. On a similar basis, they interpreted the Asunción arch in the western Paraná Basin as the site of another center from which ice radiated towards the east and southwest into the Chaco-Paraná Basin. Other smaller and still poorly defined ice-centers were located on the Pampean arch, Andean Precordillera, and Martim Garcia uplift.

Saad (1977) and Santos (1979), however, found higher a proportion of diamictite and thicker diamictite bodies associated with thicker Itararé Subgroup sections measured along the northeastern outcrop band of the Paraná Basin.

The Carboniferous glacial strata of the central Andes in Bolivia have been revised by Helwig (1972). He interpreted the Gondwana diamictites as terrestrial tillites and tilloids, the latter formed by proximal reworking of the former into fluvial and lacustrine environments associated with the presence of a subcontinental ice cap located on an eastern positive area corresponding to the emergent protocordillera rather than to local mountain glaciers. Associated red beds and the red colour of diamictites have been interpreted as indicative of arid (glacial) climate in the basin of deposition. The Carboniferous glacial sequence of the Bolivian Gondwana is followed abruptly by a predominantly marine carbonate evaporite sequence (Copacabana Group) containing a diverse Tethyan fauna indicative

of subtropical conditions (Helwig, 1972) during the early Permian.

Helwig (1972) and Rocha-Campos (1973) have pointed out some inconsistencies in the paleogeographic and paleoclimatic interpretation of the South American late Paleozoic in the context of the paleolatitudinal position of the continent. The apparently anomalous distribution of Carboniferous reef carbonates in Chile adjacent to glacial diamictites in Argentina is particularly intriguing (Helwig, 1972). Lack of a more precise correlation scheme for the South American late Paleozoic constitutes, however, a major basic difficulty in any attempt of paleogeographic interpretation of the interval (Rocha-Campos, 1973).

b) PALEONTOLOGICAL DATA

A quantitative study of the diversification patterns of late Paleozoic bivalve faunas of South America (Rocha-Campos, 1973) showed a gradient decreasing towards southeastern South America where association with glacial deposits indicates cold water conditions (Gondwana Province), in contrast with the higher diversification values in the northern part of the continent. If the data in fact reflect diversity in faunal variation, then the pattern of diversification would demonstrate a diversity gradient sloping towards the Gondwana Province. This pattern is in accordance with studies of present marine faunal diversification. Since temperature seems to be the major controlling factor of diversity, the derived temperature gradient is, in general, consistent with late Paleozoic latitudes reconstructed on the basis of paleomagnetic data.

Palynological evidence from late Paleozoic deposits in the Paganzo Basin, Argentina (Azcuy, 1975a, b), suggests that the differentiation of floristic provinces coincides with the transition from a humid to a seasonally dry climate between Westphalian and Sakmarian times. These changes may be related to paleolatitudinal displacement and the onset of late Paleozoic glaciation in southeastern South America.

The paleoclimatic and paleogeographic significance of the composition and distribution of early Permian megaflores of South America have been discussed by Archangelsky & Arrondo (1975). They recognized a Austroafromerican Subprovince within the Gondwana Province during the early Permian characterized by a "mixed" (Gondwana plus boreal) composition. The presence of immigrant taxa within the flora was interpreted as indicative of relatively rapid amelioration of climate shortly after the early Permian glaciation due to drifting of South America-Africa towards lower latitudinal positions.

Paleontological data on the age and correlation of the late Paleozoic sequences appear among others in Daemon & Quadros (1970), Millan (1970), Gonzalez (1972), Gonzalez *et al.* (1972), Lobo Boneta (1975), Azcuy (1975a, b), Rocha-Campos *et al.* (1977), Archangelsky *et al.* (1978) and Archangelsky & Marques Toigo (1978). Though palynological data indicate a longer duration for the late Paleozoic glaciation in the Paraná Basin (Stephanian-Kungurian), this differs from evidence based on invertebrates and megaplants, on the basis of which a late Carboniferous-early Permian age for the Itararé seems more acceptable. With the possible exception of the Sauce Grande Formation, all the other late Paleozoic diamictites of Argentina seem older than the *Cancrinella farleyensis* zone (early Permian?). In Bolivia the finding of *Levipustula levis* in the marine fauna of the Taiguati Formation indicates a Namurian-Westphalian age for most diamictites in the Subandean area. On a palynological basis, an early Carboniferous age has been interpreted for the lower part of the Carboniferous sequence.

c) DISTRIBUTION OF GLACIAL OR SUPPOSEDLY GLACIAL ROCKS

Knowledge of the geographical and stratigraphical distribution and characteristics of diamictites and other associated rocks of glacial or supposedly glacial origin has improved in the period due to regional mapping and stratigraphic revision in several parts of

the Paraná Basin and other sedimentary areas in Brazil.

Soares *et al.* (1973), Soares & Landim (1973) and Fiori (1973) described the main features of the Itararé Subgroup (called by them the Aquidauana Formation) in the northeastern part of the Paraná Basin (Minas Gerais and São Paulo States).

Saad (1977) and Santos (1979) revised the stratigraphy of the Itararé Subgroup in central and southern São Paulo State and offer much valuable information on the distribution, characteristics and facies of the late Paleozoic diamictites. Detailed description of lithologic associations of the upper Itararé and their environmental significance appears in Soares *et al.* (1977).

The Itararé of southern São Paulo and northern and central Paraná State has been mapped by Vieira (1973) who described the main lithologic features of the unit in the area.

A detailed account of Itararé rocks and their stratigraphy in São Paulo and Paraná States appears in Fulfaro *et al.* (1971), Medeiros (1971) and Rocha-Campos (1972). The last contains detailed descriptions of relevant outcrops of glacial rocks and features.

The stratigraphy and main features of the Itararé rocks in Paraná, Santa Catarina and Rio Grande do Sul and their paleoenvironmental interpretation has been derived from regional mapping by Petrobrás (Tommasi, 1973). A regional revision of the Paraná Basin stratigraphy by Schneider *et al.* (1974) includes additional information on distribution of diamictites and other paleoclimatically important rocks of the Itararé Subgroup.

Correa da Silva (1977, 1978) discussed the stratigraphy and facies of the Itararé Subgroup in Rio Grande do Sul, concluding that the Itararé in the area was not glacial in origin.

The best account on the characteristics and facies of late Paleozoic diamictites and associated sediments along the southwestern margin of the Paraná Basin (Aquidauana Group) appears in Farjallat (1970), who

interpreted the diamictites as subaqueous deposits (turbidite, mud-flow) with important contribution of ice-worked material. Additional information on the Aquidauana rocks in the area appears in Fulfaro & Landim (1971) and Fulfaro & Petri (1978).

Outside the Paraná Basin in Brazil, possible glacial diamictites containing striated clasts of late Paleozoic age have been recently discovered in Mato Grosso do Sul (Olivati & Ribeiro Filho, 1976) and in Rondônia (Carvalho *et al.*, 1975). In the Sergipe-Alagoas basin in northern Brazil the Batinga-Aracaré sequence, often correlated with the N'Khom and Agoula "Series" of Gabon (Karoo System), has been re-examined by Rocha-Campos & Brito Neves (in preparation). At Igreja Nova the Batinga diamictites overlie a striated and polished pavement developed on Precambrian rocks.

For the rest of South America, the useful syntheses of the late Paleozoic geology of the main Paleozoic basins of Argentina (Amos, 1972; Borrello, 1972; Furque, 1972; Harrington, 1972; Lesta & Ferello, 1972; Mimgrann & Russo, 1972; Padula, 1972) and Bolivia (Castaños & Rodrigo, 1978) contain much information on the stratigraphy and facies of diamictite-bearing sequences.

In southern Peru, Mendiivil (1976) refers to the presence of tillites in the Ambo Formation (early Carboniferous).

d) REGIONAL STRATIGRAPHIC ANALYSIS

Fulfaro (1971) and Landim & Fulfaro (1972), discussed the tecto-sedimentary and paleogeographic evolution of the Paraná Basin, including the diamictite-bearing Itararé Subgroup, through trend-surface analysis of subsurface thickness data. The results are useful for depicting the paleogeography of the glacial sequence.

Saad *et al.* (1978) presented an account of the tecto-sedimentary evolution of the Tubarão Group in the northeastern Paraná Basin and attempted to relate it to cratonic and other possible intervening factors (e.g., glacio-isostatic).

e) PALEOMAGNETIC DATA

Paleomagnetic determinations on rocks of the Itararé Subgroup in the northern part of the Paraná Basin have yielded a pole that is close to other late Carboniferous poles of South America (Valencio *et al.*, 1975). The pole for the overlying Corumbatai Formation is closer to other Permian poles for the continent and includes changes of polarity interpreted as evidence of an late Permian (Tatarian) age for the Corumbatai red beds.

A Quebrada del Pimiento age (late Permian) has been interpreted for the dolomites of the Irati Formation in the northern Paraná Basin.

Paleomagnetic data corresponding to 167 "varves" were obtained for Itararé Subgroup rhythmites at the Itu quarry by Ernesto (1977). The variation of the magnetic properties was considered as comparable to that of the Earth's present magnetic field.

Additional discussions on paleomagnetism of late Paleozoic rocks of South America by Valencio (1975, 1978) and Vilas & Valencio (1977) review the available information on the paleolatitudinal position of South America during the interval.

SUMMARY

Contributions to late Paleozoic paleoclimatology in South America in the period 1970-1979 are extensively reviewed along the following lines: i) identification of glacial features and deposits; ii) discussions on the fossil fauna and flora and their bearing on interpretation of paleoclimatic conditions, facies and age of the late Paleozoic rocks; iii) improvements in the knowledge of the regional distribution of glacial or supposedly glacial rocks and of other paleoclimatic indicators; iv) regional (basin wide) analysis of paleoclimatically important late Paleozoic rock sequences with respect to general paleoenvironmental and paleogeographic interpretations; and v) paleomagnetic analysis of the paleolatitudinal position of glacial and other late Paleozoic strata.

Nearly 60 papers have been reviewed and comments on the important results are added.

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