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Glaciation at the Ordovician - Silurian boundary in southern Bolivia

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1. INTRODUCTION

Successions of diamictites at the Ordovician-Silurian boundary belonging to the Cancañiri Fm. (Bolivia) and the Zapla (Mecoyita) Fm. (Argentina) crop out in the Central Andes within 17° and 25° S lat from southern Peru through central and southern Bolivia to NW-Argentina (Crowell et al. 1981). They first were interpreted as glacial deposits by Schlagintweit (1942) who introduced the term ”Glacial horizon of Zapla” and suggested a Silurian age.

With the worldwide reinterpretation of diamictites in the 60´s the sediments of the Cancañiri Fm. were interpreted either as resedimentation products or as glacimarine sediments (e.g. Díaz 1997a). Since the recognition of a late Ordovician ice age in NW-Africa, the Central Sahara, and other parts of Early Paleozoic Gondwana, the origin as well as the age of the Cancañiri (or Zapla) Fm. were discussed controversially.

2. LOCATION AND GEOLOGICAL SETTING

The study area is situated 17 km north of Tarija, at longitude 64°40’ W and latitude 21°23’ S between the villages of Sella and Negro Muerto. At this locality the Ordovician-Silurian boundary is exposed several times due to W-verging backthrusting caused by Andean deformation (fig. 1).

The exposed lithological units comprise Lower Ordovician to Middle Silurian anchimetamorphic siliciclastic sediments with a hiatus between Middle Arenigian and Upper Ashgillian rocks. These units are represented by the Lower Arenigian Sella Fm., the lower to middle Arenigian Rumi Orkho Fm. (formerly Caradocian ”San Benito Fm.”, see Maletz et al. 1995), the upper Ashgillian Cancañiri Fm. and the Llandoverian to Ludlowian Kirusillas Fm. with the ferriferous sandstones at its base. Below the diamictites a yet unnamed unit (Facies Group A) was observed. The age of this unit is uncertain but a late Caradocian age is suggested by the author (chapter 9). It thus divides with a second hiatus the Rumi Orkho Fm. from the Cancañiri Fm.

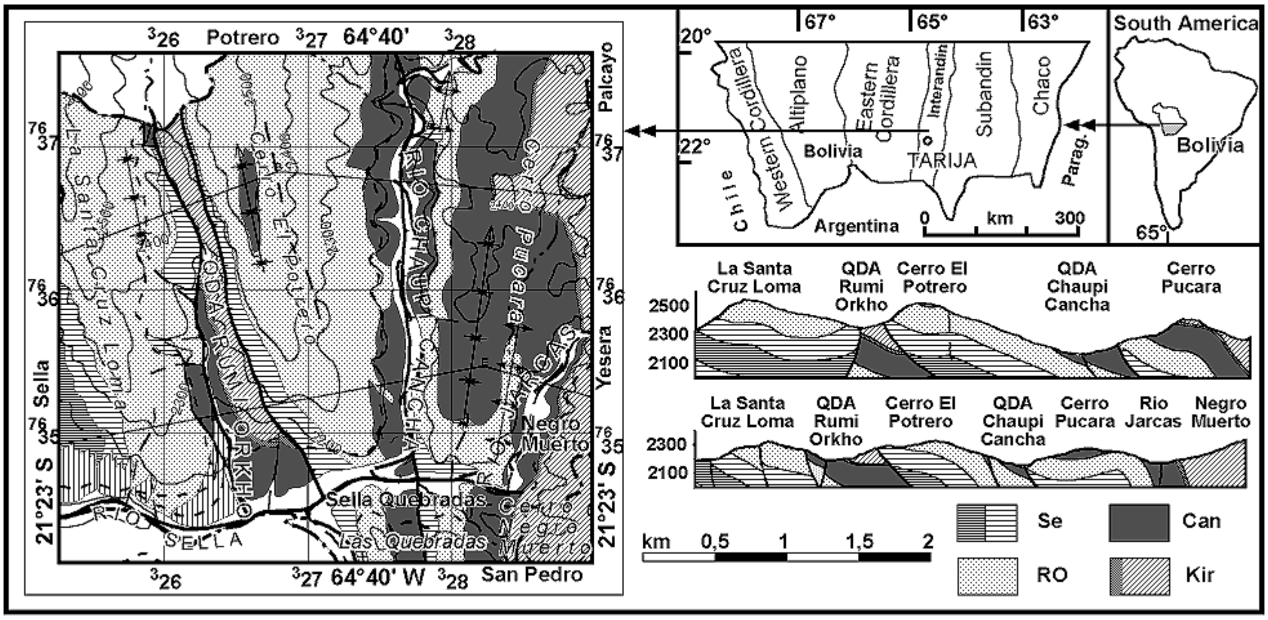

Fig. 1: Geological setting of the study area; Se: Sella Fm., RO: Rumi Orkho Fm., Can: Cancañiri Fm., Kir: Kirusillas Fm.

3. AIM OF WORK AND METHODS

The aim of this work is to describe the facies associations and variations of the Cancañiri Fm.

Facies analysis was carried out to decide whether the diamictites were deposited by resedimentation processes in a marine environment as suggested for central Bolivia by Díaz (1997a/b) or if they can directly be related to glacial activity. Special attention was paid to boundary relations of the Cancañiri Fm., to intercalated sandstone or conglomeratic beds and to the size, shape, morphology, and composition of clasts.

The Cancañiri Fm. was mapped with regard to sandstone and conglomeratic bodies. For facies description 3 general sections (fig. 2), 4 sections at the base, and 5 at the top of the formation were measured. A lithofacies code based on that provided by Moncrieff (1989) was used to describe variations within matrix, clast content, and sedimentological structures of the diamictites (fig. 2).

4. FACIES OF THE CANCAÑIRI FM.

The overall characteristics of the 175 m thick diamictite succession are those of a massive body of greenish-grey to black diamictites with a yellowish-brown weathering color. Massive or stratified sandstones and conglomerates are present as local banks or lenticular bodies in the lower part of the succession. Composition of the diamictites changes locally, laterally as well as vertically. Four facies groups could be observed, probably related to four cycles of sedimentation (figs. 1, 2). Facies Groups B to D represent the Cancañiri-Diamictites sensu strictu and were distinguished due to matrix variation, clast content, and by bordering beds of conglomeratic sandstones (fig. 2).

Facies Group A is characterized by a small unit (5-10 m) of massive, strongly bioturbated Siltstones with intercalations of sandy/silty soft-pebble conglomerates with some remnants of bivalve fossils. This facies is only present at the western flank of the Chaupi Cancha Valley and totally missing towards the East.

Facies Group B comprises muddy to intermediate diamictites with a low clast content (M[D] to I[D]) and contains abundant intercalations of lenticular bodies of mudstones, sandstones, quartzites, and conglomerates. The contacts of the latter with the massive diamictite can either be sharp (erosional) or gradually. Several layers of slightly to significantly stratified diamictites are also present. They may vertically pass into sandstones or conglomerates. This unit is topped by a massive bank of conglomeratic sandstones and/or by a gravellag and has a thickness of 55 to 75 m.

Facies Group C is mainly built up of massiv intermediate to sandy clast-poor to slightly clast-enriched diamictites (I[D], ID to S[D]) and contains similar lenticular bodies of sandstones and quartzites like group A. Nevertheless conglomerates and mudstones have not been observed in this unit. Locally significant matrix variations in the diamictite are present showing an irregular stratification. This group yields a thickness of ca. 50 m and ends with the sedimentation of massiv sandstones at its top.

Facies Group D consists almost completely of clast-rich mostly sandy diamictites (ID-SD) and shows only minor intercalations of sandstones and stratified diamictites, mostly in the order of dms. Besides these exceptions, the diamictites are massive and directly overlain by the ferriferous sandstones at the base of the Kirusillas Fm. The thickness of this group varies between 45 and 75 m.

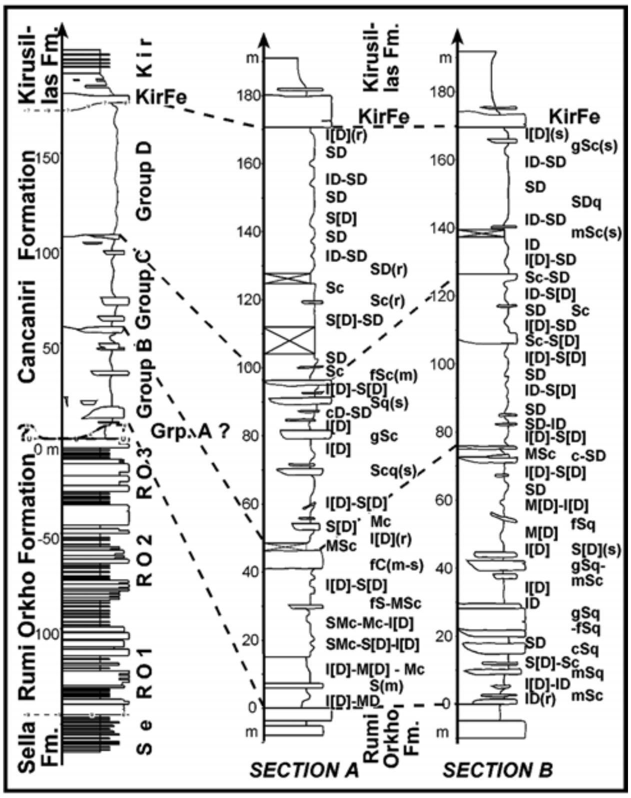

fig.2: Sections of the Cancañiri Fm. in the study area; Left: composed section; A: northern section; B: southern section (Encoding after Moncrieff 1989)

5. BOUNDARY RELATIONS

In the study area the Cancañiri Fm. unconformably overlies the shallow marine Rumi Orkho Fm. These sediments (fig.1, 2) yielded remnants of brachiopodes, bivalves, Cruziana and other traces, which where found within clasts of the Cancañiri Fm. as well (chapter 6). An erosional lower contact of the diamictites can be confirmed by the bioturbated siltstones at their base which are absent in the east.

The upper boundary of the Cancañiri Fm. at the Sella locality is represented by a sharp contact to the ferriferous sandstones at the base of the Silurian. This contact which is represented by laminated diamictites is probbably characterized by a small hiatus. Locally, at the base of the sandstones, a 20 cm thick bed is present where diamictite pebbles up to 10 cm in diameter and predominantly quartzitic clasts are embedded within the ironstones.

6. DESCRIPTION OF PEBBLES

About 300 clasts were collected, measured, and analyzed. About 70 clasts were thin-sectioned for lithological description. The pebbles, ranging in sizes from a few millimeters to dms, were collected directly from within the matrix at different levels of the diamictite succession.

The clast content of the Cancañiri Fm. is highly polymict, yielding all kinds of siliciclastic sedimentary rocks as well as metamorphic, and magmatic rocks. No significant vertical or lateral variation in clast composition within the diamictite succession could be observed. The largest clasts found within the diamictites in this area were strongly wethered outsized granitoid boulders of 1,2 and 0,9 m in diameter respectively.

The shape of the pebbles is highly variable reflecting lithology. Clasts built up of claystones and fine sandstones often show an oblate spheroid (flat-iron) or spherical shape, while harder lithologies like quartzites or igneous pebbles are mostly triaxial (bladed) or prolate spheroid in shape.

The roundness varies from angular (0.3) over subrounded (0.6) to well rounded (0.8-0.9) pebbles, but the majority of clasts has a roundness of 0.4 to 0.7 with an average of 0.56. Roundness reflects lithology as well, with rounded soft sediment clasts and less rounded pebbles of harder lithologies. The determination of roundness was difficult due to the strong facettation of the pebbles. Original roundness is likely to be less than measured.

Clasts of all lithologies are strongly facetted, often on more than one side. The rate of facetted clasts out of all collected lies at 85.5%. This facettation is in most cases directly connected with the striation of the pebbles. 71.5% of the collected clasts have striations predominantly on the facetted surfaces. A lot of them are striated in more than one direction. This together with the presence of chatter marks on some stones of harder lithologies indicates a glacial origin of the striae.

Some clasts of sedimentary origin reflect the lithology of the Rumi Orkho Fm., but from a more proximal environment to the east. Some of them also show striations. Two clasts containing Cruziana traces and several with lingulid brachiopodes and bivalves where found.

7. GENETIC INTERPRETATION

Criteria for the identification of glacigenic or non-glacigenic diamictite deposits where checked for interpretation of the diamictite succession (Schönian 1999). These criteria are ranging from macroscale to microscale features. As a result a glacial genesis is suggested for interpretation of the characteristics of the Cancañiri Fm. at this locality.

Boundaries: The erosional base of the diamictites is related to glacial erosion, although striated pavement was not observed at this locality.
Nevertheless striated pavement caused by a grounded glacier has been reported from the late Ashgillian Zapla Fm. at the Argentinan-Bolivian boundary (Martinez 1998).
The upper contact with the ferriferous sandstones is characterized by resedimentation at the top of the diamictites and by a locally visible transgressive conglomerate at the base of the shallow marine bar-like sandstones of variable thickness (3-20 m).

The lower boundary of a turbiditic succession with gravitational resedimentation as well as of glacimarine deposits is usually not represented by a hiatus and by significant erosion. At other localities the Cancañiri Fm. concordantly overlies the upper Ordovician marine Tokochi Fm. and is topped by the turbiditic succession of the Llandoverian Llalluga Fm. (Díaz 1997a).

Facies association: The association of massive diamictites with local, mostly lenticular bodies of siliciclastics of different grain size reflects a highly variable environment typical for a glaciated area. A facies association of non-sorted sediments (diamictites) with open-marine background sedimentation (shales, mud- or siltstones) and turbiditic intercalations is missing at this locality. Associations of diamictites with shallow marine siliciclastics are also absent.

Facies: Features for resedimentation by gravity flow or related processes and for glacimarine deposition reported by Díaz (1997a/b) for central Bolivian localities of the Cancañiri Fm. were not observed.

The massive diamictites are interpreted as true tillites deposited by a grounded glacier. Small lenses of poorly stratified diamictites can thus be caused by small scale gravity flow processes. Well stratified diamictites, sandstones, and conglomerates can be related to flowing water of different velocities and are interpreted as glacial outwash deposits. The observed three facies groups (B-D) could reflect three advances of glacier to this area. This also explains the relatively thick tillite sequence.

Microfacies: Sorting of matrix grains of the diamictites is variable but generally poor. The lateral and vertical gradation of the facies types into each other caused by outwash processes resulted in a differentiation of sorting grade as well as of the main fraction grain size. The matrix grains reflect the lithologies of the clasts with a shift in quantity towards quartz particles typical for tillites. Authigenic minerals indicating a marine environment are absent in the matrix as well as fragments of marine fossils or bioturbations.

Within sandstones and fine conglomerates there is a significant shift towards quartz particles. Remnants of granitic fragments (feldspar and mica) are abundant. Pebbles of diamictites within sandstone bodies, elongated and flattened parallel to bedding (till pellets), are unique to a glacial environment.

Fossils: The Cancañiri Fm. is generally poor in fossils. In the study area only one reworked specimen of an orthid brachiopod was found at its base and several in part highly fossiliferous clasts containing bivalves, brachiopods, and trace fossils mainly out of the Rumi Orkho facies were collected. Authochthonous fossils within the matrix or coquina beds are absent which indicates a non-marine environment.

Pebbles: The polymict clasts of the Cancañiri Fm. are indicating a large source area where a great variety of rock types were present. Clasts derived directly from underlying Ordovician siliciclastic rocks were found as well as far travelled erratica from a basement area most probably from the Brazilien Shield to the east. Some metasedimentary and metamorphic fragments could be related to Puncoviscanan basement. Size, shape, roundness, and facetted surfaces together with striations and chatter marks indicate a glacial transport path for the great majority of the pebbles.

The observed glaciation is characterized by the deposition of massive tillites, intercalated wash-out, resedimentation, quiet water deposits, and postglacial resedimentation processes.

8. AGE OF THE CANCAÑIRI FM.

The age of the Cancañiri Fm. is widely discussed, since their sediments are generally poor in autochthon fossils.

Between central Bolivia and N-Argentina a regional angular unconformity devides the base of the Cancañiri Fm. from Ordovician rocks of Tremadocian to early Ashgillian age (Suárez 1995). The upper boundary is not easier to constrain, for there are not a lot of indicative fossils in the lower parts of the Kirusillas Fm. A Llandoverian to Wenlockian age was proposed for the Cancañiri Fm. in central Bolivia indicated by microfossils from within and the top of the succession and from macrofossils of Wenlockian age from above the diamictites (Suárez 1995). For NW-Argentina there is nowadays agreement about the late Ashgillian age of the Zapla Fm. due to trilobites from within the succession (Monaldi et al. 1987) and due to latest Ashgillian - early Llandoverian graptolites at the base of the Lipeon Fm. just above the lowermost ferriferous sandstone bed (Monteros et al. 1993).

The author points toward the strong affinity of lithofacies of the Cancañiri and Kirusillas Fms. in southern Bolivia to the northern Argentinan Zapla and Lipeon Fms. The differences of facies and age of the Cancañiri successions between southern and central Bolivia is best be explained by diachronous sedimentation. Following this hypothesis unconsolidated late Ashgillian glacial sediments in the southern and eastern (?) parts of the Cancañiri realm were subjected to marine resedimentation throughout Late Ashgillian and Llandoverian in the central parts of the basin.

9. SUMMARY

Facies interpretation and multiple criteria analysis have revealed a glacial history for the the Cancañiri Fm. at the locality Sella. Lithostratigraphic correlation of the Cancañiri and basal Kirusillas Fms. with the correspondent units of the northern Argentinan Zapla and Lipeon Fms. strongly suggests a late Ashgillian age of the glaciation. Thus the late Ordovician glaciation of Gondwana could not only be recognized in the Argentinan Precordillera (Buggisch and Astini 1992), but also in the NW-Argentinan Zapla (Martinéz 1998) and the S-Bolivian Cancañiri Fms.

The bioturbated siltstones at the base of the Cancañiri Fm. at the locality Sella where removed by glacial erosion in the east. They may represent a transgressional phase between the subaerial exposure of the shallow marine deposits of the Rumi Orkho Fm. in late Arenigian times and the onset of glaciation. A correlation with the late Caradocian transgressive maximum seems to be the most plausible explanation for these marine sediments.

The glaciers seemed to have reached the study area from the east in three phases. Directly after the glaciation the deposited tillites of the last cycle where subaerially exposed as is evident from limnic to marine-brackish resedimentation at their very top. This short period was abruptly ended by the latest Hirnantian - early Llandoverian transgression represented like in NW-Argentina by transgressive ferriferous sandstones at the base of the early to middle Silurian Kirusillas Fm.

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