Heavy mineral analysis of sediments from the Ordovician of the Andean Eastern Cordillera (Southern Bolivia).

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Introduction

Recent studies of heavy mineral suites of different sedimentary rocks suggest that heavy mineral assemblages supply information and serve as relatively reliable and decisive indicators of plate-tectonic settings associated with continental margins (NECHAEV & ISPHORDING 1993).

Sedimentary rocks of Ordovician age are the main constituent of the Eastern Cordillera of southern Bolivia. Its structure and tectonic evolution was recently summarized by KLEY et al. (1997). However, the basin development during the Early Palaeozoic is still poorly understood. In the Eastern Cordillera a shallow marine shelf formed during the Late Cambrian due to extension of late Brazilian basement (MOYA 1988). The Ordovician sedimentation occurred in a back-arc basin. Whether it was floored by oceanic crust or by ensialic crust is still a matter of debate (e.g. COIRA et al. 1982, DALZIEL & FORSYTHE 1986, BAHLBURG 1990).

We selected a classical section located between Tarija and Tojo in the south of the country with a well established litho- and biostratigraphic control. Heavy mineral analysis was carried out in order to show the vertical variation of the silt/sand-sized heavy mineral fraction, as a function of depositional environment, and to determine provenance relations.

A total of 20 texturally homogenous samples of coarse siltstones to medium-grained sandstones were washed, dried and broken. The fractions 63 - 125 and 200 - 500 µm were selected. Acids were not used during preparation. Most heavy mineral species are identified by SEM/EDS and XRD analysis, by their distinctive composition and morphology.

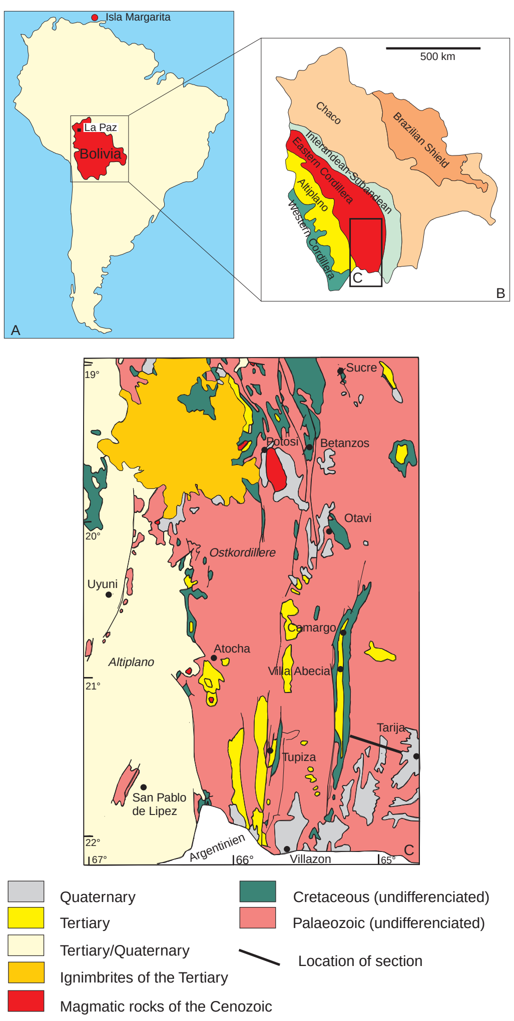

Figure 1 The study area in the Central Andes of Bolivia, their morphotectonic units (A, B), and a generalized geological sketch map of southern Bolivia with the location of the section (C).

Geological setting

The Eastern Cordillera of southern Bolivia mainly consists of a thick succession of anchimetamorphic predominantly fine-grained siliciclastic marine sediments of Ordovician age (Fig. 1). They are in places unconformably overlain by Cretaceous and/or Tertiary sedimentary and volcanic rocks. The development of folds, slaty cleavage, and anchimetamorphism in the Ordovician strata are due to a Devonian/Carboniferous compressive deformation. The Eastern Cordillera is subdivided by the Camargo-Tojo Thrust into an eastern and a composite western part. The Proterozoic to Ordovician rocks east of the Camargo-Tojo Thrust are structurally related to the thin-skinned fold-and-thrust belt of the Interandean and Subandean of the eastern flank of the Andes (KLEY 1993), and continue southward to northern Argentina (MENDEZ et al. 1979). In contrast, the western part of the Bolivian Eastern Cordillera terminates as a morphological unit at about 22° S, plunging southward under the Tertiary and Quaternary cover of the Argentinian Puna.

The portion east of the Camargo-Tojo Thrust corresponds to the Yuncharà segment. Underlying the Ordovician is the Upper Cambrian Sama Quartzite. The Ordovician sedimentary sequence, originally described by RIVAS et al. (1969), is subdivided into the following units:
(1) The Iscayachi Formation consists of medium grained cross-bedded quartzites and fossiliferous fine-grained sandstones with siltstone intercalations. Trilobites and graptolites reveal a Tremadocian age (SUAREZ-SORUCO 1975).
(2) The Cieneguillas Formation and Obispo Formation are dominated by cherty dark shales, laminated dark silty shales and thin chert layers, reflecting a transgressive trend.
(3) In the Agua y Toro Formation and Pircancha Formation turbiditic sandstones are intercalated in varying proportions.

The overall thickness of the Ordovician succession amounts to about 4500 m (MALETZ et al. 1995). The biostratigraphy of the type section was recently reevaluated based on new fossil material (ERDTMANN et al. 1995, MALETZ et al. 1995). The youngest Ordovician strata preserved within the Yuncharà Segment are of Mid-Arenigian age.

West of the Camargo-Tojo Thrust the Mochará segment extends westward to the Nazareno basin. Approximately 3000 m of predominantly pelitic rocks with intercalations of fine grained turbiditic sandstones are exposed. They range in age at least from the Tremadocian/Arenigian boundary to the Upper Arenigian (ERDTMANN et al. 1995). The Atocha segment, situated west of the latter and bounded by the San Vicente Thrust in the west, exhibits a lower sandy-silty unit (Kollpani unit), and an upper unit of dark shales with few intercalations of quartzitic turbidites (Tapial unit). The total thickness is at least 4200 m. It contains the youngest Ordovician strata of the Eastern Cordillera. Graptolite discoveries indicate Llandeilian to Lower Caradocian stages (MüLLER et al. 1996).

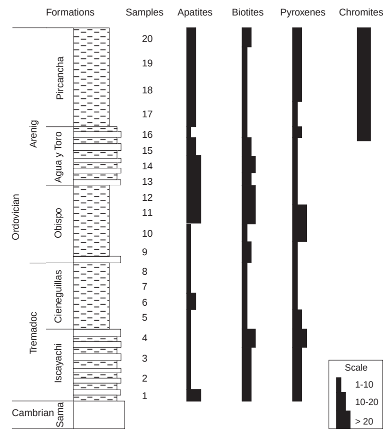

Figure 2 Distribution of the main heavy-minerals of the fraction 63 - 200 µm in the Sama-Chaupi Uno section. Thickness of lines (scale) represent quantity of grains present in the preparates. Location of the section is indicated in Fig. 1.

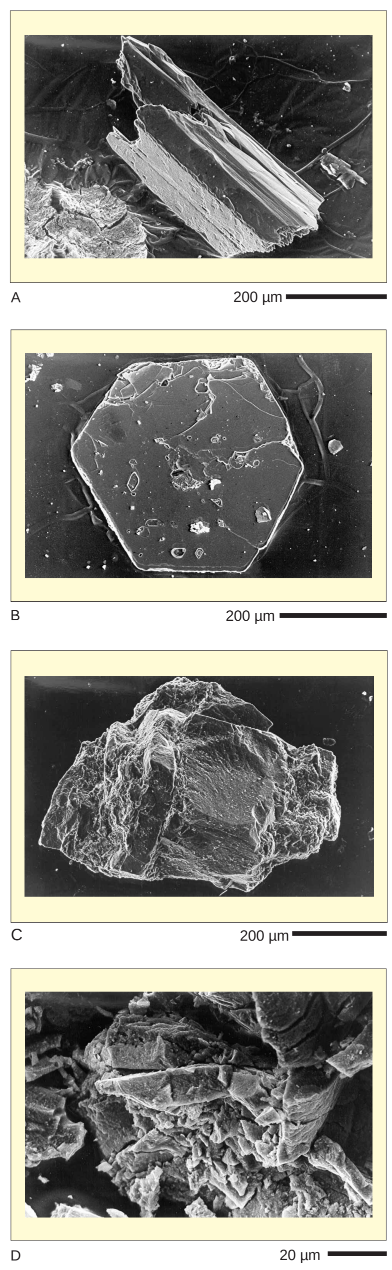

Figure 3 SEM photomicrographs of fine-grained heavy minerals found in the Ordovician sequence of Sama-Chaupi Uno.
A. Prismatic grain of Ca-Pyroxene.
B. Euhedral grain of biotite with pitch structures.
C. Alternation of apatite layers and silicoclastic material.
D. Chromite grains in concretions of Fe-oxides.

Biotites

Elements Wt %	Sample 11	Sample 2
Mg	12.257	10.192
Al	10.725	10.737
Si	30.502	36.082
K	13.521	13.416
Ti	6.450	
Fe	26.546	29.574

Apatites

Elements Wt %	Sample 1	Sample 16
P	30.124	20.305
Ca	69.876	79.695

Pyroxenes

Elements Wt %	Sample 2	Sample 3	Sample 5	Sample 5
Mg	11.394	11.954	11.105	13.405
Al	3.055	13.557		
Si	37.469	38.463	38.606	39.906
Ca	31.736	17.310	32.402	30.554
Ti	1.490			
Fe	14.856	18.716	17.888	16.135

Table 1 Chemical composition of representative biotites, pyroxenes and apatites from heavy-mineral samples out of the Ordovician sedimentary sequence. Position of the samples are indicated in Fig. 2.

Results

The concentration of heavy minerals is low in the 63 - 200 µm and very low in the 200 - 500 µm fraction. The main portion of the total amount of heavy minerals are opaque species. Minerals of high chemical and mechanical stability (zircon, tourmaline and rutile) were not detected. The most abundant heavy minerals, beside the opaque ones, are pyroxene, biotite and apatite.

Pyroxenes are distributed throughout all samples (Fig. 2,3). Representative analysis using EDS show a limited compositional range of the pyroxenes. All fall into the field of calcium-rich pyroxenes (Table 1). Most are idiomorphous crystals, some of those possess facettes. Others are fragments of idiomorphous crystals, but without any sign of rounding. Pits are present as irregularly distributed surface structures

Biotites occur in all samples (Fig. 2, 3). Their habitus is idiomorphous, or broken fragments of pheno-crystals exist. Their colour is brown. They also show pits. Their chemical composition varies between titano-biotite and biotite (Table 1).

Apatites appear in all samples and all granulometric classes in both fractions (Fig. 2, 3). They are generally present in horizons of interlayered apatite, quartz, and micas. From Table 1 it can be seen, that the measured apatite layers are homogeneous, which can be referred chemically to a hydroxyl-apatite.

Opaque minerals were detected in both fractions and all samples. The main components of the opaque suite are microcrusts of Fe-Mn-oxides comparable to the ones of the Ordovician shales (MANUTSOGLU et al. 1996). At the base of the Agua y Toro Formation a peak occurrence of the microcrusts was detected. However, they are distributed in minor quantities throughout all samples. Less frequent are pyrites, copper-minerals, ilmenites, leukoxens, hematites. Magnetites with an idiomorphous habitus are present only in two samples. Chromites occur in both fractions in samples 16-20, only (Fig. 2, 3). They were analysed with X-ray methods because they are integrated as small size crystals into concretions of Fe-oxides.

Discussion

Heavy mineral analysis represents a tool to characterize provenance areas in a chemical and palaeogeographical way (MORTON & HALLSWORTH 1994). The suite of heavy minerals detected in the sedimentary column of Tremadocian to Middle Arenigian age offers an opportunity to differentiate related provenance areas, which are in close connection with the evolution of the back arc basin. The apatites, chromites, calcium-rich pyroxenes, magnetites and biotites are of special importance.

The apatites are related to the formation of biogeneous phosphorites (VALETON 1988). This reflects the existence of a broad shelf area, which was postulated by RIVAS et al. (1969) and MOYA (1988).

Calcium-rich pyroxenes, biotites and magnetites were transported out of a volcanic source area of mafic to intermediate composition into the Ordovician basin. In the neighbourhood a chain of volcanoes existed in the „Faja Eruptiva de la Puna Oriental" (e.g. BAHLBURG 1990), which is a possible source area for the suite in the Ordovician sequence.

In several basinal sedimentary successions, e.g. the South- and Austroalpine flysch sequences of the Alps (e.g. BERNOULLI & WINKLER 1990) chromite heavy mineral grains were interpreted to derive directly from oceanic crust. The occurrence of chromites in our samples (16-20) are interpreted as an indication for an oceanic basement, which was composed mainly of serpentinites and mafic rocks. The existence of such an oceanic crust was presumed by COIRA et al. (1982) and BAHLBURG (1990). The determination of chromites is an indirect positive confirmation for their ideas.

Conclusions

The heavy mineral assemblage consists mainly of opaque minerals, namely Fe-Mn-oxides as microcrusts, pyrite, leukoxen, ilmenite, hematite, and magnetite. Transparent minerals are calcium-rich pyroxene, biotite, and apatite. This association is typical for the Tremadocian and Lower Arenigian. Since the Middle Arenigian, chromites are a further ingredient of the suite. All grains are well preserved, and intrastratal solution is missing. Therefore the distance of transport is presumably not very long.

Provenances of the heavy minerals are different. Three source areas are distinguished:

1. The apatites were derived from a shallow marine passive shelf presumably located towards the east.
2. The calcium-rich pyroxenes, biotites and most of the opaque heavy minerals derived from the volcanic suite of the „Faja Eruptiva de la Puna Oriental" located towards the southwest.
3. The chromites derived from oceanic crust present towards the south in northwestern Argentina.

This heavy mineral study represents a contribution to the geodynamic evolution of the Ordovician basin development along the western margin of Gondwana in this region of the Andes.

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