TERTIARY TO RECENT SEDIMENT PROVENANCE ACCORDING TO GEOCHEMICAL ANALYSIS: OCOÑA-COTAHUASI, MAJES-COLCA VALLEYS AND THE MOQUEGUA SEQUENCE, CENTRAL ANDES, PERU

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ABSTRACT

The major and trace elements analyses on modern (loose sand and mud from rivers) and ancient (sandstones from Moquegua A, B, C, and D) sediments allow us to reconstruct the provenance of the Cenozoic Western Andean escarpment and the deepest canyon sediments in Southern Peru. However this chemical analysis has to be completed with other methods as heavy minerals and isotopes analyses in order to perform provenance and mass balance of sediments.

INTRODUCTION

Ocoña-Cotahuasi and Majes-Colca are the deepest valleys of the South American continent. They are Late Miocene landforms (Thouret et al., 2007) and localized in South Peru between 14 and 16°S. At present day the climate in this area is arid. The rainfall average is less than 100-200 mm/y but it has changed through time; sediments on the Altiplano indicates a period of increased precipitation at 7 Ma (Gaupp et al., 1999) thus the drainage system has been modified through time. Actually Ocoña and Cotahuasi rivers form the Ocoña drainage basin. The Ocoña catchments cover 4200 km² from the Altiplano to the Pacific Ocean, across the Western Cordillera, with a maximum depth of 2.5-3.5 km (Fig. 1). The valley flanks expose Cretaceous intrusive rocks, Jurassic sedimentary rocks and Paleozoic to Proterozoic metamorphic rocks (Fig. 2). The Majes and Colca rivers form the Camana drainage basin. The Camana catchments cover 5500 km² across the Western Cordillera, from the frontal arc to the Pacific Ocean with a maximum depth of 1.5-2.5 km (Fig. 1). The valley flanks expose Cretaceous intrusive rocks and Jurassic sedimentary rocks (Fig. 2).

For our study we divided Ocoña and Camana basins respectively in two parts: upstream and downstream reflecting the elevation and the sediment composition changes. Within Camana basin, going to the ocean from Camana upstream, the valley incision cuts the 500 m thick Cenozoic sediments of the Moquegua Group from the Majes section (Roperch et al., 2006).

During the Cenozoic the landscape at the western margin of South America changed dramatically due to the tectonic evolution of the Andes (Isacks, 1988) and variations in climate (Gregory-Wodzicki, 2000). Some evidence show that those changes are recorded in the Moquegua basin sediments, hence it is important to understand the different mechanisms of their formation through time and to know where those sediments are derived from. The uplift of the Andes started 30-25 My ago (Isacks, 1988) while the base of the Moquegua Group (Moquegua A Formation) is dated at 55 Ma and the base of Moquegua B at 45 Ma (Roperch et al., 2006). This implies that a river system with sediment deposition was already developed before the Andean uplift. According to Marocco (1984), Moquegua A has been deposited in a lacustrine sedimentation system while Moquegua B sedimentation occurred in a meandering fluvial system. This change of deposition environment can be explained by a climatic change at 45 My ago. In the field we observed that no volcanic material is present in Moquegua A and B Formation but are well represented in Moquegua C and D. The sedimentation of Moquegua C and D started 30 My ago, contemporary to the Tacaza arc activity. This arc ended about 15 My ago and was followed by Miocene explosive volcanism (e.g. Huaylillas, Caraveli ignimbrites) and the Barroso arc with Sencca ignimbrites between 14 and 1 My ago (Thouret et al., 2007). Since 1 My ago the volcanic activity forms the Frontal arc.

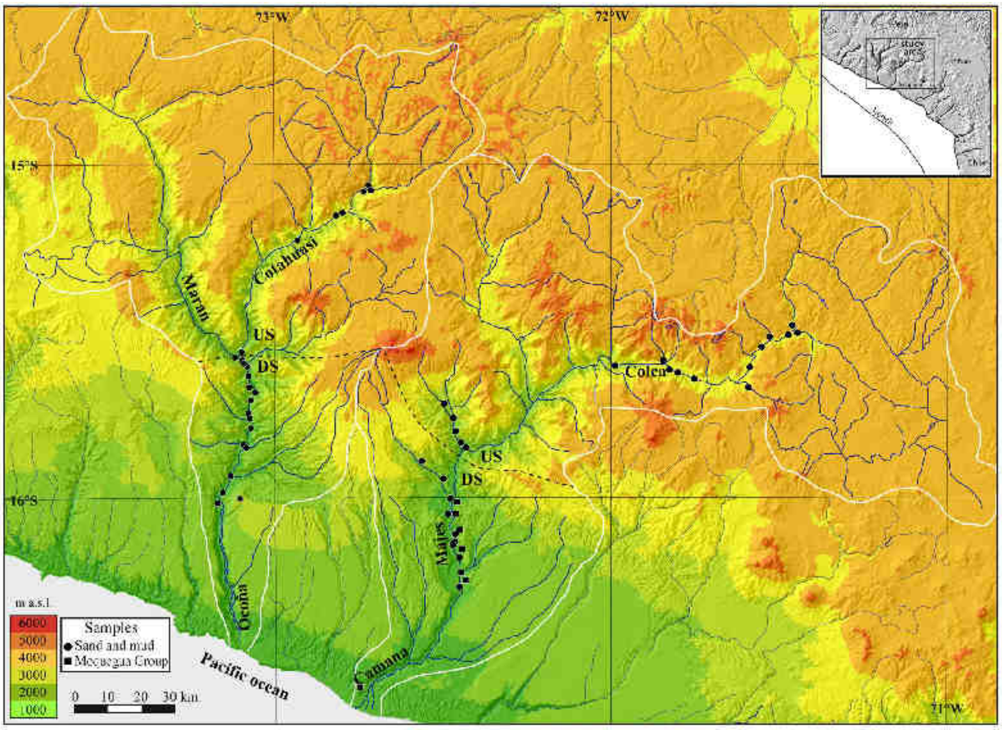

Fig. 1. Shaded relief topographic image with the sample location of the Ocoña and Camana basins. Heavy white lines delineate the catchments area. Dashed line is the boundary between the UP (upstream) and DS (downstream) samples, reflecting the elevation and the sediment composition changes.

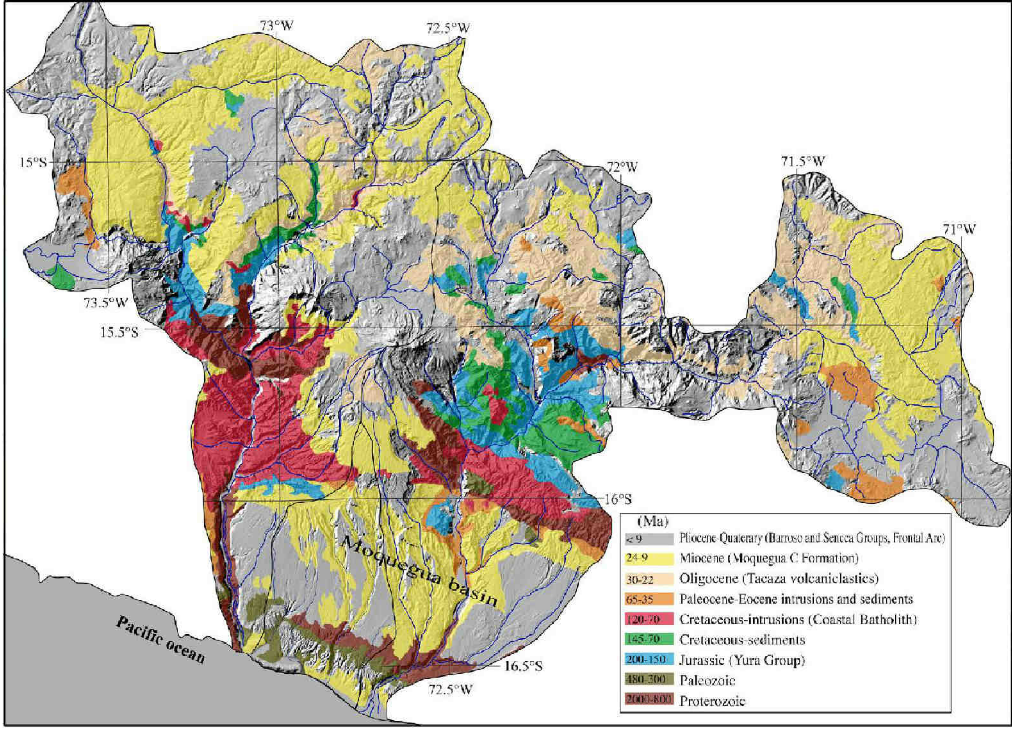

Fig. 2. Simplified geological map of the Ocoña and Camana drainage basins.

The chemical analysis of the modern (loose sand and mud from rivers) and ancient (sandstones from Moquegua A, B, C, and D) sediments in combination with heavy mineral analysis allow us to reconstruct the sediment provenance, alteration and their variation through time. For this study we present major and trace elements analyses of bulk sediment. Further work will include geochemical mass balance of Tertiary and Recent sediments, and separation of heavy minerals that will be used for thermochronological studies.

SAMPLING AND ANALYTICAL TECHNIQUES

Both coarse (loose sand) and fine-grained (mud) lithologies were sampled upstream and downstream of Ocoña and Camana drainage basins (Fig. 1). Small rivers were collected close to their confluence with the main rivers to characterize the chemical diversity of the local basements. We sampled also sedimentary rocks from the Moquegua Group (< 55 Ma, Roperch et al., 2006). These samples span the entire sedimentary section of Moquegua A, B, C and D Formations at Majes outcrop.

The major and trace element analyses were obtained on powdered bulk sediment samples by X-Ray Flourescence at Abt. Geochemie, Göttingen, using a PANalytical AXIOS Advanced sequential X-ray spectrometer.

RESULTS

Figure 3a shows Zr/Sc ratios versus Zr concentration. Zr/Sc ratio is a good parameter for Zircon enrichment since Zr is strongly enriched in Zircon whereas Sc is not enriched during sediment recycling (McLennan et al., 1993). In addition, the main potential source rock fields are represented in this diagram. Sand samples from Ocoña upstream are strongly enriched in Zr indicating influence from the Neogene ignimbrites, Upper Barroso and Frontal arc rocks. However, the sand samples from Ocoña downstream are less enriched in Zr indicating more influence from Proterozoic, Paleozoic, Jurassic and Cretaceous units. We can distinguish two patterns within the Camana basin; the upstream area is - on average - less rich in Zr compared to downstream samples. This observation shows an evolution of source rocks changing from Cretaceous-Jurassic upstream to Paleozoic-Proterozoic downstream, respectively. Concerning the Moquegua Formation a similar variation of Zr content is also documented. Moquegua A is the most enriched in Zr, thus its source rocks either is rich in Zr or sedimentary processes concentrated Zircon, and Moquegua B Zr is less abundant, its source rock is relatively poor in Zr. Therefore we postulate a stronger influence of Proterozoic and Paleozoic source rocks for Moquegua A compared to Moquegua B.

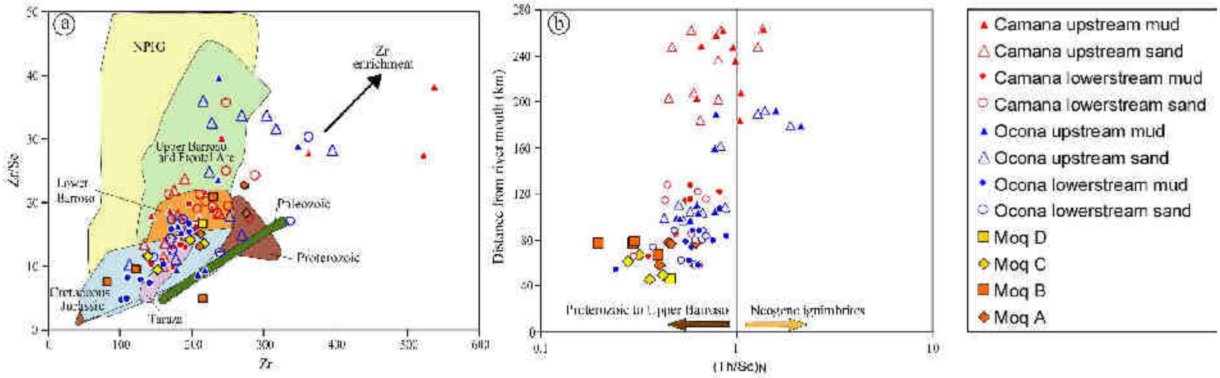

Fig. 3. a) Zr/Sc ratios versus Zr concentration, b) Distance from the river mouth versus normalized Th/Sc ratios.

Figure 3b shows the Th/Sc ratios versus the distance of the sample from the river mouth. The Th/Sc ratio is a good parameter for the igneous chemical differentiation process; Th is an incompatible element whereas Sc is compatible in igneous systems. For the Moquegua sequence it is clear that the Neogene ignimbrites are not the main source rocks, except for Moquegua D. The main sources for the Moquegua basin are Proterozoic to Miocene rocks. In the Camana basin the Neogene ignimbrites exposed between Chivay and Cabanaconde are likely source rocks for Camana upstream sediments but this signature becomes weaker going downstream. Most of Ocoña sources are from Proterozoic to Upper Barroso rocks except for four samples from Ocoña upstream, which are affected by the local ignimbrites. This local source is due to the proximity of the Lower Sencca ignimbrites in the Huachuy cliff (see Thouret et al., 2007).

Spider diagrams (Fig. 4) show trace element patterns for different source rocks in the study area. Fig. 4a shows the older sources (i.e., Proterozoic, Paleozoic, Jurassic, and Cretaceous rocks) and Fig. 4b shows the younger sources (i.e., Tacaza, Lower Barroso, Upper Barroso and the Frontal arc rocks and Neogene ignimbrites). The Proterozoic, Upper Barroso and the Frontal arc have a negative anomaly in Cs. By constrast, Jurassic, Tacaza Lower Barroso, and Neogene ignimbrite have a positive Cs anomaly. Cs is mostly contained in volcanic glass and in feldspars. The fact that the younger volcanic formations (Upper Barroso and the Frontal arc) have a negative Cs anomaly, which is not observed in the older volcanics (Tacaza and Lower Barroso) implies that the volcanic material is becoming increasingly differentiated with time. This is also shown by other incompatible trace elements (e.g. Zr). Trace element patterns in samples from the Moquegua sequence (Fig. 4c, d) show that Moquegua C and D are enriched in Cs compared with Moquegua A and B. This tells us that the composition of Moquegua C and D sediments is mainly dominated by the older volcanic source. Patterns for modern sediments from the Ocoña basin shows a positive Cs anomaly (>10), suggesting that at least one of the sources is rich in felsic components such as the Neogene ignimbrites, evolved Upper Barroso or Jurassic silicic intrusives (Fig. 4g, 4f). We note that at this stage (i.e. without heavy minerals and isotope data) it is difficult to distinguish between e.g. evolved Jurassic and Neogene ignimbrites as potential source rocks for Ocoña sediments (regarding Cs, Sc, Ni, Rb, Pb and Sr).

In the spider diagram of modern sediments from the Camana basin (Fig. 4h, 4i) there is the same positive Cs anomaly as in Ocoña. Thus a part of the source rocks of Camana is also rich in felsic components. When we compare the Camana pattern with the young source rock patterns (Fig. 4i) we note that one potential source are Tacaza and the Neogene ignimbrites. However, comparison with the old-source pattern (regarding Ni, Cs, Ba Th, U and K, Fig. 4h) shows that a contribution of Jurassic is also possible (see above). Hf and Zr enrichment is more pronounced in Ocoña than in Camana sediments. This means that the principal sources of Camana are volcanics (Tacaza and Neogene ignimbrite) and the main sources of Ocoña is the old basement (Proterozoic and Jurassic).

FIRST CONCLUSIONS

The comparisons between the trace element patterns, Zr/Sc and Th/Sc ratios of sources rocks and sediments allow us to learn about the provenance of the Tertiary to Recent sediments. We present some first conclusions, which will serve as a basis for further analyses on heavy mineral and isotope compositions and sedimentary mass balances.

The sources of Moquegua A are Proterozoic to Cretaceous Formations (dominated by the Proterozoic and Paleozoic rocks). The sources of Moquegua B are Proterozoic to Cretaceous Formations (dominated by the Jurassic and Cretaceous rocks). The sources of Moquegua C are the Proterozoic to Cretaceous Formations, as Moquegua A and B, but with Tacaza and Neogene ignimbrite contribution. The sources of Moquegua D are Jurassic, Cretaceous, Tacaza, Lower and Upper Barroso, Neogene ignimbrite and the frontal arc.

The sources of Ocoña upstream sediments are the Tacaza and Lower Barroso rocks, and Neogene ignimbrites. Ocoña downstream sediments sources are dominated by the Proterozoic and Jurassic basement with the input of Neogene ignimbrite, Lower and Upper Barroso and Tacaza arc.

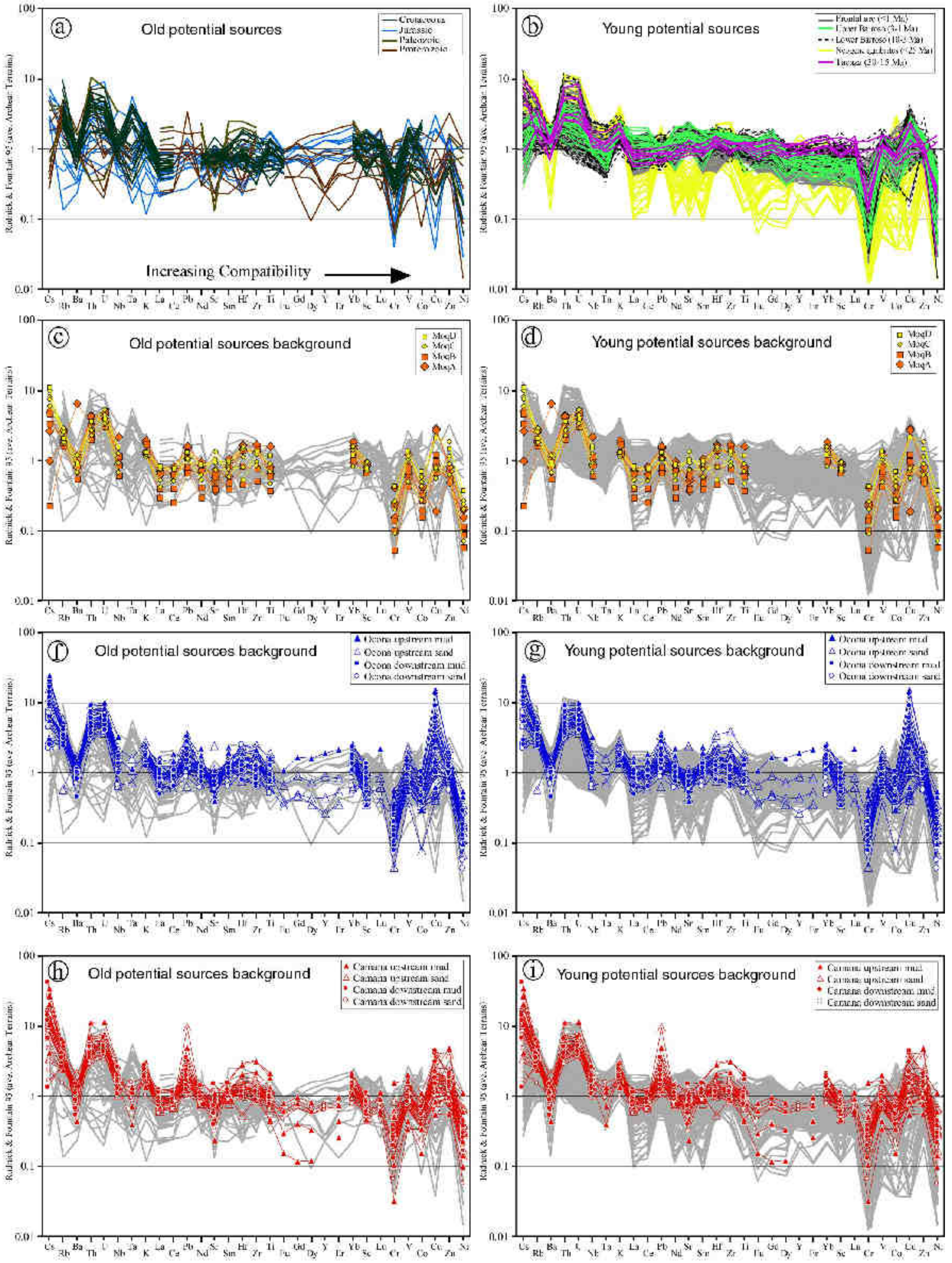

Fig. 4. Incompatibility plots (spidergrams) for important sedimentary sources in the Central Andes (a, b), sedimentary units of Cenozoic Moquegua Group (c, d) and modern sediments of Ocoña and Camana basins (f, g, h, i). Trace elements normalized against average of Archean Terrains (Rudnick and Fountain, 1995). Shaded lines in c, d, f, g, h, i, encompasse the potential old (Fig. 4a) and young (Fig. 4b) sources.

The sources of Camana upstream sediments are mainly local Neogene ignimbrites, Tacaza, Lower and Upper Barroso and Frontal arcs rocks. Camana downstream sediments have likely input from the Proterozoic and Jurassic basement.

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