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Lithology of lacustrine deposits in the Colca Valley

Józef Kukulak [a], Andrzej Paulo [b, *], Tomasz Kalicki [c]

[a] Institute of Geography, Pedagogical University of Kraków, 2 Podchorążych Str., 30-084 Kraków, Poland
[b] Faculty of Geology, Geophysics and Environment Protection, AGH University of Science and Technology, 30 Mickiewicza Ave., 30-059 Kraków, Poland
[c] Institute of Geography, The Jan Kochanowski University in Kielce, 15 Swietokrzyska Str., 25-406 Kielce, Poland

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ABSTRACT

Remnant lacustrine sediments of three major lakes are preserved in the Rio Colca Valley in the Western Cordillera of the Central Andes, SW Peru. The older lake extended between Pinchollo and Coporaque until 0.61 Ma, while two Late Pleistocene lakes lied upstream of Chivay. The river cut through the sediments to a depth of approximately 300 m between Chivay and Pinchollo, over a distance of 30 km and formed several terraces in the lacustrine deposits. The highest outcrops of lacustrine sediments lie now at elevations of 3500–3600 m. Three types of lacustrine deposits are present. Spatially dominant are regularly layered and laminated fine-grained sediments (silt, sand, and locally diatomaceous ooze). The second type are coarse gravels and sands accumulated in deltas, and the third - colluvial material. The lacustrine sediments are weakly cemented. Petrographic and mineralogical analysis of the fine-grained varieties showed that their material came from many sources. Its major part came from the lake catchment and was supplied by the river, like gravels and coarse sands. Similar in origin are dark-gray fine sands derived from local regolith. White silts and fine sands are of volcanic origin (tuffites), probably derived from nearby volcanic pyroclastic covers of the Barroso and Tacaza groups. Additional pyroclastic material was supplied by volcanic ash falling out directly to the lake. Activity of nearby stratovolcanoes (eg. Hualca Hualca, Sabancaya, Ampato, Huarancante) and dwarf volcanoes of the Andahua Group during the existence of the lake is confirmed by intercalations of pumice, coarse volcanic debris and lava in the lacustrine sediments. The existence of the lakes between Pinchollo and Chivay can be related to the period of the Latest Pliocene – Late Pleistocene.

1. Introduction

Lithology of lacustrine sediments preserves an integrated register of tectonic, geomorphologic, climatic and ecologic forcings. Its deciphering helps in our understanding of continental Quaternary paleoclimate change, reconstruction of the ancient drainage pattern, in calculating the rate of erosional incision, deciphering the nature and rate of sedimentation and the usually high facial diversity. Nevertheless, lakes typically display short residence times, abrupt changes in sedimentary facies, and their deposits are easily eroded or hidden under younger covers.

Limnological studies of central Andean lakes focus on endorheic Altiplano and the Atacama-Puna region (e.g. Hastenrath and Kutzbach, 1985; Grosjean et al., 1995; Valero-Garcés et al., 1999, Rigsby et al., 2005; McGlue et al., 2013). Evidence of Quaternary lake deposits in the cordilleran region of south Peru is increasing (Cordova et al., 1991; Mendivil and Dávila, 1994; Carlotto et al., 2011).

The geological structure of the Andes includes elements of different ages, typologically diverse and tectonically disturbed to various degrees. Older rocks (Precambrian and Paleozoic) are generally metamorphosed and incorporated in the Mesozoic and Cenozoic fold structures of the Andes. The consequence of the multiphase Andean orogeny, running from mid-Cretaceous to modern times, is the creation of discrete magmatic arcs, intramontane uplifted blocks and sinking grabens (Megard, 1984; Sebrier et al., 1988) and the tectonic involvement of young, even Quaternary sediments (Żaba et al., 2012, 2013). Strings of parallel mountain ranges separated by grabens or erosional depressions are now characteristic for the tectonic and orographic pattern of the Andes (Megard et al., 1984; Klinck et al., 1986; Leeder, 1987; Thouret et al., 2005). A similar bundle pattern of the Western Cordillera ranges is found in the basin of the Rio Colca (Klinck and Palacios, 1985; Denevan et al., 1986; Paulo, 2008), and two of the local

* Corresponding author.
E-mail addresses: andrzej.paulo@interia.pl, paulo@geol.agh.edu.pl (A. Paulo).

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grabens are used by the river itself in its middle course (Kalicki and Kukulak, 2009). Flowing from the Altiplano to the Pacific, the Rio Colca cuts across the complex structure of the Western Cordillera (Parodi, 1987), but before the breach (the Rio Colca Canyon) it meanders in the lacustrine deposits which are unusual for the rest of its catchment. These deposits fill the graben and the Rio Colca valley is incised in them over the length of over 30 km. They record the existence of once large lakes, whose ancient extent is now delineated by the highest remnants of lake sediments on the slopes of the valley (Fig. 1). The lakes left after them thick and heterogeneous sediment fills.

The several locations with lacustrine deposits described here have not been represented separately in the 1:100 000 geological map of the Chivay region (Klinck et al., 1985; Quispesivana and Navarro, 2001). They are shown as a single unit together with unlitified Quaternary deposits of other origin (colluvia, alluvia) filling the bottom and covering the lower parts of the slopes of the Colca Valley. Otherwise, in Yanque and between Yanque and Ichupampa, Quispesivana and Navarro (2001) marked the occurrence of layered tuffs, coming from an eruption of the Mismi volcano (Late Pliocene) on both sides of the river channel. Probably they are equivalents of lacustrine deposits described here. A detailed lithological description of the lacustrine series exposed in Lari (Fig. 2) was presented by Chavez (2004). He distinguished alluvial sediments and two lacustrine facies: a marginal (deltaic) facies and open lake facies. The former is dominated by dark gravels, sands and silts, and the second by laminated gray-yellowish mudstones. Chavez (2004) considered a large share of poorly rounded volcanic material, especially pumice, in the sediments of the marginal facies as an indicator of synchrony with eruptions of the nearby volcanoes. However, the assumed correlation was not supported with research data. Moreover, the geosite in Lari supplies important observations but cannot be representative for the whole lacustrine complex of the Colca Valley.

In our opinion, based essentially on the hypsometry of the sediments and the distinct lava dams at Canocota and Chivay (Fig. 3) the lacustrine complex represents two large and one minor lake, all bound to the grabens. Erosion by the river and subsequent landslides as well as neotectonic faults (Żaba et al., 2012) displaced great part of the sediments near valley axis making it difficult to document their original location. Nevertheless, central facies are preserved in many outcrops which allowed to construct a map, Fig. 3. Otherwise, the lacustrine remnants at some localities lie directly on the river bedrock or next to the valley slopes, which implies that at most studied localities the observed outcrops correspond to basal, close to basal or very proximal deposits.

As yet, there is no correlation of age, sediment type and evolution of sedimentary environment in the paleolakes of the Colca Valley with other lacustrine deposits in the Central Andes. Sediments of several present-day Altiplano lakes have been studied (Wirrmann, Mourguiart, 1995), especially those of Lake Titicaca (Wirrmann et al., 1992; Palacios et al., 1993; Abbot et al., 1997b). A correspondence between lithology of Andean lacustrine sediments and climate change has been established (Abbot et al., 1997a), and the climate change in the Central Andes is already well documented (eg. Fox, 1994; Grosjean et al., 1995; Dombusch, 1998; Klein et al., 1999; Argollo, Mourguiart. 2000). It can be expected that the lake sediments of the Colca Valley also preserve record of a number of climatic and geological events.

2. Study area

The study area is located in the Peruvian part of the Central Andes, in the department of Arequipa. It represents the middle section of the valley of the Rio Colca, about 60 km long, between the village of Tuti in the north-east and the eastern entrance of the river into the Colca Canyon at Pinchollo in the south-west (Fig. 2). In this part of the Andes, the Colca Valley separates the Cordillera Chila, culminating at the Mismi - 5597 m, on the north, from the Altiplano, extending from the southern plateau elevated about 4500–4800 m above sea level and crowned with stratovolcanoes (Hualca Hualca 6025 m, Sabancaya 5976 m, Ampato 6288 m, Huarancante 5426 m), towering above the Pliocene planation surface – puna.

The Colca Valley is 600–1200 m deep and its bottom descends from an elevation of approximately 3800 m in Sibayo above Tuti to 3050 m at the entrance to the Canyon, with an average gradient of approximately 17‰. A characteristic form of relief throughout the studied part of the Colca Valley is a staircase system of extensive terraces cut into the lacustrine sediments and alluvial gravels. It

Fig. 1. Colca Valley with the cuesta in the highest level of lacustrine deposits and agricultural terraces created on young erosional–accumulational river terraces.