SEISMITES AND PALEOTSUNAMIS DEPOSITS, ASSESSING FOR PALEOSEISMICITY IN PERU

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***Abstract:** Human occupation records in Perú provide historical record of large earthquakes prior to the 20th century. In this study, we extend our knowledge of major events by evaluating the stratigraphy and chronology of sediments exposed in various sectors of the Central Andes. These observations suggests that strong seismic activity occurred during the Quaternary, either along the subduction megathrust or on crustal faults. Indeed in Cusco and Colca regions, ,active faults affect fluvio-glacial and alluvial Holocene to Pliocene deposits. High in the topography, lacustrine deposits as well as Quaternary moraines display multiple geomorphic evidences of displacements ans seismites attesting for regional seismotectonic activity. Similarly along the Peruvian coast, 90 excavations succeeded in identifying for the first time paleo-tsunami deposits in southern Peru. Among them, the most impressive are encountered in Puerto Casma and Boca Rio and sign the historic 1619 subduction event and former unknown events (1641 ± 26 years B.P. ie 1668, as well as 2.26 ± 0.37 ka and 1.98 ± 0.23 ka respectively) .*

***Key words**: Peruvian Andes, paleoseismology, seismites, tsunami deposits.*

INTRODUCTION

Peru is located on the western rim of South America, and most of the territory is subject to high seismic hazard both within the Andes and along the Pacific coast (Fig. 1).

The instrumental and historical seismic catalog in our country is insufficient for risk assessment. Therefore we studied active faults and Quaternary outcrops according to their tectonic and sedimentary structures in order to extend the knowledge on paleoseismology and related tsunami risk.

In this paper, we present the most prominent results of multiple studies realized in Peru aiming to identify deposits with seismic background and Quaternary tectonic structures. The first part deals with deformed sedimentary structures associated with intra-continental earthquakes (seismites) and crustal active faults, while the second part is related to the identification of paleo-tsunami deposits in the Quaternary stratigraphic record along the active subduction on the Peruvian margin.

The identification and characterization of seismites were conducted in two Quaternary lake basins.

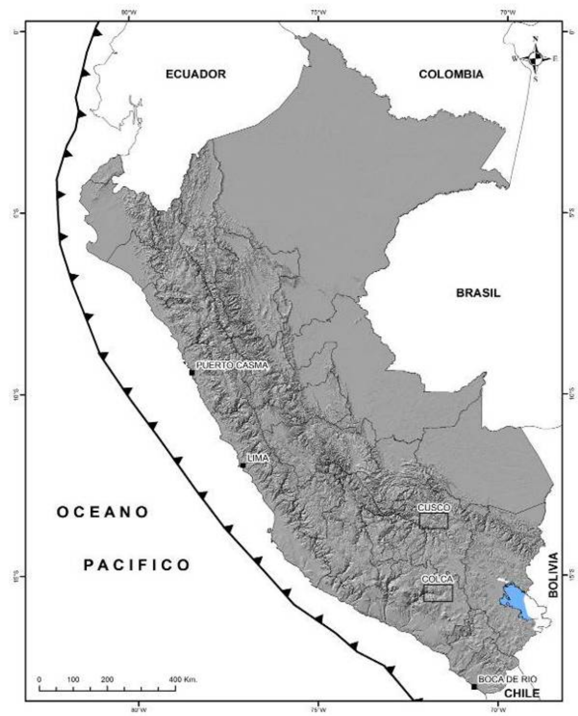

Fig. 1: Location of study area

RESULTS

Continental Peru

The identification and characterization of seismites were conducted in two Quaternary lake basins of Southern Peru.

The first basin is located between the Altiplano and Eastern Cordillera of the Peruvian Andes. The Cusco Basin is installed in a tectonic controlled area and is bordered by active fault systems (Cabrera, 1988; Benavente et al., 2010). Lacustrine deposits in the Cusco Basin are related to the occurrence of shoshonitic lavas (volcanic rocks of the Rumicolca Formation) with an age of 0.6 Ma (Carlier, G. & Lorand, 2008). The analysis of nine stratigraphic columns indicates that two lakes formed during the Quaternary in Cusco Basin (Fig. 2, see last page), damned in the SE sector of the basin, where the volcanic rocks of the Rumicolca Formation outcrop. A total of 36 levels of distinct seismites were identified, including slump-like, flame and ball, and pillow structures.

We propose that, in the early Pleistocene (Fig. 2A and 2D), the dam broke and subsequently a river system developed. During this period, several seismic events being occurred as observed on column 2I (Fig. 2; see ball and pillow structures in 20 thick meters sandbars. According to Rodriguez et al. (1998) table of seismites characterization; this event corresponds to a magnitude > 7. Subsequently a floodplain developed. An earthquake recorded in 6 different sites around the lake triggered landslides and liquefaction (Fig. 2A, 2B, 2E, 2F, 2G, 2I). The volume and geographic extention of the material affected by this event traduces an earthquake of magnitude > 7 (Rodriguez et al., 1998). In the late Pleistocene, a slump showing similar characteristics (Fig. 2A, 2FY 2H), possibly traduces a more recent lake discharge.

Tectonic activity fossilized in the deformation of lacustrine deposits is supposed to be related to seismic events on Tambomachay, Qoricocha, Chincheros Pachatusan or Chincheros fault systems, among others. These neotectonic faults are extending 50 km-long NWwards and affect fluvial to glacial deposits (10,000 BP) as well as recent alluvial sediments. These structures are 3 to 10 km away from Cusco basin and currently show seismic activity.

The second basin is located west of the first one, in the world deepest canyons: the Colca Canyon on the western flank of the Andes. Colca lacustrine deposits formed between 1.8 Ma and 0.6 Ma. Indeed K-Ar dating of lavas overlying the lacustrine deposits sequence (IV) contrains this chronology west of the town of Achoma (Klinck et al., 1986).

We propose here, based on field surveys and stratigraphic analysis that the lake was formed by a dam of Colca River. Damming was caused by an debris flow originated on the northeastern flank of the Hualca Hualca volcano, on the left bank of the river Colca. The dam lithology comprises subangular andesitic clasts fractured by rapid cooling. Gomez et al. (2004) propose a minimum volume of 1.3 km3 for the debris flow, after detailed surveying.

The dam induced a temporal lake (~ 150 m deep), evidenced by the deposition of thin white deposits with parallel lamination at the base of the basin (sequence I on Fig.2).

The consistent stratification and symmetrical sequence I, indicates that the lake was mainly stable during the Pleistocene (Fig. 2I). Later the stratification becomes asymmetric throughout the whole basin during the Lower-Middle Pleistocene? This is resulting from seismic activity, recorded in the stratigraphy by slumps (at the base of sequence II), ball and pillow and flame structures (Fig. 2A, 2B and 2C). According to Rodriguez (1998) and the nine seismic events identified in sequence II, the first two earthquakes were the largest in magnitude. These seismic events weakened the dam of the lake and induced the rupture.

Progressively a river system (sequence III) developed, associated with erosion and consequent incision of the lacustrine deposits, abandoning alluvial terraces. In sequence III, we identified only one seismite ball of pillow type, probably because in this dynamic environment, this type of sediments structures is difficult to preserve.

Overlying the fluvial sequence is another lacustrine sequence (sequence IV), which indicates another damming the river, being registered within the top of the sequence III and signs of a minor eruption of volcanic ash, which were deposited within the lake at the basal part of the sequence IV. In the upper part of the observed sequence IV ball and pillow type structures, flame and slumps, can be associated with structures generated by seismic events possibly weakening the dam and progressive development of a river system (Sequence V).

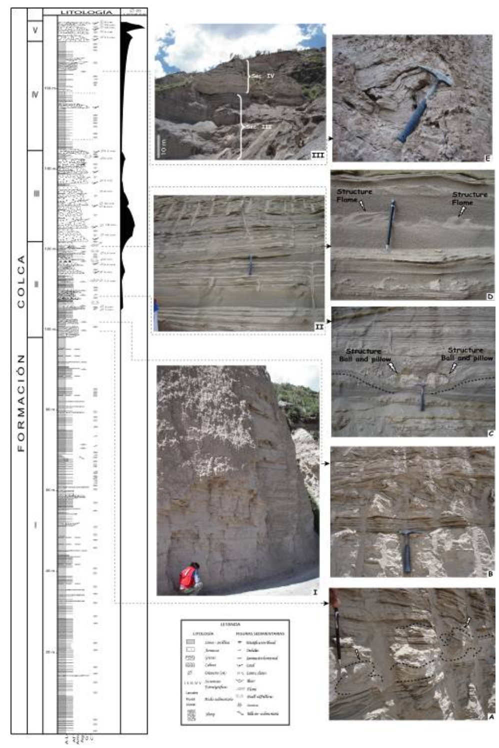

Fig. 3: Stratigraphic column type of lake deposits Colca Valley.

Finally, we present our results of newly identified paleotsunami deposits along the Peruvian margin based on new OSL dating, that notably implement Peru tsunami catalog and attest the need of further studies to constrain coastal risks.

Coastal Peru

We present two examples of tsunami deposits, located in northern and southern Peru. Presented results are largely taken Spiske et al., (In review) and Benavente et al., (2012).

Peru-Chile trench is one of the world's most active subduction zone, with high frequency of Mw>8 earthquakes and tsunami generation. We here conducted systematic exploration for deposits and / or traces of historical tsunamis performing 90 excavations and boreholes along 2400 km of the Peruvian coast.

We present two examples of tsunami deposits, located in northern and southern Peru (Spiske et al., subm and Benavente et al., 2012).

The beach of Puerto Casma is located 45 km south of Chimbote (northern Peru). In this 3 km wide bay, we identified at a depth of 0.60 m below the surface, a unusual level of sand (3-6 cm thick) within different beach sediments. This level is abnormal both in its composition and coloring (coarser, enriched in heavy minerals, plagioclase and quartz grains), in regard to beach sediments. Additionally this level contains fragments of shells, rocks and presents an erosional contact. The OSL dating (optically stimulated luminescence) reveals an age of 1641 ± 26 years B.P. Therefore, these deposits could be associated with the 1619 earthquake; previously described as non-tsunamigenic. Hence contributing another event to the tsunami catalog upgrade of Peru.

In Boca de Rio (southern Peru), we identified at 0.50 m depth, two tsunami deposits with thickness of about 4 cm. These consist of coarse sands found within fine grained marsh deposits. Both deposits show fragments of shells and towards the base have undulating contacts. The lower unit is located 0.40 m below the surface, while the upper is located 0.30 m below the surface. Both deposits interpreted as a result of two historical tsunamis that flooded the coastal plain. The dates for the deposition of the two levels by the OSL method suggest an age of 2.26 ± 0.37 ka for the lower level and 1.98 ±

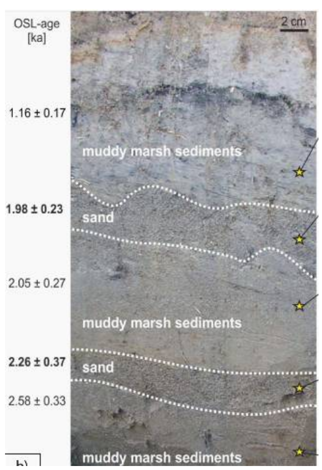

Fig. 4: Tsunami deposits located in Boca de Rio- southern Peru

0.23 ka for the top. Consequently their ages are beyond the limits of the historical of tsunamis. The mean time lapse between the two levels is approximately 272 years.

T The largest earthquakes in Southern Peru occurred in 1604 and 1868, and the lapse of time between these major events is 264 years. Furthermore it is documented that the earthquake of 1604 and 1868 had similar parameters (Dorbath et al. 1990). This is also to the case for the two levels of Boca Rio, where the modeled flow parameters are similar, as evidenced Spiske et al. (in review). These observations suggest that the levels identified in Boca Rio were produced by an earthquake sequence similar to 1604 and 1868 events.

CONCLUSIONS AND DISCUSSIONS

Paleoseismicity studies are an essential tool for determining seismic risk, especially in areas of deformation in which major earthquakes that can be separated by greater of times than the instrumental and historical records.

The regions of Cusco and Colca constitute an active tectonic zone where deformed structures (seismites) are related to reactivation of faults system failures as in the Huambo-Cabanaconde Cusco to Colca Basin cases. In addition to the long recurrences intervals of these crustal earthquakes, we can propose that these events were of magnitude greater than 7, from characterizations of seismically deformed structures.

Regarding tsunamis deposits, we can conclude that major earthquakes and tsunamis occurred frequently in the past, thus contributing to the expansion of the national catalog of tsunamis. Finally, this work should be useful in making decisions related to the plan of geological hazards and risk maps.

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References

Benavente, C., Cárdenas, J., Concha R., García, B., & Morales, M. 2010. Evidencias de paleosismos en la estratigrafía de la cuenca cuaternaria Cusco. XV Congreso Peruano de Geología, Cusco,. Resúmenes extendidos pp. 1280-1283, Sociedad Geológica del Perú.
Benavente, C., Spiske, M., Piepenbreier, J., Kunz, A., Bahlburg, H. & Steffahn, J. 2012. Sedimentología y dataciones por Luminiscencia Estimulada Ópticamente (osl) de depósitos de paleotsunamis a lo largo de la costa peruana. XVI Congreso Peruano de Geología, Resúmenes extendidos. Sociedad Geológica del Perú.
Cabrera J. (1988). Néotectonique et sismotectonique dans la cordillere Andine au niveau du changement de géométrie de la subduction: La Région de Cuzco (Pérou). Thesis, pp. 268., Univ. Paris-Sud, Orsay, 1988.
Carlier, G. & Lorand, J. P. (2008). Zr-rich accessory minerals (titanite, perrierite, zirconolite, baddeleyite) record strong oxidation associated with magma mixing in the south Peruvian potassic province. Lithos, vol. 104, pp. 54-70.
Dorbath, L., Cisternas, A., Dorbath, C., 1990. Assessment of the size of large and great historical earthquakes of Peru. Bulletin of the Seismological Society of America 80 (3), 551–576.
Gómez, J. C., Macías, J. L., Siebe, C., & Ocola, L. 2004. Delimitación y análisis sedimentológico de la avalancha de escombros del volcán Hualca Hualca, valle del Colca, Arequipa-Perú. XII Congreso Peruano de Geología, Resúmenes extendidos. Sociedad Geológica del Perú, p.575-577.
Klinck, B.A., Ellison, R.A., Hawkins, M.P., 1986. The geology of the Cordillera Occidental and Altiplano, west of Lake

Titicaca southern Peru. INGEMMET, Preliminary Report Lima.

Rodriguez, M.A. (1998). Paleosismicidad y sismotectónica de las cuencas lacustres neógenas del Prebético d Albacete. Tesis para optar el Grado de Ciencias Geológicas pp.360. Universidad Complutense de Madrid.

Spiske, M., Piepenbreier, J., Benavente, C., Bahlburg, H., in review. The onshore preservation potential of siliciclastic tsunami deposits in arid climate regions. Earth-Science Reviews, in review.

Fig.2: Columns Cusco Basin stratigraphy