UNDERSTANDING EXHUMATION OF THE NORTHERN CENTRAL ANDES IN PERU, USING BALANCED CROSS SECTION AND LOW TEMPERATURE THERMOCHRONOLOGY

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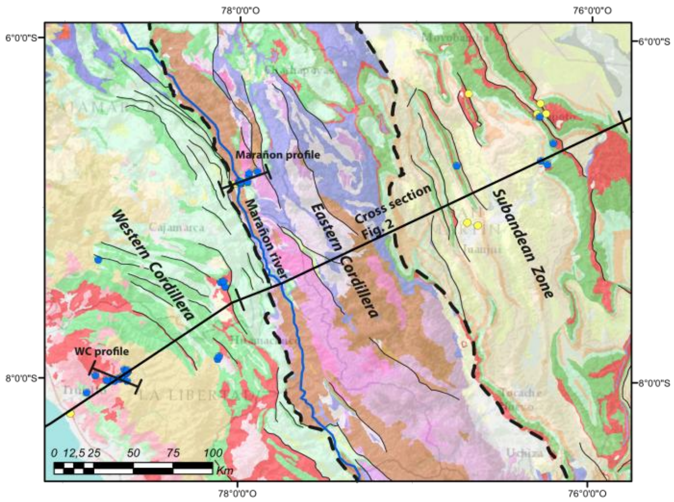
INTRODUCTION

How and when did the Andes grow remain largely debated. Most of the recent studies dealing with the Andean uplift have focused on the Altiplano (Allmendinger et al. 1997; Gregory-Wodzicki 2000; Gosh et al. 2006; Garzione et al. 2006; Mc Quarrie et al. 2008). The mechanisms responsible for its formation remain debated (see review in Barnes and Ehlers 2009). If we want to understand the evolution through time of the Altiplano, a detailed study of adjacent regions (Western and Eastern Cordilleras (WC and EC respectively) and the Subandean Zone (SAZ) could be helpful (Fig. 1a). North of the Altiplano, timing and uplift causes of the Andean orogen are largely unconstrained. Therefore, the aim of this study is to constrain precisely the deformation geometry and timing of an area from the WC to SAZ through the EC. We focused our study on a regional transect located between Trujillo and Tarapoto, where no morphological anomaly such as a large plateau is recognized (Fig. 1a). In the area the WC is thought to have formed during Eocene times (Mégard 1978, 1984; Mourier 1988; Noble et al. 1990).



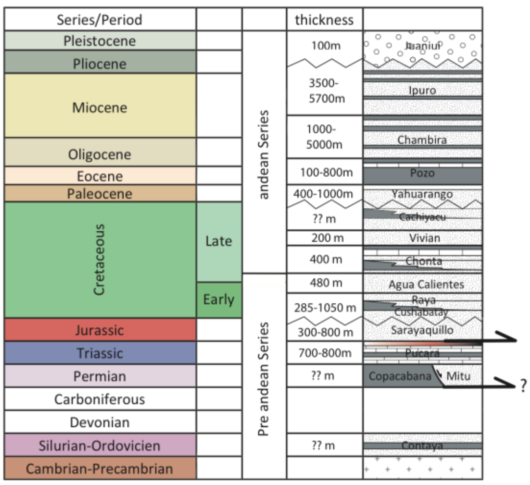


Figure 1a. Geological map of the studied area: The three morphotectonic units separated by dashed lines, AHe dating from the Marañon valley (Michalak et al. 2010), AFT ages from Huallaga basin in Subandean Zone (Kennan 2008) in yellow points, and our data (in progress) in blue points. The cross section presented in the Figure 2 is limited on the total transect by black dashes.

Figure 1b. Synthetic lithostratigraphic section of the SAZ, with location of mains décollement levels in black arrow.

For this project, we combine balanced cross section (Dahlstrom et al. 1969) with low temperature thermochronological dating (Apatite Fission-Tracks: AFT; (U-Th)/He ages on apatite: AHe) and vitrinite reflectance: Ro. Most of the data are under acquisition, but three Ro values (see Fig. 2) and some AFT ages from the Marañon valley have already been obtained.

STRUCTURAL ARCHITECTURE

The balanced cross-section based on seismic profiles (91 MPH 23 & 92 MPH 23E, Fig. 2) and field data is constructed and extended to the west to emphasize the relations between the EC and the SAZ. The EC is limited to the west by the N160 oriented Marañon east-verging imbricate thrust system of the WC (Mourier 1988). This imbricate thrust system is interpreted as the Paleocene - Eocene orogenic wedge deformed by the crustal-scale thrust propagation of the EC (Fig. 2). In the study area, the EC higher than 4000 m is formed by Precambrian to Mesozoic sedimentary series and igneous rocks. The EC defines the backbone range of the Andean fold and thrust belt. The associated foothills or SAZ corresponds to the Huallaga basin (Fig. 2) deformed by a series of thrust folds (Hermoza et al. 2005). The easternmost Chazuta thrust (Fig. 2) accommodates a shortening of 44 km. It branches onto a decollement developed within the Jurassic evaporites of the Pucara Fm. The Pungoyacu thrust, Biabo anticline and Chazuta thrust accommodate a cumulated minimum shortening of 100 km. This shortening is fed by the hinterland basement-involved duplex of the EC. The amount of shortening calculated from the balanced cross-section is 100.5 km just for the SAZ (20km more that predicted by Hermoza et al. 2005). It allows us to set geometry and position of crustal-scale ramps below the EC.

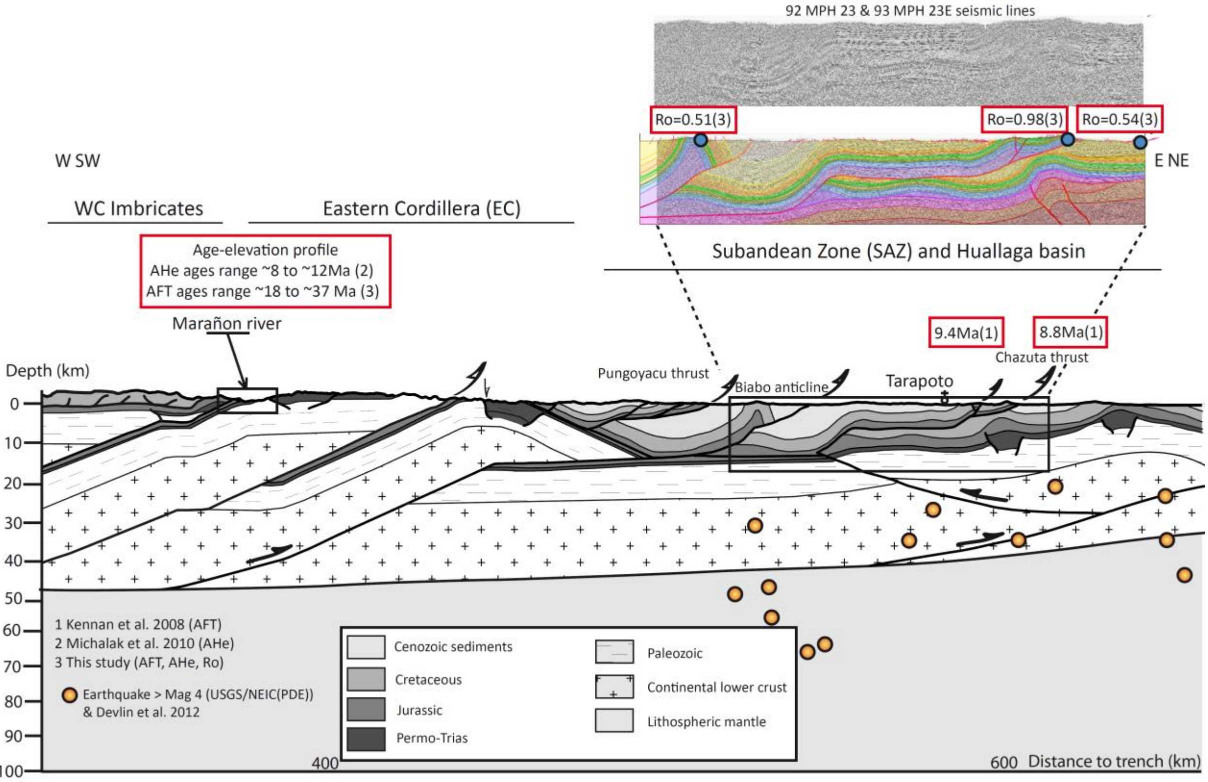


Figure 2. Structural cross-section through the EC and the SAZ (location on Fig 1a). Seismic section and its interpretation is located with our three Ro values (blue points) and preliminary AFT ages in the Marañon valley in little black rectangle.

The Ro method measures the geological maturity (coalification rank) of organic material in sediment. Vitrinite reflectance value records the maximum burial of a sample. One sample have been collected for Ro analysis, AFT, and AHe dating to estimate if thermochronometers have been potentially resetted before its exhumation. Our results show that the AFTA age of the sample coming from the front of Chazuta thrust collected has been resetted before exhumation (T_{MAX} >150°C, using Ln(Ro) = 0.0078 T_{MAX} - 1.2, Barker & Pawlewicz 1986) although the two others samples along the seismic profile did not have.

THERMOCHRONOLOGY

We sampled each thrust and thrust-related anticline (Fig. 2) for AFT and AHe dating and Ro analysis in order to constrain the timing of erosion. Following other similar studies (for example

Espurt et al., 2011), we assume that the thermochronometers recorded erosional cooling related to thrust faulting. The construction of the balanced cross-section will give us the final state of deformation and once restored the pre-deformational state. AFT and AHe cooling age are then used to calibrate intermediate stage of deformation following the methodology exposed in Espurt et al., 2011. At the end, we will propose a sequential restoration of the EC and SAZ deformation.

Table 1. Location and data of samples cited in this study. Ro means vitrinite reflectance value, AHe: (U-Th)/He age on apatite and AFT: apatite fission tracks age.

Sample name	X	Y	Z(m)	Ro	Tmax (see text)	Reference
TRU067	-76,195	-6,441	223	0,54	75	This study
TRU068	-76,269	-6,400	349,6	0,98	151	This study
TRU072	-76,756	-6,736	491	0,51	68	This study

Sample name	X	Y	Z(m)	AHe age	Error	Reference
Michalak 1	-78,025	-6,854	900	10,6	?	Michalak et al. 2010
Michalak 2	-77,991	-6,854	1162	9,3	?	Michalak et al. 2010
Michalak 3	-77,992	-6,851	1135	8,1	?	Michalak et al. 2010
Michalak 4	-77,967	-6,848	1768	12,1	?	Michalak et al. 2010

Sample name	X	Y	Z(m)	Central AFT age	Error	Reference
LK95/348	-76,291	-6,369	995	9,4	2,5	Kennan 2008
LK95/355	-76,307	-6,431	420	8,8	1,4	Kennan 2008

In the area concerned by this study, Michalak et al. (2010) have carried out four AHe dating on sample collected on the eastern flank of the Maranon valley (Fig. 2). Ages are ranging from ~ 12 to 8 Mas indicating the last stage of exhumation. Furthermore, previous published age of the Jurassic sandstones of the Chazuta thrust (Fig. 2) give similar AFT ages (9.4±2.5 Ma and 8.8±2.5 Ma) suggesting forward propagation of the thrust sequence during the Neogene. However, to understand the exhumation timing, rate and structuration of this area more thermochronological data are needed. Therefore, we collected samples along two vertical profiles in order to estimate exhumation rates of EC (Marañon profile over 2300m, Fig. 2) and in WC (Fig. 1). Preliminary AFT results give ages ranging from ~37Ma to ~18Ma.

CONCLUSION

Our preliminary results seem to indicate that exhumation in EC started in Late Eocene. More data are needed to constrain intermediate stage of deformation. Therefore new AFT and AHe are under acquisition and will be then modeled for an accurate interpretation.

REFERENCES

Allmendinger, R.W., Jordan, T.E., Kay, S.M., Isacks, B.L., 1997. The evolution of the Altiplano–Puna Plateau of the central Andes. Annual Review of Earth and Planetary Sciences 25, 139–174.

Barker Ch.E., Pawlewicz M.J., 1986. The correlation of vitrinite reflectance with maximum temperature in humic organic matter. Paleogeothermics, v.5, 79-93, doi: 10.1007/BFb0012103.

Barnes, J.B., Elhers, T.A., 2009. End member models for Andean Plateau uplift. Earth-Sc. Review, v.97, pp. 117-144. doi:10.1016/j.earscirev.2009.08.003.

Espurt, N., Barbarand, J., Roddaz, M., Brusset, S., Baby, P., Saillard, M., Hermoza, W., 2011. A scenario for the Late Neogene Andean shortening transfer in the Camisea Subandean Zone (Peru, 12°S): Implications for growth of the northern Andean plateau. *GSA Bulletin*, 123**,** 2050-2068.

Dahlstrom C.D.A., 1969. Balanced cross sections. Can. J. Earth. Sci. 6, pp. 743–757.

Devlin, S., Isacks, B.L., Pritchard, M.E., Barnhart W.D., Lohman R.B., 2012. Depths and focal mechanisms of crustal earthquakes in the central Andes determined from teleseismic waveform analysis and InSAR, Tectonics, v.31, TC2002, doi:10.1029/2011TC002914.

Garzione, C.N., Molnar, P., Libarkin, J.C., MacFadden, B.J., 2006. Rapid late Miocene rise of the Bolivian Altiplano: Evidence for removal of mantle lithosphere: Earth and Planetary Science Letters, v.241, p. 543-556.

Ghosh, P., Garzione, C.N., Eiler, J.M., 2006. Rapid uplift of the Altiplano revealed through C-13-O-18 bonds in paleosol carbonates: Science, v.311, p. 511-515.

Gregory-Wodzicki, K.M., 2000. Uplift history of the Central and Northern Andes: A review: Geological Society of America Bulletin, v.112, p. 1091-1105.

Hermoza W., Brusset S., Baby P., Gil W., Roddaz M., Guerrero N., Bolanos M., 2005. The Huallaga foreland basin evolution: Thrust propagation in a deltaic environment, northern Peruvian Andes, J. of S. Am. Earth Sci., v.19, p21-34 doi:10.1016/j.jsames.2004.06.005.

Jaillard, E., 1990. Mesozoic extension and crustal thickening in the Peruvian Andes. I ISAG, Grenoble, pp. 269–272.

Kennan L., 2008. Fission track ages and sedimentary provenance studies in Peru, and their implications for Andean paleogeographic evolution, stratigraphy and hydrocarbon systems. VI Ingepet 2008 (Expr-3-LK-36).

Mc Quarrie N., Barnes J.B., Elhers T.A., 2008. Geometric, kinematic, and erosional history of the central Andean Plateau, Bolivia (15–17°S). Tectonics, v.27, TC3007, doi:10.1029/2006TC002054.

Mégard, F., 1984. The Andean orogenic period and its major structures in central and northern Peru, J. Geol. Soc. London, 141, 893 – 900.

Mégard F., 1978. Etude géologique des Andes du Pérou central : Contribution à l'étude géologique des Andes, Mem. Orstom, v.86, 310 pp., Fr. Inst of Sci. Rech. for the Development. (ORSTOM), Paris.

Michalak M.J., Hall S.R., Farber D.L., Hourigan J.K., Rose E.J., 2010. Evidence for a late Miocene-Pliocene pulse of exhumation from low-thermochronology in the northern peruvian Andes. XV Cong. Peru. Geol. Soc. Geol. Peru, Pub. Esp. No9.

Mourier, T., 1988. La transition entre les Andes marginales et les Andes cordilleraines a ophiolites: Evolution sédimentaire, magmatique et struturale du relais de Huacabamba (3°S à 8°S; Nord Pérou-Sud Equateur), Ph.D. thesis, 302 pp., Univ. Paris XI, Orsay, France.

Noble, D.C., McKee E.H., Mourier T., Mégard F., 1990. Cenozoic stratigraphy, magmatic activity, compressive deformation and uplift in northern Peru, Geol.Soc. Am. Bull., 102, p.1105–1113.

Wilson J.J., Reyes R.R., 1964. Geologia del cuadrangulo de Pataz, Boletin No 9, INGEMMET.