Widespread Cenozoic ignimbrites in N-Chile, W-Bolivia and S-Peru (17°-20°S/71°-68°E): Stratigraphy, extension, correlation and origin.

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INTRODUCTION

Large volume monotonous ignimbrites in N-Chile, W-Bolivia and S-Peru (17°-20°S/71°-68°E) represent one of the worldwide largest silicic provinces in the Cenozoic. Several pyroclastic outflow-sheets >1.000 km^3 were deposited during Miocene and Pliocene. These magmas are interpreted as a result of large scale crustal melting in response to events of crustal thickening (~70 km) in the last 25 Ma and may represent a similar event as the "ignimbrite flare up" (deSilva, 1989) in the Salar de Atacama region (21°-24°S). The working area is distinct from the Salar de Atacama region with respect to the considerably older age of the ignimbrites, and the Andean crust showing a different style of tectonism and uplift. We present data on the timing and volume of the two major ignimbrite events in northernmost Chile and western Bolivia in Miocene and Pliocene times. These events are related to the timing and style of uplift of the Andes in this region.
At 18°S we distinguish four main phases of ignimbrite volcanism:

(1) Pre-Miocene Ignimbrites

The metamorphic basement near Belén is overlain by a sequence up to 700 m thickness of altered lava flows, lava breccias and silicified ignimbrites. These tectonized volcanics and intercalated ignimbrites are associated with proximal pyroclastic and volcaniclastic, as well as fluvio-lacustrine sediments. This sequence was correlated by Salas et al. (1966) to the Lupica-Formation at North and South (Upper Cretaceous/ Tertiary). Ignimbrites in this formation are altered and strongly folded. Within the upper member of the Lupica Formation, we found a series of 8 strongly folded unwelded and only slightly altered ignimbrites to th N and W of Belén (~500 m). These "Belén-Ignimbrites" underly an equally folded series of mafic andesite breccia and flows of large lateral distribution. Clearly the breccia and Belen-Ignimbrites are younger than the Lupic-Ignimbrites, and older than the stratigrafically higher "Kar-Ignimbrites"

A series of lithic-rich, strongly silicified ignimbrites disconformably overly these folded Cretaceous-Tertiary strata and form the highest crests of the Western Cordillera with altitudes between 4.300 and 5.200 m where they are glacially disseccted by kars ("Kar-Ignimbrites"). These ignimbrites have only local distribution and can be correlated to abundant post-tectonic silicic intrusions into the Lupica-Formation further N between Zapahuira and Putre.
This succession is composed of eight outflow-sheets with a thickness of 500 m. To the top this sequence changes to unaltered layers of andesite scoria and -breccias. The volume of these older ignimbrites cannot be determined.

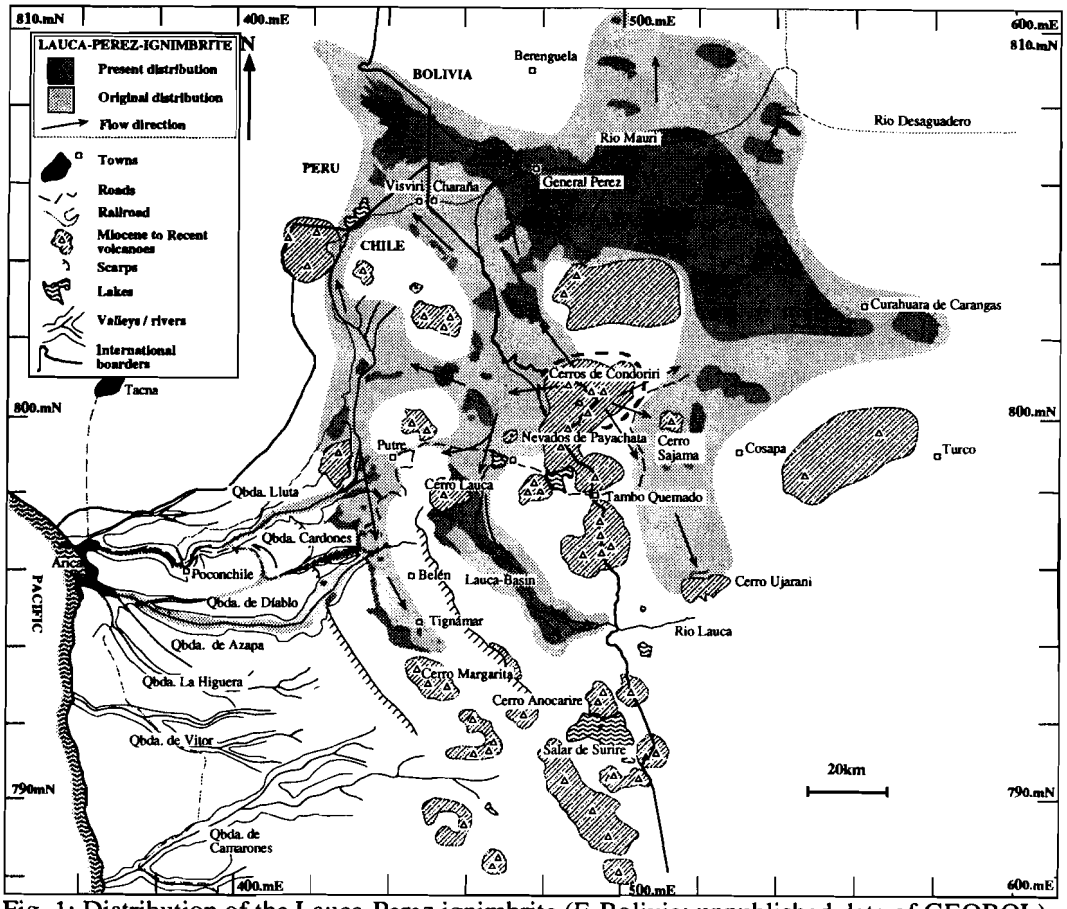

Fig. 1: Distribution of the Lauca-Perez ignimbrite (E-Bolivia: unpublished data of GEOBOL)

(2) Oxaya-Ignimbrites (20-19 Ma)

Monotonous large volume ignimbrites (~19 Ma) at 18°S form the inclined West-Andean slopes in northernmost Chile and are suggested to result from an event of extended crustal melting around 19 Ma. These ignimbrite sheets with a total thickness of up to 900 m together with the underlying >1.000 m of monotonous alluvial, fluviatile and lacustrine sediments form the Oxaya-Formation. This association suggests that the Miocene ignimbrites post-date a first major phase of crustal thickening, uplift, erosion and sedimentation.

The Oxaya ignimbrites are subdivided into four main outflow-sheets (members 1-4) with a combined maximum thickness of 930 m in the Quebrada Cardones. The uppermost welded Oxaya-Ignimbrite gave an Ar/Ar sanidine step heating age of 19.38±0,01 Ma. (Walfort et al., 1995). The Oxaya-Ignimbrites can be traced in E-W direction over a distance of 130 km from the Western-Cordillera (~4.600 m/Lago Chungará) to the Coastal Cordillera. Correated occurrences on the Altiplano have been assigned the name "Condoriri"-Ignimbrite by Salas et al (1966). Closer to the coast and, presumably, more distally, the ignimbrites are less welded but still reach 300 m at the coast near Arica.

Satellite images, air-potographs and field data show that the Oxaya ignimbrites can be correlated 300 km along the continental margin, from Southern-Peru (~17°S) to the Chilean Camarones valley (~20°S). This areal extent and measured thickness suggest total volumes of of the Oxaya ignimbrites of >3.000 km^3. The source area of the Oxaya ignimbrites is still unknown.

There is no indication of a significant time span between the individual ignimbrites because erosion between the out-flow sheets is limited. Only distally and towards the coast, the ignimbrites are intercalated by a fluvio-lacustrine sedimentary succesion up to 200-400 m thick in the Camarones valley. Nevertheless, the ignimbrites represent a large volume of silicic (crustal ?) melts erupted within a geologically short period around 19 Ma.

(3) The Lauca-Pérez ignimbrite (Huaylas-Fmt, 2,72±0,01 Ma)

A younger post-tectonic ignimbrite of the Huaylas-Formation ("Lauca-Iignimbrite")was dated by the Ar-Ar-method to 2.7±0,01 Ma (Walfort et al. 1995) and can thus be correlated with the ignimbrite of the "Pérez-Formation" which covers wide areas in western Bolivia and southern Peru.
The source area was identified by regional distribution and topography on Landsat satellite images as well as field-work to underly younger stratovolcanoes of the Cerros de Condoriri complex just E of the border between Chile and Bolivia, and NE of the Nevados de Payachata volcanoes. The caldera itself is not recognized by satellite images. However, the thickness increases up to >100 m on a flat ramp descending from the Cerro Condorir area. We also observe a higher degree of welding in an upper flow unit rich in fiamme which only occurs near the Cerro Condoriri area. These obeservations are evidence for a proximal position. Chemical data, Ar-Ar ages as well as petrographic and field correlations clearly show that the Lauca-Ignimbrite in northern Chile correlates to the Pérez-Ignimbrite 2.2-3 Ma (K-Ar, Everden et al. 1977) and 3 Ma (K-Ar, Lavenu et. al. 1989) in western Bolivia. We therefore use the name Lauca- Peréz Ignimbrite.

Today, the Lauca-Peréz Ignimbrite is strongly dissected by erosion. The initial total areal extend of ~200 km is estimated from widely distributed erosional remnants to about 15.000-20.000 km^2, with most of the area covering the flat-lying Bolivian Altiplano (Fig. 1). The maximum distance traveled is ~130 km, one of the largest distances demonstrated for an ignimbrite, comparable with the Taupo ignimbrite in New Zealand (Wilson et al., 1995). The aspect ratio (ratio of average thickness of a deposit to the diameter of a circle that covers the same area) is ~1:3.500 (Wilson 1995). A bulk volume is estimated to >775 km^3. From the relationship between caldera dimensions and the size of the associated ignimbrite the caldera to the Lauca/Pérez ignimbrite is expected to be in the order of 15-25 km wide. Such a caldera would well fit under the extensive Cerro de Condoriri stratovolcano complex.

The Lauca-Pérez ignimbrite fills in morphological depressions and valleys, onlaps and/or passes over higher topography, and thus serves as a reliable morphological and stratigraphic marker in northernmost Chile and Western Bolivia.

We subdivide the Lauca-Pérez ignimbrite into a groundsurge of 10-50 cm thickness at the base and three flow units. The lower, first flow unit is fine-grained with typical phenocryst-poor fibrous pumice 0.5 to 2 cm in size. This unit is in some places restricted to morphological lows whereas the second flow unit appears to have been more mobile. The second layer is characterized by an abundance of large qurtz-beraring pumices in its upper part. These reach diameters of 20 to 50 cm typically in the most distal parts (Alcérreca, Cerro Ujarani in Bolivia) near to the termination of the flow (see also: Wright et al. 1981). The uppermost youngest flow unit occurs only near the source area and shows evidence of intense welding (fiamme-structures). This petrographic variation and the occurrence of white-grey heterogeneous lapilli suggests magma mingling and eruption from a chemically zoned magma chamber.

The Lauca-Pérez ignimbrite flowed radially from its source but encountered the flat-lying Altiplano only to the N, W and S. This resulted in the widespread distribution of the Peréz-Ignimbrite and the mesa-like occurence on the Bolivian Altiplano. Here, the total thickness of the outflow-sheets amounts to 20-100 m in proximal areas, depending on underlying morphology. A major portion, however, flowed to the west and filled the depression between the volcanic front and the Western Cordillera (Chilean Altiplano). One large part of the flow continued S over 80 km into the Lauca-Basin (Kött et al, 1995). Another part of the flow started its descent to the coast after passing through narrow valleys and passes cutting through the Western Cordillera (Upper Lluta Valley, Portezuelo Las Quevas, Portezuele Chapiquiña). The ignimbrite descended the extreme morphology from 4.500 m to about 3000 m onto the the Pampa de Qxaya block (Uhlig et al, this meeting) where the flow again separated into different lobes. One lobe followed the half-graben along the Pampa de Oxaya 70 km to the south reaching Cerro Margarita. Several other flows concentrated into several valleys (Lluta-, Cardones-, Diablo-, Azapa- and Cerro Ujarani) and continued over a distance of 90 km to the Pacific Ocean, near the city of Arica. At the narrow passage of the Lluta-valley entrance the thickness of the ignimbrite-deposits increases strongly to over 100 m due to ponding effects. In the deeply incised Lluta- and Azapa-valleys remains of the Lauca-Pérez ignimbrite between 600 and 20 m above the present valley-bottom. This places constraints on the amount of valley incision in the past 2,7 Ma (Uhlig et al. this meeting).

The Lauca-Pérez ignimbrite suffered only minor, mostly normal faulting indicating that since about at least 2,7 Ma there was no major tectonic activity in the area, except possibly for large regional movements unrelated to small scale faulting.

(4) Local small volume ignimbrites (Pleistocene/Pliocene)

Local small-scale ignimbrites are also observed, but can be distinguished from for example the Lauca-Pérez Ignimbrite by their chemical and petrographic composition. These local ignimbrites are related to the stratovolcanoes of the volcanic front (Miocene to Recent).

CONCLUSIONS

The occurrence of ignimbrites at 18°S in the Andes mark a major episode of crustal melting at around 19 Ma which is preceeded by extensive erosion and deposition of sediment. Normal faulting with high vertical offsets in a second pulse of uplift resulted in a stair-case topography locally overprinting large-scale anticlines. This steep topography was formed between <19 Ma and about 10 Ma, and has since not been changed significantly by either erosion or subsequent tectonics (Uhlig et al., this meeting). A second, minor pulse of ignimbrite magmatism occurred at 2,7 Ma.
Timing and relative volumes of the ignimbrite volcanism at 18°S are thus quite distinct from the Salar de Atacama region. This region is mostly characterized by strike-slip displacements with strike-slip transpression and local pull-apart tectonics. Resulting dissection and crustal extension may have favoured the ascent of crustal melts and consequently the eruption of extensive ash-flow tuffs. In this region voluminous ignimbrite volcanism is observed between 4 and 10 Ma.
In the Arica area, however, large strike slip movements are absent since at least Miocene times One reason could be that only in the Arica bend area at 18°S the convergence between Nazca and South American plates is normal whereas further south the convergence is oblique.
Miocene ignimbrites at 18°S representing large magma volumes (>1.000 km^3) can be correlated over large areas, and thus be used to characterize and date the tectonic and erosional events. The "young" Lauca-Pérez ignimbrite (2,7 Ma) overlies and seals as a marker horizont the older topography. It represents a widespread ignimbrite flow and -emplacement from a high topographie with altitudes of 4.600 m over a large distance from the Bolivian Altiplano down the coastal valleys into the Pacific Ocean.

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