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**Pre-Cenozoic intra-plate magmatism along the Central Andes (17 – 34°S): composition
of the mantle at an active margin**

Friedrich Lucassen⁽¹⁾, Gerhard Franz⁽²⁾, Rolf L. Romer⁽¹⁾, Frank Schultz⁽³⁾, Peter Dulski⁽¹⁾,
Klaus Wemmer⁽⁴⁾

⁽¹⁾GeoForschungsZentrum Potsdam, Telegrafenberg, 14473 Potsdam, Germany;
lucassen@gfz-potsdam.de

⁽²⁾Technische Universität Berlin, Fachgebiet Petrologie, Ackerstr. 71-76 ; 13355 Berlin;
Germany

⁽³⁾Institute of Mineralogy and Mineral Resources, Technical University of Clausthal,
Adolph-Roemer-Strasse 2a, 38678 Clausthal-Zellerfeld, Germany

⁽⁴⁾Institut für Geologie und Dynamik der Lithosphäre, Goldschmidtstr.3, 37077 Göttingen,
Germany

corresponding author: Friedrich Lucassen
GeoForschungsZentrum Potsdam AB 4.2
Telegrafenberg
14473 Potsdam
Germany

email: lucassen@gfz-potsdam.de

phone: +49 (0) 331 288 1422

fax: +49 (0) 331 288 1474

ABSTRACT

Sr-Nd-Pb isotope ratios of alkaline mafic intra-plate magmatism constrain the isotopic compositions of the lithospheric mantle along what is now the eastern foreland or back-arc of the Cenozoic Central Andes (17 – 34°S). Most small-volume basanite volcanic rocks and alkaline intrusive rocks of Cretaceous (and rare Miocene) age were derived from a depleted lithospheric mantle source with rather uniform initial $^{143}\text{Nd}/^{144}\text{Nd}$ (~0.5127 – 0.5128) and $^{87}\text{Sr}/^{86}\text{Sr}$ (~0.7032-0.7040). The initial $^{206}\text{Pb}/^{204}\text{Pb}$ ratios are variable (18.5 – 19.7) at uniform $^{207}\text{Pb}/^{204}\text{Pb}$ ratios (15.60 ± 0.05). A variety of the Cretaceous depleted mantle source of the magmatic rocks shows elevated Sr isotope ratios up to 0.707 at constant high Nd isotope ratios. The variable Sr and Pb isotope ratios are probably due to radiogenic growth in a metasomatized lithospheric mantle, which represents the former sub-arc mantle beneath the early Palaeozoic active continental margin. Sr-Nd-Pb isotope signatures of a second mantle type reflected in the composition of Cretaceous (one late Palaeozoic age) intra-plate magmatic rocks ($^{143}\text{Nd}/^{144}\text{Nd}$ ~0.5123, $^{87}\text{Sr}/^{86}\text{Sr}$ ~0.704, $^{206}\text{Pb}/^{204}\text{Pb}$ ~17.5-18.5, and $^{207}\text{Pb}/^{204}\text{Pb}$ ~15.45-15.50) are similar to the isotopic composition of old subcontinental lithospheric mantle of the Brazilian Shield.

Published Nd and Sr isotopic compositions of Mesozoic to Cenozoic arc-related magmatic rocks (18-40°S) represent the composition of the convective sub-arc mantle in the Central Andes and are similar to those of the Cretaceous (and rare Miocene) intra-plate magmatic rocks. The dominant convective and lithospheric mantle type beneath this old continental margin is depleted mantle, which is compositionally different from average MORB-type depleted mantle. The old subcontinental lithospheric mantle did not contribute to Mesozoic to Cenozoic arc magmatism.

Key words: active continental margin; intra-plate magmatism; sub-arc mantle; Andes

1. INTRODUCTION

The western margin of South America (Fig. 1) was episodically active at least since Latest Proterozoic/Early Palaeozoic (e.g., Coira et al., 1982; Ramos, 2000). This activity reworked Proterozoic lithosphere and formed the Phanerozoic western margin of the Proterozoic cratonic South America (Fig. 1; e.g., Damm et al., 1990; Pankhurst and Rapela, 1998; Cordani et al., 2000; Lucassen et al., 2001, 2004; Schwartz and Gromet, 2004). Orogens with thickened crust formed in Cenozoic and Early Palaeozoic times at this margin. Both orogens evolved during ongoing subduction and large volumes of hybrid magmatic rocks formed. These rocks represent mixtures of variable amounts of melts derived from sub-arc mantle sources and Proterozoic to Palaeozoic mainly felsic crust. The composition of the Early Palaeozoic (e.g., Damm et al., 1990; Pankhurst and Rapela, 1998; Coira et al., 1999; Pankhurst et al., 2000; Kleine et al., 2004) and Cenozoic to Recent magmatism (e.g., Harmon et al., 1984; Francis et al., 1989; Kay et al., 1994; Trumbull et al., 1999; Lindsay et al., 2001) and the Proterozoic to Palaeozoic crust (e.g., Damm et al., 1990; Pankhurst and Rapela, 1998; Lucassen et al., 2001, 2004) has been subject of numerous studies. The composition of the sub-arc mantle source is, however, difficult to constrain. Uncontaminated mantle melts are rare in continental arcs, especially in compressional tectonic regimes with a thickened crust as in the modern Central Andes. The sub-arc mantle is the convective, asthenospheric mantle forming the mantle wedge, but substantial contributions from lithospheric mantle to the sub-arc mantle are likely during up to 200 km arc-normal shortening of the lithosphere since Cenozoic in the Central Andes (CVZ in Fig. 1b; e.g., Hindle et al., 2005 and references therein). This lithospheric mantle could comprise (i) Early Palaeozoic mantle, which formed or was modified from older mantle during the Early Palaeozoic orogeny at an active margin (references above), (ii) Proterozoic sub-continental lithospheric mantle (SCLM) belonging to

the Brazilian shield, which is thought to be progressively underthrust beneath the Present Central Andes during shortening (e.g., McQuarrie et al., 2005 and references therein), and (iii) modifications of the mantle by magmatic activity during Mesozoic extension (e.g., Viramonte et al., 1999; Sempere et al., 2002). We investigated major and trace element and radiogenic isotope (Sr, Nd, and Pb) compositions of mafic, intra-plate magmatic rocks from a transitional area between the Phanerozoic western margin of South America and the Proterozoic Brazilian Shield (Fig. 1). The new data give insights into the composition of the lithospheric mantle $\sim 17^{\circ}$ - 34° S and 64° - 66° W in the late Mesozoic, before the onset of the Cenozoic shortening in the Central Andes. Further, Miocene alkaline rocks from two locations at the eastern side of the Andes (Fig 1b) give information on the mantle after the onset of the Cenozoic orogeny. The isotopic signatures of lithospheric mantle are discussed in the framework of published data from the Jurassic to Recent sub-arc mantle, mantle xenoliths representing late Cretaceous lithospheric mantle, and the composition of SCLM of the Brazilian shield.

2. GEODYNAMIC SETTING AND GEOLOGICAL FRAMEWORK OF THE INTRA-PLATE MAGMATISM

Only magmatic rocks, which represent primary, uncontaminated, magmas, are good candidates for constraining the composition of their mantle source. Such magmas may be generated in arc, back-arc and intra-plate settings (Fig. 1c). The South American continent experienced two geodynamic settings, the Early Palaeozoic and late Palaeozoic to Recent subduction in the west (Bahlburg and Hervé, 1997; above references) and Mesozoic continental break-up with the opening of the South Atlantic in the east (e.g., Hawkesworth et al., 1992; Storey, 1995). Mafic intra-plate magmatic rocks, which are the focus of this study

(17°-34°S; Fig. 1), occupy an intermediate geographic position between the region influenced by the magmatic arcs in the west and plate separation in the east. The Jurassic and early Cretaceous magmatic arcs produced large volumes of juvenile magmatic rocks from the sub-arc mantle in (e.g., Rogers and Hawkesworth, 1989; Kramer et al., 2005; Lucassen et al., 2006). The composition of the Brazilian SCLM east of the study area is constrained by Cretaceous small volume, alkaline, intra-plate magmatic rocks (e.g., Carlson et al., 1996; Gibson et al., 1996, 1999; Comin-Chiaramonti et al., 1997, 2005; Velázquez et al., 2006), which occur between the western borders of the early Cretaceous Paraná flood basalt province (e.g., Hawkesworth et al., 1992, 2000) and western Paraguay. The Paraná flood basalt province has been ascribed to mantle plume activity whereas the small volume intra-plate magmatism was mainly triggered by recurrent lithospheric extension (above references).

The tectonic regime in the study area and much of the South American continent was dominated by extension to transpression from latest Palaeozoic to Early Tertiary (e.g., Ramos, 2000; Sempere et al., 2002). Extension to transpression also dominated the tectonics in the Mesozoic magmatic arcs during oblique subduction (e.g., Scheuber et al., 1994). The most prominent surface expression of extension in the study area is the Salta basin (e.g., Salfity et al., 1994; Marquillas et al., 2005) of the ‘Salta rift’ in northwest Argentina (Fig. 1a Galliski and Viramonte, 1988; Griers et al., 1991) with a maximum of ~ 5 km of continental sedimentation in depocentres from Early Cretaceous until Early Tertiary. Crustal thinning was not prominent in general and, where it occurred, was compensated by continental sedimentation. A Cretaceous crustal thickness in the range of 30 to 40 km is indicated by the Moho depth from seismic data in undeformed crust east of the Cenozoic orogen (e.g., Yuan et al., 2002; Fromm et al., 2004). A crustal thickness of ~35 km has been inferred in one of the sub-basins of the ‘Salta rift’ on the basis of thermo-barometry and isotopic dating on lower crust felsic and mafic granulite xenoliths in basanites (Las Conchas location; Fig. 1b; ages

~90-110 Ma; $P=1.0$ GPa; 900°C ; Lucassen et al., 1999). Spinel–lherzolite xenoliths from the same location indicate high temperatures of Cretaceous equilibration in the upper most mantle ($900\text{--}1200^{\circ}\text{C}$, $P<14\text{--}17$ kbar; Lucassen et al., 2005). The xenolith data indicate an unusually hot lithosphere. The thermal anomaly seems to be triggered by heat transfer within the mantle and the underlying process resulted in no or moderate thinning of the crust. As a consequence, the make-up of the lithosphere in the Cretaceous was still dominated by early Palaeozoic or Proterozoic rocks (Fig. 1).

The alkaline magmatism from the late Palaeozoic onwards (Fig. 1b) is of small volume (Viramonte et al., 1999) and most sub-volcanic rocks occur as dikes or sills on the meter to 10 meter scale or small alkaline intrusions of a few 100 meters (alkaline intrusions: Ayopaya, Vichacla, San Andres, La Peña, Fig. 1b). The intrusion level is in the uppermost crust. The small size of the occurrences hampers a systematic search for outcrops on satellite or aerial views and our study relies mainly on already described locations (Table 1). Key information on sample locations and references are summarized in Table 1; the approximate positions of the sample locations are in Figure 1b.

3. RESULTS

Sample preparation, analytical methods and data quality are described in the Appendix.

3.1 Age

Reliable isotopic dating is a major problem in the fine grained basic to ultrabasic rocks. Suitable minerals are commonly lacking and whole rock dating could be biased by undetected alteration. We used the K-Ar method for dating of phlogopite or amphibole separates and, where hydrous phases are absent, whole-rock samples. New and published isotopic ages are

summarized in Table 1. Details of the new K-Ar ages are in Table A1 of the electronic appendix. Effects of regional or contact metamorphism are absent and all dikes and high-level intrusions have simple cooling histories. A complex thermal evolution of the minerals can be excluded in fast cooled upper-crustal intrusions. Four age groups are discerned on the basis of new and published K-Ar ages (Fig. 1b). The majority of samples show ages between ~130 to 100 Ma (group referred as 100 Ma), or latest Cretaceous ages between ~80 to 70 Ma (group referred as 70 Ma). A late Palaeozoic alnöite (~300 Ma) is unique in our sample set, but is included here as such ages are common in extension-related magmatic rocks of Peru (compilation in Sempere et al., 2002). The late Palaeozoic and the Mesozoic ages are contemporaneous with magmatic activity in the arc. Alkaline volcanic rocks from the Tupiza area and the La Peña alkaline intrusion are Miocene in age (~20 Ma; Table 1) and fall within the age range of magmatic rocks from the active arc.

3.2 Geochemical characteristics of the magmatic rocks

3.2.1 *Sample selection*

The aim of this study is a characterization of mantle sources by the isotopic composition of mafic intra-plate magmatic rocks. Therefore, samples with obvious crustal contamination should be excluded beforehand. Further, effects of severe alteration, commonly caused by weathering, on the chemical composition cannot be completely removed by sample treatment and require sample selection. The loss on ignition (LOI, Tables 2 and A2) is used as a guide to the intensity of alteration. LOI is < 2 – 3 wt% in most samples, and traces of alteration in these rocks are absent or minor under the microscope. The samples with a LOI > 3 wt% show moderate to considerable alteration of the primary minerals, including mainly serpentinization or rare carbonatization of olivine, hydration-oxidation of opaque and Fe-Mg minerals, and sericitization of feldspars. We restrict the discussion of mantle sources to samples with (i)

LOI < 2.5 wt% or Sr contents > ~900 ppm and (ii) MgO > 6 wt%. Sr content and hence Sr isotope composition is sensitive to feldspar alteration and the general trend during basalt weathering is lowering of Ca and Sr (e.g., Patino et al., 2003). Sr content bound to possibly undetected carbonate is removed by leaching of the samples and, therefore, high Sr content (900 ppm is more than three times the value of bulk crust; Taylor and McLennan, 1995) is considered to be a primary feature. We further include alnöites (location: San Andres) and carbonatites (location: Ayopaya; Schultz et al., 2004) in the data set, which show LOI >> 2.5 wt% due to primary carbonate. Samples from the Miocene La Peña alkaline intrusion show systematic compositional variation due to magmatic differentiation (Fig. 2a, 4; see below), but little crustal influence in the radiogenic isotopes (Fig. 3 b; see below) and no alteration. They are therefore included in our sample set. The selected samples are shown in Table 2. The complete sample set is in Table A2 of the electronic appendix and includes previously studied samples of the Las Conchas (Lucassen et al., 2002a) and Ayopaya locations (Schultz et al., 2004; Pb isotope ratios of these samples were analysed in the course of this study) and the excluded samples.

The effect of sample selection is illustrated by the TAS classification diagram (Fig. 2) and Sr-Nd isotope composition (Fig. 3). The TAS classification diagram including all analysed samples of silicate rocks shows a broad compositional range from foidite to dacite (Fig. 2a). The filtering reduces the compositional variation of the silicate rocks to the foidite, basanite, basalt, and trachybasalt fields (Fig. 2b) and removes most samples suspected of crustal contamination and/or alteration according to their Sr-Nd isotope signatures (Fig. 3a, b). The excluded samples are mainly from the Tupiza and Los Condores locations. Some Tupiza rocks show severe alteration and the Sr and Nd isotopic composition of other samples indicate mixing with isotope composition of the ambient continental crust and only the most primitive sample meets the selection criteria (Fig. 3a). The Los Condores samples have been

discussed previously and found to be weakly contaminated by lower crust (Lucassen et al., 2002a). Their least contaminated samples represent a similar source as the rocks from Chaján. We show the respectively least contaminated Tupiza and Los Condores samples in the isotope and trace element diagrams.

3.2.2 Major and trace elements

All selected samples are alkaline in the TAS classification diagram (Fig. 2b) despite their different ages. Volcanic and subvolcanic rocks (70 Ma: Betanzos, Chaján, Porterillos; 100 Ma: Matancillas, Las Conchas, Belén, Dique Cadillal, Finca Rodeo; Table 1; Fig. 1b) plot in the basanite and trachybasalt fields except one sample of a phonotephrite. The Cretaceous alkaline intrusions (100 Ma: Ayopaya and Vichacla) comprise similar or more alkaline compositions compared with the volcanic rocks. The Ayopaya location is unique in the sampling area with the occurrence of Ca- and Mg-carbonatites, which were described in detail previously (Schultz, 2004; Schultz et al., 2004). The 300 Ma old San Andres samples are alnöite (foidite in the TAS nomenclature, Fig. 2b). Sodium contents accounts for the bulk alkalinity in most samples (molar $K_2O/Na_2O < 0.5$ to 0.2, except the Chaján samples with ~0.9-0.6) and only the samples from Matancillas and San Andres are strongly potassic. Systematic variations of major element contents with MgO are small in all groups (not shown). The compositional trends in the Miocene La Peña alkaline intrusion indicate magmatic differentiation of single parent magma (Fig. 2b) and the pyroxenite are the cumulates of the more evolved rocks.

Primitive mantle normalized trace element patterns of the 100 Ma and 70 Ma sample groups show enrichment of incompatible elements, but Rb and K are strongly depleted with respect to neighbouring elements (Fig. 4a, c; Chaján samples show moderate Rb and K depletion). Nb contents are high and slightly enriched with respect to Th and U. A more or

less pronounced Pb trough is common. Zr, Hf, Ti, and Y are slightly depleted with respect to neighbouring elements of similar compatibility at some locations. The potassic samples from Matancillas show high K and Rb contents (Table 2). The REE (rare earth elements) patterns are similar for the different locations and the La_N/Yb_N ratios range between ~15-30 except in samples from Chaján, which reach up to 70 (Fig. 5). The carbonatite samples from Ayopaya show extreme trace element contents and variable patterns as common in carbonatite rocks (Fig. 4b; details in Schultz et al., 2004).

The trace element composition (Fig. 4d) and age (~300 Ma) of the San Andres alnöite are very similar to that of the larger sample set from the nearby Los Alisos alnöite (Barbieri et al., 1997; Villar et al., 1997) and both most likely represent the same magmatic pulse. The REE element pattern of the alnöite is steep with La_N/Yb_N of ~70 (Fig. 5).

The high Nb content (Table 2, Table A2), the absence of a Nb trough, and the patterns of the more compatible elements and REE (Fig. 4c) of the most primitive Tupiza sample (20 Ma) are similar to those of the older rocks, but the element contents are somewhat lower in the Tupiza sample and a prominent positive Pb spike occurs. The composition of the Miocene La Peña samples is likely controlled by magmatic differentiation as seen in the evolution of the trace element patterns of pyroxenite, which forms the most primitive cumulate, malignite, and syenite (Fig. 4c) and the correlation of major and trace elements (not shown). The low Nb contents and deep Nb troughs of all La Peña samples resemble the pattern of average late Cenozoic andesite from the magmatic arc (Fig. 4c).

3.3 Radiogenic Isotopes

The effects of age correction for radioactive in-situ decay are small for most samples because Rb/Sr and Sm/Nd ratios are low (Table 2; Table A2). This enables the comparison of the Sr and Nd isotope compositions of samples of different ages of crystallization. Sr and Nd initial

isotope ratios define different compositional arrays (Fig. 3b). Many samples of the 100 Ma group (Ayopaya, Las Conchas, Belen, Cadillal, and Finca Rodeo) fall into a small field of the depleted mantle quadrant ($^{143}\text{Nd}/^{144}\text{Nd} \sim 0.5127 - 0.5128$; $^{87}\text{Sr}/^{86}\text{Sr} \sim 0.7032-0.7040$), which is similar or slightly more radiogenic in its Sr isotope composition than HIMU mantle (HIMU=high μ ; $\mu = ^{238}\text{U}/^{204}\text{Pb}$; e.g., Zindler and Hart, 1986; Hofmann, 1997). Samples from the 70 Ma (Betanzos) and 20 Ma (La Peña) groups also plot within this field. A few samples from Las Conchas and Ayopaya (100 Ma), from Matancillas (100 Ma), and the Tupiza sample (20 Ma) have $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of up to ~ 0.707 and radiogenic Nd isotope signatures ($\sim 0.5127-0.5128$). Chaján and Potrerillos (70 Ma), Vichacla and Los Condores (100 Ma), and San Andres (300 Ma) samples all plot in the field of enriched mantle composition. Their compositions are similar to EM1 (EM=enriched mantle; Zindler and Hart, 1986) and the composition of SCLM from the Brazilian Shield (Fig. 3b).

The distinction into a depleted and enriched source by the Nd (and Sr isotope ratios for many samples) ratios is largely consistent with the distinction of the respective samples in the $^{207}\text{Pb}/^{204}\text{Pb} - ^{206}\text{Pb}/^{204}\text{Pb}$ compositional field (Fig. 6a). The samples with a depleted mantle source and the samples with radiogenic Sr and Nd isotope composition show similar $^{207}\text{Pb}/^{204}\text{Pb}$ ratios (15.55-15.65, less spread at single locations), but a considerable range of $^{206}\text{Pb}/^{204}\text{Pb}$ ratios ($\sim 18.5-19.5$). HIMU mantle compositions are absent. A clear correlation between $^{207}\text{Pb}/^{204}\text{Pb}$ and $^{206}\text{Pb}/^{204}\text{Pb}$ ratios only is seen among the La Peña samples. The Pb isotope ratios of these samples (including $^{208}\text{Pb}/^{204}\text{Pb}$ ratios) also decrease with increasing Sr (Fig. 6b) and decreasing Nd isotope ratios (not shown). The $^{208}\text{Pb}/^{204}\text{Pb}$ ratios of most samples from a depleted mantle source and radiogenic Sr composition are strongly correlated with $^{206}\text{Pb}/^{204}\text{Pb}$, parallel to NHRL (Fig. 6b).

Uranogenic Pb isotope ratios of the samples from an enriched mantle source plot in or near the large Brazilian SCLM field. Their $^{206}\text{Pb}/^{204}\text{Pb}$ and $^{207}\text{Pb}/^{204}\text{Pb}$ ratios vary between

17.5 and 18.5 and 15.45 to 15.50, with somewhat higher $^{207}\text{Pb}/^{204}\text{Pb}$ ratios in the San Andres samples. Samples from an enriched source form two groups according to their $^{208}\text{Pb}/^{204}\text{Pb}$ ratios. One groups shows $^{208}\text{Pb}/^{204}\text{Pb}$ ratios significantly higher than the NHRL values at given $^{206}\text{Pb}/^{204}\text{Pb}$ ratios (similar to EM1; Vichacla, San Andres, Los Condores), the $^{208}\text{Pb}/^{204}\text{Pb}$ ratios of the other group (Chaján, Potrerillos) are similar to NHRL. Three Ayopaya carbonatite samples show very high $^{208}\text{Pb}/^{204}\text{Pb}$ ratios of ~41 to 42.7 (not shown; Table A2).

4. DISCUSSION

The interpretation of data from mantle derived magmatic rocks from continental settings in terms of mantle composition must consider (i) the role of crustal contamination versus primary mantle composition and (ii) the types of mantle involved, which could be lithospheric or asthenospheric.

4.1 Crustal contamination or primary mantle signature?

Addition of crustal material to mantle-derived magmas could occur in the mantle source by influx of crustal material in a subduction system ('source contamination'), during the ascent and storage of the magmas within the crust ('magma contamination'), and by influx of material from the country rocks during low-grade alteration or weathering at the intrusion/extrusion level ('alteration'). We restrict the discussion to the latter two processes with a focus on the isotopic composition of the samples.

Effects of alteration or obvious crustal contamination are largely avoided by sample selection (Fig. 3a) and a few general considerations are valid for all selected samples of the intra-plate magmatic rocks. (1) The rocks represent, according to their trace element

enrichment, small degrees of melting in the mantle and small volumes of melt. They have high Sr and Nd contents (after leaching) which are above typical values of crustal rocks. Any substantial change of Sr or Nd isotope ratios by crustal contamination in magmatic processes or low temperature alteration should be accompanied by major changes in the chemistry or the state of preservation of the rock. (2) The Pb contents of many samples are lower than in typical felsic crustal rocks and the Pb isotope system is potentially more sensitive to contamination by crust than the Sr and Nd systems. (3) The radiogenic isotope compositions of the mantle - similar to those of the overlying crust - are subject to time-related changes, i.e. after the change of parent/daughter ratios during metasomatism in the lithospheric part of the mantle.

4.1.1 *Nd and Sr isotopes*

The crust at the western margin of the Brazilian Shield evolved during mid-Proterozoic and early Palaeozoic orogenies (e.g., Coira et al., 1982; Lucassen et al., 2001). Its composition is that of old felsic crust and Nd and Sr isotope composition of the bulk volume of the crust plots into the lower right quadrant of the Nd-Sr diagram (Fig. 7a). Nd isotope patterns of the Palaeozoic crust are similar at distant sections even on the large regional scale of our sampling area (e.g., Pankhurst and Rapela, 1998; Bock et al., 2000; Lucassen et al., 2001, 2004; Egenhoff and Lucassen, 2003). The Sr isotopic composition can be variable between high grade metamorphic rocks (e.g., granulite facies lower crust of Early Palaeozoic age, ~ 0.715 ; Lucassen et al. 1999, 2001) and other Palaeozoic crustal rocks with more radiogenic Sr isotope compositions ($^{87}\text{Sr}/^{86}\text{Sr} > 0.715$).

Sr and Nd isotopic ratios of many intra-plate samples assemble two restricted compositional fields one indicating a depleted and second indicating an enriched reservoir (Fig. 3b). Systematic compositional variations in these fields are minor and it is not possible

to distinguish small amounts of crustal contamination from small variations in the mantle source composition. Considering the large sampling area, the depleted and enriched mantle sources are of rather uniform Nd and Sr isotope composition (Fig. 3b). Systematic variations of the Sr –Nd isotope compositions in these two groups are restricted to samples from La Peña (two deviating data points in Fig. 3b). Nd and Sr isotope compositions (and correlation of the Pb isotope ratios in these samples; Fig. 6) indicate mixing of melts from depleted mantle with small amounts of an isotopically different material with unradiogenic Nd (and Pb) and radiogenic Sr isotope composition. The isotope ratios of the La Peña samples vary with indicators of magmatic differentiation (not shown), which indicates a process occurring within the crust. The crustal material could have lower crustal composition with a Pb and Nd isotopic composition comparable to that of lower crust xenoliths near 31°30'S (Kay et al., 1996; no Sr isotopes published).

A small number of intra-plate samples have variable high $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of up to 0.707 and $^{143}\text{Nd}/^{144}\text{Nd}$ ratios similar to those of the depleted mantle samples (Fig. 3b). Such Nd - Sr isotope signatures are known to be caused by seawater alteration (e.g., Hauff et al., 2003), which, however, is very unlikely in intra-plate magmatic rocks deposited in a continental environment. A second alteration process which could explain the high $^{87}\text{Sr}/^{86}\text{Sr}$ ratios is the formation of caliche during weathering under arid conditions. Caliche is not observed in the samples and possible hidden carbonate was removed by leaching of the rock powders. Mixing with crustal melts or assimilation of crustal material could principally change the Sr isotope composition. The specific Nd-Sr isotope signature of the samples and their major and trace element composition preclude substantial contamination by an AFC process within the crust. Firstly, crustal reservoirs with radiogenic Nd and radiogenic Sr isotope compositions are largely restricted to mafic (meta)igneous rocks with metasomatic changes of their Rb and/or Sr budget. Partial melts from such rocks have very different major

and trace element compositions (e.g., Beard and Lofgren, 1991; Rapp and Watson, 1995) compared with those observed in the intra-plate magmatic rocks. Secondly, up to 50 wt% additions of crustal material would be needed to explain the observed scatter of Sr isotopes at the given high Sr content of the samples (~ three times average crust Table 2 and Table A2) and an initial $^{87}\text{Sr}/^{86}\text{Sr}$ composition of ~0.703. Crustal contamination of that extent should cause prominent changes in the Pb and Nd isotope and major and trace element composition, which is not observed in the high $^{87}\text{Sr}/^{86}\text{Sr}$ samples.

A strong argument for a source with radiogenic Sr isotope composition within the upper mantle comes from the composition spinel lherzolite xenoliths in the late Cretaceous basanite of the Las Conchas location (Lucassen et al., 2005). Clinopyroxenes from some xenoliths samples have radiogenic Nd and radiogenic Sr isotope compositions similar to the high $^{87}\text{Sr}/^{86}\text{Sr}$ samples of the intra-plate magmatic rocks (Fig. 7a). The addition of radiogenic $^{87}\text{Sr}/^{86}\text{Sr}$ to the clinopyroxene of the mantle xenoliths by weathering can be excluded and the high $^{87}\text{Sr}/^{86}\text{Sr}$ xenoliths therefore represent a variation in the composition of the upper mantle (Lucassen et al., 2005).

Such radiogenic $^{87}\text{Sr}/^{86}\text{Sr}$ compositions in mantle rocks can be explained by time-integrated growth of ^{87}Sr from elevated Rb-content, (i.e. in phlogopite with high Rb/Sr ratios). Dehydration melting of phlogopite-bearing lithospheric mantle is a common phenomenon during heating of mantle lithosphere and produces potassic melts (e.g., Comin-Chiaromonti et al., 1997; Gibson et al., 1999). The potassic high-Rb and Ba rocks from Matancillas (Table 2) represent such primary melts from dehydration melting. Clinopyroxene as the principal host of Sr in anhydrous peridotite will preserve the high $^{87}\text{Sr}/^{86}\text{Sr}$ ratios after dehydration melting. Melting of such peridotite will produce non-potassic melts with high $^{87}\text{Sr}/^{86}\text{Sr}$ ratios.

4.1.2 *Pb isotopes*

Pb isotope composition of the crust is locally and regionally more variable (e.g., Tilton and Barreiro, 1980; Macfarlane et al., 1990; Aitcheson et al., 1995; Tosdal, 1996, Kay et al., 1996; Lucassen et al., 2002b) than the Nd isotope composition. U is easily depleted and redistributed during high grade metamorphism and crustal melting, which occurred repeatedly during the protracted evolution of the Andean crust from Proterozoic onwards (e.g., Lucassen et al., 2002b). In the $^{206}\text{Pb}/^{204}\text{Pb}$ - $^{207}\text{Pb}/^{204}\text{Pb}$ space, the composition of Palaeozoic and Proterozoic basement rocks from the Andes follows a common trend (Fig. 6a) with consistently higher $^{207}\text{Pb}/^{204}\text{Pb}$ ratios than the Northern Hemisphere Reference Line (Hart, 1984).

The Pb isotope compositions of most intra-plate magmatic rocks are – despite the coincidence of individual samples with crustal compositions - not systematically related to the Pb isotope compositions of the crustal sources (Fig. 6a). Pb provinciality in the study area (CVZ north of 21°S; see Fig. 9b below; Aitcheson et al., 1995), which is evident in crust-contaminated Cenozoic andesite, is absent in the intra-plate samples. Further, the systematic differences between Pb isotope composition of the samples from depleted and enriched mantle sources argue for the dominance of primary differences reflecting Pb compositions of the mantle sources. Intra-plate magmatic rocks from depleted and enriched mantle sources passed through a compositionally similar crust and should, in the case of prominent crustal influence, show a uniform crustal Pb isotope composition. The scatter of $^{206}\text{Pb}/^{204}\text{Pb}$ ratios at similar $^{207}\text{Pb}/^{204}\text{Pb}$ in many clinopyroxenes from mantle xenoliths ratios is comparable to the scatter observed in the intra-plate magmatic rocks (Fig. 7b).

4.2 Influence of an asthenospheric mantle source?

The discussion in the previous chapter presented evidence and interpretations in favour of a mantle lithosphere-origin of the common intra-plate magmatic rocks from depleted sources. Primary potassic melts (Matancillas; San Andres), magmas with high $^{87}\text{Sr}/^{86}\text{Sr}$ and high $^{143}\text{Nd}/^{144}\text{Nd}$ ratios, and intra-plate magmatism with isotopic compositions typical for SCLM from the Brazilian Shield indicate an isotopically variable lithospheric mantle.

However, the influence of material from an asthenospheric source cannot be excluded a priori, especially in the intra-plate magmatic rocks from depleted sources. The isotopic composition of the average Pacific MORB is considered as a proxy for the composition of asthenospheric mantle. Compared with this asthenospheric mantle, the Nd isotope evolution in the depleted mantle source of the intra-plate magmatic rocks is retarded and Sr and Pb isotope compositions are more radiogenic (Fig. 7). Mixing trajectories between asthenospheric mantle MORB type mantle and depleted intra-plate magmatic rocks are absent, however (Figs. 3 and 6). The dominance of a depleted lithospheric mantle source is a reasonable assumption to explain the isotope composition of the depleted intra-plate rocks, if a MORB-type mantle source is assumed for the asthenosphere. The variations in the isotope signatures in the depleted intra-plate magmatic rocks and the mantle xenoliths could be explained by time integrated growth –as outlined below for the case of uranogenic Pb in a variably metasomatized lithospheric mantle. Relatively small scale compositional heterogeneities are more likely preserved over a long time in lithospheric than asthenospheric, convective mantle.

4.2.1 *Comparison with sub-arc asthenosphere*

The assumption of a MORB-type source composition for the convective mantle is not a unique option at an active continental margin. The composition of the convective mantle in

the mantle wedge is modified by metasomatism as long as subduction continues. Mantle derived rocks, which give insight into the composition of the mantle wedge (asthenosphere) after subduction derived metasomatism, have been studied along the Mesozoic to Recent arcs (18° - 40° S; Fig. 1; e.g., Hildreth and Moorbath, 1988; Rogers and Hawkesworth 1989; Morata and Aguirre, 2003; Lucassen et al., 2004, 2006; Kramer et al., 2005; and references therein). They occur in the Jurassic–lower Cretaceous ($\sim 18^{\circ}$ – 32° S) arc and in the Jurassic–Recent magmatic rocks of the Southern Volcanic Zone (Fig.1b). The age difference between the Jurassic to lower Cretaceous mantle wedge-derived magmas and the Cretaceous intra-plate magmatism does only cause smaller differences in radiogenic isotope composition from time-integrated radiogenic growth in possible common mantle sources. It should be mentioned, however, that the location of the Cretaceous intra-plate magmatism was up to 800 km east of the Jurassic magmatic arc (before shortening of the lithosphere in the Cenozoic orogeny) and the use of the sub-arc mantle as a proxy for the regional sub-continental asthenosphere remains speculative (but certainly not less ‘realistic’ than the comparison with compositions of standard mantle ‘endmembers’ or the Pacific MORB source).

The Nd and Sr isotopic compositions of the arc-related rocks, the intra-plate magmatic rocks from a depleted source, and many mantle xenoliths are very similar (Fig. 7a). Mixing between melts from such lithospheric mantle and sub-arc asthenospheric mantle can not be detected in the Nd and Sr isotope signatures of the respective hybrid magmatic rocks. The $^{206}\text{Pb}/^{204}\text{Pb}$ ratios are substantially lower and more uniform in the arc-related rocks than in the intra-plate rocks and most mantle xenoliths (Fig. 7b). The variation of the $^{207}\text{Pb}/^{204}\text{Pb}$ ratios is similar in arc-related and intra-plate rocks (Fig. 7b). Provided the highest $^{206}\text{Pb}/^{204}\text{Pb}$ ratios of intra-plate magmatic rocks and mantle xenoliths indicate one ‘endmember’ composition in the lithospheric mantle (Fig. 7b), mixing of melts from such source with melts from the sub-arc

mantle could account for some of the scatter in the $^{206}\text{Pb}/^{204}\text{Pb}$ ratios of the intra-plate rocks from depleted sources.

4.3 The Cretaceous depleted lithospheric mantle

As shown above, the isotopic compositions of the Cretaceous intra-plate magmatic rocks from depleted mantle sources are different from published endmember compositions (HIMU, EM1), average Pacific MORB mantle or any consistent mixing arrays between them (Figs. 3b and 6). They are, however, similar to the isotopic compositions of mantle xenoliths from local lithospheric mantle. The variations in $^{206}\text{Pb}/^{204}\text{Pb}$ (Figs. 7, 8) and rare high $^{87}\text{Sr}/^{86}\text{Sr}$ ratios are more readily explained by lithospheric mantle sources than asthenospheric mantle. This depleted lithospheric mantle likely formed during the early Palaeozoic orogeny at the active early Palaeozoic continental margin. It is compositionally different from Brazilian SCLM, which has been separated from depleted convective mantle since more than 1 Ga (e.g., Comin-Chiaramonti et al., 2001).

4.3.1 A conceptual model for the Cretaceous depleted lithosphere

The time span between early Palaeozoic and Cretaceous could explain peculiarities observed in the Nd, Pb, and Sr isotope systems by time-integrated radiogenic growth after relative Nd, U, and Rb enrichment in the early Palaeozoic depleted subarc mantle. The origin of early Palaeozoic replacement of older lithospheric mantle by depleted mantle is speculative. The formation of a mantle wedge during early Palaeozoic subduction is certainly one process of replacement of older lithosphere, but replacement may have included the same processes which were invoked for other orogens with overthickened crust and active margins. Delamination of mafic lower crust and mantle lithosphere with the subsequent influx of convective mantle (asthenosphere) seems to be common in fossil and modern orogens (e.g.,

Meissner and Mooney 1998; for the present Central Andes: Kay et al., 1994; Sobolev et al., 2006). Metasomatism of the sub-arc mantle by slab derived trace elements (e.g., Grove et al., 2002 among many others) is continuous as long as subduction proceeds. The Sr, Nd, and Pb isotope compositions of the Mesozoic to Recent mantle wedge at the Andean margin is an example of such process, which produced a relatively uniform signature different from other convective mantle reservoirs as e.g., MORB-type mantle (Lucassen et al., 2006 and references therein). The modified composition in the mantle wedge may be frozen after cease of subduction or change of the focus of the subduction zone by conversion of convective to lithospheric mantle during cooling and form the initial ‘baseline’ composition for the further evolution. Metasomatism at decreasing temperatures in the waning subduction system could raise the U/Pb and Rb/Sr and lower Sm/Nd ratios with respect to convective mantle values.

Figure 8 illustrates a simple conceptual model for the growth of radiogenic Pb in the source of the intra-plate rocks from early Palaeozoic onwards. The transformation of convective sub-arc into lithospheric mantle is followed by metasomatism in Early Paleozoic. The initial $^{206}\text{Pb}/^{204}\text{Pb}$ and $^{207}\text{Pb}/^{204}\text{Pb}$ of the Pacific MORB source at 470 Ma is assumed as a hypothetical starting condition in the early Palaeozoic depleted sub-arc mantle (Fig. 8). Slightly heterogeneous initial Pb isotope ratios and a rise of the μ ratio to values of 20 to 30 at ~ 470 Ma would result in radiogenic $^{206}\text{Pb}/^{204}\text{Pb}$ composition (at rather uniform $^{207}\text{Pb}/^{204}\text{Pb}$) at 100 Ma (Fig. 8). Such model could explain the compositional variation of the intra-plate magmatic rocks from depleted sources in the $^{207}\text{Pb}/^{204}\text{Pb}$ - $^{206}\text{Pb}/^{204}\text{Pb}$ space by compositional heterogeneities within the lithospheric mantle (Fig. 8).

4.4 Implications for the Cenozoic Andean arc magmatism

4.4.1 Contributions of SCLM

The radiogenic isotope compositions of dominantly Cretaceous (but also some late Palaeozoic and Tertiary) intra-plate magmatic rocks indicate two mantle types, a depleted mantle and an enriched mantle. The isotopic composition of the enriched mantle is comparable with compositions known from Brazilian SCLM and similar to the EM1 endmember (Figs. 3b, 6a). The influence of melts from this mantle type is not evident in the isotopic compositions of magmatic rocks from the Andean arcs. Mesozoic to modern arc magmas follow a uniform trend of crustal contamination in their Sr-Nd isotope composition (Fig 9a). Their Pb isotope compositions follow either uniform mixing patterns in between a depleted mantle source and the common Palaeozoic crust or indicate Pb provinciality related to regional heterogeneities in the crustal composition (Fig. 9b; e.g., MacFarlane et al., 1990; Aitchison et al., 1995).

The occurrences of enriched mantle lithosphere could either represent Proterozoic remnants within mainly Palaeozoic mantle (the Palaeozoic orogeny reworked mainly cratonic material) or mark the transition to the Brazilian Shield. The border between Proterozoic craton and the early Palaeozoic orogen is unknown from the surface geology. Recent seismic images of the lithosphere show that underthrust of the Brazilian Shield beneath the Cenozoic orogen does not necessarily occur at all locations (Heit, 2005 and references therein) and place the western edge of the Brazilian Shield at 21°S near longitude 65°W. This is where SCLM was sampled in late Palaeozoic at the San Andres location (Fig. 1b).

4.4.2 Depleted lithospheric mantle

The isotopic characteristics of the Mesozoic sub-arc mantle evolved consistently up to Recent and indicate a uniform composition of the mantle wedge (incoming ‘fresh’ asthenosphere plus element input from subduction) beneath this section of the Andean margin at least since Mesozoic (Fig. 9; 18°-40°S; recent summary in Lucassen et al., 2006). The only marked difference in the isotope composition between the sub-arc and depleted lithospheric

mantle sources (with unradiogenic $^{87}\text{Sr}/^{86}\text{Sr}$) is the more radiogenic Pb isotope composition of the latter (Figs. 7). Contributions of the depleted lithospheric mantle during Cenozoic to Recent shortening in the Central Andes would not be seen in the Sr and Nd isotopic composition of arc magmas from such mixed mantle source (Fig. 9a). The Pb isotope signatures of the hybrid magmatic rocks from the compressive arc of the CVZ are dominated by crustal Pb (Fig. 9b), which likely superimpose possible Pb isotope signatures from mixing of low Pb mantle sources.

The most depleted Sr, Nd (and Pb) isotopic compositions of the Miocene alkaline La Peña samples are indistinguishable from the Cretaceous intra-plate samples from depleted sources (Figs. 3a, 6a). Approximately 200 km north of the La Peña location, the Miocene Maquinas alkali basalts in the Andean back arc were investigated by Kay et al. (1991) and Kay and Abbruzzi (1996). The source of the basalts has been interpreted as lithospheric mantle. One of the samples has Nd and Sr isotope compositions identical to the least contaminated La Peña sample, but a Pb isotope composition similar to the most contaminated La Peña samples. The least contaminated sample from the Miocene Tupiza alkaline rocks in southern Bolivia also shows affinities to the depleted mantle sources and to the trace element patterns of the intra-plate magmatic rocks. Sources comparable to those of the Cretaceous intra-plate magmatism were still active in the Miocene back arc at distant localities (Fig. 1).

5. SUMMARY AND CONCLUSION

The new isotope data on the lithospheric mantle in the Cretaceous back arc suggest the dominance of depleted compositions in the mantle lithosphere on a large regional scale in the Central Andes. Isotope signatures of our sample suite show no systematic mixing relations with isotopic compositions of common mantle ‘endmembers’ (Figs. 3b, 6). The Cretaceous depleted lithospheric mantle presumably represents metasomatized sub-arc mantle of the early

Palaeozoic arc. A contribution of sub-continental asthenospheric mantle to the isotopic composition of our sample suite is either not visible due to compositional similarity (Mesozoic to Recent Andean sub-arc mantle composition) or very limited (MORB-type source). Subduction could create regionally important mantle reservoirs *sui generis* in the upper mantle.

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Appendix

Sample preparation, analytical methods, and data quality

Samples were first crushed using a hammer and, after separation of parts with visible alteration or xenoliths, passed through a jaw crusher. The crushed samples were cleaned in distilled water in order to remove the dust fraction. Most volcanic and sub-volcanic rock samples are fine-grained and we selected ~100 g of fragments (~5 - 10 mm) under the binocular microscope, avoiding altered material as filled fractures, amygdales, and weathered parts if present. Samples were ground in a tungsten-carbide shatterbox for 5 minutes. The loss of ignition was determined on ~2 g of dry (110°C) powdered sample at 1000°C. Whole rock samples were analysed for major elements and some trace elements (Sr, Ba, Cr, Nb, Ni, V, Zr) by XRF (PHILIPS PW 1404; Tables 2 and A2) at Technical University Berlin on fused glass disks using Oxiquant and X-40 Philips software. Reproducibility of the in-house standard is (n=90; wt% $\pm 1\text{sd}$): SiO₂: 60.1 $\pm$ 0.75; Al₂O₃: 19.0 $\pm$ 0.27; Fe₂O₃: 5.8 $\pm$ 0.11; MnO: 0.13 $\pm$ 0.004; MgO: 1.1 $\pm$ 0.13; CaO: 5.1 $\pm$ 0.06; Na₂O: 4.6 $\pm$ 0.23; K₂O: 2.2 $\pm$ 0.04; TiO₂: 0.56 $\pm$ 0.012; P₂O₅: 0.20 $\pm$ 0.008.

Powdered samples of silicate rocks (except carbonatite and alnöites, which contain primary carbonate) for isotope and ICP-MS analysis were treated with hot acetic acid or diluted (2N) HCl to remove possible secondary carbonate. Sr contents bound to carbonate should be lowered by leaching and substantial Sr loss should be seen in the ICP-MS Sr contents in comparison to the values obtained from XRF on unleached samples. The difference between XRF and ICP-MS Sr-values is small in most samples (except Vichacla location, probably due to dissolution of some nepheline in HCl; Table A2) and not correlated with the Sr isotope composition. The effect of a previous leaching experiment on one of the high ⁸⁷Sr/⁸⁶Sr from the Las Conchas location on Sr isotope ratios is small and does not affect

any conclusions (untreated sample: 0.706708, Sr 1160 ppm; leached sample 0.706566, Sr 1123 ppm; leachate: 0.711770; Nd and Pb isotope ratios vary within the analytical error; Lucassen et al., 2002a). The dried samples were weighed into Savillex® screw top beakers. Samples were dissolved in 52% HF on the hot plate at 180°C for at least 36 h. After drying, the samples were redissolved in 6N HCl and split into two fractions one for Pb isotope determination and one for Sr and Nd isotope analysis. Pb was separated using standard HBr – HCl chemistry; Sr and the REE fractions were separated in a first step from the same solution and Nd was isolated in a second step from the other REE using HDEHP coated Teflon® powder. Laboratory procedures at GFZ Potsdam are described in Romer et al. (2005). Rare earth element (REE), U, Th, Pb, Rb, and Sr contents were determined by ICP-MS at GFZ Potsdam (experimental procedure at GFZ Potsdam and accuracy from international reference material see Dulski, 2001). The Pb isotope ratios of the Ayopaya carbonatite were determined on carbonate separates.

All isotope ratios were determined using TIMS. Nd and Sr isotope were measured using dynamic multi-collection on a MAT 262 mass spectrometer and on a VG 54 Sector mass spectrometer at the GFZ-Potsdam, respectively. Nd isotopic ratios were normalized to $^{146}\text{Nd}/^{144}\text{Nd} = 0.7219$, Sr isotopic ratios to $^{86}\text{Sr}/^{88}\text{Sr} = 0.1194$. During the analytical work at GFZ-Potsdam the NBS 987 Sr yielded $^{87}\text{Sr}/^{86}\text{Sr} = 0.710265 \pm 28$ (2σ ; $n=47$) and the La Jolla Nd standard yielded $^{143}\text{Nd}/^{144}\text{Nd} = 0.511850 \pm 8$ (2σ , $n = 46$). Pb isotope ratios at GFZ-Potsdam were measured using static multi-collection on a MAT 262 mass spectrometer at controlled temperatures between 1220 - 1250°C. The 2σ reproducibility of all Pb isotope ratios of the NBS SRM 981 standard ($^{206}\text{Pb}/^{204}\text{Pb} = 16.902 \pm 0.015$, $n=58$) is better than 0.1% and a 2σ error of 0.1% is assumed for the measured samples. Instrumental mass-fractionation has been corrected using 0.1% per a.m.u. on the basis of the NBS SRM 981 values. Procedural blanks were < 30 pg for Pb, <50 pg Nd and < 100 pg for Sr. No blank corrections have been

applied to the measured ratios because blank contribution were insignificant in comparison to the amount of the respective elements in the sample.

K-Ar dating

Minerals were separated magnetically and by handpicking under the binocular microscope. Purified biotite was ground in pure alcohol to remove altered rims that might have experienced a loss of Ar or K. Details of sample preparation, argon and potassium analyses for the laboratory in Göttingen are given in Wemmer (1991). Potassium was determined in duplicate by flame photometry using an Eppendorf Elex 63/61. The samples were dissolved in a mixture of HF and HNO₃ according to the technique of Heinrichs and Hermann (1990). CsCl and LiCl were added as an ionization buffer and internal standard, respectively.

The argon isotopic composition was measured in a pyrex glass extraction and purification line couple to a VG 1200 C noble gas mass spectrometer operating in static mode. The amount of radiogenic ⁴⁰Ar was determined by isotope dilution method using a highly enriched ³⁸Ar spike (Schuhmacher, 1975). The spike is calibrated against the biotite standard HD-B1 (Fuhrmann et al., 1987). The age calculations are based on the constants recommended by the IUGS quoted in Steiger and Jäger (1977). The stated analytical error for the K/Ar age calculations is given at the 95% confidence level (2σ; Table A1).

For electronic Appendices

Table A1 K-Ar age data

Table A2 Geochemical composition (XRF, ICP-MS) and isotope (Pb, Sr, Nd) data of our sample set including samples, which were discarded according to the selection criteria and

published data of the intra-plate magmatic rocks (*Schultz et al., 2004; **Lucassen et al., 2002a).

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Table headings

Table 1 Sample locations, key features of the samples, new and published isotopic ages and references to the local geology.

Table 2 Chemical compositions (a) XRF (b) ICP-MS data (c) measured and age corrected Sr, Nd, and Pb isotope compositions of the selected sample set.

Figure Captions

Figure 1 Major geological provinces of the South American Mesozoic to Recent lithosphere and sample locations. (a) Large scale overview of the tectonic situation; the investigated rocks come from an area transitional between the Mesozoic to Recent subduction zones in the west (already active in the early and late Palaeozoic) and the early Cretaceous Paraná large igneous province (LIP) (related to the opening of the South Atlantic and possible plume activity; Renne et al., 1993, 1996)). A-A' indicates the position of the synoptic profile. (b) Sample locations of intra-plate magmatic rocks in the context of the distribution of Jurassic to lower Cretaceous arc-related rocks, the presently active Central Volcanic Zone (CVZ), and Southern Volcanic Zone (SVZ). In the North the sample locations are situated within the Cenozoic orogen (eastern extension is indicated by the broken line), in the South mostly east of the orogen. (c) Schematic W-E cross section through the South American lithosphere in the Cretaceous and relative spatial relations between different mantle and crustal domains. Late Mesozoic to Tertiary intra-plate magmatism occurs at various locations west of the Paraná LIP (e.g., Comin-Chiaramonte et al., in press). The Cretaceous Salta Rift marks the transition between the area influenced by the early Palaeozoic orogeny and arc and Proterozoic Brazilian Shield. Sources: (a) is modified from Schultz (2004); (c) is redrawn and modified from Schobbenhaus and Bellizzia (2001).

Figure 2 Compositional variations of the intra-plate magmatic rocks in the TAS classification diagram in terms of age groups; compositions are recalculated to dry 100%. (a) Data for all investigated silicic rocks (see Table A2); (b) selected silicic rocks based on the alteration and contamination criteria as discussed in the text; the complete selection includes carbonatites from Ayopaya not shown in this diagram.

Key to the compositional fields (a,b): (F): foidite; (P): picro-basalt; (B): basalt; (BA): basaltic andesite; (A): andesite; (D): dacite; (R): rhyolite (I): basanite; (II): phono-tephrite; (III): tephri-phonolite; (IV): phonolithe; (V): trachy-basalt; (VI): basaltic trachy-andesite; (VII): trachy-andesite; (VIII): trachyte; Le Maitre (1989).

Figure 3 Nd and Sr isotope ratios of the intraplate magmatic rocks in terms of age groups (see Fig. 1), corrected for radioactive in-situ decay using the ages from Table 1; (a) all samples (b) sample selection based on the alteration and contamination criteria as discussed in the text, but including carbonatites from Ayopaya and the least contaminated samples from Tupiza (T) and Los Condores (LC); note different scale on the $^{87}\text{Sr}/^{86}\text{Sr}$ -axis. For comparison, the fields of common mantle 'endmember compositions' are shown; MORB = average Pacific MORB compiled from the Petrological Database of the Ocean Floor <http://www.petdb.org>; the Nd isotope ratio of average MORB is corrected for in-situ decay to 100 Ma using a $^{147}\text{Sm}/^{144}\text{Nd}$ ratio of 0.214; HIMU from Hofmann (1997); EM1 Zindler and Hart (1986); SCLM = sub-continental lithospheric mantle beneath the Brazilian Shield (Carlson et al., 1996; Gibson et al., 1996, 1999; Comin-Chiaramonti et al., 1997, 2005; Velázquez et al., 2006) ; Sr isotopic composition of bulk silicate Earth is calculated at 160 Ma assuming Rb/Sr ratio of 0.03 (McDonough and Sun, 1995) and an initial $^{87}\text{Sr}/^{86}\text{Sr}$ of 0.69898 (Allegre et al., 1975).

Figure 4 Selected major and trace element patterns normalized to the primitive mantle (McDonough and Sun, 1995) and REE patterns normalized to the C1 chondrite (McDonough and Sun, 1995). The elements are listed with increasing compatibility in the mantle residue to the right. (a) Average compositions of the 100 Ma group samples. The Matancillas sample shows pronounced enrichment of Rb, Ba, and K. (b) Average compositions of the 70 Ma group samples; they are similar as the 100 Ma group, except for the steeper REE pattern of

the Chaján samples. (c) Average compositions of the 20 Ma group samples; pyroxenite from La Peña represents an early cumulate, whereas malignite and syenite represent more evolved magmas. The average composition of Cenozoic Andesite from the Central Volcanic Zone is shown for comparison (compiled from GEOROC data base; <http://georoc.mpch-mainz.gwdg.de/georoc>). (d) Extreme composition of the Ayopaya carbonatite and the San Andres alnöite (average values).

Figure 5 La_N/Yb_N and Dy_N/Yb_N ratios. Samples from enriched sources (Chaján, San Andres, and Potrerillos) indicate garnet in the source. All other samples show variations, which could be explained either by garnet free spinel lherzolite or small amounts of garnet in the mantle source.

Figure 6 Pb initial isotope compositions of the samples in comparison to the composition of Andean crust, Brazilian SCLM, average Pacific MORB, and EM1 mantle endmembers. (a) $^{208}\text{Pb}/^{204}\text{Pb}$ and $^{206}\text{Pb}/^{204}\text{Pb}$ ratios. (b) $^{208}\text{Pb}/^{204}\text{Pb}$ and $^{206}\text{Pb}/^{204}\text{Pb}$. Three carbonatite samples from Ayopaya with very high $^{208}\text{Pb}/^{204}\text{Pb}$ ratios ($\sim 41 - 42.7$; Table A2) are not shown. Both sources, depleted and enriched mantle as defined by the Nd-Sr-isotope ratios are also distinguished in the Pb isotope ratios. Simple mixing relations between a depleted MORB-type or an enriched (EM1) type mantle with the Paleozoic crust are absent. Only the samples from La Peña (grey diamonds) form a consistent array from a depleted mantle with a crustal component, the latter with a strongly unradiogenic Pb-isotope composition (Fig. 6b; see text). Data sources as in Fig. 3; Andean basement lead evolution line from Lucassen et al. (2002b), U-depleted source (e.g., Arequipa Massif of southern Peru; Tilton and Barreiro (1980).

Figure 7 (a) Sr-Nd isotope and (b) uranogenic Pb isotope compositions of Cretaceous lithospheric mantle xenoliths ($\sim 26^\circ\text{S}$; Las Conchas locations; Lucassen et al., 2005), Jurassic to early Cretaceous magmatic rocks from the arc ($18^\circ\text{-}27^\circ\text{S}$; Lucassen et al. 2002a; Kramer et al., 2005. Lucassen et al., 2006) compared with the depleted and enriched sources of the intra-plate magmatic rocks (grey shaded fields); upper (average) Palaeozoic and lower Palaeozoic crust ($21^\circ\text{-}27^\circ\text{S}$; Lucassen et al., 1999; Lucassen et al., 2002b), corrected for in-situ decay to 100 Ma. Other sources and endmember compositions see Figs. 3 and 6. The xenoliths show a similar range of Nd-Sr-Pb compositions as the depleted mantle source, as defined for the intraplate magmatic rocks.

Figure 8 Model for the evolution of the uranogenic Pb in the intra-plate magmatic rocks and many of the xenoliths. The Pacific MORB source is considered as a proxy of depleted mantle, the Mesozoic sub-arc mantle represents the ‘true’ asthenospheric beneath the arc; The Pacific MORB is corrected for radioactive in-situ decay using the present average Pb isotope composition of Pacific MORB and a μ ratio of 8.1. The average early Palaeozoic magmatic and metamorphic basement (Pz crust; $21^\circ - 27^\circ\text{S}$; Lucassen et al., 2001; 2002b) is a good approximation to a common crustal endmember in the Central and Southern Andes. Deviations from this scheme are less radiogenic than this crust at 470 Ma, e.g., old ($> 1\text{Ga}$) U-depleted rocks (e.g., Arequipa Massif of southern Peru; Tilton and Barreiro, 1980). The Pb isotope composition the Pz crust at 470 Ma is represented by Pb isotope composition of feldspar and may be also common in the U depleted lower crust up to Present (Lucassen et al. 1999; 2002b). The lines labelled 20μ and 30μ represent 370 Ma of Pb growths starting from different initial Pb composition at 470 Ma.

Figure 9 Relations between the Nd, Sr, and Pb isotopic composition of mantle derived and crust-contaminated (hybrid) magmatic rocks of the Mesozoic to Recent arcs (18°- 27°S; CVZ and 34-40°S; SVZ; Fig.1b) and the composition of the intra-plate magmatism. (a) Nd-Sr isotopic compositions follow a uniform trend between a depleted mantle source, which is very similar in the CVZ and SVZ, and the ambient Palaeozoic crust. Major influence of an enriched mantle source is not seen. (b) Systematic differences between the Pb isotope composition of the Jurassic and late Cenozoic (age <20Ma) mantle derived rocks could be explained by an evolving mantle source (comparable to the evolution of MORB between 160 to 0 Ma) plus crustal contribution in the subduction system. Andesite of the CVZ south of 21°S are intermediate in composition between mantle derived rocks from SVZ (representing the modern sub-arc mantle composition) and ignimbrite from CVZ, which contain high proportions of melts from the Palaeozoic crust. Pb-provinciality of the crust is known from the Pb isotope composition of Cenozoic andesite from CVZ north of 21°S (Aitchison et al., 1995), but not seen in the intraplate igneous rocks which also comprise some locations north of 21°S.

Data sources: magmatic rocks of the Jurassic to lower Cretaceous magmatic arcs (Lucassen et al., 2002a, Kramer et al., 2005; Lucassen et al., 2006); the late Cretaceous to early Cenozoic magmatic rocks and late Cenozoic andesite and ignimbrite from the CVZ (Rogers and Hawkesworth, 1989; Francis et al., 1989; Aitchison et al., 1995; Ort et al., 1996; Trumbull et al., 1999; Lindsay et al., 2001; Haschke et al., 2002); SVZ volcanic rocks (<http://georoc.mpch-mainz.gwdg.de/georoc/> and Lucassen et al., 2004 and references therein); other sources as in Figures 3 and 6.

Location [W Long. S Lat.]	Mode of occurrence	Petrography	Isotopic age K-Ar data [Ma]	References
Ayopaya (1) 66°45', 17°00'	alkaline intrusions, subvolcanic rocks and dikes in Ordovician sedimentary rocks; map in ref. (1)	lamprophyre, nepheline-syenite, calcio- and magnesio- carbonatite, and kimberlite	on biotite (1; three ages) ~100 on biotite (2) 98±3	(1) Schultz et al., 2004 (2) Kennan et al., 1995
Betanzos Arollo Chorillos 65°25.69', 19°33.25'	various dikes (<2 m, extension ~10-20 m) in Ordovician sedimentary rocks	occasionally biotite bearing basanites; small lherzolite xenoliths	on biotite 82.0 ±3.3 81.5±3.0	this work
Vichacla (3) 65°33.02', 20°38.33'	small alkaline complex (diameter ~100 m); coarse grained sub-volcanic rocks and dikes in Ordovician sedimentary rocks	rocks of variable composition: pyroxene ≤40 vol% hornblende ≤40, biotite ≤20, plagioclase + nepheline ≤30; titanite, apatite ≤2 fresh material	on hornblende (1) 114.3±2.8 on biotite (1) 118.1±3.2; on biotite (2) 120±0.5	(1) this work (2) Tawackoli et al., 1999 (3) Santivañez et al., 1996.
NE Tupiza 65°43.17', 21°24.64'	dacitic plug with autobreccia (diameter ~50 m) in Ordovician sedimentary rocks	trachyandesite – dacite; fresh material	on hornblende 19.8±0.8 on biotite 21.2±0.8	this work
S of Tupiza; Road Tupiza-Villazon 65°41.57', 21°31.10'	basaltic flows < 10 m and dikes in Ordovician sedimentary rocks	subalkaline basalt – trachyandesite, variable degrees of weathering, small altered lherzolite xenoliths	on biotite 19.2±0.8	this work
San Andres – Rio Seco/Oran 64°46.79', 23°06.19' near-by Los Alisos/Oran 64°46'; 23°02' (1,2)	boulders from the dry valley; sheet like small intrusion into Palaeozoic sedimentary rocks (Ordovician?)	homogeneous alnöite (1, 2,4) small scatter in mineral modes: olivine, pyroxene, biotite, melilite, titanite, some primary carbonate; fresh material	on biotite (3), Los Alisos 303±10; on biotite (4), San Andres 304±7; 300±7; 310±6; 304±10	(1) Barbieri et al., 1997 (2) Villar et al., 1997 (3) Mendez and Villar, 1979 (4) this work
Matancillas near S.A.d.I.Cobres; 66°19.81', 23°55.06'	dike ~3m x 50m in Ordovician sedimentary rocks	biotite-rich phonotephrite fresh material	on biotite 109±3 108±2	this work
Las Conchas (1, 2) Amblayo (north of Las Conchas) 65°50.37', 25°26.53'	numerous stratigraphically controlled dikes and small sills in Cretaceous rift-related sedimentary rocks; map in ref. (2)	basanite, lherzolite xenoliths, lower crust xenoliths (Sm-Nd age ca.100 Ma (3) fresh material		(1)Viramonte et al., 1999 (2) Lucassen et al., 2002a (3) Lucassen et al., 1999
Dique Cadillal near Tucuman, 65°11.25', 26°37.01'	trachyte intrusion and basanite dike in Palaeozoic sedimentary rocks	trachyte, basanite; basanite contains small lherzolite xenoliths; fresh material	on whole rock (1) 100-130	(1) Bossi & Wampler, 1969
Finca del Rodeo 64°57.48', 26°39.34	dikes in weakly metamorphosed Palaeozoic basement	basanite, some alteration of olivine; contains small lherzolite xenoliths	on whole-rock 95±3 (96±3 repeat) 98±3 (99±3 repeat)	this work
Belén, Puerta de San José (1) 66°59.52', 27°32.76'	pyroclastic flows over Cretaceous (?) redbeds and Ordovician granite; ~30 m basanite flows	basanite, variable degree of alteration of olivine; small lherzolite xenoliths	on whole rock ~130 Ma	(1) Rossello et al., 1999
Los Condores (1,	various cogenetic	basalt – trachybasalt;	whole rock (cited	(1) Lagorio,

Location [W Long. S Lat.]	Mode of occurrence	Petrography	Isotopic age K-Ar data [Ma]	References
2) 64°30', 32°10- 32°20'	centres on/in Palaeozoic sedimentary rocks map in ref. (2)		by 1) 115 – 130	1998 (2) Lucassen et al., 2002a
Chaján (1, 2) 64°00', 33°40'	lava- and intercalated pyroclastic flows in/ on Palaeozoic sedimentary and granitoid rocks map in ref. (2)	basanite; fresh material; lherzolite xenoliths with garnet pseudomorphs (1)	on biotite (2) ~67 Ma	(1) Escayola et al., 1998 (2) Lucassen et al., 2002a
La Peña (2, 3) 69°00', 32°42'	small alkaline intrusive complex in Palaeozoic metasedimentary rocks; maps in (2, 3)	malignite (nepheline + plagioclase ≤ 60 vol% - garnet ≤ 20 , hornblende + pyroxene in variable proportions ≤ 20 , titanite, opaque minerals ≤ 5); clinopyroxenite (with biotite, hornblende), nepheline-syenite fresh material	on biotite from pyroxenite (1) 18.8 ± 0.5 on amphibole (1) 17.9 ± 0.5 18.5 ± 0.5 , 19.5 ± 0.6 on amphibole (Ar- Ar) from malignite (3) 18.7 ± 0.5	(1) this work (2) Villar & Zappettini, 2000 (3) Zappettini et al., 2005
Potrerrillos 65° 50', 32° 50'	small plug intruding granitoid batholith (2)	transition trachybasalt – basanite; fresh material	on whole rock (1) 78.7 ± 2.6	(1) this work (2) Lopez & Sola., 1981

Table 2a XRF data; major element oxides in wt%, trace elements in ppm; < outside the calibrated range; b.d.l. = not detected

Location	Ayopaya	Vichacla				Matancillas		Las Conchas	Belén					Finca Rodeo	
Sample	I40	220900-24	220900-26	220900-32	220900-33	02-70	02-71	170900-5	131000-1	02-93	02-94	02-97	081000-5	02-98	02-74
Rock type	Ca-carbonatite	nepheline gabbroid	nepheline gabbroid	nepheline gabbroid	nepheline gabbroid	phono-tephrite	phono-tephrite	basanite	basanite	basanite	basanite	basanite	basanite	basanite	basanite
Age (Ma)	100	120	120	120	120	100	100	100	130	130	130	130	100	130	100
SiO ₂	0.3	44.6	44.2	44.7	43.3	50.3	47.1	45.3	45.3	44.7	44.9	44.5	45.2	44.2	41.9
Al ₂ O ₃	0.1	13.0	14.2	13.9	13.1	19.0	17.3	10.6	14.4	14.6	14.6	14.7	14.8	14.6	13.6
Fe ₂ O ₃	3.4	13.0	12.6	12.8	13.0	7.5	7.4	14.7	13.8	14.1	14.1	13.4	10.7	13.7	12.4
MnO	0.92	0.19	0.21	0.21	0.19	0.14	0.14	0.19	0.26	0.20	0.20	0.17	0.19	0.24	0.19
MgO	0.71	10.0	7.8	8.6	9.4	6.0	6.8	10.6	6.3	7.8	7.6	7.6	10.4	8.2	10.9
CaO	48.3	8.9	8.8	8.8	9.2	5.0	9.7	10.4	8.6	8.1	8.2	8.9	10.3	9.0	12.3
Na ₂ O	0.1	3.7	4.9	3.6	4.2	1.6	2.2	4.3	4.0	3.5	3.4	4.1	4.4	3.5	4.1
K ₂ O	0.03	2.7	3.4	2.8	3.3	7.9	6.7	0.8	2.3	1.8	1.9	1.5	0.8	1.4	0.6
TiO ₂	0.04	3.4	3.3	3.9	3.6	1.9	1.9	2.2	4.0	4.1	4.1	4.1	2.2	4.1	3.2
P ₂ O ₅	1.3	0.58	0.70	0.73	0.68	0.74	0.65	0.92	1.2	1.0	1.1	1.0	0.94	1.0	0.79
L.O.I	41.0	0.8	2.2	1.6	1.2	3.0	6.0	2.4	4.9	3.3	3.7	3.4	3.4	3.7	3.2
Sr	14500	1360	1850	1260	1280	1160	893	788	1120	1140	1100	1020	894	1200	965
Ba	8750	939	1100	1230	1080	1910	1550	776	820	913	1240	790	755	801	974
Cr	<3	249	153	189	224	110	138	342	99	97	102	151	324	161	232
Nb	2025	90	137	130	101	152	125	92	96	85	85	83	94	86	71
Ni	<3	206	121	142	173	51	67	236	87	59	60	80	228	90	146
V	32	286	236	300	277	172	171	226	253	224	222	224	215	245	256
Zr	439	374	521	496	393	166	149	253	387	322	320	322	259	309	196

Table 2a XRF data; major element oxides in wt%, trace elements in ppm

Table 2a. Hf data, major element oxides in wt%, trace elements in ppm																
Location	Finca Rodeo		Los Condores*	Betanzos			Chaján						Potrerillos			
Sample	02-75	02-78	13398- 15 trachy- basalt	230900- 36	230900- 43	230900- 46	02-25	02-28	02-29	121000- 17	121000- 19	121000- 21	03-13b trachy- basalt	03-13a trachy- basalt	03-15 trachy- basalt	03-16 trachy- basalt
Rock type	basanite	basanite	basalt	basanite	basanite	basanite	basanite	basanite	basanite	basanite	basanite	basanite	basalt	basalt	basalt	basalt
Age (Ma)	100	100	110	80	80	80	80	80	80	70	70	70	80	80	80	80
SiO2	41.3	41.4	46.2	45.0	43.0	42.4	43.0	43.1	43.6	41.3	42.2	40.7	48.4	48.5	48.2	48.3
Al2O3	13.6	13.5	11.6	13.9	13.3	14.5	14.0	13.4	14.3	8.8	9.8	9.5	11.8	11.8	11.9	11.9
Fe2O3	12.5	12.5	11.4	12.5	13.2	14.0	13.8	13.4	13.5	12.9	11.9	11.8	10.1	10.0	10.1	10.0
MnO	0.18	0.19	0.16	0.28	0.22	0.21	0.19	0.21	0.19	0.19	0.17	0.18	0.13	0.13	0.13	0.13
MgO	11.0	11.0	11.1	8.2	9.0	7.2	7.5	9.6	7.2	14.6	14.1	14.5	9.6	9.5	9.7	9.5
CaO	12.4	12.3	10.1	11.1	10.4	10.8	10.5	10.4	10.2	12.1	12.5	13.1	9.0	8.9	9.1	9.0
Na2O	4.3	4.4	3.7	3.3	4.0	4.7	4.4	3.6	4.6	2.8	2.0	2.7	4.0	4.2	4.3	4.2
K2O	0.8	0.8	1.4	1.4	1.9	1.4	1.9	1.5	1.7	2.8	2.7	2.5	2.7	2.8	2.3	2.6
TiO2	3.2	3.2	3.3	3.3	3.8	3.9	3.9	3.8	3.9	3.8	3.4	3.3	2.9	2.9	2.9	2.9
P2O5	0.79	0.76	0.91	0.88	1.2	0.95	0.84	1.1	0.83	0.84	1.38	1.62	1.33	1.33	1.37	1.33
L.O.I	2.4	2.4	4.6	3.2	1.6	1.2	1.2	2.9	1.6	1.9	3.8	2.4	2.6	2.5	3.1	2.7
Sr	1300	976	1480	1190	1350	1170	990	1180	1000	2360	2230	2450	1920	1950	1940	1950
Ba	958	915	1190	1060	1020	959	861	890	934	1340	1230	1370	1110	1100	1070	1090
Cr	239	219	366	274	236	71	98	286	96	401	421	428	264	278	279	270
Nb	71	71	82	143	144	127	103	121	110	184	169	191	89	91	91	92
Ni	147	144	288	150	231	75	56	204	59	371	356	398	207	209	211	204
V	261	261	227	275	290	372	319	276	316	220	186	171	125	114	123	115
Zr	181	194	413	411	404	354	275	319	284	543	519	566	259	262	261	260

*Lucassen et al., 2002a

Table 2a XRF data; major element oxides in wt%, trace elements in ppm

Location	south of										San Andres			
Sample	Tupiza	La Pena									02-1	02-4	02-5	02-6
Rock type	basalt	Pyroxenite	Pyroxenite	Pyroxenite	Pyroxenite	Pyroxenite	Malignite	Malignite	Syenite	Syenite	alnöite	alnöite	alnöite	alnöite
Age (Ma)	20	20	20	20	20	20	20	20	20	20	300	300	300	300
SiO ₂	48.4	35.3	42.1	41.3	38.4	36.6	50.6	49.5	55.6	58.9	37.5	39.5	37.0	37.6
Al ₂ O ₃	17.4	6.2	12.1	16.5	13.1	7.8	19.7	16.8	18.4	19.9	5.0	5.6	4.6	5.4
Fe ₂ O ₃	10.9	22.5	14.0	15.4	16.6	22.1	7.7	10.6	7.4	4.3	13.6	13.7	14.0	12.9
MnO	0.23	0.24	0.23	0.32	0.33	0.34	0.32	0.26	0.17	0.18	0.16	0.17	0.17	0.17
MgO	7.3	10.6	5.1	5.5	6.3	7.7	1.3	2.9	1.8	0.7	22.2	22.1	23.0	22.8
CaO	9.0	19.4	13.0	15.0	15.6	20.3	7.9	9.6	6.6	4.8	13.4	11.5	13.8	13.5
Na ₂ O	3.1	0.0	1.6	2.1	1.7	0.5	3.7	3.1	4.9	5.6	0.5	0.0	0.0	0.0
K ₂ O	1.4	1.0	4.0	0.8	1.1	0.2	7.3	5.2	4.0	5.0	1.9	2.3	1.8	2.4
TiO ₂	1.8	2.3	1.7	1.8	1.9	2.5	1.1	1.4	0.9	0.6	4.1	4.1	4.1	4.1
P ₂ O ₅	0.40	2.50	1.25	1.18	1.46	1.85	0.29	0.59	0.34	0.12	1.6	1.0	1.6	1.1
L.O.I	2.4	0.0	1.3	0.7	0.7	0.4	2.6	2.0	1.0	1.9	4.5	4.1	3.5	4.4
Sr	407	560	1680	2150	2000	779	2630	2130	1840	1550	640	622	691	911
Ba	632	475	876	529	466	313	1120	1160	1380	1080	771	1030	623	1010
Cr	199	<20	<20	22	21	27	26	21	28	<20	782	816	776	765
Nb	41	6	14	7	8	8	21	16	13	12	139	127	135	135
Ni	43	<20	<20	b.d.l.	b.d.l.	b.d.l.	b.d.l.	b.d.l.	<20	b.d.l.	494	542	527	523
V	199	586	420	304	420	734	236	301	122	60	174	195	201	203
Zr	161	98	172	85	165	194	207	159	180	278	241	248	289	267

Table 2b ICP-MS trace element data in ppm

Location	Ayopaya	Vichacla				Matancillas		Las Conchas	Belén					Cadillal	Finca Rodeo
Sample	I40	220900 -24	220900 -26	220900 -32	220900 -33	02-70	02-71	170900 -5	131000 -1	02-93	02-94	02-97	02-98	081000 -5	02-74
Rb		27	36	23	29	266	201	3	47	47	55	24	32	7	13
Sr	13440	1010	1450	959	883	1120	891	795	1120	1150	1130	1010	1180	801	970
Y	185.7	21.4	28.7	32.9	23.5	22.0	20.7	20.1	16.0	31.8	32.2	29.4	28.9	21.0	26.7
La	911	54.6	99.9	83.7	76.2	73.4	64.8	29.5	17.7	68.8	67.7	68.1	66.2	28.6	64.2
Ce	1600	105.4	183.9	158.6	145.4	121.1	108.0	62.4	40.8	137.3	137.1	133.0	128.8	60.8	117.6
Pr	160.4	11.8	19.5	17.6	15.4	12.1	11.1	7.6	5.2	16.1	15.5	15.3	14.4	7.5	13.1
Nd	538.4	44.9	70.1	65.9	56.8	41.4	37.7	31.4	23.1	62.5	60.7	59.0	57.0	31.6	50.1
Sm	86.0	8.3	12.0	12.1	9.6	6.5	6.2	6.5	5.3	11.7	11.5	10.8	10.4	6.4	9.2
Eu	26.8	2.5	3.7	3.6	3.0	2.0	1.8	2.1	2.0	3.6	3.6	3.4	3.3	2.1	3.0
Gd	69.4	7.1	9.7	10.4	7.9	5.4	5.4	5.7	4.8	10.0	10.0	9.1	9.1	6.0	8.2
Tb	9.41	0.96	1.29	1.40	1.04	0.77	0.69	0.83	0.68	1.29	1.32	1.26	1.19	0.84	1.10
Dy	44.63	5.05	6.88	7.66	5.54	4.45	4.20	4.65	3.83	7.12	7.05	6.59	6.42	4.71	5.91
Ho	7.34	0.88	1.19	1.32	0.95	0.83	0.77	0.86	0.66	1.25	1.19	1.12	1.13	0.85	1.02
Er	17.77	2.24	2.87	3.38	2.40	2.35	2.26	2.20	1.82	3.21	3.16	3.01	2.91	2.29	2.58
Tm	2.31	0.27	0.36	0.42	0.31	0.32	0.32	0.29	0.23	0.40	0.40	0.40	0.37	0.30	0.33
Yb	14.19	1.71	2.11	2.50	1.79	2.15	1.93	1.98	1.56	2.48	2.38	2.40	2.28	1.96	1.93
Lu	1.90	0.23	0.29	0.34	0.24	0.32	0.30	0.29	0.23	0.36	0.35	0.35	0.33	0.30	0.27
Hf	0.15	7.86	10.19	10.46	8.19	4.30	4.06	5.58	9.45	9.43	9.26	9.40	9.30	6.29	6.49
Pb	22.16	7.16	8.25	43.05	8.62	3.65	4.44	5.58	5.10	6.88	6.92	7.98	7.06	5.52	7.10
Th	13.15	7.15	11.84	10.19	7.84	11.29	9.22	5.00	6.05	7.90	7.85	7.88	7.56	5.64	7.84
U	3.48	2.52	3.78	3.51	2.57	2.51	2.10	1.47	2.42	2.07	2.04	2.24	2.06	1.43	1.53

Table 2b ICP-MS trace element data in ppm

	Finca		Los						Chaján			Potrerillos				
Location	Rodeo		Condores*	Betanzos												
			13398	230900	230900	230900				121000	121000	121000				
Sample	02-75	02-78	-15	-36	-43	-46	02-25	02-28	02-29	-17	-19	-21	03-13b	03-13a	03-15	03-16
Rb	13	18	15	8	22	15	19	22	14	58	47	47	45	58	41	35
Sr	1280	989	1410	888	1330	1140	992	1120	990	2970	2840	3100	1950	1900	1910	1760
Y	26.3	27.0	29.3	26.5	23.5	23.2	29.1	29.5	28.4	27.6	24.7	26.3	24.6	24.7	24.7	23.1
La	62.1	63.8	86.0	83.3	44.4	36.1	76.1	92.8	78.5	119	109	123	71.5	71.3	72.3	68.7
Ce	114.3	119.9	166.8	159.5	93.5	80.6	145.9	172.7	149.6	238	220	250	150.4	150.6	150.0	144.0
Pr	12.9	13.4	19.7	17.4	11.3	10.1	16.7	19.2	16.8	27.8	26.0	29.4	18.8	18.9	19.0	18.3
Nd	49.7	51.0	70.8	64.7	45.8	42.2	63.8	71.6	64.1	108	101	114	76.7	75.0	77.5	74.9
Sm	9.2	9.7	12.5	10.9	8.8	8.5	11.5	12.2	11.4	17.8	16.0	18.0	13.8	13.5	14.0	13.5
Eu	2.9	3.0	3.7	3.4	3.1	3.1	3.4	3.7	3.4	5.13	4.73	5.26	4.1	4.1	4.1	4.0
Gd	8.1	8.4	10.4	8.9	7.4	7.5	9.5	9.7	9.7	12.4	11.5	12.7	10.4	10.8	11.1	10.2
Tb	1.08	1.08	1.31	1.16	1.03	1.01	1.22	1.29	1.26	1.49	1.36	1.50	1.28	1.25	1.27	1.21
Dy	5.82	5.88	6.51	6.30	5.56	5.62	6.72	6.92	6.63	7.00	6.19	6.89	6.12	6.29	6.10	5.97
Ho	1.00	1.03	1.11	1.11	0.98	0.94	1.17	1.21	1.17	1.11	1.01	1.07	0.97	0.95	0.96	0.94
Er	2.58	2.65	2.72	2.86	2.49	2.49	3.02	3.03	2.96	2.50	2.29	2.45	2.20	2.27	2.26	2.24
Tm	0.32	0.32	0.34	0.35	0.34	0.33	0.35	0.38	0.37	0.29	0.26	0.27	0.26	0.26	0.26	0.26
Yb	1.88	1.91	1.98	2.18	2.11	1.98	2.22	2.31	2.22	1.65	1.55	1.59	1.44	1.53	1.55	1.47
Lu	0.26	0.26	0.29	0.32	0.29	0.30	0.32	0.33	0.31	0.25	0.24	0.25	0.20	0.21	0.21	0.19
Hf	6.50	6.74	8.51	8.19	9.83	8.93	8.48	9.22	6.95	9.28	8.93	9.58	7.38	7.23	8.81	7.28
Pb	6.73	7.34	7.68	5.07	4.85	3.78	7.11	7.73	4.27	5.24	5.16	5.11	7.38	7.82	11.16	7.39
Th	7.65	7.86	8.63	10.04	10.06	6.54	9.99	11.31	9.42	8.95	7.54	8.86	7.80	7.98	7.62	6.47
U	1.49	1.73	1.26	3.06	3.18	1.70	2.56	3.25	2.60	2.41	1.93	2.29	2.18	2.41	2.39	2.43

*Lucassen et al., 2002a

Table 2b ICP-MS trace element data in ppm

south of														
Location	Tupiza	La Pena	San Andres											
Sample	02-58	03-2a	03-3	03-4	03-5	03-10	03-6	03-7	03-9	03-12	02-1	02-4	02-5	02-6
Rb	32	37	89	11	19	7	194	117	76	119	56	76	52	79
Sr	415	578	1700	2120	1980	786	2610	2090	1810	1540	638	626	702	915
Y	27.1	26.5	29.1	36.0	42.2	42.3	38.8	34.8	30.5	23.9	27.9	23.8	28.9	23.2
La	33.7	30.4	42.8	45.0	61.9	59.6	71.3	52.1	44.2	51.0	148.1	129.4	156.5	125.5
Ce	67.8	75.2	92.9	105.2	139.6	136.8	147.0	118.4	96.4	97.1	301.9	276.8	334.0	250.5
Pr	7.8	11.0	12.5	14.2	19.1	18.8	18.3	15.7	12.5	11.4	35.3	33.1	38.5	28.8
Nd	30.8	52.7	54.7	63.6	84.0	81.0	74.3	64.7	52.1	41.2	139.5	126.8	149.3	108.6
Sm	6.1	12.2	12.2	14.0	18.0	18.1	14.8	13.7	10.6	7.7	23.3	21.6	25.1	17.9
Eu	2.0	3.7	3.6	4.5	5.5	5.5	4.5	4.2	3.2	2.3	6.4	5.7	6.9	4.9
Gd	6.1	11.7	10.7	12.6	15.7	16.9	12.6	11.6	9.1	6.4	17.1	15.3	17.8	13.1
Tb	0.91	1.37	1.36	1.60	1.97	2.04	1.67	1.51	1.18	0.87	1.91	1.65	2.07	1.48
Dy	5.27	6.50	6.86	8.31	9.83	10.24	8.41	7.94	6.54	4.81	8.46	7.45	9.09	6.63
Ho	1.05	1.04	1.16	1.43	1.69	1.63	1.47	1.35	1.19	0.87	1.21	1.07	1.33	0.96
Er	2.99	2.46	2.83	3.63	4.10	4.02	3.81	3.62	3.16	2.53	2.63	2.38	2.82	2.27
Tm	0.39	0.27	0.36	0.43	0.52	0.48	0.50	0.48	0.40	0.34	0.27	0.24	0.28	0.24
Yb	2.63	1.57	2.10	2.64	3.01	2.79	3.16	2.94	2.56	2.19	1.42	1.31	1.53	1.29
Lu	0.38	0.22	0.31	0.40	0.44	0.41	0.47	0.40	0.36	0.33	0.20	0.18	0.21	0.19
Hf	5.15	5.67	5.52	5.46	5.66	5.87	6.94	6.90	4.90	5.73	8.44	6.81	8.08	6.98
Pb	25.32	6.03	8.04	11.50	1.92	3.25	19.06	9.00	5.13	18.20	4.76	3.96	2.57	4.83
Th	4.70	1.59	4.77	2.04	3.23	4.54	8.90	5.13	5.24	7.24	19.96	17.59	19.64	16.30
U	1.12	0.38	1.52	0.38	0.88	0.75	3.38	1.78	1.58	2.36	3.10	2.71	3.16	2.80

Table 2c Nd, Pb, and Sr isotope data; (t) indicates ratios corrected for in-situ decay

Location	Ayopaya Vichacla				Matancillas				Las Conchas	Belén				Cadillal	Finca Rodeo
Sample	I40	220900 -24	220900 -26	220900 -32	220900 -33	02-70	02-71	170900 -5	131000 -1	02-93	02-94	02-97	02-98	081000 -5	02-74
Age (Ma)	100	110	110	110	110	100	100	100	130	130	130	130	130	100	100
$^{87}\text{Sr}/^{86}\text{Sr}$	0.703291	0.705192	0.705147	0.704579	0.704092	0.707424	0.707118	0.703617	0.703601	0.703799	0.704039	0.704158	0.705162	0.703694	0.704032
$\pm 2 \sigma(m)$	0.000008	0.000010	0.000010	0.000008	0.000008	0.000007	0.000007	0.000008	0.000007	0.000008	0.000008	0.000007	0.000006	0.000010	0.000007
$^{87}\text{Rb}/^{86}\text{Sr}$		0.076	0.073	0.070	0.093	0.682	0.651	0.015	0.121	0.117	0.141	0.068	0.078	0.024	0.039
$^{87}\text{Sr}/^{86}\text{Sr}(t)$	0.70329	0.70508	0.70504	0.70448	0.70396	0.70645	0.70619	0.70360	0.70343	0.70363	0.70384	0.70406	0.70505	0.70366	0.70398
$^{143}\text{Nd}/^{144}\text{Nd}$	0.512794	0.512507	0.512522	0.512301	0.512486	0.512730	0.512756	0.512830	0.512775	0.512753	0.512759	0.512769	0.512771	0.512830	0.512818
$\pm 2 \sigma(m)$	0.000006	0.000008	0.000009	0.000007	0.000008	0.000006	0.000006	0.000008	0.000008	0.000006	0.000005	0.000006	0.000007	0.000007	0.000006
$^{147}\text{Sm}/^{144}\text{Nd}$	0.0967	0.1119	0.1038	0.1110	0.1026	0.0953	0.0994	0.1241	0.1380	0.1128	0.1144	0.1107	0.1105	0.1222	0.1116
$^{143}\text{Nd}/^{144}\text{Nd}(t)$	0.51273	0.51243	0.51245	0.51223	0.51242	0.51267	0.51269	0.51275	0.51268	0.51268	0.51268	0.51270	0.51270	0.51275	0.51275
$^{206}\text{Pb}/^{204}\text{Pb}$	carbonate	18.72	18.76	18.45	18.64	19.36	19.11	18.89	19.76	19.58	19.60	19.71	19.70	18.88	19.37
$^{207}\text{Pb}/^{204}\text{Pb}$		15.54	15.54	15.60	15.53	15.60	15.60	15.57	15.60	15.58	15.59	15.59	15.59	15.57	15.60
$^{208}\text{Pb}/^{204}\text{Pb}$		38.84	38.96	38.59	38.81	39.59	39.29	38.73	39.28	39.47	39.49	39.54	39.56	38.71	39.44
$^{238}\text{U}/^{204}\text{Pb}$		25.9	33.8	6.0	21.9	51.6	35.2	19.4	35.6	22.6	22.1	21.1	22.0	19.1	16.1
$^{232}\text{Th}/^{204}\text{Pb}$		74.0	106.6	17.4	67.3	234.0	155.8	66.5	89.7	86.8	85.8	74.8	81.3	75.8	83.3
$^{206}\text{Pb}/^{204}\text{Pb}(t)$	19.20	18.32	18.23	18.35	18.30	18.56	18.56	18.58	19.21	19.23	19.26	19.38	19.35	18.58	19.12
$^{207}\text{Pb}/^{204}\text{Pb}(t)$	15.64	15.52	15.51	15.60	15.51	15.56	15.58	15.56	15.57	15.56	15.57	15.57	15.58	15.56	15.59
$^{208}\text{Pb}/^{204}\text{Pb}(t)$	39.15	38.47	38.43	38.50	38.48	38.43	38.52	38.40	38.83	39.04	39.07	39.17	39.16	38.33	39.03

Table 2c Nd, Pb, and Sr isotope data; (t) indicates ratios corrected for in-situ decay

Location	Finca Rodeo		Los Condores* Betanzos							Chaján			Potrerillos			
Sample	02-75	02-78	13398	230900	230900	230900	02-25	02-28	02-29	121000	121000	121000	03-13b	03-13a	03-15	03-16
Age (Ma)	100	100	110	80	80	80	80	80	80	70	70	70	80	80	80	80
$^{87}\text{Sr}/^{86}\text{Sr}$	0.704698	0.703986	0.705546	0.703375	0.703447	0.703205	0.703367	0.703875	0.703413	0.704160	0.704176	0.704114	0.704145	0.704136	0.704124	0.704190
$\pm 2 \sigma(\text{m})$	0.000007	0.000008	0.000004	0.000008	0.000008	0.000011	0.000010	0.000007	0.000008	0.000008	0.000008	0.000007	0.000008	0.000008	0.000010	0.000008
$^{87}\text{Rb}/^{86}\text{Sr}$	0.030	0.051	0.035	0.027	0.049	0.037	0.055	0.056	0.042	0.116	0.105	0.071	0.067	0.088	0.063	0.057
$^{87}\text{Sr}/^{86}\text{Sr}(\text{t})$	0.70466	0.70391		0.70334	0.70338	0.70315	0.70329	0.70380	0.70335	0.70400	0.70403	0.70401	0.70405	0.70401	0.70404	0.70411
$^{143}\text{Nd}/^{144}\text{Nd}$	0.512806	0.512800	0.512273	0.512813	0.512822	0.512832	0.512806	0.512800	0.512808	0.512435	0.512437	0.512418	0.512402	0.512374	0.512375	0.512376
$\pm 2 \sigma(\text{m})$	0.000006	0.000007	0.000006	0.000009	0.000007	0.000006	0.000006	0.000006	0.000003	0.000007	0.000010	0.000007	0.000007	0.000006	0.000005	0.000007
$^{147}\text{Sm}/^{144}\text{Nd}$	0.1120	0.1145	0.1092	0.1023	0.1161	0.1220	0.1085	0.1033	0.1081	0.0961	0.0940	0.0947	0.1088	0.1087	0.1093	0.1090
$^{143}\text{Nd}/^{144}\text{Nd}(\text{t})$	0.51273	0.51273	0.51220	0.51275	0.51275	0.51275	0.51273	0.51273	0.51274	0.51237	0.51238	0.51236	0.51233	0.51230	0.51230	0.51230
$^{206}\text{Pb}/^{204}\text{Pb}$	19.40	19.41	18.22	19.90	20.10	20.07	19.88	20.13	19.95	18.51	18.34	18.44	18.51	18.51	18.47	18.49
$^{207}\text{Pb}/^{204}\text{Pb}$	15.58	15.59	15.51	15.63	15.61	15.61	15.62	15.63	15.62	15.50	15.50	15.51	15.55	15.51	15.51	15.51
$^{208}\text{Pb}/^{204}\text{Pb}$	39.42	39.40	38.93	39.71	39.76	39.71	39.64	39.93	39.72	38.35	38.22	38.29	38.12	38.00	38.00	38.01
$^{238}\text{U}/^{204}\text{Pb}$	16.6	17.7	12.0	45.7	49.8	34.1	27.2	32.0	46.0	48.6	40.6	44.8	21.4	22.3	15.5	23.9
$^{232}\text{Th}/^{204}\text{Pb}$	85.6	80.7	82.8	151.0	158.6	132.2	107.0	112.2	168.2	172.5	136.0	138.8	77.3	74.5	49.8	63.9
$^{206}\text{Pb}/^{204}\text{Pb}(\text{t})$	19.14	19.14	18.03	19.18	19.32	19.53	19.45	19.63	19.24	17.75	17.71	17.74	18.17	18.16	18.23	18.12
$^{207}\text{Pb}/^{204}\text{Pb}(\text{t})$	15.57	15.58	15.50	15.59	15.57	15.59	15.60	15.60	15.59	15.46	15.47	15.47	15.53	15.49	15.50	15.50
$^{208}\text{Pb}/^{204}\text{Pb}(\text{t})$	38.99	39.00	38.52	38.96	38.97	39.06	39.11	39.38	38.88	37.50	37.55	37.60	37.74	37.63	37.75	37.70

*Lucassen *et al.*, 2002a

Table 2c Nd, Pb, and Sr isotope data; (t) indicates ratios corrected for in-situ decay

Location	south of Tupiza	La Pena	San Andres											
Sample	02-58	03-2a	03-3	03-4	03-5	03-10	03-6	03-7	03-9	03-12	02-1	02-4	02-5	02-6
Age	20	20	20	20	20	20	20	20	20	20	300	300	300	300
$^{87}\text{Sr}/^{86}\text{Sr}$	0.705066	0.703682	0.704003	0.703931	0.703760	0.703876	0.703851	0.703958	0.704611	0.704521	0.705325	0.705675	0.705041	0.704968
$\pm 2 \sigma(\text{m})$	0.000007	0.000008	0.000010	0.000008	0.000008	0.000007	0.000007	0.000008	0.000008	0.000008	0.000007	0.000010	0.000008	0.000010
$^{87}\text{Rb}/^{86}\text{Sr}$	0.225	0.183	0.152	0.015	0.028	0.027	0.214	0.162	0.121	0.222	0.255	0.349	0.213	0.248
$^{87}\text{Sr}/^{86}\text{Sr}(\text{t})$	0.70500	0.70363	0.70396	0.70393	0.70375	0.70387	0.70379	0.70391	0.70458	0.70446	0.70424	0.70419	0.70413	0.70391
$^{143}\text{Nd}/^{144}\text{Nd}$	0.512666	0.512827	0.512782	0.512778	0.512794	0.512808	0.512777	0.512729	0.512670	0.512614	0.512554	0.512583	0.512584	0.512539
$\pm 2 \sigma(\text{m})$	0.000006	0.000007	0.000006	0.000005	0.000007	0.000006	0.000004	0.000006	0.000006	0.000004	0.000006	0.000007	0.000005	0.000004
$^{147}\text{Sm}/^{144}\text{Nd}$	0.1192	0.1405	0.1349	0.1328	0.1296	0.1353	0.1201	0.1284	0.1225	0.1127	0.1011	0.1028	0.1015	0.0997
$^{143}\text{Nd}/^{144}\text{Nd}(\text{t})$	0.51265	0.51281	0.51276	0.51276	0.51278	0.51279	0.51276	0.51271	0.51265	0.51260	0.51236	0.51238	0.51238	0.51234
$^{206}\text{Pb}/^{204}\text{Pb}$	18.49	18.81	18.91	18.74	19.05	18.85	18.95	18.72	18.55	18.60	23.52	21.15	23.02	20.34
$^{207}\text{Pb}/^{204}\text{Pb}$	15.63	15.59	15.63	15.58	15.64	15.59	15.60	15.56	15.56	15.56	15.85	15.74	15.84	15.69
$^{208}\text{Pb}/^{204}\text{Pb}$	38.61	38.73	38.85	38.63	39.13	38.84	38.91	38.56	38.42	38.46	48.92	44.39	48.23	42.15
$^{238}\text{U}/^{204}\text{Pb}$	3.2	4.6	13.9	2.4	34.1	17.0	13.1	14.5	22.4	9.5	57.7	55.9	107.6	45.5
$^{232}\text{Th}/^{204}\text{Pb}$	13.7	19.6	44.1	13.1	126.1	103.8	34.7	42.1	75.1	29.3	374.4	365.8	673.4	267.2
$^{206}\text{Pb}/^{204}\text{Pb}(\text{t})$	18.48	18.79	18.87	18.73	18.94	18.80	18.91	18.67	18.48	18.57	20.77	18.49	17.90	18.17
$^{207}\text{Pb}/^{204}\text{Pb}(\text{t})$	15.63	15.59	15.62	15.57	15.63	15.59	15.60	15.56	15.56	15.56	15.71	15.60	15.57	15.57
$^{208}\text{Pb}/^{204}\text{Pb}(\text{t})$	38.59	38.71	38.81	38.62	39.00	38.74	38.88	38.52	38.34	38.43	43.33	38.92	38.16	38.16

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6

Figure 7

Figure 8

Figure 9

Table-A-1 K/Ar - age determinations

Ar - Isotopic Abundance		Spike - Isotopic Compo.		Decay Constants [1/a]:		Potassium		
40 Ar :	99.6000%	40 Ar :	0.0099980%	$\lambda \ \varepsilon$:	5.810E-11	40K :	0.011670%	
38 Ar :	0.0630%	38 Ar :	99.9890000%	$\lambda \ \beta$:	4.962E-10	K2O/K :	0.8302	
36 Ar :	0.3370%	36 Ar :	0.0009998%	$\lambda \ \text{tot}$:	5.543E-10	Atomic Weight [g/mol]:		
Standard Temperature Pressure (STP)				Mol. Vol.		tot Ar :	39.9477	
0°C; 760 mm Hg				[ml]		40Ar :	39.9624	
Normal Atmosphere (DIN 1343)				:		tot K :	39.1027	
273,15K; 1013,25 mbar								
Location/Sample		Spike	K2O	40 Ar *	40 Ar *	Age	2s-Error	2s-Error
mineral		[No.]	[Wt. %]	[nl/g] STP	[%]	[Ma]	[Ma]	[%]
Betanzos (Arollo Chorrillos; 19°33.25; 65°25.69)								
02-23	biotite	3322	8.06	21.80	80.13	82.0	3.3	4.0
02-28	biotite	3335	3.02	8.124	82.79	81.5	3.0	3.7
south of Tupiza 21°31.10; 65°41.57								
210900-4	biotite	3078	9.49	5.92	47.30	19.2	0.8	4.2
north of Tupiza 21°24.64'; 65°43.17'								
210900-14	hornblende	3075	1.19	0.76	63.25	19.8	0.8	4.0
210900-18	biotite	3092	9.07	6.23	88.05	21.2	0.8	3.8
Vichacla; 20°38.33; 65°33.02								
210900-24	hornblende	3074	2.02	7.69	91.50	114.3	2.8	2.4
210900-26	biotite	3093	8.98	35.36	95.06	118.1	3.2	2.7
San Andres; 23°06.19; 64°46.79								
02-01	biotite	3303	9.17	99.94	99.06	309.8	6.4	2.1
02-06	biotite	3290	8.89	95.06	96.64	304.4	9.5	3.1
02-07	biotite	3269	9.37	100	98.00	303.9	6.7	2.2
02-07	repeat	3270	9.37	98.59	98.58	299.9	6.6	2.2
Matancillas; 23°55.06; 66°19.81								
02-71	biotite	3271	8.98	32.52	97.39	108.9	2.7	2.5
02-72	biotite	3301	9.01	32.22	93.82	107.6	2.4	2.2
Finca del Rodeo; near Tucuman 64°57.48', 26°39.34								
02-74	whole rock	3481	0.61	1.909	64.64	94.5	3.0	3.2
02-74	repeat	3470	0.61	1.933	65.25	95.7	3.0	3.1
02-75	whole rock	3480	0.84	2.729	71.20	98.0	2.8	2.9
02-75	repeat	3469	0.84	2.747	66.12	98.7	3.0	3.0
La Peña; 32°42; 69°00								
03-2a	biotite	3337	9.88	6.012	80.89	18.8	0.5	2.7
03-05	hornblende	3343	1.97	1.183	80.62	18.5	0.5	2.7
03-05	biotite	3345	8.51	4.950	75.72	17.9	0.5	2.8
03-14	hornblende	3344	2.12	1.344	65.32	19.5	0.6	3.1
Potrerillos 65° 50', 32° 50'								
03-16	whole rock	3333	2.52	6.541	62.52	78.7	2.6	3.3

Table A-2 Major and trace element and Sr, Nd, Pb measured and initial isotope composition. Major elements are recalculated to 100 wt% dry composition. (except the Ayopaya samples) * Ayopaya samples (except I-40) from Schultz et al. (2004) Pb isotopes from this study; **Las Conchas, Los Condores and Chaján samples from Lucassen et al. 2002. b.d.l. not detected; < outside calibrated range of the XRF

location/sample	rock type	age	SiO2 wt% XRF	Al2O3 wt% XRF	Fe2O3 wt% XRF	MnO wt% XRF	MgO wt% XRF	CaO wt% XRF	Na2O wt% XRF	K2O wt% XRF	TiO2 wt% XRF	P2O5 wt% XRF	L.O.I wt% XRF	Ba ppm XRF	Co ppm XRF	Cr ppm XRF	Cu ppm XRF	Ga ppm XRF	Nb ppm XRF	Ni ppm XRF	Rb ppm XRF	Sr ppm XRF	V ppm XRF	Y ppm XRF	
south of Tupiza																									
210900-2a	trachy-basalt	20	48.7	17.0	12.1	0.27	5.1	7.8	4.6	1.1	2.5	0.83	2.0	961	64	39	321	21	86	25	46	586	229	33	
210900-04	trachyandesite	20	58.1	15.5	6.7	0.16	2.0	8.1	4.0	4.0	1.0	0.51	3.9	1060	49	58	56	21	76	21	158	1410	116	30	
260900-66	dacite	20	64.5	16.8	4.1	0.10	2.0	3.9	4.2	3.2	0.8	0.41	2.3	1280	110	28	34	22	87	<20	168	1160	74	25	
02-55	trachyandesite	20	54.2	16.0	10.5	0.08	3.4	5.3	8.2	0.4	1.7	0.37	4.2	95	77	139	<20	13	36	36	<30	57	79	26	
02-57	strong alteration	20	42.9	14.4	9.1	0.38	6.8	18.5	5.9	0.11	1.5	0.34	14.2	82	30	139	<20	13	29	32	b.d.l.	148	63	23	
02-58	basalt	20	48.4	17.4	10.9	0.23	7.3	9.0	3.1	1.4	1.8	0.40	2.4	632	44	199	119	21	41	43	31	407	199	25	
north of Tupiza																									
210900-9	basaltic trachy-andesite	20	55.9	16.0	8.1	0.07	4.1	6.9	2.9	3.7	1.4	0.90	1.8	1180	54	171	68	24	60	52	141	1130	198	28	
210900-14	trachy-andesite	20	58.3	17.0	7.4	0.11	3.0	5.5	2.9	3.7	1.3	0.67	0.9	981	67	65	76	25	52	23	171	902	158	29	
210900-18	dacite	20	65.8	16.0	5.0	0.06	1.0	3.3	4.2	3.4	0.8	0.45	1.8	1070	39	<20	33	25	83	<20	118	1300	84	22	
Vichacla																									
220900-24	nepheline gabbroid	120	44.6	13.0	13.0	0.19	10.0	8.9	3.7	2.7	3.4	0.58	0.8	939	78	249	44	21	90	206	73	1360	286	27	
220900-26	nepheline gabbroid	120	44.2	14.2	12.6	0.21	7.8	8.8	4.9	3.4	3.3	0.70	2.2	1100	64	153	48	27	137	121	108	1850	236	28	
220900-30	syenite	120	58.4	16.1	5.7	0.21	1.8	4.3	7.9	4.2	1.0	0.33	1.2	1000	69	57	48	24	86	32	119	2310	85	93	
220900-32	nepheline gabbroid	120	44.7	13.9	12.8	0.21	8.6	8.8	3.6	2.8	3.9	0.73	1.6	1230	75	189	41	23	130	142	64	1260	300	40	
220900-33	nepheline gabbroid	120	43.3	13.1	13.0	0.19	9.4	9.2	4.2	3.3	3.6	0.68	1.2	1080	98	224	53	21	101	173	100	1280	277	24	
220900-34	nepheline gabbroid	120	49.8	16.4	11.4	0.19	6.1	4.7	7.0	b.d.l	3.6	0.81	7.0	387	66	74	48	28	122	48	<30	646	242	28	
02-40	basalt	120	45.2	11.8	13.7	0.23	11.3	10.8	2.3	0.8	3.2	0.60	8.2	617	37	376	22	16	56	193	34	517	236	17	
Betanzos																									
230900-36	basanite	80	45.0	13.9	12.5	0.28	8.2	11.1	3.3	1.4	3.3	0.88	3.2	1060	75	274	82	19	143	150	<30	1190	275	33	
230900-43	basanite	80	43.0	13.3	13.2	0.22	9.0	10.4	4.0	1.9	3.8	1.2	1.6	1020	83	236	57	17	144	231	35	1350	290	31	
230900-46	basanite	80	42.4	14.5	14.0	0.21	7.2	10.8	4.7	1.4	3.9	0.95	1.2	959	96	71	74	23	127	75	<30	1170	372	32	
230900-51	trachy-basalt	80	49.3	11.5	16.0	0.24	2.8	11.1	5.1	0.73	2.4	0.74	9.9	707	62	128	<20	12	104	45	36	742	237	18	
02-25	basanite	80	43.0	14.0	13.8	0.19	7.5	10.5	4.4	1.9	3.9	0.84	1.2	861	71	98	52	17	103	56	<30	990	319	29	
02-28	basanite	80	43.1	13.4	13.4	0.21	9.6	10.4	3.6	1.5	3.8	1.1	2.9	890	57	286	40	19	121	204	<30	1180	276	27	
02-29	basanite	80	43.6	14.3	13.5	0.19	7.2	10.2	4.6	1.7	3.9	0.83	1.6	934	53	96	61	16	110	59	<30	1000	316	28	
Ayopaya*																									
I 28	nepheline syenite	100	46.6	19.2	8.3	0.24	2.7	5.3	8.7	4.5	1.4	0.49	1.4	1630	20	57	15	26	270	30	198	1310	90	40	
I 29	iyolite	100	43.6	15.1	10.4	0.19	6.5	9.9	5.8	3.5	2.4	0.71	1.0	1220	38	219	57	22	171	109	122	1220	190	33	
I 30	foyaite	100	53.2	21.2	4.2	0.14	0.5	2.6	9.2	5.7	0.7	0.12	1.3	1490	4	<3	14	25	183	<3	203	1520	38	19	
I 46	nepheline syenite	100	44.4	16.4	10.3	0.17	4.1	7.8	4.7	3.1	2.6	0.92	4.8	1120	44	30	22	19	121	22	113	866	193	26	
I 36	nephelinite	100	41.0	12.6	11.7	0.17	9.5	10.7	2.7	2.1	2.4	0.91	5.5	666	56	310	35	18	104	150	93	819	206	24	
I74	Mg-carbonatite	100	2.3	0.1	9.9	2.20	23.6	17.1	0.1	0.16	0.01	0.43	40.9	2560	5	4	3	<2	144	2	55	6300	195	92	
I78	Mg-carbonatite	100	0.1	<0.05	8.8	1.60	17.0	27.3	0.0	0.03	0.004	0.01	44.1	156	3	13	2	<2	8	4	2	824	84	87	
I79	Mg-carbonatite	100	0.7	<0.05	24.1	2.94	20.6	5.0	0.1	0.03	0.01	1.0	37.8	50900	3	5	2	<2	14	8	5	1770	38	79	
I77	Mg-carbonatite	100	0.2	0.1	9.2	1.66	18.1	26.0	0.0	<0.01	<0.001	0.01	43.7	75	<2	18	<1	<2	3	7	<20	790	58	97	
I81	Mg-carbonatite	100	0.1	0.1	6.0	1.05	17.3	28.7	0.0	0.01	0.02	0.76	44.7	616	2		2	94	40	4	<2	665	104	109	
I22	Fe-carbonatite	100	8.8	2.6	15.0	3.02	6.7	24.8	0.1	1.9	0.17	0.48	32.5	11400	9	218	19	<3	52	42	50	4870	242	131	
I40	Ca-carbonatite	100	0.3	0.1	3.4	0.92	0.71	48.3	0.1	0.03	0.04	1.3	41.0	8750	7	<3	<10	<2	2025	<3	<2	14500	32	201	
I53a	Ca-carbonatite	100	2.2	0.1	4.2	0.81	1.1	47.1	0.7	0.06	0.14	0.33	40.7	5410	8	18	2	9	1534	4	12	19750	183	171	
I34	syenite	100	55.6	18.8	6.4	0.17	2.0	3.7	6.2	4.3	0.85	0.27	1.2	732	18	63	22	25	139	29	200	582	57	27	
I6a	mellilite	100	35.7	9.3	9.3	0.28	13.7	10.6	3.9	3.0	2.0	0.67	10.4	2101	58	936	60	11	128	411	206	1490	202	50	
AY22	kimberlite	100	29.3	3.5	10.5	0.18	21.2	12.5	0.0	0.03	2.2	0.67	23.8	542	73	1371	8	90	780	5	754	189	15		
I1	kimberlite	100	24.8	3.4	10.6	0.13	22.2	10.0	0.1	0.02	2.2	0.48	19.3	310	79	1481	43	11	95	1058	22	373	166	13.6	
San Andres																									
02-1	alnôite	300	37.5	5.0	13.6	0.16	22.2	13.4	0.5	1.9	4.1	1.6	4.5	771	64	782	25	<8	139	494	60	640	174	27	
02-2	alnôite	300	41.4	8.2	12.8	0.17	17.0	12.0	0.0	2.8	3.6	1.9	10.8	2030	40	504	53	<8	129	284	91	927	228	31	
02-4	alnôite	300	39.5	5.6	13.7	0.17	22.1	11.5	0.0	2.3	4.1	1.0	4.1	1030	74	816	35	<8	127	542	68	622	195	25	
02-5	alnôite	300	37.0	4.6	14.0	0.17	23.0	13.8	0.0	1.8	4.1	1.6	3.5	623	65	776	27	<8	135	527	48	691	201	28	
02-6	alnôite	300	37.6	5.4	12.9	0.17	22.8	13.5	0.0	2.4	4.1	1.1	4.4	1010	62	765	44		8	135	523	84	911	203	21
Matancillas																									
02-70	phono-tephrite	100	50.3	19.0	7.5	0.14	6.0	5.0	1.6	7.9	1.9	0.74	3.0	1910	28	110	33	9	152	51	253	1160	172	25	
02-71	phono-tephrite	100	47.1	17.3	7.4	0.14	6.8	9.7	2.2	6.7	1.9	0.65	6.0	1550	36	138	48	13	125	67	204	893	171	22	
Las Conchas																									
A-70**	basanite	100	43.3	12.4	12.9	0.19	14.0	10.6	2.9	1.0	2.3	0.54	1.5	409	71	378	45		44	394		565		252	
A-78**	basanite	100	43.1	13.8	12.3	0.21	10.2	11.2	4.3	1.4	2.6	0.89	0.7	662	48	281	69		90	223		875		273	
matrix**		100																							

		SiO2	Al2O3	Fe2O3	MnO	MgO	CaO	Na2O	K2O	TiO2	P2O5	L.O.I	Ba	Co	Cr	Cu	Ga	Nb	Ni	Rb	Sr	V	Y	
A- 82**	basanite	100	43.4	13.3	12.3	0.21	11.1	10.9	3.7	1.6	2.5	0.90	0.8	691	59	355	55		87	272		889		263
A-93**	tephrite	100	48.2	16.6	10.6	0.17	6.0	8.1	3.2	3.8	2.6	0.79	4.2	887	33	117	39		75	80		687		201
A-95**	basanite	100	45.1	13.0	14.1	0.21	11.1	9.5	3.3	0.6	2.4	0.80	3.0	829	62	444	72		86	338		1160		189
matrix**		100																						
6/186**	basanite	100	45.5	14.7	11.8	0.19	9.9	9.3	4.6	0.7	2.5	0.68	1.0	552	48	334	62		66	253		668		224
matrix**		100																						
7/173**	basanite	100	45.5	14.0	11.5	0.18	11.9	9.2	4.1	0.7	2.2	0.66	1.0	555	69	410	74		62	368		642		232
A-119**	basanite	100	42.0	12.3	13.9	0.23	10.7	10.8	4.6	1.4	2.6	1.4	1.0	779	55	302	20		113	254		1130		215
A-12**	trachy-basalt	100	47.8	13.8	12.4	0.19	9.7	7.2	4.2	1.6	2.3	0.75	1.8	512	57	360	38		51	278		517		170
4/295 B**	basanite	100	45.9	14.4	12.9	0.19	9.5	8.8	3.7	1.3	2.8	0.66	1.9	694	62	250	42		74	211		816		228
4/146**	basanite	100	44.5	12.8	13.4	0.20	10.2	9.2	3.8	1.8	3.1	0.98	0.7	666	69	338	42		85	247		972		231
A-44**	basanite	100	44.4	12.1	13.2	0.20	12.1	8.3	4.5	1.3	2.9	1.1	1.2	585	61	455	77		68	365		796		195
170900-5	basanite	100	45.3	10.6	14.7	0.19	10.6	10.4	4.3	0.8	2.2	0.92		776	81	342	72	21	92	236 <30		788	226	26
Belén																								
131000-1	basanite	130	45.3	14.4	13.8	0.26	6.3	8.6	4.0	2.3	4.0	1.2	4.9	820	71	99	24	22	96	87	56	1120	253	29
02-93	basanite	130	44.7	14.6	14.1	0.20	7.8	8.1	3.5	1.8	4.1	1.0	3.3	913	41	97	28	16	85	59	42	1140	224	30
02-94	basanite	130	44.9	14.6	14.1	0.20	7.6	8.2	3.4	1.9	4.1	1.1	3.7	1240	46	102	28	16	85	60	49	1100	222	28
02-97	basanite	130	44.5	14.7	13.4	0.17	7.6	8.9	4.1	1.5	4.1	1.0	3.4	790	52	151	35	15	83	80 29<		1020	224	29
02-98	basanite	130	44.2	14.6	13.7	0.24	8.2	9.0	3.5	1.4	4.1	1.0	3.7	801	49	161	40	14	86	90 28<		1200	245	26
Cadillal																								
081000-1	trachyte	100	68.9	16.4	3.7	0.08	0.8	0.6	1.2	7.3	0.7	0.28	2.3	671	32 b.d.l.	<20		18	109	<20	233	143	44	37
081000-5	basanite	100	45.2	14.8	10.7	0.19	10.4	10.3	4.4	0.8	2.2	0.94	3.4	755	74	324	78	20	94	228 <30		894	215	27
Finca Rodeo																								
02-74	basanite	100	41.9	13.6	12.4	0.19	10.9	12.3	4.1	0.6	3.2	0.79	3.2	974	59	232	45	20	71	146 15<		965	256	25
02-75	basanite	100	41.3	13.6	12.5	0.18	11.0	12.4	4.3	0.8	3.2	0.79	2.4	958	65	239	45	18	71	147 7<		1300	261	23
02-78	basanite	100	41.4	13.5	12.5	0.19	11.0	12.3	4.4	0.8	3.2	0.76	2.4	915	64	219	54	18	71	144 12<		976	261	27
Los Condores																								
13398-15**	trachy-basalt	110	46.2	11.6	11.4	0.16	11.1	10.1	3.7	1.4	3.3	0.91	4.6	1190	59	366	41	23	82	288	18	1480	227	33
13398-20**	basanite	110	45.6	11.3	11.6	0.16	11.4	9.8	4.3	1.3	3.6	0.90	3.8	1180	73	371	39	20	85	297	15	1460	235	33
13398-18**	trachy-basalt	110	49.0	13.2	10.2	0.13	8.1	8.6	3.3	3.3	3.3	0.85	3.1	1050	63	243	25	23	69	184	29	1030	202	29
12997-23**	trachy-basalt	110	49.1	13.6	10.2	0.12	8.5	8.7	4.6	1.6	2.8	0.70	4.1	856	49	212	26	19	70	174	13	1030	198	25
G16**	basalt	110	48.5	12.3	10.7	0.15	10.2	9.6	3.3	1.2	3.3	0.79	5.0	1070	69	378	40	17	68	311	22	1940	191	27
G9**	basalt	110	46.2	11.4	11.7	0.21	11.6	10.7	2.9	1.3	3.1	0.75	3.8	1530	73	519	49	19	73	374	13	1010	242	34
Chajan																								
13398-7**	basanite	70	41.4	8.9	12.7	0.18	14.3	11.8	3.3	2.9	3.7	0.80	2.0	1160	73	413	53	21	170	366	65	2090	214	29
13398-6**	basanite	70	40.9	8.6	12.0	0.18	15.0	12.2	3.3	3.1	3.4	1.42	1.8	1090	79	481	66	23	186	408	54	2410	194	32
121000-7	host granite (Palaeozoic)		75.4	14.5	0.7	0.13	0.1	0.4	4.1	4.4	0.0	0.14	0.6	82	102 b.d.l.	<20		21	16 b.d.l.		251	19 <10	12	
121000-17	basanite	70	41.3	8.8	12.9	0.19	14.6	12.1	2.8	2.8	3.8	0.84	1.9	1340	89	401	72	16	184	371	72	2360	220	28
121000-19	basanite	70	42.2	9.8	11.9	0.17	14.1	12.5	2.0	2.7	3.4	1.38	3.8	1230	76	421	58	12	169	356	73	2230	186	21
121000-21	basanite	70	40.7	9.5	11.8	0.18	14.5	13.1	2.7	2.5	3.3	1.62	2.4	1370	77	428	74	12	191	398	62	2450	171	26
La Pena																								
03-2a	Pyroxenite	20	35.3	6.2	22.5	0.24	10.6	19.4	0.0	1.0	2.3	2.50	0.0	475	61 <20		432	20	<6	<20	39	560	586	25
03-3	Pyroxenite	20	42.1	12.1	14.0	0.23	5.1	13.0	1.6	4.0	1.7	1.25	1.3	876	62 <20		123	18	14	<20	77	1680	420	29
03-4	Pyroxenite	20	41.3	16.5	15.4	0.32	5.5	15.0	2.1	0.8	1.8	1.18	0.7	529	66		103	19	7 b.d.l.		<30	2150	304	37
03-5	Pyroxenite	20	38.4	13.1	16.6	0.33	6.3	15.6	1.7	1.1	1.9	1.46	0.7	466	66	21	192	19	8 b.d.l.		<30	2000	420	44
03-10	Pyroxenite	20	36.6	7.8	22.1	0.34	7.7	20.3	0.5	0.2	2.5	1.85	0.4	313	74	27	490	18	8 b.d.l.		<30	779	734	43
03-6	Malignite	20	50.6	19.7	7.7	0.32	1.3	7.9	3.7	7.3	1.1	0.29	2.6	1120	58	26	96	19	21 b.d.l.		173	2630	236	38
03-7	Malignite	20	49.5	16.8	10.6	0.26	2.9	9.6	3.1	5.2	1.4	0.59	2.0	1160	56	21	107	20	16 b.d.l.		114	2130	301	34
03-9	Syenite	20	55.6	18.4	7.4	0.17	1.8	6.6	4.9	4.0	0.9	0.34	1.0	1380	58	28	41	20	13 <20		67	1840	122	34
03-12	Syenite	20	58.9	19.9	4.3	0.18	0.7	4.8	5.6	5.0	0.6	0.12	1.9	1080	47 <20		<20	21	12 b.d.l.		113	1550	60	26
Potreriillos																								
03-13b	trachy basalt	80	48.4	11.8	10.1	0.13	9.6	9.0	4.0	2.7	2.9	1.33	2.6	1110	116	264	32	18	89	207	63	1920	125	24
03-13a	trachy basalt	80	48.5	11.8	10.0	0.13	9.5	8.9	4.2	2.8	2.9	1.33	2.5	1100	66	278	33	14	91	209	52	1950	114	21
03-15	trachy basalt	80	48.2	11.9	10.1	0.13	9.7	9.1	4.3	2.3	2.9	1.37	3.1	1070	73	279	45	17	91	211	38	1940	123	24
03-16	trachy basalt	80	48.3	11.9	10.0	0.13	9.5	9.0	4.2	2.6	2.9	1.33	2.7	1090	56	270	44	18	92	204	41	1950	115	22

location/sample	Zn ppm XRF	Zr ppm XRF	Rb ppm ICP-MS	Sr ppm ICP-MS	Y ppm ICP-MS	Cs ppm ICP-MS	Ba ppm ICP-MS	La ppm ICP-MS	Ce ppm ICP-MS	Pr ppm ICP-MS	Nd ppm ICP-MS	Sm ppm ICP-MS	Eu ppm ICP-MS	Gd ppm ICP-MS	Tb ppm ICP-MS	Dy ppm ICP-MS	Ho ppm ICP-MS	Er ppm ICP-MS	Tm ppm ICP-MS	Yb ppm ICP-MS	Lu ppm ICP-MS	Hf ppm ICP-MS	Pb ppm ICP-MS	
south of Tupiza																								
210900-2a	405	236		12	450	25.8	2.1	718	37.7	78.8	9.2	35.5	6.6	2.2	6.3	0.93	5.46	1.01	2.86	0.38	2.53	0.38	4.59	20.69
210900-04	88	315		147	1230	26.1	9.0	819	87.9	156.0	15.9	54.8	8.5	2.3	6.6	0.92	5.19	0.98	2.70	0.39	2.51	0.36	3.16	15.67
260900-66	78	371		153	1070	16.9	39.0	1061	73.4	119.4	11.2	34.7	5.0	1.8	3.6	0.55	3.19	0.60	1.85	0.27	1.97	0.31	6.95	25.73
02-55	185	169		7	66	24.9	0.4	41	19.2	49.6	6.1	23.3	4.6	1.4	4.8	0.75	4.84	0.99	2.85	0.38	2.57	0.38	3.89	20.72
02-57	355	124		4	157	21.5	2.6	47	24.3	68.0	5.9	23.1	4.5	1.5	4.5	0.69	4.21	0.78	2.31	0.31	1.96	0.30	3.70	16.55
02-58	159	161		32	415	27.1	7.8	539	33.7	67.8	7.8	30.8	6.1	2.0	6.1	0.91	5.27	1.05	2.99	0.39	2.63	0.38	5.15	25.32
north of Tupiza																								
210900-9	122	274		83	967	26.2	8.1	1007	83.3	156.8	17.0	60.1	9.7	2.6	7.6	0.98	5.53	1.00	2.78	0.38	2.46	0.36	6.20	14.54
210900-14	102	279		101	777	21.4	13.9	790	65.9	120.9	12.3	42.8	6.9	2.0	5.4	0.77	4.42	0.83	2.37	0.33	2.26	0.34	6.79	16.90
210900-18	90	298		107	1240	19.5	10.3	924	91.8	159.2	16.0	53.6	8.0	2.2	5.7	0.77	4.11	0.75	2.04	0.26	1.70	0.25	4.00	15.38
Vichacla																								
220900-24	136	374		27	1010	21.4	0.3	716	54.6	105.4	11.8	44.9	8.3	2.5	7.1	0.96	5.05	0.88	2.24	0.27	1.71	0.23	7.86	7.16
220900-26	155	521		36	1450	28.7	0.6	938	99.9	183.9	19.5	70.1	12.0	3.7	9.7	1.29	6.88	1.19	2.87	0.36	2.11	0.29	10.19	8.25
220900-30	135	453		101	1710	53.7	1.9	523	155.4	229.5	20.5	65.7	11.3	3.5	10.0	1.57	9.37	1.88	5.56	0.86	5.81	0.76	8.84	34.07
220900-32	284	496		23	959	32.9	0.4	1007	83.7	158.6	17.6	65.9	12.1	3.6	10.4	1.40	7.66	1.32	3.38	0.42	2.50	0.34	10.46	43.05
220900-33	127	393		29	883	23.5	0.3	846	76.2	145.4	15.4	56.8	9.6	3.0	7.9	1.04	5.54	0.95	2.40	0.31	1.79	0.24	8.19	8.62
220900-34	163	428		1	534	23.6	0.2	310	65.4	122.9	12.9	46.6	8.1	2.5	6.9	0.98	5.41	0.93	2.42	0.31	1.83	0.25	8.86	34.59
02-40	62	176		36	538	19.9	4.5	550	37.4	75.3	8.8	34.7	7.0	2.2	6.4	0.86	4.63	0.77	1.91	0.22	1.46	0.19	4.58	5.40
Betanzos																								
230900-36	119	411		8	888	26.5	0.7	864	83.3	159.5	17.4	64.7	10.9	3.4	8.9	1.16	6.30	1.11	2.86	0.35	2.18	0.32	8.19	5.07
230900-43	125	404		22	1330	23.5	2.4	1003	44.4	93.5	11.3	45.8	8.8	3.1	7.4	1.03	5.56	0.98	2.49	0.34	2.11	0.29	9.83	4.85
230900-46	122	354		15	1140	23.2	0.5	839	36.1	80.6	10.1	42.2	8.5	3.1	7.5	1.01	5.62	0.94	2.49	0.33	1.98	0.30	8.93	3.78
230900-51	64	282		16	768	13.4	24.2	695	29.7	58.0	5.6	20.4	3.5	1.1	3.2	0.45	2.77	0.51	1.40	0.18	1.15	0.16	7.29	45.58
02-25	106	275		19	992	29.1	2.9	792	76.1	145.9	16.7	63.8	11.5	3.4	9.5	1.22	6.72	1.17	3.02	0.35	2.22	0.32	8.48	7.11
02-28	104	319		22	1120	29.5	9.2	774	92.8	172.7	19.2	71.6	12.2	3.7	9.7	1.29	6.92	1.21	3.03	0.38	2.31	0.33	9.22	7.73
02-29	103	284		14	990	28.4	4.4	830	78.5	149.6	16.8	64.1	11.4	3.4	9.7	1.26	6.63	1.17	2.96	0.37	2.22	0.31	6.95	4.27
Ayopaya*																								
I 28	195	493						108.0	181.0	16.5	52.7	8.4	2.4	7.2	1.10	6.50	1.24	3.81	0.54	3.65	0.54			14.00
I 29	122	324						134.0	165.0															
I 30	76	304						27.8	59.3	6.7	24.5	4.3	1.3	3.7	0.56	3.13	0.57	1.71	0.25	1.79	0.30			
I 46	106	249						62.4	118.0	13.1	49.7	8.9	2.6	7.9	1.05	5.59	1.00	2.77	0.38	2.25	0.35			
I 36	99	210						49.3	90.7	10.5	41.3	7.9	2.5	7.1	0.94	4.81	0.82	2.09	0.25	1.51	0.23			
I 74	1311	56						1730	3520	397.0	1370	182.0	44.6	95.1	8.68	28.30	3.25	5.10	0.48	2.61	0.55			
I 78	161	27						1450	2580	257.0	852	102.0	24.0	53.1	4.98	18.00	2.23	3.54	0.31	1.80	0.38			
I 79	365	52						1140	2670	327.0	1080	129.0	32.1	68.2	6.81	23.00	2.68	3.96	0.38	1.95	0.69			
I 77	142	8						1760	2480		807	109.0	27.5							1.90	0.29			
I 81	94	26						3790	6560	695.0	2140	252.0	52.8	162.0	10.10	37.70	4.10	7.70	0.70	2.20	0.40			34.00
I 22	959	267						585	1650	186.0	715.0	178.0	52.2	139.0	13.40	45.70	5.15	9.72	0.86	5.01	0.71			
I 40	27	439		13440	185.7	0.0	2446	911	1600	160.4	538.4	86.0	26.8	69.4	9.41	44.63	7.34	17.77	2.31	14.19	1.90	0.15	22.16	
I 53a	262	489						1220	1850	187.0	640.0	88.8	26.7	62.8	7.06	33.00	5.09	12.20	1.38	7.65	1.02			
I 34	130	514						61.7	124.0	10.5	33.3	5.4	1.2	4.7	0.73	4.32	0.83	2.59	0.40	2.73	0.43			
I 6a	181	180						205.0	400.0	44.9	138.0	18.3	4.9	13.1	1.68	9.02	1.63	4.31	0.61	3.59	0.48			
AY22	78	179						87.3	174.0	20.8	72.9	12.1	3.5	9.8	0.90	3.71	0.54	0.93		0.51				
I 1	78	121						78.3	162.0	19.7	77.9	13.1	3.5	9.7	1.08	4.56	0.64	1.43	0.15	0.76	0.10			
San Andres																								
02-1	69	241		56	638	27.9	2.3	668	148.1	301.9	35.3	139.5	23.3	6.4	17.1	1.91	8.46	1.21	2.63	0.27	1.42	0.20	8.44	4.76
02-2	90	384		91	939	35.0	4.1	1814	113.7	224.4	25.4	94.8	17.4	4.7	14.4	1.72	8.54	1.36	3.20	0.36	2.10	0.31	8.72	10.28
02-4	77	248		76	626	23.8	2.4	944	129.4	276.8	33.1	126.8	21.6	5.7	15.3	1.65	7.45	1.07	2.38	0.24	1.31	0.18	6.81	3.96
02-5	78	289		52	702	28.9	2.4	534	156.5	334.0	38.5	149.3	25.1	6.9	17.8	2.07	9.09	1.33	2.82	0.28	1.53	0.21	8.08	2.57
02-6	76	267		79	915	23.2	2.2	906	125.5	250.5	28.8	108.6	17.9	4.9	13.1	1.48	6.63	0.96	2.27	0.24	1.29	0.19	6.98	4.83
Matancillas																								
02-70	53	166		266	1120	22.0	247.3	1744	73.4	121.1	12.1	41.4	6.5	2.0	5.4	0.77	4.45	0.83	2.35	0.32	2.15	0.32	4.30	3.65
02-71	50	149		201	891	20.7	202.2	1381	64.8	108.0	11.1	37.7	6.2	1.8	5.4	0.69	4.20	0.77	2.26	0.32	1.93	0.30	4.06	4.44
Las Conchas																								
A-70**	19	94		17	555	19.9	1.8	412	33.0	64.7	7.7	28.9	5.7	1.9	5.6	0.77	4.13	0.76	1.96	0.25	1.55	0.23	4.67	2.91
A-78**	35	96		24	824	31.3	1.5	634	63.3	116.2	13.2	47.0	8.6	2.6	7.8	1.12	6.16	1.14	3.10	0.43	2.71	0.39	6.21	3.89
matrix**																								

	Zn	Zr	Rb	Sr	Y	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Pb
A- 82**	33	91	33	896	31.7	1.3	676	71.0	126.6	14.3	50.7	9.1	2.8	8.1	1.14	6.35	1.23	3.15	0.45	2.69	0.39	5.75	4.81
A-93**	29	100	186	662	23.6	14.5	799	52.3	97.3	11.0	38.9	7.0	2.1	6.3	0.87	4.79	0.89	2.42	0.34	2.06	0.31	5.70	19.88
A-95**	32	116	41	1130	29.1	24.5	807	67.4	119.2	13.1	45.6	8.4	2.7	8.0	1.09	5.93	1.09	2.83	0.37	2.28	0.34	5.91	5.26
matrix**																							
6/186**	33	90																					
matrix**																							
7/173**	27	94	30	654	31.5	3.2	774	90.4	158.2	17.5	60.5	10.5	3.3	9.2	1.27	6.64	1.18	3.07	0.39	2.43	0.36	6.15	7.31
A-119**	29	113	41	1120	25.2	4.7	482	42.1	79.9	9.3	34.3	6.9	2.2	6.7	0.95	5.17	0.95	2.48	0.34	2.08	0.30	6.18	4.20
A-12**	24	98	22	513	25.1	7.5	658	49.1	93.4	11.1	40.1	7.6	2.4	7.0	0.98	5.28	0.95	2.48	0.34	1.97	0.30	6.29	4.32
4/295 B**	27	104	19	792	30.7	1.1	658	60.9	121.4	14.8	56.0	10.9	3.4	9.9	1.31	6.85	1.20	2.92	0.39	2.26	0.32	8.77	7.14
4/146**	33	127	14	962	29.5	2.9	587	56.7	112.4	13.7	51.7	10.1	3.2	9.2	1.22	6.34	1.12	2.82	0.37	2.15	0.30	8.05	4.92
A-44**	28	130																					
170900-5	80	253	3	795	20.1	5.3	633	29.5	62.4	7.6	31.4	6.5	2.1	5.7	0.83	4.65	0.86	2.20	0.29	1.98	0.29	5.58	5.58
Belén																							
131000-1	113	387	47	1120	16.0	281.6	841	17.7	40.8	5.2	23.1	5.3	2.0	4.8	0.68	3.83	0.66	1.82	0.23	1.56	0.23	9.45	5.10
02-93	104	322	47	1150	31.8	599.1	811	68.8	137.3	16.1	62.5	11.7	3.6	10.0	1.29	7.12	1.25	3.21	0.40	2.48	0.36	9.43	6.88
02-94	100	320	55	1130	32.2	606.0	1156	67.7	137.1	15.5	60.7	11.5	3.6	10.0	1.32	7.05	1.19	3.16	0.40	2.38	0.35	9.26	6.92
02-97	98	322	24	1010	29.4	675.5	729	68.1	133.0	15.3	59.0	10.8	3.4	9.1	1.26	6.59	1.12	3.01	0.40	2.40	0.35	9.40	7.98
02-98	97	309	32	1180	28.9	572.7	743	66.2	128.8	14.4	57.0	10.4	3.3	9.1	1.19	6.42	1.13	2.91	0.37	2.28	0.33	9.30	7.06
Cadillal																							
081000-1	58	485	132	105	24.1	6.6	546	58.5	124.5	12.3	44.1	7.5	1.9	5.8	0.84	4.82	0.90	2.68	0.38	2.64	0.40	6.34	7.80
081000-5	90	259	7	801	21.0	24.0	706	28.6	60.8	7.5	31.6	6.4	2.1	6.0	0.84	4.71	0.85	2.29	0.30	1.96	0.30	6.29	5.52
Finca Rodeo																							
02-74	79	196	13	970	26.7	14.0	880	64.2	117.6	13.1	50.1	9.2	3.0	8.2	1.10	5.91	1.02	2.58	0.33	1.93	0.27	6.49	7.10
02-75	88	181	13	1280	26.3	1.4	849	62.1	114.3	12.9	49.7	9.2	2.9	8.1	1.08	5.82	1.00	2.58	0.32	1.88	0.26	6.50	6.73
02-78	86	194	18	989	27.0	1.5	853	63.8	119.9	13.4	51.0	9.7	3.0	8.4	1.08	5.88	1.03	2.65	0.32	1.91	0.26	6.74	7.34
Los Condores																							
13398-15**	116	413	15	1410	29.3	0.7	1136	86.0	166.8	19.7	70.8	12.5	3.7	10.4	1.31	6.51	1.11	2.72	0.34	1.98	0.29	8.51	7.68
13398-20**	122	431	20	1370	28.7	0.6	1118	85.5	163.3	19.4	71.0	12.7	3.7	10.1	1.32	6.60	1.09	2.66	0.32	1.89	0.27	8.94	7.34
13398-18**	111	493	27	992	25.1	0.5	1001	76.3	153.7	18.4	66.8	11.6	3.4	9.3	1.19	5.77	0.96	2.30	0.30	1.69	0.24	11.34	6.69
12997-23**	105	421	46	998	21.2	0.6	682	76.3	148.8	17.3	61.5	10.1	3.0	7.9	1.01	4.87	0.80	1.90	0.23	1.40	0.20	10.47	7.36
G16**	117	367	16	1840	26.1	0.7	1076	57.7	115.6	14.3	56.0	11.3	3.4	9.4	1.20	5.95	1.00	2.36	0.29	1.63	0.23	6.89	5.59
G9**	118	356	12	888	27.4	0.6	1447	62.9	123.7	14.9	55.8	10.5	3.2	9.2	1.21	6.23	1.07	2.63	0.35	1.94	0.27	7.81	
Chajan																							
13398-7**	132	529	62	1980	27.9	0.7	1132	108.7	219.5	27.1	99.6	16.6	4.9	12.1	1.42	6.76	1.05	2.44	0.30	1.66	0.24	10.27	5.01
13398-6**	119	572	50	2210	28.9	0.6	1046	124.5	251.7	30.8	114.6	18.4	5.3	13.1	1.52	7.02	1.10	2.56	0.30	1.69	0.24	10.48	6.06
121000-7	<20	<50	206	12	10.0	15.8	33	2.8	6.9	0.9	3.4	1.2	0.1	1.1	0.26	1.85	0.33	0.96	0.16	1.32	0.18	1.40	13.21
121000-17	139	543	59	2966	27.6	0.757	1088	119	238	27.8	108	17.8	5.13	12.4	1.49	7.00	1.11	2.50	0.29	1.65	0.25	9.28	5.24
121000-19	112	519	47	2839	24.7	0.507	982	109	220	26.0	101	16.0	4.73	11.5	1.36	6.19	1.01	2.29	0.26	1.55	0.24	8.93	5.16
121000-21	128	566	47	3102	26.3	0.690	1112	123	250	29.4	114	18.0	5.26	12.7	1.50	6.89	1.07	2.45	0.27	1.59	0.25	9.58	5.11
La Pena																							
03-2a	92	98	37	578	26.5	1.0	381	30.4	75.2	11.0	52.7	12.2	3.7	11.7	1.37	6.50	1.04	2.46	0.27	1.57	0.22	5.67	6.03
03-3	101	172	89	1700	29.1	3.1	807	42.8	92.9	12.5	54.7	12.2	3.6	10.7	1.36	6.86	1.16	2.83	0.36	2.10	0.31	5.52	8.04
03-4	148	85	11	2120	36.0	1.1	461	45.0	105.2	14.2	63.6	14.0	4.5	12.6	1.60	8.31	1.43	3.63	0.43	2.64	0.40	5.46	11.50
03-5	134	165	19	1980	42.2	0.6	367	61.9	139.6	19.1	84.0	18.0	5.5	15.7	1.97	9.83	1.69	4.10	0.52	3.01	0.44	5.66	1.92
03-10	112	194	7	786	42.3	0.5	226	59.6	136.8	18.8	81.0	18.1	5.5	16.9	2.04	10.24	1.63	4.02	0.48	2.79	0.41	5.87	3.25
03-6	131	207	194	2610	38.8	7.2	1056	71.3	147.0	18.3	74.3	14.8	4.5	12.6	1.67	8.41	1.47	3.81	0.50	3.16	0.47	6.94	19.06
03-7	114	159	117	2090	34.8	2.4	1035	52.1	118.4	15.7	64.7	13.7	4.2	11.6	1.51	7.94	1.35	3.62	0.48	2.94	0.40	6.90	9.00
03-9	57	180	76	1810	30.5	1.9	1267	44.2	96.4	12.5	52.1	10.6	3.2	9.1	1.18	6.54	1.19	3.16	0.40	2.56	0.36	4.90	5.13
03-12	103	278	119	1540	23.9	4.6	985	51.0	97.1	11.4	41.2	7.7	2.3	6.4	0.87	4.81	0.87	2.53	0.34	2.19	0.33	5.73	18.20
Potreriños																							
03-13b	93	259	45	1950	24.6	2.1	944	71.5	150.4	18.8	76.7	13.8	4.1	10.4	1.28	6.12	0.97	2.20	0.26	1.44	0.20	7.38	7.38
03-13a	107	262	58	1900	24.7	2.1	992	71.3	150.6	18.9	75.0	13.5	4.1	10.8	1.25	6.29	0.95	2.27	0.26	1.53	0.21	7.23	7.82
03-15	101	261	41	1910	24.7	2.0	950	72.3	150.0	19.0	77.5	14.0	4.1	11.1	1.27	6.10	0.96	2.26	0.26	1.55	0.21	8.81	11.16
03-16	101	260	35	1760	23.1	1.6	836	68.7	144.0	18.3	74.9	13.5	4.0	10.2	1.21	5.97	0.94	2.24	0.26	1.47	0.19	7.28	7.39

	Th	U	⁸⁷ Sr/ ⁸⁶ Sr	±2 σ(m)	⁸⁷ Rb/ ⁸⁶ Sr	⁸⁷ Sr/ ⁸⁶ Sr	¹⁴³ Nd/ ¹⁴⁴ Nd	±2 σ(m)	¹⁴⁷ Sm/ ¹⁴⁴ Nd	¹⁴³ Nd/ ¹⁴⁴ Nd	²⁰⁶ Pb/ ²⁰⁴ Pb	²⁰⁷ Pb/ ²⁰⁴ Pb	²⁰⁸ Pb/ ²⁰⁴ Pb	²³⁸ U/ ²⁰⁴ Pb	²³² Th/ ²⁰⁴ Pb	²⁰⁶ Pb/ ²⁰⁴ Pb	²⁰⁷ Pb/ ²⁰⁴ Pb	²⁰⁸ Pb/ ²⁰⁴ Pb	²⁰⁶ Pb/ ²⁰⁴ Pb
location/sample	ppm ICP-MS	ppm ICP-MS				initial				initial				μ-ratio	ω-ratio	initial	initial	initial	
south of Tupiza																			
210900-2a	5.32	1.39	0.707800	0.000010	0.074	0.70778	0.512708	0.000007	0.1131	0.51269	18.52	15.62	38.63	4.9	19.0	18.51	15.62	38.61	
210900-04	16.94	5.33	0.705613	0.000008	0.342	0.70552	0.512627	0.000008	0.0934	0.51261	18.94	15.62	39.02	25.2	80.6	18.86	15.62	38.94	
260900-66	36.54	9.33	0.706278	0.000013	0.412	0.70616	0.512504	0.000007	0.0879	0.51249	18.99	15.63	39.10	26.9	106.1	18.90	15.62	38.99	
02-55	4.39	1.40	0.709313	0.000007	0.315	0.70922	0.512630	0.000005	0.1185	0.51261	18.53	15.63	38.63	4.9	15.6	18.52	15.63	38.61	
02-57	3.33	0.69	0.711794	0.000007	0.067	0.71178	0.512676	0.000006	0.1186	0.51266	18.44	15.63	38.55	3.1	14.8	18.43	15.63	38.53	
02-58	4.70	1.12	0.705066	0.000007	0.225	0.70500	0.512666	0.000006	0.1192	0.51265	18.49	15.63	38.61	3.2	13.7	18.48	15.63	38.59	
north of Tupiza																			
210900-9	15.96	3.79	0.706072	0.000008	0.249	0.70600	0.512525	0.000005	0.0973	0.51251	18.91	15.63	38.97	19.3	81.8	18.85	15.63	38.88	
210900-14	15.18	3.77	0.706762	0.000007	0.375	0.70666	0.512479	0.000006	0.0981	0.51247	18.93	15.63	38.96	16.5	66.9	18.88	15.63	38.90	
210900-18	24.08	5.12	0.705381	0.000008	0.250	0.70531	0.512616	0.000005	0.0907	0.51260	18.98	15.62	39.08	24.7	116.9	18.90	15.62	38.97	
Vichacla																			
220900-24	7.15	2.52	0.705192	0.000010	0.076	0.70508	0.512507	0.000008	0.1119	0.51243	18.72	15.54	38.84	25.9	74.0	18.32	15.52	38.47	
220900-26	11.84	3.78	0.705147	0.000010	0.073	0.70504	0.512522	0.000009	0.1038	0.51245	18.76	15.54	38.96	33.8	106.6	18.23	15.51	38.43	
220900-30	47.50	3.05	0.704721	0.000010	0.170	0.70448	0.512423	0.000006	0.1037	0.51236	18.44	15.55	39.08	6.6		18.34	15.55	38.56	
220900-32	10.19	3.51	0.704579	0.000008	0.070	0.70448	0.512301	0.000007	0.1110	0.51223	18.45	15.60	38.59	6.0	17.4	18.35	15.60	38.50	
220900-33	7.84	2.57	0.704092	0.000008	0.093	0.70396	0.512486	0.000008	0.1026	0.51242	18.64	15.53	38.81	21.9	67.3	18.30	15.51	38.48	
220900-34	11.02	3.32	0.706766	0.000008	0.007	0.70676	0.512600	0.000009	0.1046	0.51253	18.43	15.60	38.62	7.0	23.5	18.32	15.59	38.51	
02-40	5.26	1.50	0.710100	0.000009	0.195	0.70982	0.512717	0.000006	0.1216	0.51264	18.70	15.62	38.86	20.4	72.3	18.38	15.61	38.50	
Betanzos																			
230900-36	10.04	3.06	0.703375	0.000008	0.027	0.70334	0.512813	0.000009	0.1023	0.51275	19.90	15.63	39.71	45.7	151.0	19.18	15.59	38.96	
230900-43	10.06	3.18	0.703447	0.000008	0.049	0.70338	0.512822	0.000007	0.1161	0.51275	20.10	15.61	39.76	49.8	158.6	19.32	15.57	38.97	
230900-46	6.54	1.70	0.703205	0.000011	0.037	0.70315	0.512832	0.000006	0.1220	0.51275	20.07	15.61	39.71	34.1	132.2	19.53	15.59	39.06	
230900-51	9.67	2.80	0.703457	0.000010	0.062	0.70337	0.512792	0.000006	0.1048	0.51272	18.58	15.64	38.61	4.5	15.7	18.51	15.63	38.53	
02-25	9.99	2.56	0.703367	0.000010	0.055	0.70329	0.512806	0.000006	0.1085	0.51273	19.88	15.62	39.64	27.2	107.0	19.45	15.60	39.11	
02-28	11.31	3.25	0.703875	0.000007	0.056	0.70380	0.512800	0.000006	0.1033	0.51273	20.13	15.63	39.93	32.0	112.2	19.63	15.60	39.38	
02-29	9.42	2.60	0.703413	0.000008	0.042	0.70335	0.512808	0.000003	0.1081	0.51274	19.95	15.62	39.72	46.0	168.2	19.24	15.59	38.88	
Ayopaya*																			
I 28	19.00	28.00	0.703946	0.000005	0.437	0.70333	0.512734	0.000005	0.0929	0.51267	feldspar						19.18	15.65	39.14
I 29			0.703887	0.000018	0.245	0.70354	0.512727	0.000015	0.0999	0.51266									
I 30			0.703948	0.000005	0.385	0.70340	0.512753	0.000017	0.0968	0.51269	feldspar						19.01	15.65	38.96
I 46			0.704558	0.000017	0.229	0.70423	0.512736	0.000014	0.1158	0.51266									
I 36			0.704651	0.000020	0.152	0.70443	0.512796	0.000012	0.1170	0.51272									
I 74	240		0.703930	0.000004	0.025	0.70389	0.512785	0.000008	0.0803	0.51273	carbonate						19.30	15.66	41.01
I 78	277		0.704542	0.000023	0.007	0.70453	0.512812	0.000008	0.0724	0.51276	carbonate						18.69	15.66	42.19
I 79	405		0.706211	0.000008	0.008	0.70620	0.512793	0.000007	0.0726	0.51275									
I 77	267		0.704787	0.000005	0.073	0.70468	0.512809	0.000009	0.0817	0.51276	carbonate						18.72	15.67	42.75
I 81	600	0.55	0.703473	0.000022	0.029	0.70343	0.512831	0.000005	0.0714	0.51278									
I 22	405		0.705289	0.000006	0.030	0.70525	0.512781	0.000011	0.1472	0.51268									
I 40	13.15	3.48	0.703291	0.000008	0.000	0.70329	0.512794	0.000006	0.0967	0.51273	carbonate						19.20	15.64	39.15
I 53a			0.703441	0.000006	0.002	0.70344	0.512777	0.000006	0.0839	0.51272	carbonate						19.16	15.64	39.21
I 34			0.705639	0.000033	0.879	0.70439	0.512647	0.000012	0.0963	0.51258									
I 6a			0.704362	0.000025	0.377	0.70383	0.512697	0.000011	0.1006	0.51263									
AY22			0.705398	0.000032	0.018	0.70537	0.512637	0.000006	0.1036	0.51257									
I 1			0.707137	0.000004	0.170	0.70690	0.512683	0.000006	0.1017	0.51262	feldspar						19.28	15.66	39.42
San Andres																			
02-1	19.96	3.10	0.705325	0.000007	0.255	0.70424	0.512554	0.000006	0.1011	0.51236	23.52	15.85	48.92	57.7	374.4	20.77	15.71	43.33	
02-2	12.76	3.44	0.710442	0.000007	0.280	0.70925	0.512604	0.000006	0.1112	0.51239	19.17	15.64	39.30	24.9	93.3	17.98	15.57	37.90	
02-4	17.59	2.71	0.705675	0.000010	0.349	0.70419	0.512583	0.000007	0.1028	0.51238	21.15	15.74	44.39	55.9	365.8	18.49	15.60	38.92	
02-5	19.64	3.16	0.705041	0.000008	0.213	0.70413	0.512584	0.000005	0.1015	0.51238	23.02	15.84	48.23	107.6	673.4	17.90	15.57	38.16	
02-6	16.30	2.80	0.704968	0.000010	0.248	0.70391	0.512539	0.000004	0.0997	0.51234	20.34	15.69	42.15	45.5	267.2	18.17	15.57	38.16	
Matancillas																			
02-70	11.29	2.51	0.707424	0.000007	0.682	0.70645	0.512730	0.000006	0.0953	0.51267	19.36	15.60	39.59	51.6	234.0	18.56	15.56	38.43	
02-71	9.22	2.10	0.707118	0.000007	0.651	0.70619	0.512756	0.000006	0.0994	0.51269	19.11	15.60	39.29	35.2	155.8	18.56	15.58	38.52	
Las Conchas																			
A-70**	4.67	1.15	0.703570	0.000020	0.077	0.70346	0.512836	0.000033	0.1214	0.51276	19.31	15.64	39.23	29.5	120.6	18.84	15.62	38.63	
A-78**	8.61	2.13	0.703379	0.000022	0.089	0.70325	0.512812	0.000010	0.1112	0.51274	19.45	15.65	39.45	41.1	167.2	18.81	15.62	38.62	
matrix**			0.703336	0.000020	0.092	0.70320	0.512826	0.000022	0.1120	0.51275									

	Th	U	⁸⁷ Sr/ ⁸⁶ Sr	±2 σ(m)	⁸⁷ Rb/ ⁸⁶ Sr	⁸⁷ Sr/ ⁸⁶ Sr	¹⁴³ Nd/ ¹⁴⁴ Nd	±2 σ(m)	¹⁴⁷ Sm/ ¹⁴⁴ Nd	¹⁴³ Nd/ ¹⁴⁴ Nd	²⁰⁶ Pb/ ²⁰⁴ Pb	²⁰⁷ Pb/ ²⁰⁴ Pb	²⁰⁸ Pb/ ²⁰⁴ Pb	²³⁸ U/ ²⁰⁴ Pb	²³² Th/ ²⁰⁴ Pb	²⁰⁶ Pb/ ²⁰⁴ Pb	²⁰⁷ Pb/ ²⁰⁴ Pb	²⁰⁸ Pb/ ²⁰⁴ Pb
A- 82**	9.18	2.19	0.703430	0.000005	0.084	0.70331	0.512784	0.000008	0.1118	0.51271	19.17	15.61	39.06	33.8	142.8	18.64	15.58	38.35
A-93**	10.22	2.10	0.706958	0.000024	0.807	0.70581	0.512615	0.000009	0.1096	0.51254	18.77	15.66	38.89	7.8	38.1	18.65	15.65	38.70
A-95**	11.15	2.48	0.706708	0.000005	0.045	0.70664	0.512847	0.000006	0.1146	0.51277	19.51	15.65	39.62	35.5	159.9	18.95	15.63	38.82
matrix**			0.706566	0.000016	0.100	0.70642	0.512838	0.000009	0.1136	0.51276	19.47	15.67	39.58	30.8	141.7	18.99	15.65	38.88
6/186**			0.703431	0.000023	0.044	0.70337	0.512826	0.000031	0.1203	0.51275	19.24	15.63	39.20	33.3	133.5	18.72	15.60	38.54
matrix**			0.703412	0.000028	0.043	0.70335	0.512805	0.000010	0.1200	0.51273								
7/173**	14.96	3.29	0.703518	0.000006	0.108	0.70336	0.512814	0.000006	0.1227	0.51273	18.81	15.63	38.75	27.1	119.7	18.39	15.61	38.16
A-119**	6.12	1.49	0.703465	0.000005	0.079	0.70335	0.512808	0.000005	0.1056	0.51274	19.27	15.64	39.32	33.6	154.4	18.74	15.61	38.56
A-12**	6.97	1.59	0.703980	0.000006	0.229	0.70366	0.512820	0.000006	0.1209	0.51274	19.37	15.67	39.35	26.5	109.8	18.95	15.65	38.80
4/295 B**	8.15	2.13	0.704060	0.000006	0.088	0.70393	0.512800	0.000007	0.1195	0.51272	19.21	15.66	39.25	27.4	121.2	18.78	15.64	38.65
4/146**	7.71	2.02	0.703582	0.000005	0.074	0.70348	0.512875	0.000013	0.1147	0.51280	18.99	15.65	38.82	22.1	85.0	18.64	15.64	38.40
A-44**			0.703544	0.000005	0.051	0.70347	0.512829	0.000010	0.1209	0.51275	19.61	15.67	39.46	30.9	118.7	19.12	15.65	38.87
170900-5	5.00	1.47	0.703617	0.000008	0.015	0.70360	0.512830	0.000008	0.1241	0.51275	18.89	15.57	38.73	19.4	66.5	18.58	15.56	38.40
Belén																		
131000-1	6.05	2.42	0.703601	0.000007	0.121	0.70343	0.512775	0.000008	0.1380	0.51268	19.76	15.60	39.28	35.6	89.7	19.21	15.57	38.83
02-93	7.90	2.07	0.703799	0.000008	0.117	0.70363	0.512753	0.000006	0.1128	0.51268	19.58	15.58	39.47	22.6	86.8	19.23	15.56	39.04
02-94	7.85	2.04	0.704039	0.000008	0.141	0.70384	0.512759	0.000005	0.1144	0.51268	19.60	15.59	39.49	22.1	85.8	19.26	15.57	39.07
02-97	7.88	2.24	0.704158	0.000007	0.068	0.70406	0.512769	0.000006	0.1107	0.51270	19.71	15.59	39.54	21.1	74.8	19.38	15.57	39.17
02-98	7.56	2.06	0.705162	0.000006	0.078	0.70505	0.512771	0.000007	0.1105	0.51270	19.70	15.59	39.56	22.0	81.3	19.35	15.58	39.16
Cadillal																		
081000-1	15.57	1.91	0.714441	0.000009	3.646	0.70926	0.512546	0.000006	0.1025	0.51248	18.74	15.62	39.32	18.2	149.1	18.46	15.60	38.58
081000-5	5.64	1.43	0.703694	0.000010	0.024	0.70366	0.512830	0.000007	0.1222	0.51275	18.88	15.57	38.71	19.1	75.8	18.58	15.56	38.33
Finca Rodeo																		
02-74	7.84	1.53	0.704032	0.000007	0.039	0.70398	0.512818	0.000006	0.1116	0.51275	19.37	15.60	39.44	16.1	83.3	19.12	15.59	39.03
02-75	7.65	1.49	0.704698	0.000007	0.030	0.70466	0.512806	0.000006	0.1120	0.51273	19.40	15.58	39.42	16.6	85.6	19.14	15.57	38.99
02-78	7.86	1.73	0.703986	0.000008	0.051	0.70391	0.512800	0.000007	0.1145	0.51273	19.41	15.59	39.40	17.7	80.7	19.14	15.58	39.00
Los Condores																		
13398-15**	8.63	1.26	0.705546	0.000004	0.035	0.70550	0.512273	0.000006	0.1092	0.51220	18.22	15.51	38.93	12.0	82.8	18.03	15.50	38.52
13398-20**	7.53	1.00	0.705467	0.000004	0.030	0.70542	0.512284	0.000005	0.1160	0.51221	18.27	15.56	39.11	10.0	75.9	18.11	15.56	38.73
13398-18**	8.65	1.66	0.705698	0.000004	0.081	0.70558	0.512384	0.000013	0.1067	0.51231	18.83	15.68	39.62	18.5	97.1	18.54	15.66	39.13
12997-23**	8.90	1.68	0.706289	0.000010	0.135	0.70610	0.512253	0.000007	0.1056	0.51218	18.81	15.65	39.52	17.0	90.7	18.54	15.64	39.08
G16**	7.35	1.41	0.707987	0.000006	0.033	0.70794	0.512316	0.000006	0.1230	0.51224	18.52	15.59	39.17	13.9	68.7	18.30	15.57	38.83
G9**	7.25	1.11	0.705477	0.000005	0.040	0.70542	0.512338	0.000008	0.1138	0.51226	18.45	15.60	39.31	4.6	30.3	18.37	15.59	39.16
Chajan																		
13398-7**	9.33	2.42	0.704149	0.000005	0.090	0.70402	0.512412	0.000006	0.1028	0.51234	18.29	15.52	38.12	35.0	135.8	17.74	15.50	37.44
13398-6**	10.29	2.66	0.704198	0.000005	0.065	0.70411	0.512399	0.000007	0.1008	0.51233	18.17	15.52	38.06	31.7	123.7	17.68	15.50	37.44
121000-7	2.35	0.52	1.081724	0.000015	50.972	0.70395	0.512669	0.000007	0.2057	0.51253	18.71	15.65	38.13	2.9	13.1	18.66	15.64	38.07
121000-17	8.95	2.41	0.704160	0.000008	0.116	0.70400	0.512435	0.000007	0.0961	0.51237	18.51	15.50	38.35	48.6	172.5	17.75	15.46	37.50
121000-19	7.54	1.93	0.704176	0.000008	0.105	0.70403	0.512437	0.000010	0.0940	0.51238	18.34	15.50	38.22	40.6	136.0	17.71	15.47	37.55
121000-21	8.86	2.29	0.704114	0.000007	0.071	0.70401	0.512418	0.000007	0.0947	0.51236	18.44	15.51	38.29	44.8	138.8	17.74	15.47	37.60
La Pena																		
03-2a	1.59	0.38	0.703682	0.000008	0.183	0.70363	0.512827	0.000007	0.1405	0.51281	18.81	15.59	38.73	4.6	19.6	18.79	15.59	38.71
03-3	4.77	1.52	0.704003	0.000010	0.152	0.70396	0.512782	0.000006	0.1349	0.51276	18.91	15.63	38.85	13.9	44.1	18.87	15.62	38.81
03-4	2.04	0.38	0.703931	0.000008	0.015	0.70393	0.512778	0.000005	0.1328	0.51276	18.74	15.58	38.63	2.4	13.1	18.73	15.57	38.62
03-5	3.23	0.88	0.703760	0.000008	0.028	0.70375	0.512794	0.000007	0.1296	0.51278	19.05	15.64	39.13	34.1	126.1	18.94	15.63	39.00
03-10	4.54	0.75	0.703876	0.000007	0.027	0.70387	0.512808	0.000006	0.1353	0.51279	18.85	15.59	38.84	17.0	103.8	18.80	15.59	38.74
03-6	8.90	3.38	0.703851	0.000007	0.214	0.70379	0.512777	0.000004	0.1201	0.51276	18.95	15.60	38.91	13.1	34.7	18.91	15.60	38.88
03-7	5.13	1.78	0.703958	0.000008	0.162	0.70391	0.512729	0.000006	0.1284	0.51271	18.72	15.56	38.56	14.5	42.1	18.67	15.56	38.52
03-9	5.24	1.58	0.704611	0.000008	0.121	0.70458	0.512670	0.000006	0.1225	0.51265	18.55	15.56	38.42	22.4	75.1	18.48	15.56	38.34
03-12	7.24	2.36	0.704521	0.000008	0.222	0.70446	0.512614	0.000004	0.1127	0.51260	18.60	15.56	38.46	9.5	29.3	18.57	15.56	38.43
Potreriillos																		
03-13b	7.80	2.18	0.704145	0.000008	0.067	0.70405	0.512402	0.000007	0.1088	0.51233	18.51	15.55	38.12	21.4	77.3	18.17	15.53	37.74
03-13a	7.98	2.41	0.704136	0.000008	0.088	0.70401	0.512374	0.000006	0.1087	0.51230	18.51	15.51	38.00	22.3	74.5	18.16	15.49	37.63
03-15	7.62	2.39	0.704124	0.000010	0.063	0.70404	0.512375	0.000005	0.1093	0.51230	18.47	15.51	38.00	15.5	49.8	18.23	15.50	37.75
03-16	6.47	2.43	0.704190	0.000008	0.057	0.70411	0.512376	0.000007	0.1090	0.51230	18.49	15.51	38.01	23.9	63.9	18.12	15.50	37.70