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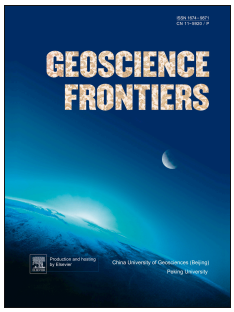

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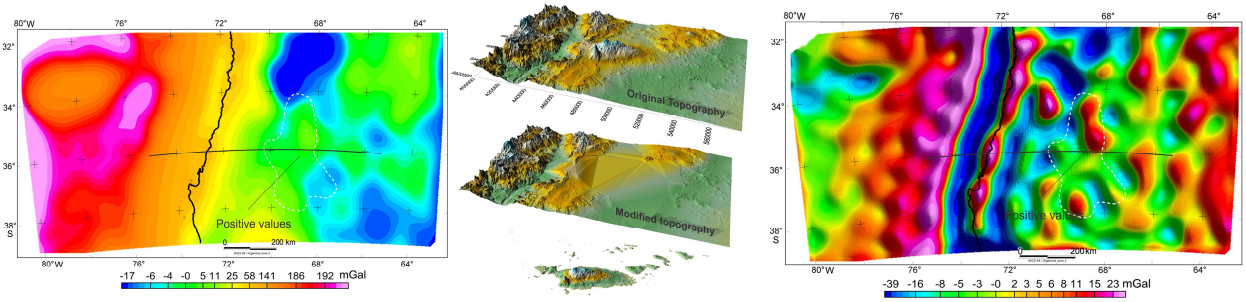

Payenia Quaternary flood basalts (Southern Mendoza, Argentina): Geophysical constraints on their volume

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Abstract

The Quaternary volcanic province of Payenia is located in southern Mendoza and northern Neuquén provinces of Argentina and is characterized by a dominant basaltic composition. The volcanic province covers an area larger than 40,000 km^2 and its origin and evolution has been the center of several studies. In this study we analyzed

gravity data together with more accurate volcanic volumes calculations in order to investigate the subsurface structure of the Payenia volcanic province. The volume of material was calculated using digital elevation models and geographic information system (GIS) techniques to estimate the volume of material erupted and then, with those values, make an estimation of the intrusive material that could be located within the crust. The results of the calculations were compared with different 2D-sections constructed to model the gravity data and compare with the observed satellite gravity. After evaluating different models which have been generated to match both: the observed gravity data and the subsurface material calculated, we discuss those that best fit with observation. The results clearly indicate that the lithosphere is attenuated below the region.

Keywords: Payenia; Gravimetric model; Plume; Uplift; Andes

1. Introduction

In this study we used two independent techniques to study the subsurface structure of the Payenia volcanic province. We used geographic information system (GIS) techniques for volume calculations and gravimetric modeling to obtain a quantification of the volume of igneous material by each independent method and then we combined those results. The Southern Volcanic Zone of the Andes has a Quaternary basaltic province along the retroarc which has a unique tectonic setting. The presence of Payenia, a large Quaternary volcanic province of basaltic composition in the foreland region, behind the active volcanic arc is unique in the entire Andean chain from Colombia to Tierra del Fuego (Fig. 1). This volcanic province erupted through more than 800 volcanic centers in the last ~2 Ma, is developed between 33º30′ and 38º over more than 40,000 km^2 parallel to the active volcanic arc of the Southern Volcanic Zone (Stern et al., 2004).

The entire volcanic region of mostly basaltic magmas was grouped by Ramos and Folguera (2011) into three genetically related segments: (1) the northern sector between 33º30′ and 35ºS is characterized by monogenetic volcanoes and cinder cones

with ages of less than 1.2 Ma; (2) the central section (~35º to 36º30′S) dominated by large volcanic centers, and the Cerro Nevado, Llancanelo and Payún Matrú volcanic fields, and represents the largest erupted volume of the area; and (3) the southern sector (~36.5º to 38ºS), which is dominated by the Auca Mahuida and Tromen volcanoes together with several minor centers like Cerro Morado, La Carne, Carrizo, and Cerro Los Loros (Ramos and Folguera, 2011).

The three segments share similar volcanic histories which postdate a common continuous basaltic plateau (erupted after 2 Ma) characterized by intraplate geochemical signatures (Ramos and Kay, 2006). This initial event, which would have developed from south to north, is the basement over which the later volcanic fields and monogenetic centers were established from 1.5 to 0.005 Ma (Ramos and Folguera, 2011).

The focus of this study is to arrive to a plausible density model of the subsurface structure of the Payenia volcanic province, based mainly on gravimetric studies supported by estimations of the extrusive and intrusive material volume. The scope is to reconcile the large volumes of volcanic rocks with possible subsurface material emplaced in the crust and the geodynamic evolution of the area.

We start the study by analyzing the gravity data in section 2 and follow with the volume calculations techniques to constrain the subsurface structure of the Payenia volcanic province. In order to obtain a 2D density model of the central sector of the Payenia, we determined a rough geometry from magnetotelluric information using the subsurface data from Burd et al. (2008, 2014) because it is an independent method and give ancillary information for the properties and densities of the materials. Then we refined the profile to match the modeled gravity with the observed gravity values obtained freely from the ICGEM (http://icgem.gfz-potsdam.de/ICGEM/). The observed values were derived from the EGM-2008 model (Pavlis et al., 2008, 2012) which uses complete spherical harmonics up to a degree and order of 2150 and contains additional coefficients to reach the degree of 2190 and order 2159. Finally we quantified volcanic volume erupted based on the topography and then we estimated the volume of associated intrusive material with those extrusive rocks. These results of these calculations helped to constrain the amount of material and density contrasts in the 2D-

sections used in the gravity modeling. The obtained section was then discussed within the geodynamic context for the area since Cretaceous times, in which the Payenia volcanic province developed.

2. Modeling gravity anomalies

2.1. Gravity data

Several geophysical studies have been done in order to understand the thermal state across the Payenia region especially dedicated to infer the crustal thickness associated with the geodynamical setting. From the very beginning it was observed that the region of the Payenia was not isostatically compensated (Diez Rodríguez and Introcaso, 1986). Assuming densities of 2.67 g/cm^3 for the topography above the sea level, 2.9 g/cm^3 for the crust, and 3.2 g/cm^3 for the mantle, a simple relation can be used to calculate the roots of a given topography using the Eq. (1)

$$R = 6.675 \cdot h \qquad (1)$$

where *h* is the topography and *R* is the thickness of the roots for each topographic point (Introcaso, 1997). Using a digital elevation model (DEM) SRTM-30, (which was slightly smoothed for the calculations) and assuming that all the crust is isostatically compensated by the Airy hypothesis, the thickness of the crust was calculated from Eq. (1) and adding a normal crust of 35 km to the root thicknesses. The calculation of the crustal thickness and the Isostatic correction was done with the software Oasis Montaj. This result was then compared with the observed gravity derived from the EGM-2008 model obtained from the ICGEM (International Centre for Global Earth Models) (http://icgem.gfz-potsdam.de/ICGEM/) (Fig. 2). The subtraction of the isostatic correction from the Bouguer anomaly, assuming a perfectly compensated model, should yield a zero isostatic anomaly. As seen in Fig. 2, the topographic profile at 36ºS is near to be fully compensated, but there are local anomalies which indicate that another geodynamic process, and/or density heterogeneities present within the crust, would be affecting the gravity signal.

It is well known that the Bouguer anomaly contains the sum of gravimetric effects of different sources and there are many techniques that allow a proper separation of

such effects. Techniques using different frequencies were applied to identify those different sources, like the upward continuation technique and Butterworth filter (Ancilliary fig. 1) (e.g., Blakely, 1995).

In order to isolate the short wave-lengths anomalies, which mostly correspond to upper crustal gravimetric effects, we have discounted long wave-length anomalies using an upward continuation analyses. These types of analyses recomputed the gravimetric field to an arbitrary height above the registration level. The difference between the upward continuation computed and the measured Bouguer anomalies constitutes a residual grid that reflects short wave-lengths gravimetric components that mostly correspond to upper crustal density contrasts.

The Airy decompensated isostatic anomaly was obtained by doing an upward continuation up to 35 km above the sea level (Fig. 3a), to eliminate the superficial anomaly sources and short wavelengths. This grid which reflects the long-wave anomalies was subtracted to the original isostatic anomaly to obtain the short wave-length components (Cordell, 1985). The value chosen for the h= 35 km to generate the upward continuation was based on regional estimated values of crustal thickness. The final grid represents a residual isostatic anomaly associated with bodies emplaced in the upper crust. The results show that the larger anomalies coincide with the main volcanic edifices like Cerro Nevado and Auca Mahuida located in the NE and SW of the Payenia province respectively (Fig. 1). Both centers are characterized by high gravity values that could be associated either with the superficial volcanic edifices itself and/or with subvolcanic bodies emplaced in the upper crust. However, in the central part of the Payenia, where the Payún Matru is located, there are no high gravity values, indicating that shallow high density bodies are not sources of important anomalies (Fig. 3b). On the other hand, by analyzing the upward continuation itself over the central area, a positive anomaly is observed. This implies a deep high density source. To verify this hypothesis for the anomaly we applied a filtering technique called Butterworth Filter with a cutoff of 300 km and filter order 8 (Blakely, 1995). This filter eliminates anomalies higher than 300 km wave-length but in the filtered grid a central positive anomaly can be still observed favoring the hypothesis of an anomaly source at depth (Ancillary Fig. 1).

2.2. Model construction

To identify the sources responsible of the observed gravimetric anomalies, different models in 2-D cross sections were generated to simulate their gravimetric response. The simulated gravity profile of each section was compare with the observed gravity data in order to verify their validity. These models were constrained by the magnetotelluric data from Burd et al. (2008, 2014) who presented a conductivity model for the first 500 km depth at 36º30′S; geometries and depth derived from seismic and magnetotelluric data (Gilbert et al., 2006; Tassara, 2006); passive seismic studies performed by Yuan et al. (2006) at 39ºS; and the works of Folguera et al. (2007) and Ramos y Folguera (2011), which proposed an attenuation of the crust under the area of the Payenia supported by seismic data, which also show subcrustal low velocity zones (Wagner et al., 2005; Gilbert et al., 2006). Based on all these results we constrained the geometry of the density bodies in the cross section from which we obtained a modeled Bouguer anomaly with the Oasis Montaj software that could be directly compared with the observed Bouguer anomaly derived from the EGM-2008.

Using these geometries, fixed by independent data, we were allowed to test different densities based on the “geological standard model” (Table 1), available seismic velocity model for the wells near the area of study and previous papers after Ruiz and Introcaso (1999); Introcaso et al. (2000); Fromm et al. (2004); Gilbert et al. (2006); Giménez et al. (2006, 2009); Tassara et al. (2007) and Burd et al. (2014) for thermal conditions. We obtained, after different tests, two plausible 2D-density models where the calculated gravity fits with observed gravity.

In the first model that we show (Fig. 4a) we reproduced the derived geometry from seismic and magnetotelluric sections from Gilbert et al. (2006) and Burd et al. (2008, 2014) assigning different densities depending on the composition and thermal state of the material. The model includes a plume of hotter material, which is uprising from the 660 km mantle discontinuity, potentially from stagnant subducted oceanic slabs. This strong asthenospheric influx due to the steepening of the subducted Nazca plate has been invoked to trigger the large amount of the Pliocene to Quaternary retroarc volcanism of the Payenia (Bertotto etal., 2009; Folguera et al., 2009; Burd et al., 2014; Ramos et al., 2014). We also included in the model, together with this plume

of hot material (Burd et al., 2014), an attenuated crust towards the foreland area below Payenia province. The crustal attenuation in the model is in the order of 10 km. This amount of crustal thinning is needed to match the modeled and observed gravity, and it is in agreement with passive seismic data (Gilbert et al., 2006, Ramos and Folguera, 2011). This crustal attenuation could be inferred from the decompensated isostatic anomaly map that indicates an excess of mass at depth where normal crustal material would be replaced by dense mantle material.

Despite the gravimetric anomalies of the model from Fig. 4a match the observed data, an alternative model was tested in which we incorporated a 13 km thick planar body of dense subvolcanic material instead of the attenuation of the crust (Fig. 4b). Both models are plausible, and have a similar gravimetric response, but to verify which of the two models is more appropriate we estimated the amount of material that could have been emplaced below as a function of the extruded material**.**

2.3. Volcanic volume calculations

To calculate the volume of volcanic material emplaced in the crust, we first made an estimation of the eruptive volume, based on DEMs analyses. We used radar topography from Shuttle Radar Topography Mission (SRTM) (Farr et al., 2007) and topographic data from Advanced Spaceborne Thermal Emission and Reflection Radiometer data (ASTER GDEM Version 1, Fujisada et al., 2005). The calculated eruptive volume is based on the definition of two surfaces: a lower one represented by a mean base level, and the upper one which is the present topography. This methodology proves to be efficient for individual volcanoes (Völker et al., 2011). The volume calculations were made in a sequential mode, based on the different ages of volcanism, starting by the younger ones and continuing to subsequent older material. First we performed a Geographic Information System (GIS) using the ages and maps compiled from Ramos and Folguera (2011) together with the topography of the area. Later on we grouped the material into three intervals based on the different ages (Table 2). The first interval between the present and 0.6 Ma, the second one between 0.6 and 1.165 Ma, and the third one between 1.165 and 2.5 Ma. These time lapses were based on three stages of

evolution of the Payenia volcanic field (Ramos and Folguera, 2005; Folguera et al., 2008; Risso et al., 2008; Ramos and Folguera, 2011).

After defining the time intervals, we calculated the volume for the first one placing the lower plane at the base of the volcanoes with ages younger than 0.6 Ma and for the top surface we used the topography. After calculating the volume between these two surfaces we cut the topographic grid, erasing any topography within that interval. Then the grid was interpolated again to cover removed parts and we obtained a new topographic grid without the younger material. The new grid was used as entry for the subsequent interval calculations, as the top surface, placing a new lower plane at the base of the 1.165 Ma old material and repeated the procedure. Finally, the total volume calculated for the volcanic centers, adding the figures from the three intervals, is 1469 km^3 (Table 2).

All these local centers stand above a basaltic plateau younger than ~2 Ma. Llambías et al. (2010) mentioned that in the distal parts the plateau is between 6 and 20 m thick, constraining the minimum thickness value. The total area, including the basal plateau, is ~40,660 km^2. Taking into account this measurement and the regional slope, a conservative number for the thickness of this volcanic platform at the center of the plateau could be between 150 and 200 m. Based on these values and the total area measured from the DEM, the volume of the plateau is between 6100 and 8132 km^3, which together with the previous 1469 km^3 measured for the individual volcanic centers, results in a total volume between 7569 and 9601 km^3. These figures are in agreement with previous estimations of ~8400 km^3 (Risso et al., 2008; Németh et al., 2011; Ramos and Folguera, 2011).

With these results of the estimations of erupted volume, the next step was to estimate the volume of intrusive material emplaced on the upper crust to compare this result with the thickness of the subsurface material predicted by the gravity models (see section 2.1). Studies of intrusive volcanism suggest a role for intrusive bodies as the hidden component of the broader volcanic system that is expressed at the surface as volcanism. A compilation of magma emplacement and volcanic output gives ratios of intrusive to extrusive volumes in the ranges 5:1 for oceanic settings and 10:1 for continental ones (Crisp, 1984). Others estimations for the relation between intrusive and

erupted volumes vary between 3:1 and 16:1 (Smith and Shaw, 1975, 1979; Crisp, 1984; Francis and Hawkesworth, 1994; de Silva et al., 2007), being 3:1 and 5:1 the most conservative ones (Crisp, 1984; White et al., 2006; de Silva et al., 2007). Despite these rates between intrusive vs. extrusive material were not calculated for an exact similar environment as the Payenia volcanism, we consider that are applicable and conservative ones sincere present a broad stiles of volcanic settings.

Using these relations, we first estimated the volume of subsurface material and then, divided that value by the area enclosed by the surface volcanism to obtain the thickness of a possible tabular body emplaced under the surface (Table 3). In the next section we discuss the relation between the thickness values for the subcrustal igneous material obtained by the calculations, and the 2D density sections of the gravity modeling.

3. Conclusions

In section 2.1 we discussed two possible density models to explain observed gravity: one introducing a crustal thinning, and a second one without such a crustal thinning but considering the emplacement of an important amount of mafic material within the crust. This last model requires a large amount of material equivalent to a 13 km thick body to match the modeled gravity with the observed one. This thickness is incompatible with the volume calculations made in section 2.3. We showed that with an end member relation of intrusive-extrusive material rate of 16:1 the thickness of subsurface material would be around 4 km which is a much lower value than the required to match the gravity data if we only consider the presence of subsurface dense material. This result shows that crustal thinning is crucial to explain the gravity values and subsurface denser material by itself, can´t explain the gravity data. Based on this conclusion we finally present a model where we incorporated both: subsurface dense material and crustal thinning (Fig. 6). In the 2-D section we incorporated a 4 km thick denser body and then we adjust the base of the crust to match the observed gravity. This model explains gravity observations and is compatible with the volcanic volume calculations together with the intrusive material estimations. In this last model we also incorporated the geometry of hotter material spots by Burd et al. (2014) instead of a

mean geometry defining a plume feature as shown in their previous work (Burd et al., 2008, 2014). Moreover, the spectral analysis of magnetic anomalies allows evaluating the depth to the Curie temperature (Bhattacharyya and Leu, 1975; Blakely, 1988, 1995; Tanaka et al., 1999), which would be associated with changes in the vertical distribution of temperatures in the crust (Zorin y Lepina, 1985; Ruiz and Introcaso, 2001). If in fact the crustal thinning predict by the model of Fig. 6 exists then the magnetic anomalies must show a similar scenario. Following Tanaka et al. (1999), and using the world magnetic anomalies model WMM2010, Novara (2012) calculated the depth of the isotherm of 573 ºC for this region which is assumed to correspond to the Curie depth point, and therefore the crustal thermal structure can be directly inferred from magnetic data (Fig. 7). The Curie isotherm is shallower in the studied area towards the foreland, indicating a higher heat flux under the Payenia and supporting the model from Fig. 6 that shows there is a crustal attenuation zone. Moreover, Søager et al. (2013) demonstrated, based on geochemical analysis of the volcanic rocks from Payenia, that extensive melting of lower crust occurred, and was probably related to the low thickness of the lithospheric mantle and preheating of the lower crust by earlier Mio-Pliocene volcanism. They also suggest a thinner lithosphere in the western Payenia region compared to the eastern one (Søager et al., 2013), a characteristic that it is also seen in Fig. 7. This crustal thinning episode could be related to an extensional setting that postdated the slab shallowing episode of 18–4 Ma and would be related to a steepening of the slab that favored the emplacement of hot material.

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References

Blakely, R.J., 1995. Potential Theory in Gravity and Magnetic Applications. Cambridge University Press, Cambridge, 441 pp.

Burd, A. Booker, J.R., Mackie, R., Favetto, A., Pomposiello, M.C., 2014. Three-dimensional electrical conductivity in the mantle beneath the Payún Matrú Volcanic Field in the Andean backarc of Argentina near 36.5°S: evidence for decapitation of a mantle plume by resurgent upper mantle shear during slab steepening. Geophysical Journal International 198 (2), 812-827. doi:10.1093/gji/ggu145.

Burd, A. Booker, J.R., Pomposiello, M.C., Favetto, A., Larsen, J., Giordanengo, G. and Orozco Bernal, L., 2008. Electrical conductivity beneath the Payún Matrú Volcanic Field in the Andean back-arc of Argentina near 36.5°S: Insights into the magma source. 7th International Symposium on Andean Geodynamics (Nice), Extended abstract, 90-93.

Cordell, L., 1985. Techniques, applications, and problems of analytical continuation of New Mexico aeromagnetic data between arbitrary surfaces of very high relief. Proceedings of the International Meeting on Potential Fields in Rugged Topography, Institute of Geophysics, University of Lausanne, Bulletin 7, 96-99.

Crisp, J.A., 1984. Rates of magma emplacement and volcanic output. Journal of Volcanology and Geothermal Research 20(3), 177–221.

de Silva, S.L. y Gosnold, W.D., 2007. Episodic construction of batholiths: Insights from the spatiotemporal development of an ignimbrite flare-up. Journal of Volcanology and Geothermal Research 167 (1), 320-335.

Diez Rodriguez, A. and Introcaso, A., 1986. Perfil transcontinental sudamericano en el paraleo 39°S. Geoacta 13 (2), 179-281.

Folguera, A., Bottesi, G., Zapata T.,Ramos, V.A. 2008. Crustal collapse in the Andean back-arc since 2 Ma: Tromen volcanic plateau, Southern Central Andes (36º40´–37º30´S). Tectonophysics (Special Issue Andean Geodynamics) 459, 140-160.

Folguera, A., Introcaso, A., Giménez, M., Ruiz, F., Martinez, P., Tunstall, C., García Morabito, E., Ramos, V.A., 2007. Crustal attenuation in the Southern Andean retroarc (38°–39°30 ′ S) determined from tectonic and gravimetric studies: The Lonco-Luán asthenospheric anomaly. Tectonophysics 439, 129–147.

Fromm, R., Zandt, G., Beck, S.L., 2004. Crustal thickness beneath the Andes and Sierras Pampeanas at 30°S inferred from Pn apparent phase velocities. Geophysical Research Letters 31, L06625.

Francis, P.W., Hawkesworth, C.J., 1994. Late Cenozoic rates of magmatic activity in the Central Andes and their relationships to continental crust formation and thickening. Journal of the Geological Society 151, 845–854.

Gilbert, H., Beck, S., Zandt, G., 2006. Lithospheric and upper mantle structure of central Chile and Argentina. Geophysical Journal International 165, 383–398

Giménez, M.E., Martínez,M.P., Bustos, G., Jordan, T., Lince Klinger, F., Mallea, M. , Girardi Gallego Guardia, A., 2006. Evaluación del Movilismo Hidrostático del Valle De La Rioja, La Rioja Argentina Revista Ciencias - FCEFN- UNSJ 10 (1), 3–11.

Giménez, M.E., Martinez, M. P., Jordan, T., Ruiz, F., Lince Klinger, F., 2009. Gravity characterization of the La Rioja Valley Basin, Argentina. Geophysics 74(3), B83–B94.

Introcaso, A., 1997. Gravimetría. UNR Editora, Rosario. Argentina, 355 pp.

Introcaso, A., Pacino, M.P., Guspí, F., 2000. The Andes of Argentina and Chile: Crustal configuration, Isostasy, Shortening and Tectonic features from Gravity Data. Temas de Geociencia 5 UNR Editora.

Németh, K., Risso, C., Nullo, F., Kereszturi, G., 2011. The role of collapsing and cone rafting on eruption style changes and final cone morphology: Los Morados scoria cone, Mendoza, Argentina. Central European Journal of Geosciences 3 (2), 102-118.

Pavlis, N.K., Holmes, S.A., Kenyon, S.C. and Factor, J.K., 2008. An earth gravitational model to degree 2160: EGM2008. Paper Presented at the 2008 General Assembly of the European Geosciences Union, Vienna, Austria.

Pavlis, N.K., Holmes, S.A., Kenyon, S.C. and Factor, J.K., 2012.The development and evaluation of the Earth Gravitational Model 2008. Journal of Geophysical Research: Solid Earth 117 (4), B04406

Prezzi, Claudia B., Götze, H-J., Schmidt, S., 2009. 3D density model of the Central Andes. Physics of the Earth and Planetary Interiors 177(3–4), 217–234.

Ramos, V. A. and Folguera, A., 2011. Payenia volcanic province in the Southern Andes: An appraisal of an exceptional Quaternary tectonic setting. Journal of Volcanology and Geothermal Research 201(1–4), 53-64. doi: http://dx.doi.org/10.1016/j.jvolgeores.2010.09.008.

Ramos, V.A., Folguera, A., 2005. Tectonic evolution of the Andes of Neuquén: Constraints derived from the magmatic arc and foreland deformation". In: Veiga, G., Spalletti, L., Howell J., Schwarz E. (Eds.), The Neuquén Basin: A case study in sequence stratigraphy and basin dynamics. Geological Society, Special Publication, London, 252p.

Ramos, V.A., Kay, S.M., 2006. Overview of the Tectonic Evolution of the Southern Central Andes of Mendoza and Neuquén (35°– 39°S Latitude). In: Kay, S.M.,

Ramos, V.A. (Eds.), Evolution of an Andean margin: A tectonic and magmatic view from the Andes to the Neuquén Basin (35°–39°S latitude). Geological Society of America, Special Paper 407, 1-18.

Risso, C., Németh, K., Combina, A.M., Nullo, F., Drosina, M., 2008. The role of phreatomagmatism in a Plio-Pleistocene high-density scoria cone field: Llancanelo Volcanic Field (Mendoza), Argentina. Journal of Volcanology and Geothermal Research 169, 61–86.

Ruiz, F., Introcaso, A., 1999. Geophycical evidence of crustal ancient juntion in Desaguadero-Bermejo megafault (San Juan-La Rioja Province, Argentina). Acta Geodética el Geophysica Hungarica. Sopron.

Ruiz, F., Introcaso, A., 2001. Profundidades al punto de Curie en la Precordillera Cuyana obtenidas por análisis espectral de anomalías magnéticas. Temas de Geociencia 8, UNR Editora, Rosario.36 pp.,

Smith, R.L., Shaw, H.R., 1975. Igneous Related Geothermal Systems. Assessment of Geothermal Resources of the United States — 1975. In: White, D.E, Williams, D.L. (Eds.) United States Geological Survey Circular 726, 58–83.

Soager, N., Holm, P.M., Llambias, E.J., 2013. Payenia volcanic province, southern Mendoza, Argentina. Chemical Geology 349, 36 - 53.

Tanaka, A., Obuko Y., Matsubayashi, O., 1999. Curie point depth based on spectrum analysis of the magnetic anomaly data in East and Southeast Asia. Tectonophysics 306, 461-470.

Tassara, A., 2006. Factors controlling the crustal density structure underneath active continental margins with implications for their evolution. Geochemistry, Geophysics, Geosystems 7 (1),Q01001.

Tassara, A. , Swain, C., Hackney, R., Kirby J., 2007. Elastic thickness structure of South America estimated using wavelets and satellite-derived gravity data. Earth and Planetary Science Letters 253, 17–36.

Völker, D., Kutterolf, S., Wehrmann, H., 2011. Comparative mass balance of volcanic edifices at the southern volcanic zone of the Andes between 33°S and 46°S. Journal of Volcanology and Geothermal Research 205 (3), 114-129.

Wagner, L. S. Beck, S., Zandt, G., 2005. Upper mantle structure in the south central Chilean subduction zone (30º to 36ºS). Journal of Geophysical Research 110, B01308. doi:10.1029/2004JB003238.

White, S.M., Crisp, J.A., Spera, F.A., 2006. Long-term volumetric eruption rates and magma budgets. Geochemistry, Geophysics, Geosystems 7, Q03010. doi:10.1029/2005GC001002.

Yuan, X., Asch, G., Bataile, K., Bohm, M., Echtler, H., Kind, R., Onchen, O., Wölbern, I., 2006. Deep seismic images of the Southern Andes. In: Kay, S.M., Ramos, V.A. (Eds.), Late Cretaceous to Recent Magmatism and Tectonism of the Southern Andean Margin at the Latitude of the Neuquen Basin (36–39°S). Geological Society of America, Special Paper 407, 61–72 pp.

Zorin, Y.A., Lepina, S.V., 1985. Geothermal aspects of development of asthenospheric upwellings beneath continental rift zones. Journal of Geodynamics 3, 1–22.

Figure captions

Figure 1. (A–A′) Location of the gravimetric profile modeled in this work. B–B′ magnetotelluric and seismic tomography profiles from Gilbert et al. (2006) and Burd et al. (2008); dashed line represents the array from Burd et al. (2014). Inset shows the three volcanic segments of the studied area and ages of the main volcanic centers (Ramos and Folguera, 2011).

Figure 2. (a) Calculated Bouguer and isostatic Airy gravity anomalies based on (b) estimated roots of the Andes at 36ºS from a topographic profile and Eq. (1).

Figure 3. (a) Upward continuation to 35 km in altitude derived from model EGM-2008 (Pavlis et al., 2008, 2012). Note that the area below the Payenia (white dashed line) shows relative high gravity values. (b) Decompensated isostatic anomaly that shows anomalies caused by shallow density contrasts. All positives represent bodies with densities higher than 2.6 g/cm^3

Figure 4. (a) Density model considering crustal attenuation below the Payenia and (b) density model with a high density intracrustral material emplaced (dashed line represents the modeled anomaly and full thin line the observed one).

Figure 5. Graphic sequence of the methodology used to compute the volcanic eruptive volume. Color bar code represents topographic values in meters.

Figure 6. Final density model based on Burd et al. (2014) and estimations of intracrustal high density material from this work (dashed line represents the modeled anomaly while full thin line the observed one).

Figure 7. Map showing the depth to the Curie isotherm. Payenia flood basalts province is enclosed in a black full line and modeled profile discussed in the text in dashed line. The Curie isotherms show a crustal attenuation zone to the east of the profile in agreement with the gravity models.

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496 **Table headings**

497 Table 1 Used densities in the 2-d sections (Giménez et al., 2006, 2009).

498

499 Table 2 Volcanic volume calculated based on the topography and the age
500 intervals.

501

502 Table 3 Results of the extrusive vs. intrusive volumes of volcanic material.

Table 1 Used densities in the 2-d sections (Giménez et al., 2006, 2009).

Parameters	Values
Topographic density above sea level	2.67 g/cm^3
Sediments average density	2.3 g/cm^3
Top crust density	2.7 g/cm^3
Lower crust density	2.9 g/cm^3
Lithosphere mantle density	3.2 g/cm^3
Asthenospheric material density	2.9 g/cm^3
Oceanic slab density	3.15 g/cm^3
Crust normal thickness	35 km

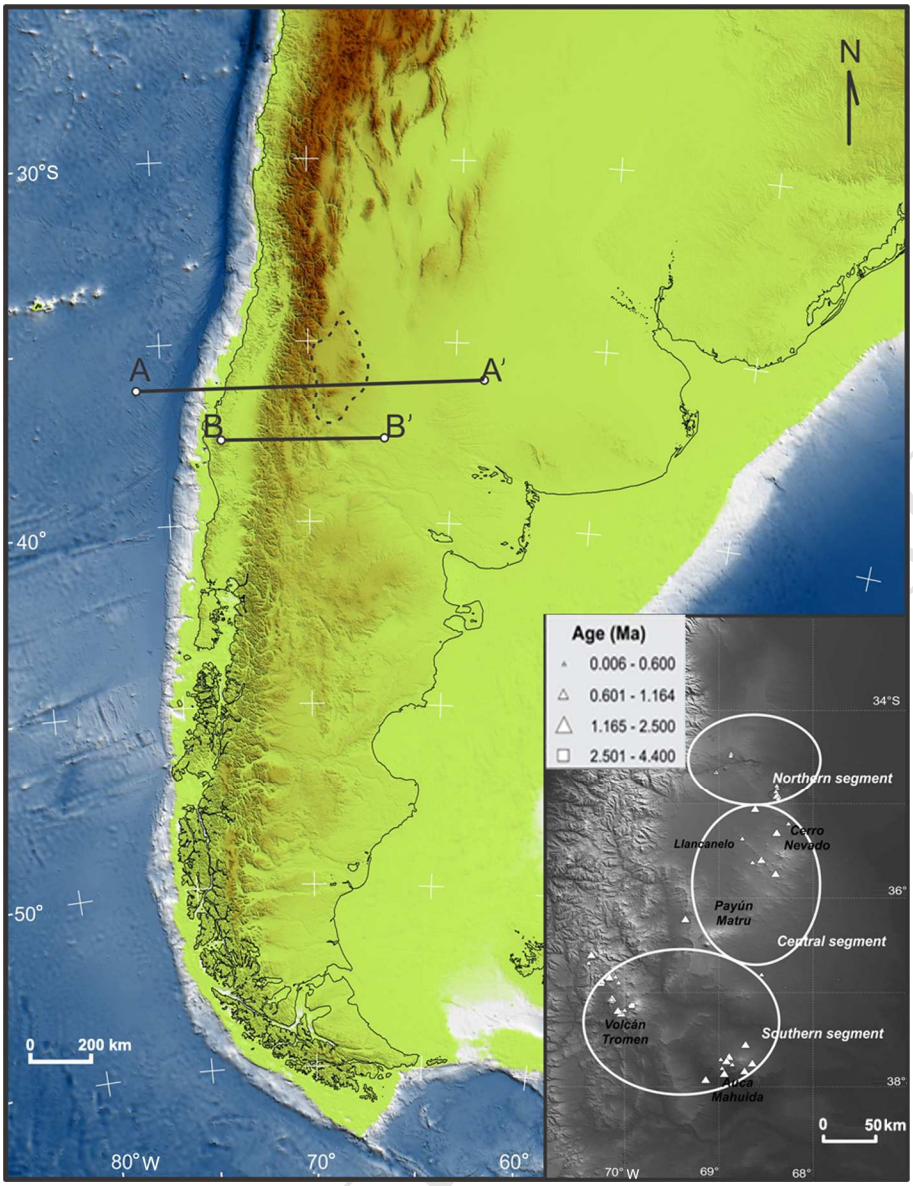
Table 2 Volcanic volume calculated based on the topography and the age intervals.

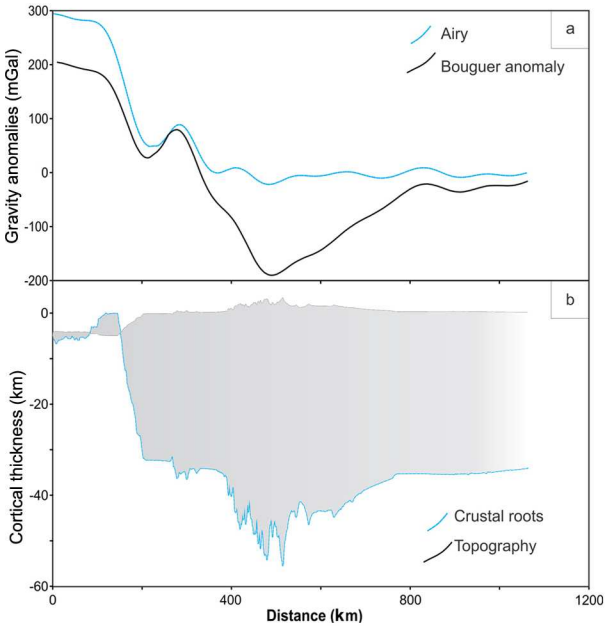
Age interval (My)	**Area (km^2)**	**Volume (km^3)**
0.0 – 0.6	3035.4	117.40
0.6 – 1.165	4049.8	418.28
1.165 – 2.5	19,603.9	933.48
Total	26,689	1469

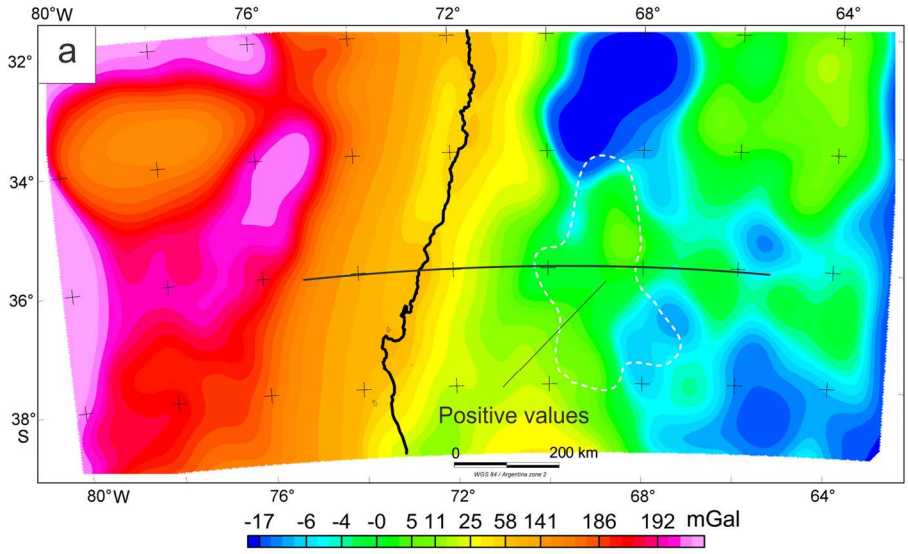
Table 3 Results of the extrusive vs. intrusive volumes of volcanic material.

Surface (km^2)	Eruptive volume (km^3)	Relation 16:1		5:1		3:1	
		Intrusive volume (km^3)	Thickness (km)	Intrusive volume (km^3)	Thickness (km)	Intrusive volume (km^3)	Thickness (km)
40,660 [a]	9600	153,619	3.78	48,006	1.18	28,803	0.71
39,638 [b]	8400	134,192	3.38	41,935	1.06	25,161	0.64

[a]This work; [b]Ramos and Folguera (2011)



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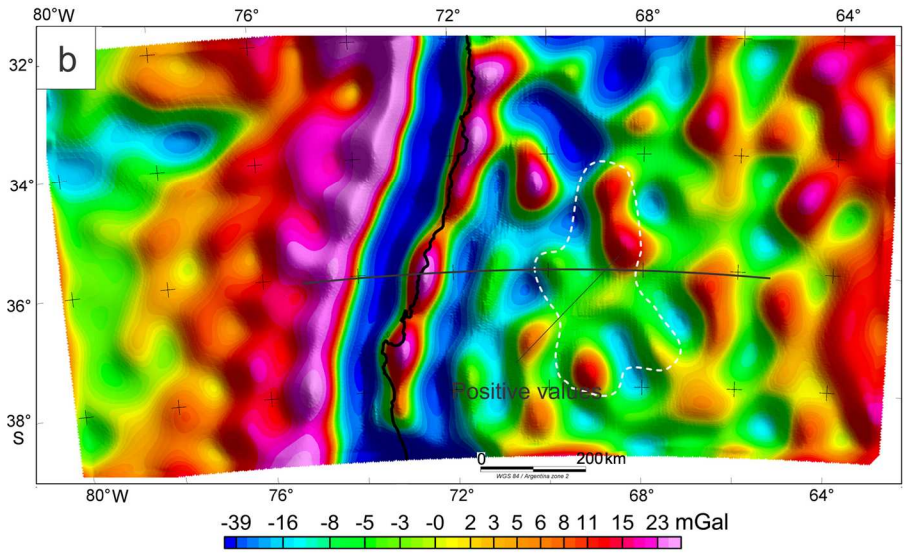
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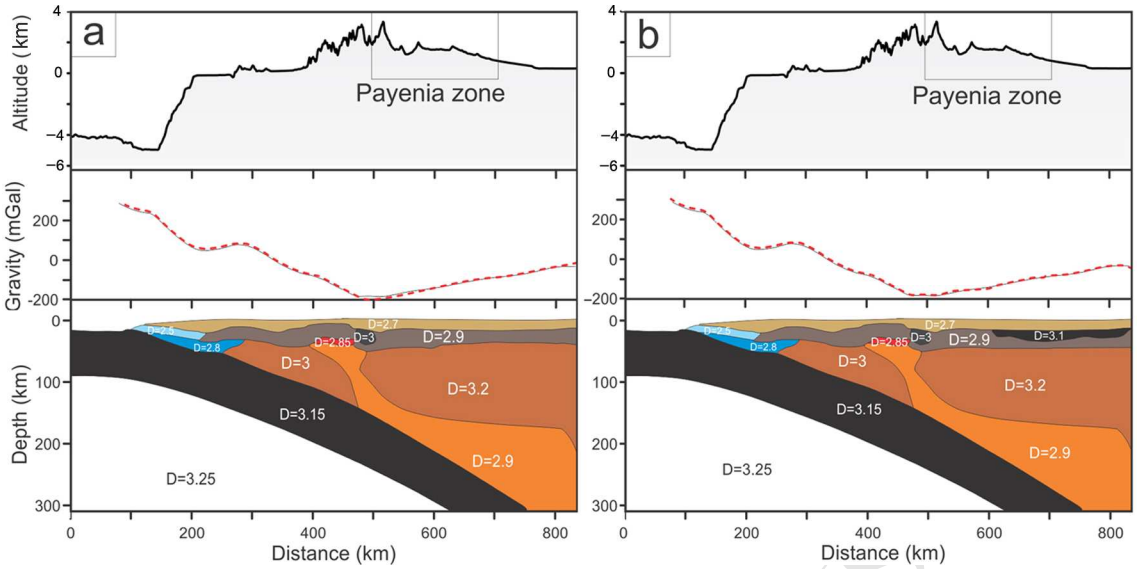

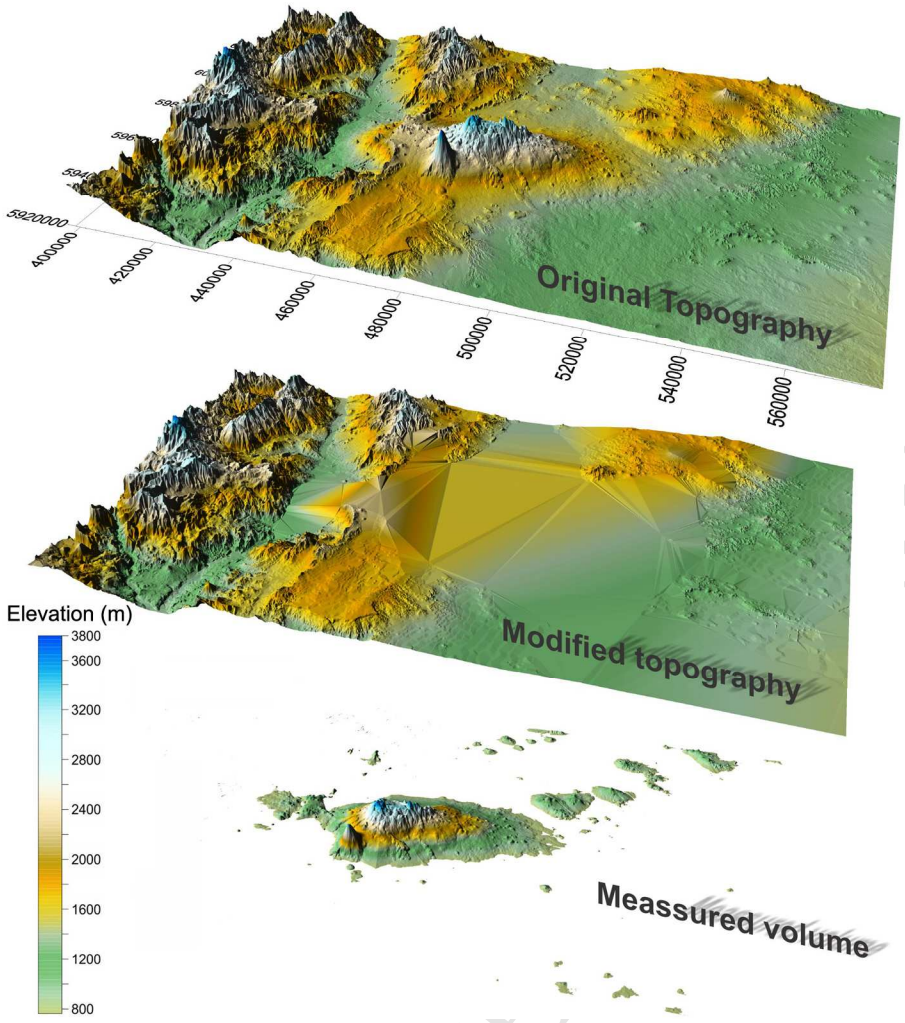

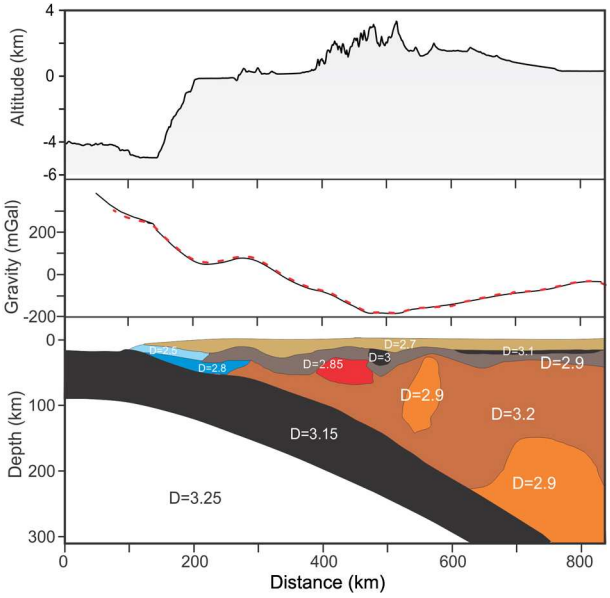

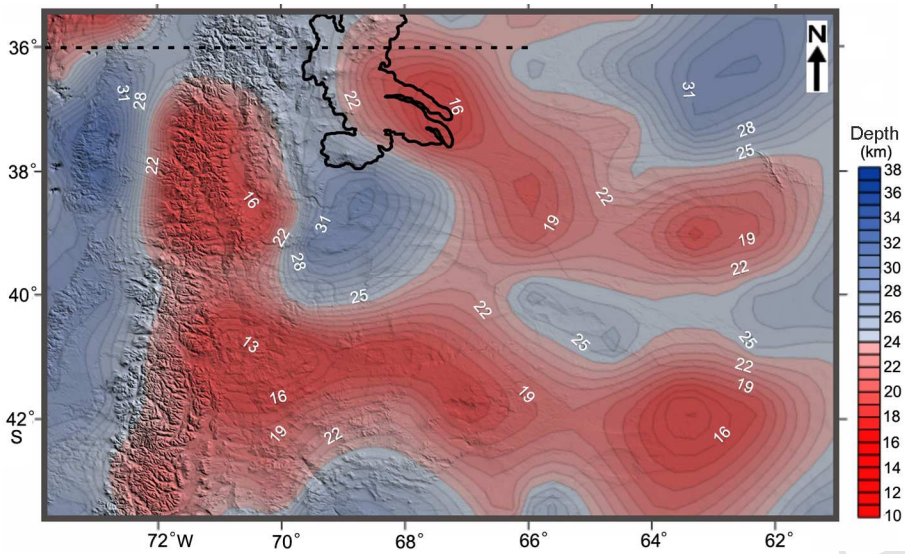

Payenia Quaternary flood basalts (Southern Mendoza, Argentina): Geophysical constraints on their volume

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Highlights

- We model different possible subsurface density model for Payenia.
- We examine gravity data to evaluate different models.
- We calculated the volume of volcanic material for Payenia region.
- We conjugate different lines of evidences to explain the density models.