Journal of Iberian Geology **40 (2) 2014:** 261-282
http://dx.doi.org/10.5209/rev_JIGE.2014.v40.n2.45298

www.ucm.es/info/estratig/journal.htm
ISSN (print): 1698-6180. ISSN (online): 1886-7995

Journal of Iberian Geology
AN INTERNATIONAL PUBLICATION OF EARTH SCIENCES

Origin and provenance of igneous clasts from late Palaeozoic conglomerate formations (Del Ratón and El Planchón) in the Andean Precordillera of San Juan, Argentina

G. Gallastegui[1]*, L. González-Menéndez[2], A. Rubio-Ordóñez[3], A. Cuesta[3], A. Gerdes[4]

[1]*Instituto Geológico y Minero de España (IGME). C/ Matemático Pedrayes 25, 33005 Oviedo, Spain.*
[2]*Instituto Geológico y Minero de España (IGME). C/ Real 1, 24006 León, Spain.*
[3]*Departamento de Geología, Universidad de Oviedo. C/ Jesús Arias de Velasco, s/n, 33005 Oviedo, Spain.*
[4]*Institut für Geowissenschaften Mineralogie, Abt. Geochemie & Petrologie, Altenhöferallee 1, D-60438 Frankfurt am Main, Germany.*

*e-mail addresses: g.gallastegui@igme.es (G.G., *corresponding author); l.gonzalez@igme.es (L.M.); arubio@geol.uniovi.es (A.R.); acuesta@geol.uniovi.es (A.C.); gerdes@em.uni-frankfurt.de (A.G.)*

Received: 2 October 2013 / Accepted: 5 May 2014 / Available online: 25 June 2014

Abstract

Late Palaeozoic conglomerate formations (Del Ratón and El Planchón) from the Andean Precordillera (Argentina) were studied to unravel their age, composition and provenance. The conglomerates from the Del Ratón Formation are formed by igneous clasts of acid, intermediate and basic compositions (volcanic and plutonic). Laser Ablation (ICP-MS) zircon U-Pb study has yielded an age of 348±2 Ma (late Tournaisian) for the crystallization of a granitic clast, interpreted as a maximum deposition age for the Del Ratón Formation. Geochemistry of these clasts (high LILE/HFSE and La/Yb ratios, negative Nb-Ta anomalies) suggests a calc-alkaline batholithic source, probably located along the Andean Frontal Cordillera currently to the west, where similar calc-alkaline igneous rocks have been described. The El Planchón Formation overlies the Del Ratón Formation and, in the studied conglomerates, there are only igneous clasts of mafic composition (volcanic/subvolcanic). These mafic clasts have a very similar petrography and geochemistry to the Late Ordovician mafic igneous rocks of the Western Precordillera (low LILE/HFSE and La/Yb ratios, no negative Nb-Ta anomalies). Therefore we suggest that the El Planchón conglomerate clasts were probably delivered mainly from northern sources within the Precordillera terrane. This change in clast provenance is tentatively related to a shift in mountain uplift from the Frontal Cordillera (in the west) to the Precordillera (in the east) after the early Visean.

Keywords: Late Palaeozoic, conglomerates, igneous clasts, U-Pb ICP-MS geochronology, sedimentary provenance, Gondwana, Andes

Resumen

Las formaciones conglomeráticas del Paleozoico superior (Del Ratón y El Planchón) de la Precordillera Andina (Argentina) fueron estudiadas con el fin de determinar su edad, composición y procedencia. Los conglomerados de la Formación Del Ratón están constituidos por clastos de rocas ígneas (volcánicas y plutónicas) ácidas, intermedias y básicas. Un estudio en circones con espectrometría de masas con plasma acoplado por inducción con ablación láser (LA-ICP-MS) proporciona una edad de 348±2 Ma (Tournaisiense superior) para la cristalización de un clasto granítico, que interpretamos como la máxima edad del depósito de la Formación Del Ratón. La geoquímica de los clastos (altas relaciones LILE/HFSE y La/Yb, anomalías negativas de Nb-Ta) sugiere que probablemente derivan de batolitos calcoalcalinos descritos en algunos sectores de la Cordillera Frontal Andina localizada actualmente al oeste. La Formación El Planchón se superpone a la Formación Del Ratón y los clastos estudiados en los conglomerados de esta formación son únicamente de rocas ígneas básicas (subvolcánicas/volcánicas). Estos clastos tienen una petrografía y geoquímica similar a las rocas ígneas máficas del Ordovícico Superior de la Precordillera Occidental (bajas relaciones LILE/HFSE y La/Yb, ausencia de anomalías negativas en Nb-Ta). Por ello nosotros sugerimos que los clastos de los conglomerados de la Formación El Planchón proceden de materiales localizados al norte dentro de la propia Precordillera. Este cambio en la procedencia de los clastos es tentativamente relacionado con una transferencia de la deformación desde la Cordillera Frontal (al oeste) a la Precordillera (al este), provocando el levantamiento de la Precordillera a partir del Viseense inferior.

Palabras clave: Paleozoico superior, conglomerados, clastos ígneos, geocronología U-Pb ICP-MS, procedencia sedimentaria, Gondwana, Andes

1. Introduction and aims of this study

In this work we investigate the age and origin (provenance) of late Palaeozoic conglomerate formations of central-western Argentina. Conglomerates are sediments closely related to source areas and frequently linked with tectonically active basin margins. The investigation of such rocks, when formed by igneous clasts, permits direct geochronology and petrology studies that help improve the stratigraphic knowledge and location of possible source areas by comparing igneous clasts with known igneous rocks nearby.

The late Palaeozoic sequences of central-western Argentina are the most complete stratigraphic record for this time in South America (Limarino and Spalletti, 2006; Astini *et al*., 2011). This is one of the few regions of Gondwana with a continuous fossil record from early Carboniferous to Permian, including abundant plant remains, palynomorphs and invertebrates, widely represented in the Río Blanco, Calingasta-Uspallata, San Rafael and Paganzo basins (Césari *et al*., 2011 and references therein). However, the age of these sequences established by palynofloras, macrofloras, and marine faunas remains under discussion in some areas due to the absence of species having worldwide biochronological value and the scarcity of radiometric ages (Césari *et al*., 2011).

Thick sequences of early Carboniferous rocks (Mississippian) crop out along the Western Argentine Precordillera (Fig. 1a, b). This stratigraphic interval is often poorly represented in West Gondwana (Limarino and Spalletti, 2006; Limarino *et al*., 2006). Within these sequences the Angualasto Group represents the remains of much larger deposits that once occupied most of the Río Blanco (to the north of study area) and Calingasta-Uspallata basins (Fig. 1b) (Limarino and Césari, 1993). In these arc-related basins, the early Carboniferous deposits are considered synorogenic sequences of the Chanic orogeny (Limarino and Spalletti, 2006; Limarino *et al*., 2006; Heredia *et al*., 2012; Limarino *et al*., 2012). This Late Devonian-early Carboniferous orogeny has been ascribed to the docking of the Chilenia terrane to southwestern Gondwana margin, formed by the previously accreted Cuyania terrane (Fig. 1a) (Ramos, 1988).

The Angualasto Group, defined by Limarino and Césari (1993), includes the Malimán and Cortaderas formations in the Río Blanco basin, north of the Río Jáchal, and the Del Ratón Formation in the Calingasta-Uspallata basin, outcropping in the vicinity of the Río San Juan within the study area (Fig. 1b). The Del Ratón Formation is stratigraphically equivalent (Sessarego and Césari, 1986) or partially equivalent (Azcuy *et al*., 2000) to the Malimán Formation. The age attributed to the Malimán Formation and equivalent units, from invertebrates and palaeoflora, is late Tournaisian-early Visean; the Cortaderas Formation is late Visean, based on palynomorphs (references in Césari *et al*., 2011).

Despite the importance of these deposits, the age and stratigraphic relationships between the Del Ratón Formation and other late Palaeozoic units, El Planchón and Del Salto formations, is very controversial. In this work we provide a U-Pb zircon age from an igneous clast in the conglomeratic lower section of the Del Ratón Formation, which establishes the maximum age of deposition, thus confirming the fossil-based age previously assigned to this formation and the start of synorogenic deposits of the Chanic orogeny in this region. We also undertake a detailed geochemical study of igneous clasts from conglomerates of the Del Ratón and El Planchón formations and compare them with known igneous complexes. This provenance study indicates substantial source differences between these formations.

2. Geological framework

2.1. General overview

The Argentine Precordillera forms the northern part of Cuyania, one of the larger terranes accreted to the southwestern Gondwana margin during the Palaeozoic (Ramos *et al*., 1986) (Fig. 1a). This terrane has been the focus of intense research to unravel its palaeogeographic links usually interpreted in terms of its accretion to southwestern margin of Gondwana (1, in Fig. 1a) in early Palaeozoic times (Ramos *et al*., 1986; Ramos, 1988; Astini *et al*., 1995; Dalziel, 1997; Thomas *et al*., 2002; Thomas and Astini, 2003; Finney, 2007) and the later accretion of the Chilenia terrane against it (2, in Fig. 1a) in Late Devonian-early Carboniferous times (Ramos *et al*., 1984, 1986).

The Argentine Precordillera is a fold-and-thrust belt (Baldis and Chebli, 1969; Limarino *et al*., 2006; Limarino and Spalletti, 2006; Alonso *et al*., 2008; Ramos and Folguera, 2009; among others) about 80 km wide (Fig. 1b) formed by Palaeozoic and Tertiary sediments (Bracaccini, 1946; Heim, 1952), that according to stratigraphic and structural features, has been divided into Western, Central and Eastern domains (Fig. 1b). The Eastern and Central Precordillera represent a stable carbonate platform during Cambrian and Early Ordovician (Bordonaro, 1999). The Western Precordillera is characterised by Cambrian-Ordovician olistostrome or mélange deposits related to extensional tectonics in a continent-ocean transition (Astini, 1997; Keller, 1999), and ocean floor-like sediments with pillow basalts in the westernmost part (Kay *et al*., 1984), indicating the existence of an ancient continental margin (e.g. Spalletti *et al*., 1989; Astini, 1997; Keller, 1999). This early Palaeozoic continental margin (2, in Fig. 1a) was affected by extension during Ordovician and remained stable until the Late Devonian (Alonso *et al*., 2008). Subsequently, the accretion of the Chilenia terrane against the western Cuyania margin generated the Late Devonian-early Carboniferous Chanic tectonic phase of the Famatinian orogenic cycle (Ramos *et al*., 1984, 1986) or Chanic orogeny (Heredia *et al*., 2012). This collision resulted in a complex deformation and low-grade metamorphism that affected mainly pre-Car-

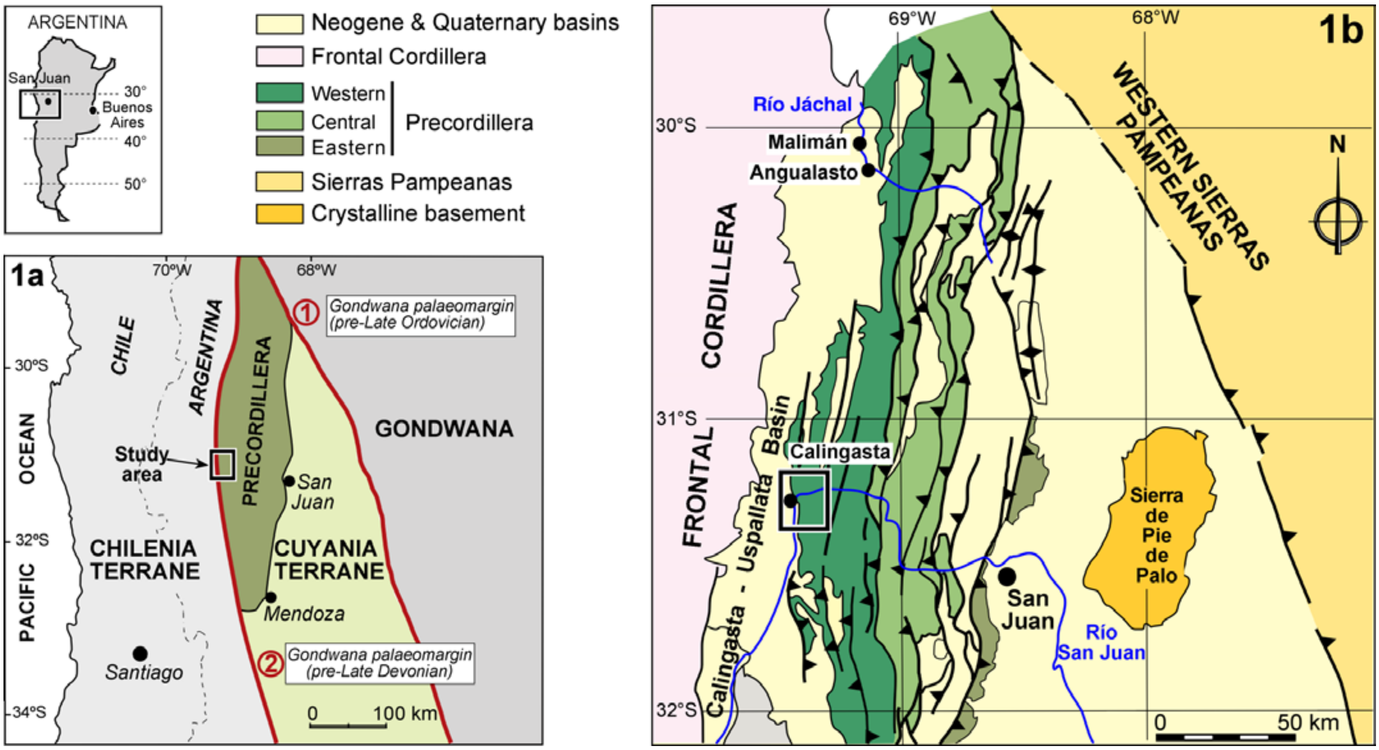

Fig. 1.- a) Terranes of the Central Andes basement and location of the study area. b) Geological domains of the Argentine Precordillera (modified from Alonso *et al*., 2008) showing the zone of the present study in the Western Precordillera.

boniferous rocks (Furque, 1979) of the Western Precordillera (Keller *et al*., 1993; Gosen, 1997; Davis *et al*., 2000). Chanic synorogenic deposits of the early Carboniferous Angualasto Group (Limarino and Césari, 1993) in Western Precordillera overlie folded and cleaved rocks of Devonian age with a strong angular unconformity (Azcuy *et al*., 1981; Limarino and Césari, 1993; López Gamundi and Rossello, 1993; Alonso *et al*., 2008; Amenábar and di Pasquo, 2008; Colombo *et al*., 2012; among others).

2.2. Stratigraphic relations of the late Palaeozoic formations in the studied area.

South of the Río San Juan (Fig. 2), Devonian rocks consist of a sequence of sandstones and shales denominated Codo Formation (Guerstein *et al*., 1965; Sessarego, 1988) unconformably underlying the Del Ratón Formation (Azcuy *et al*., 1981; López Gamundi and Rossello, 1993) of Angualasto Group (Limarino and Césari, 1993). The Codo Formation has been tentatively dated as Givetian-Frasnian according its palynological assemblage (Amenábar and di Pascuo, 2008). The Del Ratón Formation (Guerstein *et al*., 1965; Quartino *et al*., 1971) is a conglomeratic unit with subordinate sandstones and shales, divided in two cycles (De Rosa, 1983), three members (Sessarego and Césari, 1988), and recently in two sections (Colombo *et al.*, 2012). A fact highlighted by different authors is the presence of up to 60 % of igneous clasts in the conglomerates of this formation (Quartino *et al*., 1971; De Rosa, 1983; Tófalo *et al*., 1985; Sessarego *et al*., 1990), including granites, quartz monzonites, quartz syenites, syenites, rhyolites, rhyodacites and basaltic rocks (Sessarego *et al*., 1990). According to Colombo *et al*. (2012), the erosive surface over the Codo Formation is marked by a pavement of disordered and heterometric (30-50 cm) granitic clasts. Over this pavement, within the lower section, there are various metric conglomeratic layers with rounded or subrounded clasts of 3-5 cm in size, of whitish granites (70%), metamorphic rocks (20%) and sedimentary rocks (10%). Alternating with these conglomerates appear layers with clasts sizes of 30-40 cm. In the upper section, and above an erosive discordance, matrix-supported reddish conglomerates include clasts of sandstones and greywacke (65%), pinkish granites and rhyolites (30%), quartz and metamorphic rocks (5%). In this upper section there are also disordered and poorly sorted conglomerates with very coarse clasts (40-50 cm) of reddish granites and rhyolites. The age assigned to the Del Ratón Formation is Tournaisian-Visean, based on fossiliferous assemblages (Scalabrini Ortiz, 1973; Sessarego and Césari, 1988; Césari and Gutiérrez, 2001), or early Visean from palynological data (Amenábar and di Pascuo, 2008).

Other late Palaeozoic deposits cropping out south of the Río San Juan are the El Planchón and Del Salto formations (Fig. 2). The El Planchón Formation (Quartino *et al*., 1971; Sessarego, 1983, 1988) consists of shales and sandstones which grade laterally into conglomerates (Colombo *et al*., 2012). Its stratigraphic relationships with the Del Ratón and

Del Salto formations are very controversial and the age remains undetermined because the El Planchón Formation is palynologically barren (Amenábar and Di Pascuo, 2008). Some authors proposed a Devonian age based on marine fossils (Kerlleñevich, 1967), suggesting that it would be stratigraphically below the Del Ratón Formation (Sessarego, 1983) or in fault contact with it (Amenábar and Di Pascuo, 2008). Others consider that the El Planchón Formation rests unconformably over the Del Ratón Formation and constitutes the lower part of the Del Salto Formation (Quartino *et al*., 1971; Alonso *et al*., 2005). However according to Colombo *et al*. (2012), the El Planchón Formation is overlain unconformably by the Del Salto Formation (Fig. 2). The age proposed for the Del Salto Formation is late Carboniferous (Pennsylvanian)-early Permian based on marine fossils (Azcuy *et al*., 2007). The Del Salto Formation represents the synorogenic sequences of late Carboniferous-early Permian Gondwanan orogeny (Colombo *et al*., 2012). Pre-orogenic late Carboniferous (Pennsylvanian) deposits related to this orogeny are absent in this area, and in most of the Western Precordillera. The absence of most late Carboniferous sediment record is explained because the pre-Precordillera (Proto-Precordillera) probably formed a horst-like topographic high inherited from the Chanic cordillera (Limarino and Spalletti, 2006; Heredia *et al*., 2012). Therefore, the El Planchón conglomerate Formation could belong to the early Carboniferous (Mississippian) deposits of Angualasto Group synorogenic with the Late Devonian-early Carboniferous Chanic orogeny.

3. Samples and analytical techniques

For this study a set of 36 samples were collected south of the Río San Juan, between the 114 and 118 km markers on the RN 20 road, near of Calingasta (Fig. 2). Most of the samples (31) correspond to igneous clasts from the conglomerates of the Del Ratón Formation cropping out at the Quebrada Km 117 valley. In this formation we have studied two different conglomerate layers. One of these is a disordered and poorly sorted boulder conglomerate formed by very coarse clasts (up to 30-50 cm) of reddish or pinkish acid-intermediate igneous rocks, and smaller dark-coloured clasts of basic igneous rocks (Fig. 3a). The other conglomerate layer studied in this formation, and located above, is a poorly sorted cobble-pebble conglomerate formed by clasts smaller than 15 cm within a micro-conglomeratic matrix. Clasts are of whitish acid-intermediate igneous rocks, basic igneous rocks, and in smaller proportion, of sedimentary and metamorphic rocks (Fig. 3b). For comparative purposes, we also collected 5 representative samples in a conglomerate layer from the upper part of the El Planchón Formation, at the Quebrada del Salto valley (Fig. 2). This conglomeratic layer is 2 metres thick, poorly sorted, formed by clasts up to 15 cm within a sand-mudstone matrix. All the clasts are dark-coloured mafic igneous rocks.

3.1. Major and trace element analyses

From the total sample set, 17 representative igneous clasts (boulders) were selected for major and trace element analyses. Major and some trace elements (V to Pb) were analysed by X-ray fluorescence (XRF) in the Technical-Scientific Services of Oviedo University (Spain) using a WD-XRF spectrometer (model 2404; PANalytical) coupled with a Rh tube. Major element analyses were performed using glass beads of powdered rocks after fusion with lithium tetraborate. Precision of the XRF technique was better than ± 1% relative. Trace elements were determined on pressed pellets with Elvacite. Raw data were processed using Pro-Trace-XRF PANalytical software. Other trace elements (U, Th, Hf, Ta) and rare earth elements (REE) were analysed by inductively coupled plasma mass spectrometry (ICP-MS) following sample decomposition with lithium metaborate at the Geochronology and Geochemistry-SGIker facility of El País Vasco University/EHU (Spain) (see García de Madinabeitia *et al*., 2008 for additional details).

3.2. U-Pb ICP-MS isotopic analyses

An igneous clast of the lower conglomerates layers from the Del Ratón Formation (sample AN47) was processed for zircon separation and U-Pb geochronology. Rock pulverization and mineral separation using a Wilfley table, heavy liquids, and a Frantz isodynamic separator were performed at University of Oviedo (Spain). The selected zircon fractions were hand picked under a binocular microscope. The zircon mount was prepared using double-sided tape, a plexiglass ring, and Buehler Epoxicure resin. BSE and CL images of the individual grains were obtained with the Cameca SX100 electron microprobe of Oviedo University to assess the internal morphology before carrying out the U-Pb laser work.

Zircon U-Pb analyses were carried out at Johann Wolfgang Goethe-University Frankfurt/JWG (Germany) using a Thermo-Finnigan Element II SF-ICP-MS coupled to a New Wave UP213 ultraviolet laser system. Laser spot-sizes varied from 20 to 40 μm for zircon. The typical depth of the ablation crater was ~20 μm. Data were acquired in peak-jumping mode over 900 mass scans during 20 s background measurement followed by 32 second sample ablation. A teardrop-shaped, low volume laser cell was used to enable the precise detection of heterogeneous material (e.g., inclusions or different growth zones) during time resolved data acquisition (see Janousek *et al*., 2006).

Laser-induced elemental fractionation and instrumental mass discrimination were corrected by normalization to the reference zircon GJ-1 (Jackson *et al*., 2004). Prior to this normalization, the change of elemental fractionation (e.g., the Pb/Th and Pb/U ratios as a function of ablation time and thus crater depth) was corrected for each set of isotope ratios (*c.* 40) collected during the time of each single spot analysis. The

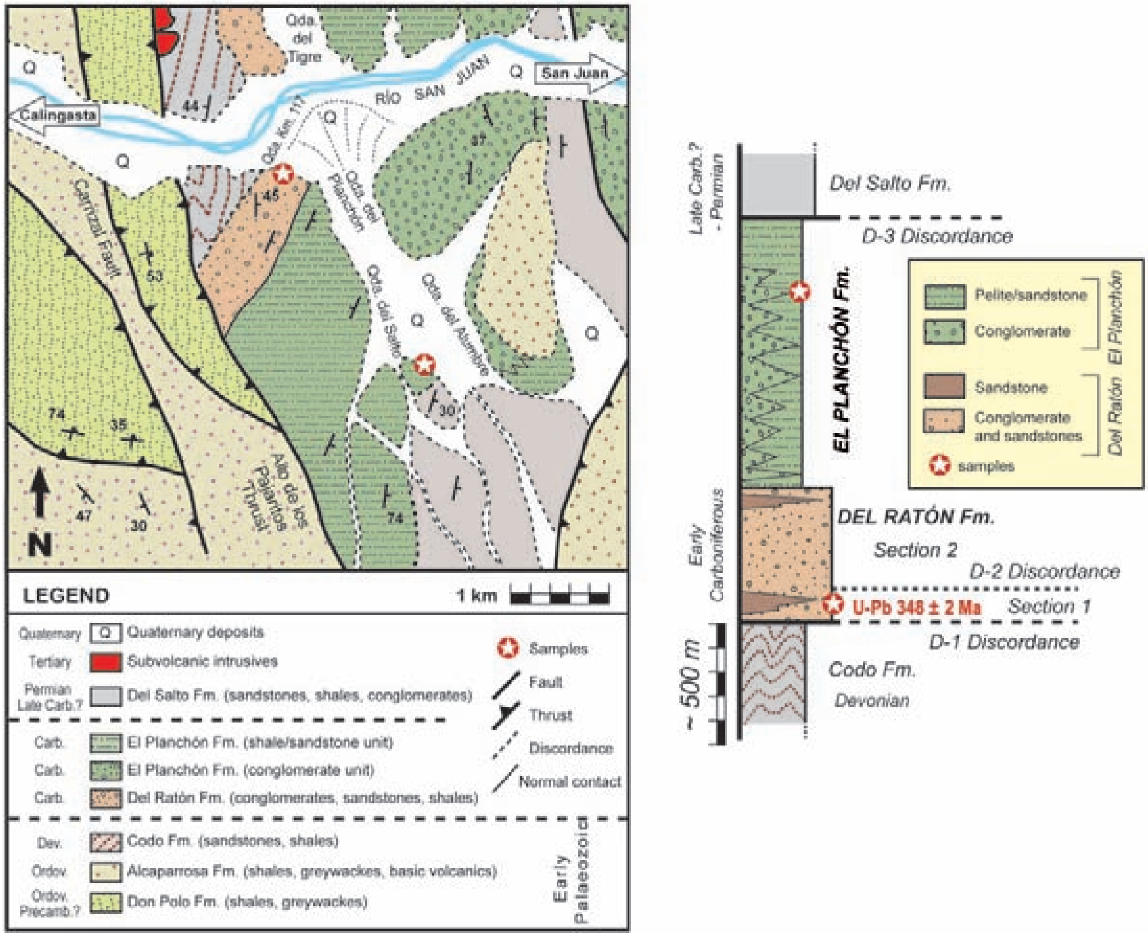

Fig. 2.- Simplified geological map of study area (after Alonso et al., 2008 and Amenábar and di Pascuo, 2008) and schematic stratigraphic section of the Del Ratón and El Planchón formations, based on Colombo *et al*. (2012), with the location of sampled sites.

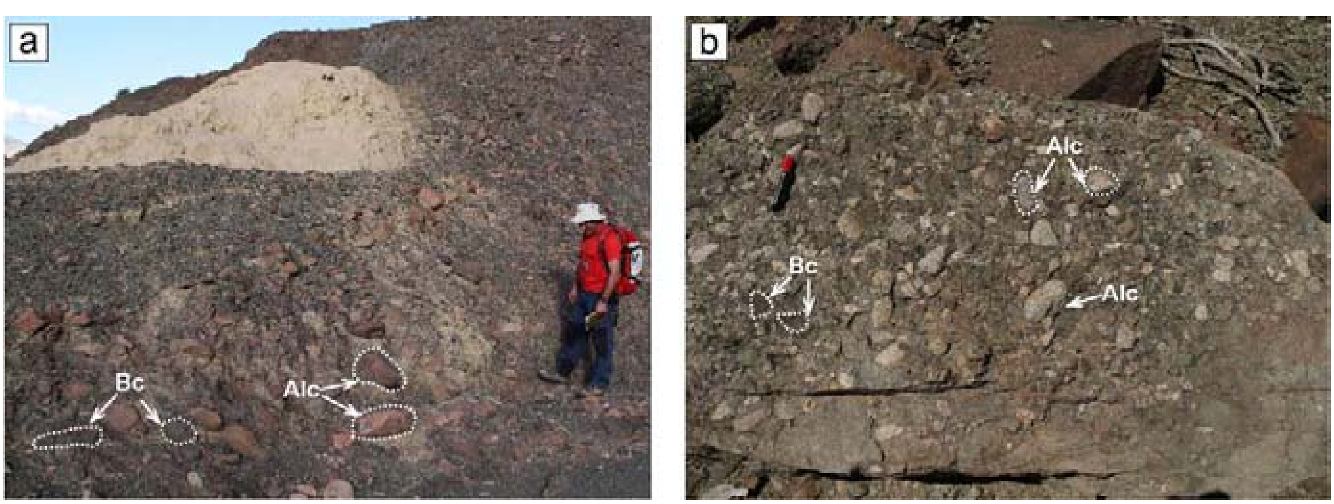

Fig. 3.- Field appearance of the Del Ratón Formation conglomerates at the Quebrada Km 117 valley. a) Conglomerate consisting mainly of large clasts of reddish-coloured acid-intermediate igneous rocks (AIc) and dark-coloured basic igneous rocks (Bc). b) Conglomerate formed by clasts, smaller than 15 cm, of acid-intermediate (AIc) and basic igneous rocks (Bc).

correction was done by applying a linear regression through all measured ratios. The total offset of the measured drift-corrected $^{206}Pb/^{238}U$ ratio from the "true" ID-TIMS value of the analysed GJ-1 grain was about 3-4%. Reported uncertainties (2σ) were propagated by quadratic addition of the external reproducibility (2 s.d.) obtained from the standard zircon GJ-1 (n = 20; 1.3% and 1.2% for the $^{207}Pb/^{206}Pb$ and $^{206}Pb/^{238}U$, respectively) during the analytical session and the within-run precision of each analysis (2 s.e.). For further details on analytical protocol and data processing for the U-Pb method see Gerdes and Zeh (2006, 2009).

4. Petrography

A set of 36 thin sections of igneous clasts from the conglomerate layers of the Del Ratón and El Planchón formations were studied. The petrographic classification of the igneous clasts is just an approximation because it is impossible to know if they were part of plutonic, subvolcanic or volcanic igneous complexes. The main petrographic features of individual clasts are summarised in Table 1.

4.1. Boulder conglomerate from the Del Ratón Formation.

In this conglomerate (Fig. 3a), the studied clasts are plutonic and volcanic rocks, ranging in composition from acid to basic, although acid-intermediate compositions are prevalent. Samples were divided in two main groups: i) plutonic -volcanic rocks and ii) pyroclastic rocks. In most of the cases, but especially in the rocks of intermediate to acid composition, the rocks show moderate to severe hydrothermal alteration, with the development of potassic minerals (sericite, K-feldspar), prehnite, and carbonates accompanied by other secondary minerals (epidote, quartz, chlorite, titanite).

i) Plutonic-volcanic rocks. This group includes a wide variety of rocks ranging from gabbros and basalts to granites and rhyolites.

Gabbros. These are the least abundant rocks. Their texture is coarse- to medium-grained, porphyritic to ophitic and subophitic, with a doleritic matrix. The mineral assemblage includes clinopyroxene, plagioclase, opaque minerals, and smectites (probably pseudomorphs after olivine). Clinopyroxene is the most abundant phase (Fig. 4a), and constitutes phenocrysts in the porphyritic rocks, with sizes up to 4 mm.

Sample	Fm	Rock type	Texture	Main mineralogy	Dominant secondary phases
ANC1	RaFm	Dacitic vitric-tuff (+C+Lc)		Pl+Qz+Afs+(Bt)	Ab+Ser+Qz+(Chl,Hem,Ttn).*Cb+Qz
ANC10	RaFm	Granite/ Qz-syenite	Allotriomorphic	Afs+Qz+(Bt)	kfs+Qz+Prh+Ttn>< Cb
ANC3	RaFm	Greywacke		Qz+Pl+Ms/Chl+(Opq)	Cb
ANC4	RaFm	Gabbro	Subophitic	Pl+Cpx+Ilm	Ab+Amp+Chl+Sme+Tlc+(Ttn,Hem,Qz).*Cb
ANC5	RaFm	Gabbro	Ophitic	Cpx+Pl+Ilm+(Ol?)	Amp+Ab+Ep+Tlc+Sme+Hem+Ttn+(Chl)
ANC6	RaFm	Dacitic vitric-tuff (+C+Lc)		Qz+Pl+Afs+(Bt+Amp)	Hem+Qz+Chl+(Ttn)
ANC7	RaFm	Rhyolitic ash-tuff			Ser+Qz
ANC8	RaFm	Microgabbro	Ophitic	Cpx+Pl+Opq	Ep+Hem+(Chl,Amp,Ttn)
ANC9	RaFm	Bt-Granite	Hypidiomorphic	Qz+Afs+Pl+Bt+Opq	Qz+Ab+Ser+(Ep,Kfs,Chl)><Cb+(Qz)
AN47	RaFm	Bt-Granite	Hypidiomorphic	Afs+Pl+Qz+(Bt)	Ser+Kfs+Qz+Chl+Cb
AN48	RaFm	Basalt	Doleritic	Pl+(Amp+Opq)	Hem+Chl+Ep+Qz+Cb
AN49	RaFm	Dacitic crystal-rich tuff (+Vc)		Pl+Qz+(Bt)	Qz+Chl+Ser+(Hem). *Cb+Chl+Qz
AN50	RaFm	Dacitic/Rhyolitic crystal-rich tuff (+Vc)		Pl+Afs+Qz+(Bt)	Ser+Qz +Hem+(Chl,Ep,Ttn). *Cb+Qz
AN51	RaFm	Andesite	Porphyritic	Pl+Bt+Qz+Hem	Ab+Chl+Hem+Qz+(Ep,Ttn). *Cb
AN51$_{enc}$	RaFm	Basaltic andesite	Doleritic	Pl+(Amp/Bt)+Vesc	Ab+Chl+Ep. *Mor+Chl+Qz+Cb
AN52A	RaFm	Dacitic vitric-tuff (-15% C)		Pl+Qz+(Bt)	Ser+(Ttn)+Qz
AN52B	RaFm	Dacitic vitric-tuff (-15% C)		Pl+Qz+(Bt+Amp?)	Ser+(Ttn)+Qz
AN20	RaFm	Andesite	Doleritic	Pl+Qz+(Amp?+Bt?)	Chl+Hem+Ttn+Sme+Qz. *Cb
AN21A	RaFm	Andesite	Doleritic	Pl+Afs+Qz+(Bt+Amp)	Ser+Qz+Chl+Ep+Ttn. *Cb
AN21B	RaFm	Bt-Granite	Hypidiomorphic	Afs+Pl+Qz+(Bt+Amp)	Ser+Kfs+Qz+(Hem,Ttn). *Cb
AN22	RaFm	Monzogranite	Allotriomorphic	Afs+Qz+Pl+Bt	Qz+Ab+Ser+(Ep,Kfs,Chl). *Cb+(Qz)
AN23	RaFm	Granodiorite	Hypidiomorphic	Afs+Qz+Pl+Bt+Amp	Qz+Ab+Ser+(Ep,Kfs,Chl)+Ttn. *Cb+(Qz)
AN24	RaFm	Basaltic andesite	Trachytic	Pl+(Bt)	Ep+Chl+Ttn+Ab+Qz. *Cb
AN25	RaFm	Andesitic crystal-rich tuff		Pl+Afs+(Bt+Amp+Ol?)	Chl+Hem+Ttn+Ep+Qz+(Amp,Ap,Afs)
AN26	RaFm	Dacitic crystal-rich tuff		Afs+Qz+Pl+(Bt)	Chl+Qz+Ser+Ttn+(Ep,Hem)
AN27	RaFm	Andesitic/Dacitic crystal-rich tuff		Pl+Bt+Qz	Chl+Qz+Ser+Ttn+(Ep,Hem)
AN20A	PlaFm	Gabbro/basalt	Doleritic	Pl+Cpx+Ilm+(Ol?)	Amp+Ser+Ep+Ttn+(Chl)
AN20B	PlaFm	Gabbro/basalt	Ophitic	Cpx+Ilm+(Pl)	Amp+Ser+Ep+Ttn+(Chl)
AN20C	PlaFm	Gabbro/basalt	Ophitic	Cpx+Pl+Ilm	Amp+Ser+Ep+Ttn+(Chl,Tlc)
AN20D	PlaFm	Gabbro/basalt	Doleritic	Cpx+Pl+Ilm	Amp+Chl+Ep+Qz+Ttn±Hem+Cb
AN20E	PlaFm	Gabbro/basalt	Subophitic	Cpx+Pl+Ilm	Amp+Chl+Ser+Ep+(Qz)

C: Crystals. Lc: Lithic clasts. Vc: Vitriclasts. Enc: Enclave. In parentheses: minerals in very low %. (*): Minerals related with a later alteration

Table 1.- Main petrographic features of the igneous clasts from the Del Ratón (RaFm) and El Planchón (PlaFm) conglomerate formations.

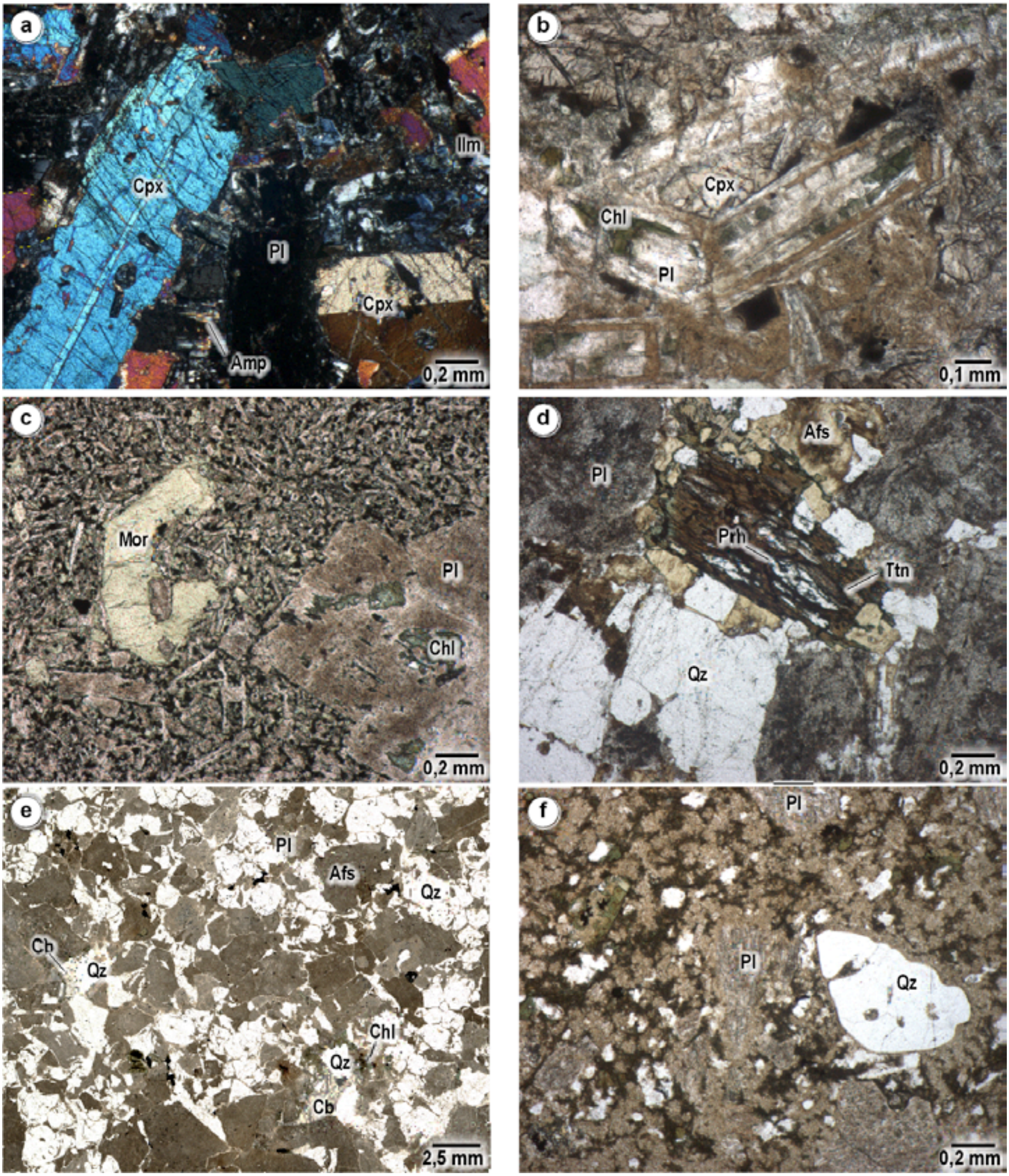

Fig. 4.- Photomicrographs showing the petrography of large igneous clasts (up 30-50 cm) from the conglomerates of the Del Ratón Formation. a) Texture of Cpx-rich gabbro. b) Altered gabbro, with development of Chl and Mor (brown colour). c) Moderately altered andesite. It shows Mor totally replacing previous mafic minerals and development of Ab+Chl+Hem. d) Granite with partially altered Bt to Chl (+Prh+Ttn). e) Texture of the granite sample selected for U-Pb zircon analyses (AN47), showing pervasive silicification. f) Crystal-rich tuff of rhyolitic composition, showing a vitreous matrix with spherulitic and perlitic textures. Mineral abbreviations (Whitney and Evans, 2010): Cpx (clinopyroxene), Amp (amphibole), Pl (plagioclase), Ilm (ilmenite), Chl (chlorite), Mor (mordenite), Qz (quartz), Afs (alkali feldspar), Ttn (titanite), Prh (prehnite), Cb (carbonate), Hem (hematite), Ab (albite), Bt (biotite).

All these rocks show a moderate hydrothermal alteration that produced chlorite, smectites (mordenite), talc, titanite, actinolite, albite, quartz, and carbonates (Fig. 4b).

Basalts and basalt andesites. These are equigranular rocks, mainly with doleritic textures but in some cases with microlithic or fluidal microlithic textures. Their mineralogy is formed by plagioclase, amphibole, and biotite. The samples show a moderate hydrothermal alteration, with nearly complete replacement of mafic minerals by a secondary paragenesis dominated by chlorite and epidote, with hematite, quartz, and carbonates. One sample of basaltic andesite presents vugs larger than 3 mm filled by mordenite, chlorite, quartz, and carbonates.

Andesites. These are porphyritic and hypocrystalline rocks that occasionally host basic enclaves. The mineral assemblage is formed by plagioclase, biotite, quartz, and hematite. Plagioclase phenocrysts are larger than 8 mm and form > 40% of the rock (Fig. 4c). The groundmass is altered and replaced by a granoblastic mixture of quartz, plagioclase, and hematite, with grain sizes below 0.1 mm. The hydrothermal paragenesis of these rocks includes chlorite, mordenite, albite, hematite, quartz, and carbonates, with minor epidote and titanite. Some of these minerals represent pseudomorphs after previous mafic minerals (Fig. 4c).

Granites. There are several samples of granitic clasts whose composition varies from quartz-syenites (alkali feldspar rich) to biotite-amphibole granodiorites and biotitic monzogranites. These rocks have pinkish to reddish colours, indicating hydrothermal alteration. The mineral assemblage includes K-feldspar, quartz, plagioclase, altered biotite, ± amphibole (Fig. 4d). The texture is medium to coarse-grained hypidiomorphic or allotriomorphic (2-10 mm crystal size). An important potassic alteration generated K-feldspar overgrowths and a decrease of quartz content. Other secondary minerals are carbonate, sericite, prehnite, titanite, chlorite, and minor epidote and hematite. In some samples is possible to recognize a sequence of alteration events. Initially, the rock developed pervasive potassic alteration where plagioclase was partially replaced by K-feldspar. This potassic alteration stage also produced quartz leaching, biotite replacement by chlorite (± prehnite, ± titanite), and concentration of accessory minerals such as zircon and monazite. In a second stage, the rock underwent a process of light to moderate silicification (Fig. 4e); this produced re-precipitation of euhedral quartz filling voids. There is also evidence of infiltration and precipitation of feldspar in cracks and crystallization of chlorite and mordenite, covering the interior of the previous voids. Finally, a stage of carbonatization affected the rock, with the partial replacement of feldspar by calcite, and a complete fill of previous voids.

ii) Pyroclastic rocks. This group is formed by rocks whose composition ranges from andesite to rhyolite. Different textures are observed, from crystal-rich tuffs to vitriclastic tuffs.

Andesitic tuffs. This group includes a great diversity of textures and mineral assemblages. It varies from crystal-rich tuffs (20-70% of crystals) to vitreous-rich tuffs (>30% of vitriclasts) of andesitic composition. Crystals are mainly plagioclase, quartz, ± biotite. In some samples K-feldspar, amphibole or pseudomorphs of mafic minerals (probably olivine) were observed. All these rocks were affected by low to severe hydrothermal alteration that generated albite, sericite and quartz, with minor titanite, hematite, chlorite, and epidote ± carbonates.

Dacite-Rhyolite tuffs. These rocks are mainly crystal-rich tuffs, with K-feldspar, quartz, and minor plagioclase, biotite or amphibole. Lithic clasts are less abundant and are similar in mineralogy to the host rock. The groundmass was replaced by a granoblastic aggregate of quartz, sericite, and opaque minerals, but it is still possible to recognize ghosts of devitrification textures, such as perlitic, spherulitic and patchy structures or sintaxial growths over the crystals (Fig. 4f). Scarce samples of vitreous-tuffs occur, including microcrystalline sericite-quartz cineritic clasts.

4.2. Cobble-pebble conglomerate from the Del Ratón Formation.

This conglomerate layer (Fig. 3b) is composed by clasts very similar in texture and composition to those in the conglomeratic unit described above. The samples selected correspond mainly to the micro-conglomeratic matrix between large clasts (< 15 cm). The same two groups of rocks described above also occur in this unit (plutonic-volcanic and volcaniclastic). The most abundant clasts are crystal-rich and vitreous-rich tuffs of light brown colour (Fig. 5a, b), with variable phenocrysts content, and evidence of glass hydration (devitrification) textures (perlitic, spherulitic, patchy textures, etc.). Less abundant, granitic and basaltic clasts (Fig. 5c, d) have textures, composition, and hydrothermal alteration similar to those described in the previous unit.

4.3. Cobble conglomerate from the El Planchón Formation.

In this conglomeratic layer one type of igneous clasts was found. These are gabbros/basalts, with different proportions of clinopyroxene, plagioclase, ± ilmenite, affected by hydrothermal alteration. All the clasts are dark-coloured and coarse-grained equigranular to porphyritic, although doleritic, ophitic and sometimes subophitic textures are observed (Fig. 5e, f). The phenocrysts of plagioclase or clinopyroxene are larger than 4 mm of long, while the groundmass is fine-grained and less than 0.8 mm. The studied samples record light to moderate hydrothermal alteration that generated amphibole, sericite, epidote, hematite, titanite, and in some cases talc, quartz, and carbonates.

5. U-Pb zircon age of the Del Ratón Formation

A representative igneous clast sample (≈ 50 cm in size) was selected for U-Pb isotopic analyses. This is a pinkish

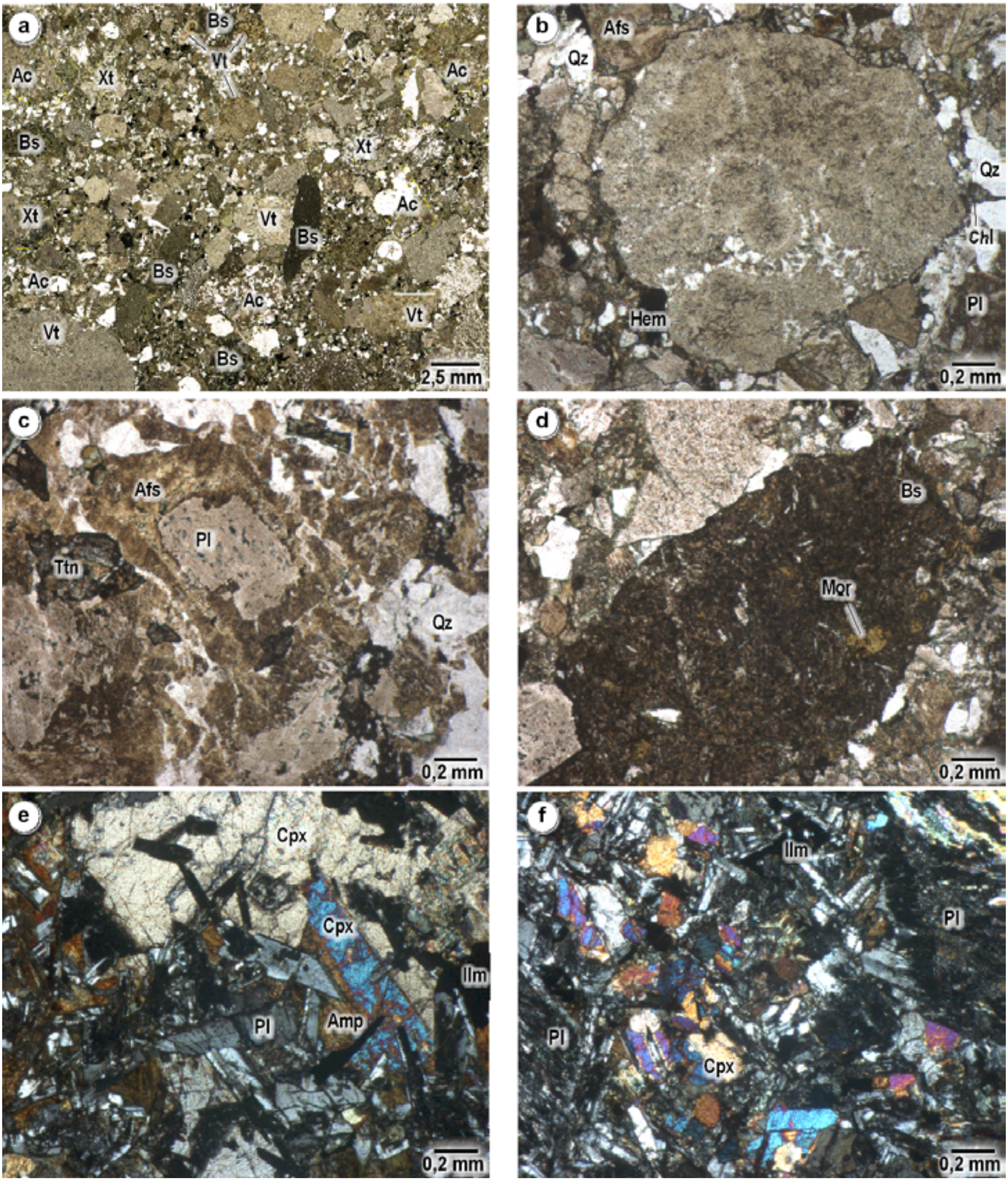

Fig. 5.- Petrography of the matrix from conglomerates of clasts < 15 cm of the Del Ratón Formation (a-d), and clasts from the El Planchón conglomerate (e-f). a) Micro-conglomerate matrix formed by basalt and gabbro clasts (Bs), vitreous-rich tuff (Vt), crystal-rich tuff (Xt), and granites (Ac). b) Clast of vitreous-rich tuff with spherulitic texture and incipient silicification. c) Granite clast with potassic alteration. d) Basaltic clast with pervasive alteration assemblage that includes Mor, Ab and Hem. e) Gabbro/basalt clast with subophitic texture. f) Doleritic texture in the matrix of a porphyritic gabbro/basalt clast, with phenocrystals of partially altered Pl. Mineral abbreviations as in figure 4.

coloured medium- to coarse-grained holocrystalline rock of granitic composition (sample AN47), with a moderate hydrothermal alteration (Fig. 4e). Its mineralogy is composed by K-feldspar, plagioclase, and quartz, with minor biotite (replaced by chlorite ± prehnite ± titanite). Its textural features are dominated by secondary processes, with pervasive potassic alteration and less important carbonatization that are superimposed on the previous granitic texture (see Table 1).

In this study 29 isotopic analyses were obtained from 28 magmatic zircons (Table 2). The backscattered electron (BSE) images taken with electron microprobe show that the zircons are euhedral to subhedral short-prismatic crystals, with rhythmic concentric growth zoning parallel to crystal outlines (Fig. 6). Prior to isotopic analyses, zircons were classified following the method of Pupin and Turco (1972). These zircons fall into the S8 to L5 morphologies, mainly S4-S5, characteristic of rocks crystallized at low temperature (650-700 ºC). Of the 29 analyses, 27 provide a Concordia age of 348±2 Ma that was interpreted as the crystallization age of the granite clast (Fig. 6). This places the granite crystallization very close to the Tournaisian-Visean boundary, established at 346.3 Ma in a global Carboniferous chronostratigraphic time scale (Davydov *et al*., 2010) or 347 Ma in the Geological Time Scale (Walker *et al*., 2012). This age represents the maximum possible for deposition of the Del Ratón Formation that is bound to be just at the end of the Tournaisian or more likely in the Visean, in agreement with palynological data (Amenábar and di Pascuo, 2008). This age also suggests that some of the granitic clasts incorporated into the Del Ratón Formation conglomerates come from the erosion of early Carboniferous igneous rocks related to Chanic magmatism.

5.1. Comparison with ages from known igneous complexes

Within the Precordillera, the existence of igneous rocks of early Carboniferous age is restricted to dykes recognised in the Devonian Codo Formation, to the north of study area (Sessarego *et al*., 1990). These authors describe dykes of granodiorites, diorites, quartz monzonites, trachytes, basalts, andesites, and rhyolites, with a Rb-Sr age of 337±10 Ma, related to Chanic magmatic activity.

To the E and NE of the Precordillera, minor but widespread Devonian to early Carboniferous igneous rocks are present in the Sierras Pampeanas (Fig. 1b) (Dahlquist et al., 2006; Grosse *et al*., 2009; among many others). This early Carboniferous magmatism is represented by A-type granites and syenogranites, alkaline S-type granodiorites to granites, and alkaline I-type tonalites to granites (Dahlquist *et al*., 2010; Alasino *et al*., 2012 and references in both) generated during crustal extension (Grosse *et al*., 2009), with U-Pb ages of 350-323 Ma (references in Alasino *et al*., 2012). Further

																Age (Ma)							
grain	L-No.	$^{207}Pb^a$ (cps)	U^b (ppm)	Pb^b (ppm)	Th^b/U	$^{206}Pb/^{204}Pb$	$^{206}Pb^c/^{238}U$	±2σ (%)	$^{207}Pb^c/^{235}U$	±2σ (%)	Rho [d]	$^{208}Pb^c/^{232}Th$	±2σ (%)	$^{207}Pb^c/^{206}Pb$	±2σ (%)	$^{206}Pb/^{238}U$	±2σ (Ma)	$^{207}Pb/^{235}U$	±2σ (Ma)	$^{208}Pb/^{232}Th$	±2σ (Ma)	$^{207}Pb^c/^{206}Pb$	±2σ (Ma)
2	a22	5287	282	19	1,81	6674	0,05806	1,8	0,4265	3,0	0,59	0,01765	1,8	0,05328	2,4	364	6	361	9	354	6	341	55
3	a23	943	53	3,3	0,83	4796	0,05530	2,1	0,4042	8,5	0,25	0,01685	5,0	0,05301	8,3	347	7	345	25	338	17	329	187
4	a24	2576	145	9,1	0,68	19678	0,05503	1,8	0,4061	3,4	0,53	0,01713	2,6	0,05352	2,9	345	6	346	10	343	9	351	66
8	a25	5418	301	19	1,41	3778	0,05493	2,1	0,4097	4,3	0,49	0,01709	2,7	0,05410	3,7	345	7	349	13	343	9	375	84
9-1	a26	4256	244	15	0,80	6397	0,05539	1,8	0,3979	3,4	0,54	0,01752	2,2	0,05210	2,8	348	6	340	10	351	8	290	65
9-2	a27	8486	465	30	0,92	10478	0,05619	1,9	0,4160	2,8	0,69	0,01752	2,0	0,05369	2,0	352	7	353	8	351	7	358	45
11	a28	2443	136	8,7	1,19	2543	0,05584	2,3	0,4102	4,9	0,47	0,01761	2,6	0,05328	4,3	350	8	349	15	353	9	341	98
12	a29	1405	77	4,9	1,52	10659	0,05608	1,9	0,4168	4,4	0,42	0,01726	2,8	0,05390	4,0	352	6	354	13	346	9	367	90
13	a31	5989	315	20	1,84	6043	0,05647	2,6	0,4085	8,7	0,30	0,01646	7,0	0,05247	8,3	354	9	348	26	352	9	325	104
17	a32	6545	382	24	1,11	51365	0,05445	2,2	0,3911	3,6	0,60	0,01687	7,8	0,05210	2,9	342	7	335	10	330	23	306	189
18	a33	3089	169	11	1,49	23416	0,05612	1,8	0,4173	3,9	0,47	0,01691	2,3	0,05393	3,4	352	6	354	12	338	26	290	66
20	a1	1719	100	6,3	0,96	6654	0,05534	2,2	0,4027	4,2	0,52	0,01719	2,7	0,05278	3,6	347	7	344	12	344	9	319	82
21	a2	2703	157	9,8	1,03	7837	0,05470	2,1	0,4045	4,4	0,47	0,01721	2,8	0,05364	3,9	343	7	345	13	345	10	356	87
23	a3	3086	182	11	0,95	9045	0,05498	2,1	0,4013	4,6	0,46	0,01782	2,8	0,05294	4,1	345	7	343	13	357	10	326	93
28	a5	8483	494	31	1,09	22129	0,05511	2,1	0,4071	3,0	0,69	0,01714	2,4	0,05358	2,2	346	7	347	9	344	8	354	50
30	a6	2326	135	8,5	1,49	8913	0,05556	2,1	0,4083	4,5	0,47	0,01706	2,2	0,05330	4,0	349	7	348	13	342	8	341	90
31	a7	3838	205	13	1,30	2977	0,05529	2,6	0,4039	5,3	0,49	0,01732	3,0	0,05299	4,6	347	9	345	16	347	10	328	105
32	a8	2321	134	8,5	1,39	1484	0,05538	2,3	0,4135	4,2	0,54	0,01740	3,0	0,05415	3,6	347	8	351	13	349	10	377	80
35	a9	6205	360	23	1,01	15170	0,05652	2,2	0,4125	3,7	0,59	0,01780	2,9	0,05293	3,0	354	7	351	11	357	10	326	68
38	a10	4757	281	18	1,06	1223	0,05483	2,3	0,4054	8,6	0,26	0,01717	3,3	0,05363	8,3	344	8	346	25	344	11	355	187
40	a11	7978	434	29	1,11	10637	0,05917	2,5	0,4410	4,0	0,63	0,01890	3,4	0,05406	3,1	371	9	371	13	378	13	374	71
43	a12	1094	67	4,1	0,79	4219	0,05396	2,8	0,3940	7,1	0,39	0,01724	3,1	0,05296	6,6	339	9	337	21	345	11	327	149
45	a13	3615	187	12	0,54	2780	0,05524	2,3	0,4109	7,3	0,32	0,01716	3,5	0,05395	6,9	347	8	350	22	344	12	369	155
48	a14	1484	89	5,7	1,19	5874	0,05674	2,4	0,4037	4,9	0,48	0,01735	2,5	0,05160	4,3	356	8	344	14	348	9	268	99
49	a15	5583	322	21	1,03	3131	0,05618	2,3	0,4199	4,0	0,56	0,01696	3,1	0,05420	3,3	352	8	356	12	340	10	380	75
52	a16	1581	96	6,0	1,26	6110	0,05470	2,1	0,3987	4,7	0,44	0,01699	2,8	0,05286	4,3	343	7	341	14	341	9	323	97
53	a17	2183	128	8,2	0,93	8320	0,05634	2,3	0,4164	4,3	0,52	0,01724	2,6	0,05360	3,7	353	8	353	13	346	9	354	84
54	a18	1362	84	5,3	1,05	5311	0,05493	2,3	0,3969	5,0	0,47	0,01723	2,9	0,05240	4,4	345	8	339	14	345	10	303	100
55	a19	6870	413	26	0,91	7615	0,05501	2,1	0,4069	3,4	0,61	0,01734	2,4	0,05364	2,7	345	7	347	10	347	8	356	61

Diameter of laser spot = 30μm; depth of crater ~15-20 μm. [a] Within run background-corrected mean ^{207}Pb signal in counts per second. [b] U and Pb content and Th/U ratio were calculated relative to GJ-1 reference (LA-ICP-MS values, Gerdes, unpublished). [c] corrected for background, common Pb and within-run Pb/U fractionation and subsequently normalised to GJ-1 (ID-TIMS value/measured value). $^{207}Pb/^{235}U$ calculated using $^{207}Pb/^{206}Pb/(^{238}U/^{206}Pb \times 1/137.88)$. Uncertainties propagated following Gerdes & Zeh (2006, 2009). [d] Rho is the error correlation defined as $err^{206}Pb/^{238}U/err^{207}Pb/^{235}U$

Table 2.- Results of U-Pb (LA-ICP-MS) zircon isotopic analyses of a medium- to coarse-grained Bt-granite clast (sample AN47) from the lower unit conglomerates of the Del Ratón Formation.

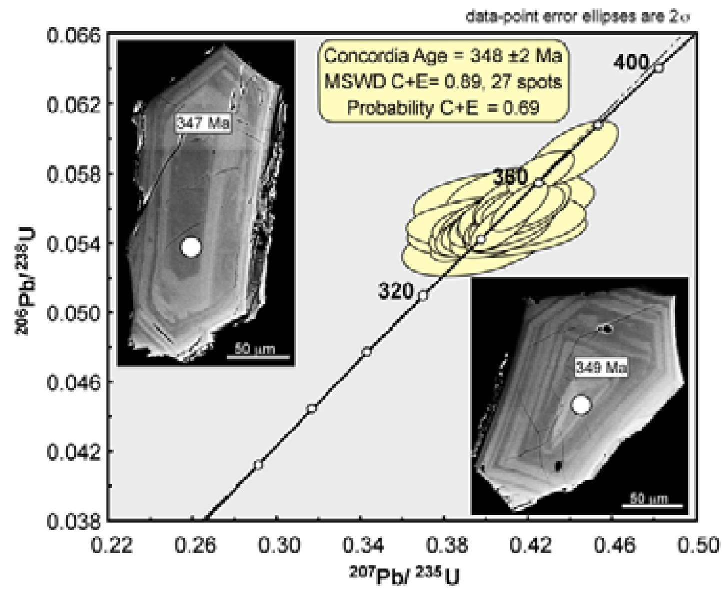

Fig. 6.- Concordia plot of U-Pb zircon isotopic analyses from medium- to coarse-grained Bt-granite clast of the Del Ratón conglomerate (sample AN47). Backscattered electron images of short-prismatic zircons with rhythmic concentric growth zoning.

north, Martina *et al*. (2011) describe an important early Carboniferous volcanic event related to coeval A-type granites of the Sierras Pampeanas and also generated in an extensional environment. This volcanism consists of calc-alkaline/A-type rhyolites similar in age (348-342 Ma) to the granitic clast of the Del Ratón conglomerate.

To the W of the Precordillera, in the Andean Frontal Cordillera (Fig. 1b) there are no known early Carboniferous igneous rocks at this latitude. However, further south of the study area in the Frontal Cordillera of Mendoza, there are outcrops of calc-alkaline igneous rocks of Early Devonian-early Carboniferous age (Caminos *et al*., 1979; Gregori *et al*., 1996; Tickyj *et al*., 2009; Tickyj, 2011), for example the Pampa de las Avestruces granodiorite of Early Devonian age (Tickyj et al., 2009) and the Carrizalito Tonalite dated at 334±17 Ma (K-Ar whole rock; Dessanti and Caminos, 1967). Also in this south sector (Cordón del Portillo) there is a plutonic association of gabbros and tonalites to granodiorites, and a volcanic sequence of andesites and dacites to rhyodacites and rhyolites (Polanski, 1972). One of these calc-alkaline rocks (Cerro Punta Blanca granodiorite) has been dated at 348±35 Ma (Rb-Sr) and 337±15 Ma (K-Ar) (Caminos *et al*., 1979). This calc-alkaline magmatism in the Frontal Cordillera of Mendoza has been interpreted as a magmatic arc (Tickyj, 2011), that could be associated with west-dipping subduction (Davis *et al*., 2000) prior to the accretion of the Chilenia terrane to the Precordillera (Cuyania terrane) and with crustal thickening during Chanic collision (Heredia *et al*., 2012).

6. Geochemistry

The geochemistry study of the igneous clasts in these conglomerates (Del Ratón and El Planchón) might test the possibility of a genetic relationship among the different clasts. In this way we could judge whether the clasts were derived from a single igneous complex or from unrelated intrusives. Clast geochemistry is also an important tool to identify possible sources by comparison with known igneous complexes.

6.1. Rock classification

The studied conglomerates are formed by different igneous clasts, as previously shown in the field and petrography sections. The different composition of these clasts is also observed in their geochemistry (Table 3). The rock classification using immobile trace elements (Nb, Y) combined with major elements (Winchester and Floyd, 1977) defines these rocks as subalkaline basalts/gabbros (basic clasts), andesites, dacites/rhyodacites (intermediate clasts), and rhyolites/granites, comendites/pantellerites (acid clasts) (Fig. 7a). Regarding the two different conglomerates, the El Planchón conglomerate includes only basic clasts whereas the Del Ratón conglomerate contains basic-intermediate-acid clasts.

In the Del Ratón clasts, the Daly gap (Dickin *et al*., 1984) is observed in the lower abundance of intermediate clasts compared to the acid and basic ones. Some of the intermediate clasts from the Del Ratón conglomerate had a slight alkaline (A-type) signature defined by their higher content in Zr+Nb+Ce+Y (Fig. 7b), but caution is necessary since many S-type peraluminous granitoids can also have such relatively high contents in these elements. Other geochemical parameters also indicate this alkaline signature for these samples (AN27, AN51): relatively high Na_2O+K_2O-CaO (≈ 7-8) and Fe_2O_3t/Fe_2O_3t+MgO (≈ 0.8) together with high Zr-saturation temperatures (TºC ≈ 850-900).

Regarding peraluminosity, the basic clasts are metaluminous but two groups can be established (Fig. 7c): the El Planchón basic clasts have the lowest values of ASI (Al_2O_3/ Na_2O+K_2O+CaO in molar proportions ≈ 0.4-0.6) whereas the Del Ratón basic clasts display higher and more variable ASI values (≈ 0.55-0.88-0.95). Such high values (0.88-0.95) for these basic compositions are probably related to contamination with peraluminous crustal lithologies or/and caused by higher sub-surface/surface alteration.

Intermediate and acid clasts from the Del Ratón conglomerate show variable ASI values, some of them are peraluminous to strongly peraluminous (AN52) while other clasts are metaluminous and metaluminous with elevated values of the agpaitic index (Na_2O+K_2O/Al_2O_3 in molar proportions) and felsic compositions. The reason for these high values is the high content of Na_2O relative to K_2O and Al_2O_3 (AN47-50-51 with Na_2O wt.% of ≈ 5-7.8). These high Na_2O contents produce high normative Ab values relative to normative Or and An giving a trondhjemitic signature to these rocks (Fig. 7d).

In order to compare the Del Ratón and El Plachón basic clasts with known compositions from mafic igneous rocks located nearby we have included in some of the plots the composition of Late Ordovician basalts and gabbros from the Western Precordillera (Sierra del Tigre basalts and gabbros; data from González-Menéndez *et al*., 2013). As observed in the figures 7 b and c, the El Planchón basic clasts are similar to the mafic compositions of the Western Precordillera basalts and gabbros in Zr+Nb+Ce+Y contents, as well as in ASI and Na_2O+K_2O/CaO values. On the other hand, the basic clasts from the Del Ratón conglomerate show higher ASI and Na_2O+K_2O/CaO values.

Formation	Del Ratón igneous clasts												El Planchón igneous clasts				
R. Type	Basic rocks			Intermediate rocks					Acid rocks				Basic rocks				
Sample	AN20	AN48	AN24	AN25	AN22	AN51	AN-27	AN26	AN52	AN49	AN50	AN47	AN20b	AN20c	AN20e	AN20d	AN20a
Major elements (wt %)																	
SiO_2	43.86	45.86	46.99	57.73	60.05	65.31	65.84	69.82	70.43	72.41	73.02	75.72	45.43	45.85	46.63	47.02	47.07
TiO_2	1.98	2.08	1.95	0.89	0.63	0.83	0.81	0.43	0.45	0.39	0.27	0.19	1.67	2.18	1.60	1.72	1.79
Al_2O_3	16.65	16.15	14.74	18.09	16.54	15.48	15.16	12.94	14.59	12.54	11.75	12.11	10.15	14.46	14.80	14.86	16.17
Fe_2O_3	13.86	13.73	8.09	5.95	6.62	3.78	5.14	4.04	3.20	3.73	1.79	0.99	13.87	12.95	11.34	11.74	11.24
MnO	0.38	0.30	0.26	0.10	0.12	0.10	0.09	0.09	0.06	0.07	0.06	0.04	0.21	0.19	0.17	0.17	0.18
MgO	5.12	5.37	2.92	2.31	2.86	1.26	1.17	1.24	1.61	1.05	0.47	0.23	11.53	7.45	8.22	7.14	6.54
CaO	6.45	7.47	10.24	4.42	5.36	1.95	1.05	1.26	0.38	0.50	2.62	1.22	12.69	11.04	12.10	11.50	11.58
Na_2O	3.10	2.54	4.40	4.53	2.66	7.86	4.59	3.61	1.14	3.90	5.02	6.9	1.16	2.05	1.79	2.19	2.47
K_2O	0.70	0.42	0.75	3.19	2.43	0.55	3.01	2.59	4.04	3.16	1.43	0.21	0.31	0.33	0.19	0.34	0.45
P_2O_5	0.19	0.21	2.14	0.25	0.18	0.42	0.02	0.10	0.14	0.06	0.11	0.03	0.14	0.21	0.13	0.15	0.17
LOI	6.71	5.19	6.91	1.89	2.05	1.82	2.34	2.68	3.14	1.58	2.81	1.55	2.25	2.59	2.51	2.51	2.28
Total	99.29	99.28	99.40	99.35	99.50	99.37	99.22	98.79	99.17	99.40	99.35	99.18	99.42	99.31	99.57	99.35	99.94
Trace elements (ppm)																	
V	380	308	164	107	183	56	86	44	44	60	26	9	376	323	289	309	285
Cr	351	199	48	25	79	3	30	21	6	6	3	4	422	324	614	312	212
Co	51	58	32	32	43	39	42	40	25	39	45	140	66	52	55	50	53
Ni	101	96	18	6	12	2	22	11	14	4			225	137	152	103	77
Cu	393	42	10	18	12		11	35	12	12		10	95	162	119	118	106
Zn	167	175	102	82	73	76	73	55	55	48	16	9	95	95	80	85	77
Ba	236	130	118	1073	501	228	850	495	292	932	299	502	120	137	67	51	121
Nb	7.8	9.9	15.9	9.2	7.4	37.2	33.1	22.6	24.6	20.3	18.5	22.9	6.6	8.1	5.8	7.1	7.5
Rb	16	12	20	137	96	10	69	62	129	74	32	5	10	11	9	11	13
Sr	336	360	575	494	332	292	262	131	48	206	123	115	180	266	215	238	242
Y	34	30	51	26	46	47	62	14	23	14	19	22	22	27	20	21	22
Zr	124	146	282	360	131	587	548	212	294	207	139	156	90	118	78	90	105
Pb	20	20.3	10.0	12.5	15.7	9.6	12.7	6.1	11.0	8.8	8.2	10.3	4.3	4.9	3.7	4.8	3.4
U	1.9	1.0	3.5	4.9	1.7	2.4	2.0	2.0	1.7	1.6	3.3	1.8	2.2	1.6	1.6	2.0	
Th		1.1	4.7	9.7	9.0	8.1	12.3	11.2	8.4	9.9	13.7	13.3					
Hf	3.90	3.68	5.10	8.30	4.00	13.74	12.70	4.20	8.46	5.37	4.70	5.27	2.33	3.23	2.37	2.48	2.62
Ta	0.62	0.49	1.10	0.75	0.73	2.24	2.23	1.97	2.15	1.82	2.02	1.70	0.46	0.69	0.49	0.54	0.56
La	20.08	25.27	94.60	30.48	23.18	108.40	78.71	54.37	49.89	14.02	42.75	40.94	7.02	10.38	7.12	7.56	8.25
Ce	45.39	48.48	172.90	67.31	54.46	221.90	154.60	86.11	100.90	27.90	81.08	76.55	16.97	25.47	17.56	18.53	20.31
Pr	6.35	6.26	23.94	9.21	7.45	24.57	19.45	11.49	11.58	3.32	8.34	7.35	2.38	3.75	2.45	2.59	2.86
Nd	25.88	26.54	89.22	34.69	30.06	86.40	63.34	37.61	38.40	11.49	27.57	21.81	12.14	18.04	12.21	12.92	13.92
Sm	6.38	6.18	15.95	6.68	7.35	13.52	11.31	5.56	5.94	2.22	4.53	3.39	3.48	4.93	3.47	3.62	3.89
Eu	1.88	1.91	4.13	1.78	1.34	3.04	2.04	1.09	0.95	0.60	0.76	0.44	1.18	1.61	1.26	1.31	1.35
Gd	7.03	6.60	15.62	6.25	7.66	12.08	12.43	5.13	5.37	2.21	4.14	3.39	3.89	5.30	3.78	4.01	4.16
Tb	1.12	1.04	2.00	0.90	1.32	1.58	1.84	0.59	0.70	0.34	0.55	0.48	0.69	0.89	0.66	0.68	0.71
Dy	6.62	6.21	10.07	4.94	8.37	8.79	11.26	2.84	4.12	2.20	3.21	3.08	4.14	5.28	3.97	4.13	4.26
Ho	1.31	1.20	1.88	0.97	1.78	1.70	2.29	0.54	0.85	0.46	0.66	0.67	0.82	1.05	0.78	0.81	0.84
Er	3.54	3.26	5.13	2.84	5.44	5.06	7.02	1.67	2.74	1.42	2.09	2.25	2.23	2.81	2.11	2.19	2.31
Tm	0.49	0.45	0.66	0.42	0.83	0.72	1.08	0.27	0.44	2.23	0.34	0.39	0.32	0.41	0.31	0.32	0.33
Yb	2.92	2.85	3.86	2.68	5.11	4.73	6.75	1.76	3.02	1.55	2.38	2.83	1.96	2.49	1.84	1.92	2.08
Lu	0.41	0.39	0.58	0.40	0.74	0.71	1.02	0.27	0.47	0.25	0.36	0.43	0.28	0.36	0.27	0.28	0.30

Table 3.- Whole-rock analyses of major and trace elements of the igneous clasts from the Del Ratón and El Planchón conglomerate formations.

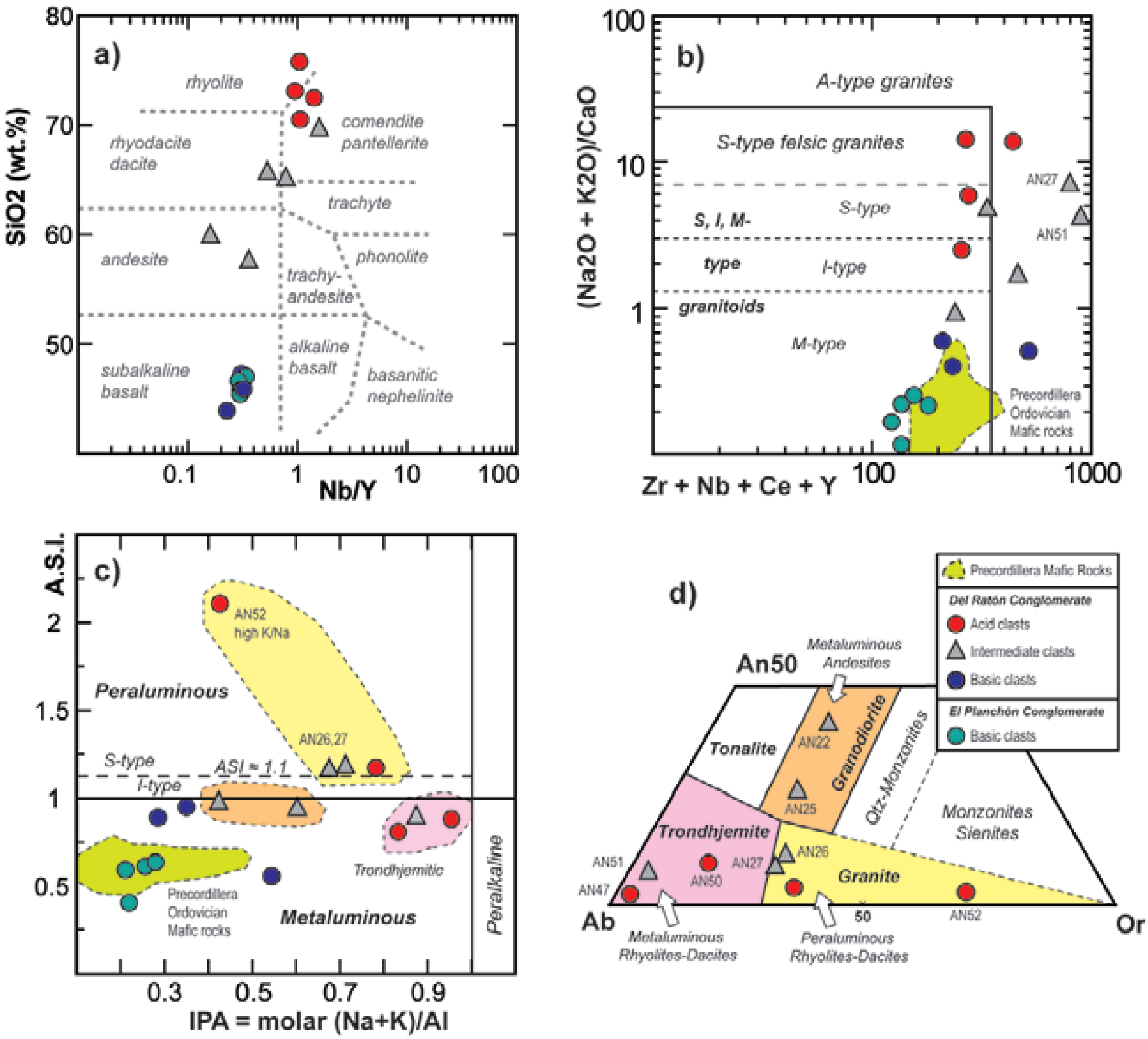

Fig. 7.- Geochemistry classifications of the Del Ratón and El Planchón igneous clasts. Data from the Western Precordillera Late Ordovician mafic rokcs is shown for comparison (González-Menéndez et al., 2013). a) Nb/Y vs. SiO_2 classification diagram of Winchester and Floyd (1977). b) (Na_2O + K_2O/CaO) vs. Zr+Nb+Ce+Y diagram of Whalen et al. (1987) for discriminating between A-type granitoids from other igneous rocks. c) Aluminium saturation index (A.S.I. = Al_2O_3/CaO+Na_2O+K_2O, mol) vs. Agpaitic index (I.P.A. = Na_2O+K_2O/Al_2O_3, mol) with fields of peraluminous (S- and I-types), metaluminous and peralkaline granitoids. d) Triangular Ab-Or-An for felsic granitoid classification of O´cconor (1965) modified by Baker (1979).

6.2. Geochemical variation trends

When all the samples are plotted in Harker diagrams some correlations can be observed: SiO_2 correlates well with TiO_2 (Fig. 8a) and Fe_2O_3, but less with MnO, MgO, and CaO. Other major elements such as Al_2O_3, Na_2O, K_2O, and P_2O_5 show no correlation with SiO_2 (Fig. 8b, c). The elements Na_2O and K_2O are prone to alteration and hence mobile, which could explain the absence of correlations. On the other hand, when only intermediate and acid clasts are considered (Fig. 8b), decreasing Al_2O_3 correlates well with increasing SiO_2. Correlations are also observed for some trace elements such as V, Sr (decrease with increasing SiO_2), and trace element ratios such as Nb/La that increase slightly with increasing SiO_2 (Fig. 8d, f). Other trace elements show considerable scatter (Ba, Nb, Y, Zr, REE, Th) except for Rb and U, which have similar trends to Sr and Al_2O_3, decreasing with increase SiO_2. All these trends could suggest an absence of petrogenetic relationship between the basic clasts and the intermediate-acid ones. The basic clasts fall away from the trends defined by the acid-intermediate ones for Al_2O_3, V, Sr, Rb, and U. There are also some differences in trace element ratios such as Nb/La, or La/Sm. Fractionation vectors were generated by linear mixing calculations (Ragland, 1989) for the intermediate-acid clasts. A combination of Pl+Bt+Amp fractionation (≈ 30%Amp + 40%Pl; 30%Bt) could explain part of the data such as the variations of Al_2O_3 and TiO_2 with the SiO_2 (Fig. 8a, b) but other element variations such as Na_2O and K_2O

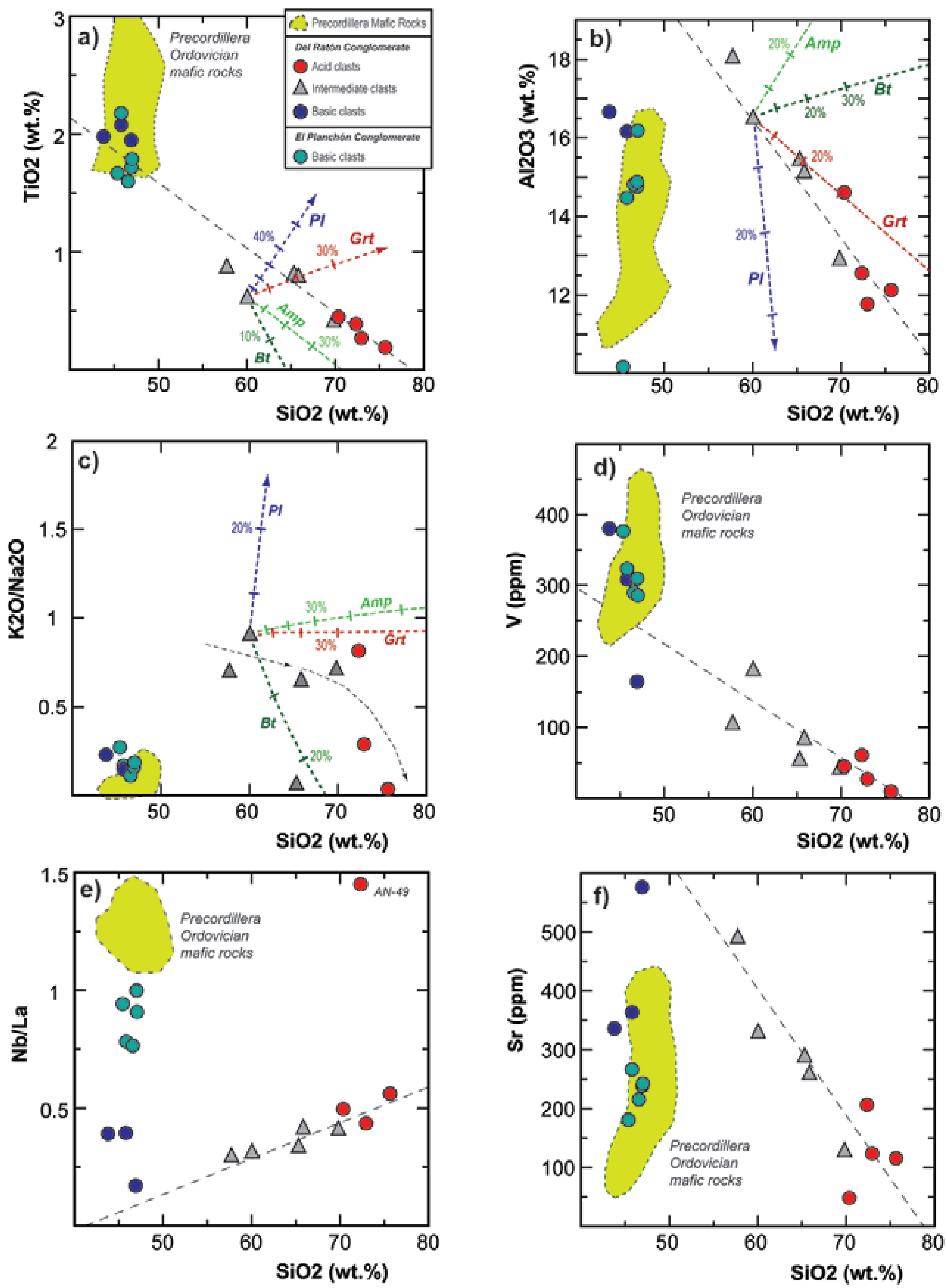

Fig. 8.- Diagrams of SiO_2 vs. major and trace elements (TiO_2, Al_2O_3, V, Sr) and element ratios (K_2O/Na_2O, Nb/La). Black dashed line shows the approximate trend defined by part of the rocks plotted. Basic rocks fall away from these trends defined by the acid-intermediate compositions. Colour dashed lines are linear mixing models generated by the fractionation of different mineral phases from a selected starting composition (Del Ratón Formation sample AN22). Marks on the lines are intervals of 10% crystallization.

(Fig. 8c) cannot be reproduced with these calculations (this could also be valid for some of the mentioned scattered trace elements). This lack of adjustment to simple differentiation processes could be due to the effect of alteration or to a lack of direct petrogenetic relationship.

6.3. Outstanding trace element features and REE data

Some trace element ratios and the REE contents can help to identify the existence or absence of petrogenetic links among the different clasts of these conglomerates. The La/Nb ratio can be used to investigate the volcanic arc vs. non arc-derived sources for basic to intermediate igneous rocks (Gill, 1981). The studied rock clasts show some scatter in the La vs. Nb diagram but two groups can be established (Fig. 9a). Many of the Del Ratón clasts plot in the volcanic arc settings with La/Nb > 2 values. The El Planchón basic clasts have La/Nb values < 2 and plot in the MORB field close to the Western Precordillera Late Ordovician basalts and gabbros (OIB/Within plate field). The Nb/La ratios compared with the Sr/Nd ones (Hawkesworth and Kemp, 2006) also show these differences: the basic clasts from the El Planchón conglomerate have Nb/La-Sr/Nd compositions close to primitive mantle and MORB while the ones from the Del Ratón conglomerate plot close to upper and bulk crust values and also close to the field of continental arcs (Fig. 9b). Regarding REE, it is noticeable that the basic clasts from the Del Ratón conglomerate have high La/Yb (> 5) and La/Sm (> 2.5) ratios compared to those from the El Planchón basic clasts, which have similar REE patterns to those of

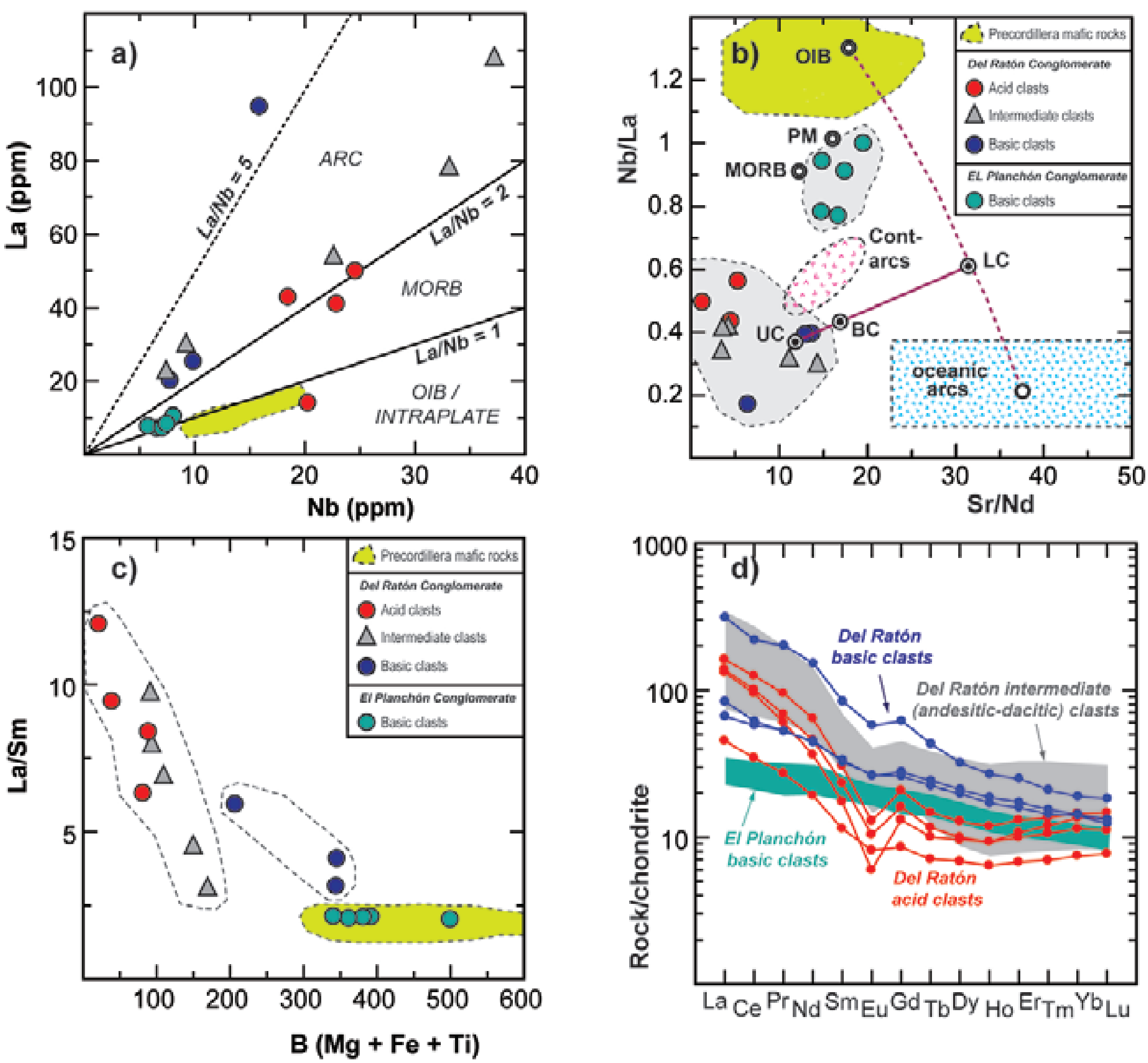

Fig. 9.- Trace and rare earth elements (REE) from the Del Ratón and El Planchón igneous clasts. a) Fields in the Nb vs La diagram are from Gill (1981). b) Fields and data in the Nb/La vs. Sr/Nd diagram are from Rudnick *et al*. (1995): MORB (Mid Ocean Rift Basalts), OIB (Oceanic Island Basalts), LC (Lower Crust), UC (Upper Crust), BC (Bulk Crust). c) La/Sm vs. B diagram. B parameter is from Debon and Lefort (1983) (B = Fe+Ti+Mg). d) REE diagram normalized to chondrites (Boynton, 1984).

the Late Ordovician Precordillera basalts and gabbros. The La/Sm vs. B (Mg+Ti+Fe) diagram (Fig. 9c) shows a correlation trend, defined by the Del Ratón intermediate-acid clasts, of increasing La/Sm (LREE-MREE fractionation), with decreasing B (or with SiO_2 increase) possibly related to increasing concentration of LREE rich accessories typical of felsic melts (Bea, 1996). The basic clasts from the Del Ratón conglomerate fall away from this trend suggesting an absence of petrogenetic relation to the intermediate-acid clasts.

The REE normalized patterns of the different clasts (Fig. 9d) show also the differences between the El Planchón basic clasts (smooth, low fractionated REE patterns, similar to those of tholeiites/enriched tholeiites, essentially without Eu negative anomalies) and the Del Ratón basic clasts. The latter show contrasting patterns, some samples have fractionated patterns with relatively high La/Yb (6-8) but other samples (AN24) have much higher fractionation (La/Yb = 25) and similar La/Sm values to some of the Del Ratón intermediate clasts. The Del Ratón intermediate and acid clasts have enriched LREE, marked Eu negative anomalies, and nearly flat HREE. The difference between these two groups (intermediate and acid clasts) lies in the absolute lower REE contents, higher LREE fractionation, and decreasing middle-heavy REE in the acid clasts. The comparison with other early Carboniferous igneous complexes such as A-type granitoids from the Sierras Pampeanas (Dahlquist *et al*., 2010; Alasino *et al*., 2012), located to the E and NE, and also to calc-alkaline granitoids from the Frontal Cordillera (Gregori et al., 1996), located to the SW, shows differences in both REE contents and normalized patterns (Fig. 10): A-type granitoids have higher total REE contents (some with significantly higher HREE), lower La/Sm ratios (flatter REE normalized patterns) and stronger negative Eu anomalies. Calc-alkaline granitoids show lower total contents of REE, lower La/Sm (but more similar to the Del Ratón clasts than A-type granitoids) and lower Eu anomalies.

6.4. Normalized trace elements and further comparisons with other magmatic units

Multi-element diagrams normalized to a primordial mantle composition (Sun and McDonough, 1989) were used for comparison between the studied conglomerates and possible igneous rock sources. As shown previously, the El Planchón basic clast compositions are different from the Del Ratón basic clasts. Their mantle-normalized pattern is smooth showing low fractionation between large ion lithophile elements (LILE) and high field strength elements (HFSE). Only some negative anomalies in K and P and slightly high Rb contents break this nearly flat pattern (Fig. 10a). This geochemistry is quite similar to that of the Late Ordovician basalts and gabbros from the Western Precordillera (data from González-Menéndez *et al*., 2013). Some differences are the higher positive Ba and negative K anomalies and lower Rb contents of some of the Precordilleran basalts and gabbros (Fig. 10a).

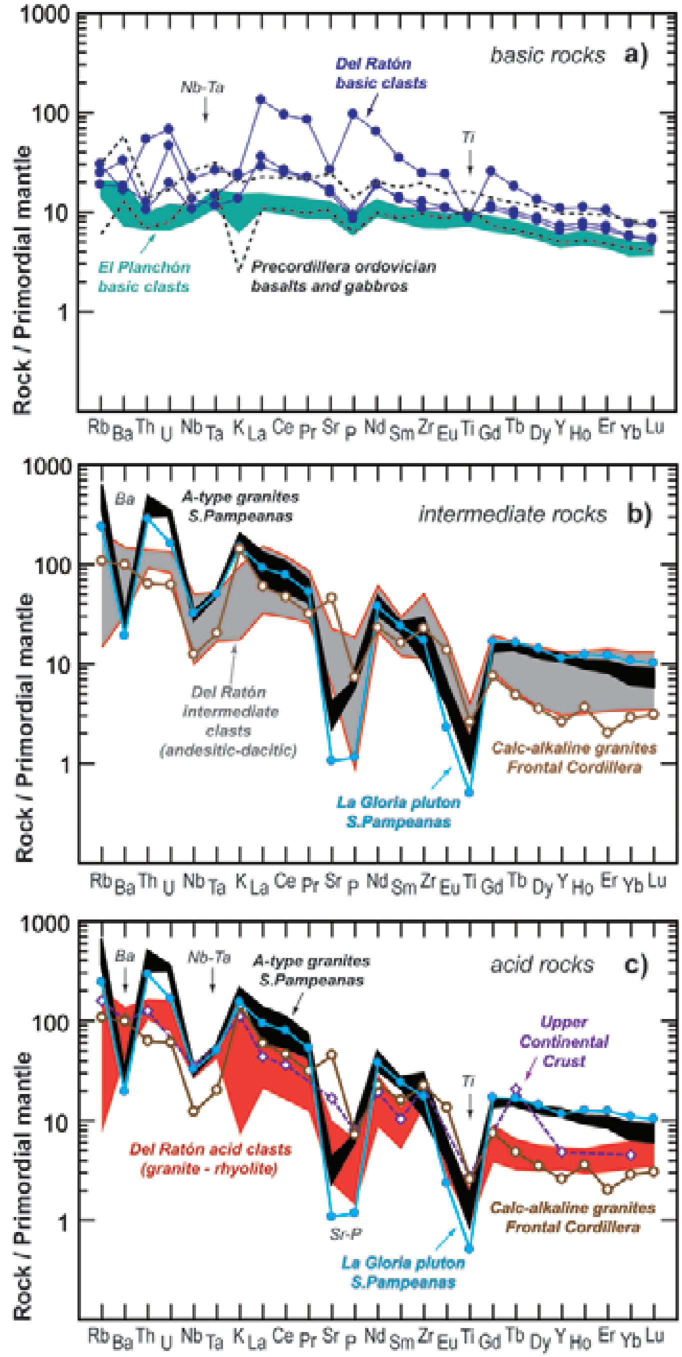

Fig. 10.- Multielement diagrams normalized to primordial mantle values (Sun and McDonough, 1989). Data from the Del Ratón and El Planchón conglomerates are plotted together with, basalts and gabbros from the Western Precordillera (González Menéndez *et al*., 2013), A-type granites from the Sierras Pampeanas (Dahlquist et al., 2010; Alasino *et al*., 2012), calc-alkaline granitoids from the Frontal Cordillera (Gregori *et al*., 1996), and average contents of the upper continental crust (Rollingson, 1993 and references therein. a) Basic clasts from the Del Ratón and El Planchón conglomerates. b) Intermediate clasts from the Del Ratón conglomerate. c) Acid clasts from the Del Ratón conglomerate.

The Del Ratón basic clasts have much higher contents in Th, U, LREE, and negative anomalies in Nb-Ta, P, and Ti. Some of these basic clasts have a normalized pattern similar to the intermediate clasts (Fig. 10b). The Del Ratón intermediate clasts have spiked mantle-normalized patterns with marked Nb-Ta, P, and Ti negative anomalies and Zr positive ones (Fig. 10b). This pattern is similar to that of the upper continental crust (but somewhat higher in REE contents). The Del Ratón acid clasts (Fig. 10c) have normalized patterns similar to those of the intermediate clasts and display negative anomalies in Nb-Ta, P and Ti and positive ones in Zr, but also show negative anomalies in Sr and K in some samples. The acid clasts normalized abundances are very similar to those of the upper continental crust.

For comparison with known possible early Carboniferous igneous sources, A-type igneous rocks (Dahlquist *et al*., 2010; Alasino *et al*., 2012) from the Sierras Pampeanas (located to the E and NE) and representative calc-alkaline granitoids (Gregori *et al*., 1996) from the Frontal Cordillera (located to SW) were plotted on the multi-element diagrams (Fig. 10b, c). The selected A-type granitoids have marked negative anomalies in Ba, positive ones in Rb-Th-U, and very strong Nb-Ta troughs. These are the main differences with the clasts from the Del Ratón conglomerate. In a more detailed comparison with the intermediate Del Ratón clasts, A-type granitoids also have stronger negative Eu, Sr and Ti anomalies, and higher REE contents. The Frontal Cordillera calc-alkaline granitoids show a very similar pattern to the Del Ratón clasts with only slightly higher Sr and lower HREE than the intermediate clasts, and higher Sr and deeper Nb-Ta trough than the acid clasts.

7. Discussion

7.1. Geochemical relationships among the different clasts

The petrography and geochemistry reveals that the basic clasts from the El Planchón conglomerate are different from the rest of the studied rocks. The geochemistry also indicates that the most probable source of the El Planchón basic clasts is the Late Ordovician basalts and gabbros of the Western Precordillera mafic belt (Haller and Ramos, 1984; Kay *et al*., 1984; Davis *et al*., 2000; Ramos *et al*., 2000; González Menéndez *et al*., 2013). Both have tholeiitic to transitional geochemistry probably related to extensional continental or continental-oceanic transitional settings (OIB/Withinplate/MORB).

The basic clasts from the Del Ratón conglomerate have a subduction-related geochemistry (Nb-Ta negative anomalies, elevated LILE/HFSE and La/Yb ratios, La/Nb >2) suggesting a provenance from a mantle arc source, or/and, from mantle-derived basalts contaminated with continental crust materials.

Intermediate clasts from the Del Ratón conglomerate also have similar arc-related features and could have been derived by partial melting of mafic arc rocks. An alternative model could be that these intermediate rocks resulted from the magmatic differentiation of mafic arc magmas (crystal fractionation, crustal contamination). These supposed mafic precursors could be the basalt clasts mentioned above. The observed magmatic trends of the basic and intermediate rocks are substantially different for some elements (Al, Sr) but not for others (Ti, V, Mg), which seems to negate simple fractional crystallization or binary mixing.

Intermediate and acid clasts from the Del Ratón conglomerate could be related by straight differentiation (fractional crystallization) processes. The observed trends in the Harker diagrams (Fig. 8) are continuous between both groups of rocks (intermediate and acid clasts). The fractionation vectors calculated by linear mixing show that coupled fractionation of Pl+Amp+Bt could explain the actual trends for most of the major elements (Al, Ti, Mg, Mn, Ca, K, Na). The amphibole fractionation could also explain the middle-heavy REE decreasing in the acid clasts (Fig. 9d).

7.2. Implications for the provenance of the clasts

The composition of the clasts from the Del Ratón conglomerate and their comparison with the Frontal Cordillera calc-alkaline igneous rocks (Fig. 10) indicates a source area probably located along this Frontal Cordillera (Fig. 11a). In this N-S orientated range, the igneous calc-alkaline granitoids occur presently to the southwest of the Del Ratón outcrops. These calc-alkaline complexes are Devonian to early Carboniferous in age and mostly consists of igneous rocks including gabbros, tonalites, granodiorites, granites, andesites, dacites, rhyodacites and rhyolites (Polanski, 1972; Caminos *et al*., 1979; Gregori *et al*., 1996; Tickyj, 2011). Such a provenance is in agreement with the observed similar geochemistry of the Del Ratón clasts (Fig. 10b, c) and also with the U-Pb (~348 Ma) age obtained in one of these clasts. The geochemistry also indicates that the acid and intermediate clasts probably come from a single igneous batholithic complex. The basic clasts, given their calc-alkaline signature, could be either mafic intrusives forming part of the same batholithic complex as the intermediate and acid clasts or derived from different intrusive units in other domains of the Frontal Cordillera. Recent palaeocurrent research (Colombo *et al*., 2012) indicates that the main provenance source for the Del Ratón clasts is from the Frontal Cordillera, from the west and northwest from its present outcrops. This contrasts with the absence of early carboniferous igneous rocks at this latitude. A possible solution is that such early Carboniferous calc-alkaline granitoids originally cropping out farther north in the Frontal Cordillera (Fig. 11a, b) have been oblitered by subsequent erosion and profuse Permo-Triassic plutonism (Colangüil batholith; Llambías and Sato, 1990, 1995; Sato et al., 1990) and volcanism (Choiyoi Group; Sato and Llambías, 1993; Llambías *et al*., 2003).

Another possible early Carboniferouos source for the Del Ratón conglomerate could be calc-alkaline/A-type rhyolites, A-type granites and syenogranites, alkaline S-type granodiorites to granites, and alkaline I-type tonalites to granites, located to the N and NE in the Sierras Pampeanas (Dahlquist et al., 2010; Martina *et al*., 2011; Alasino *et al*., 2012) (Fig.

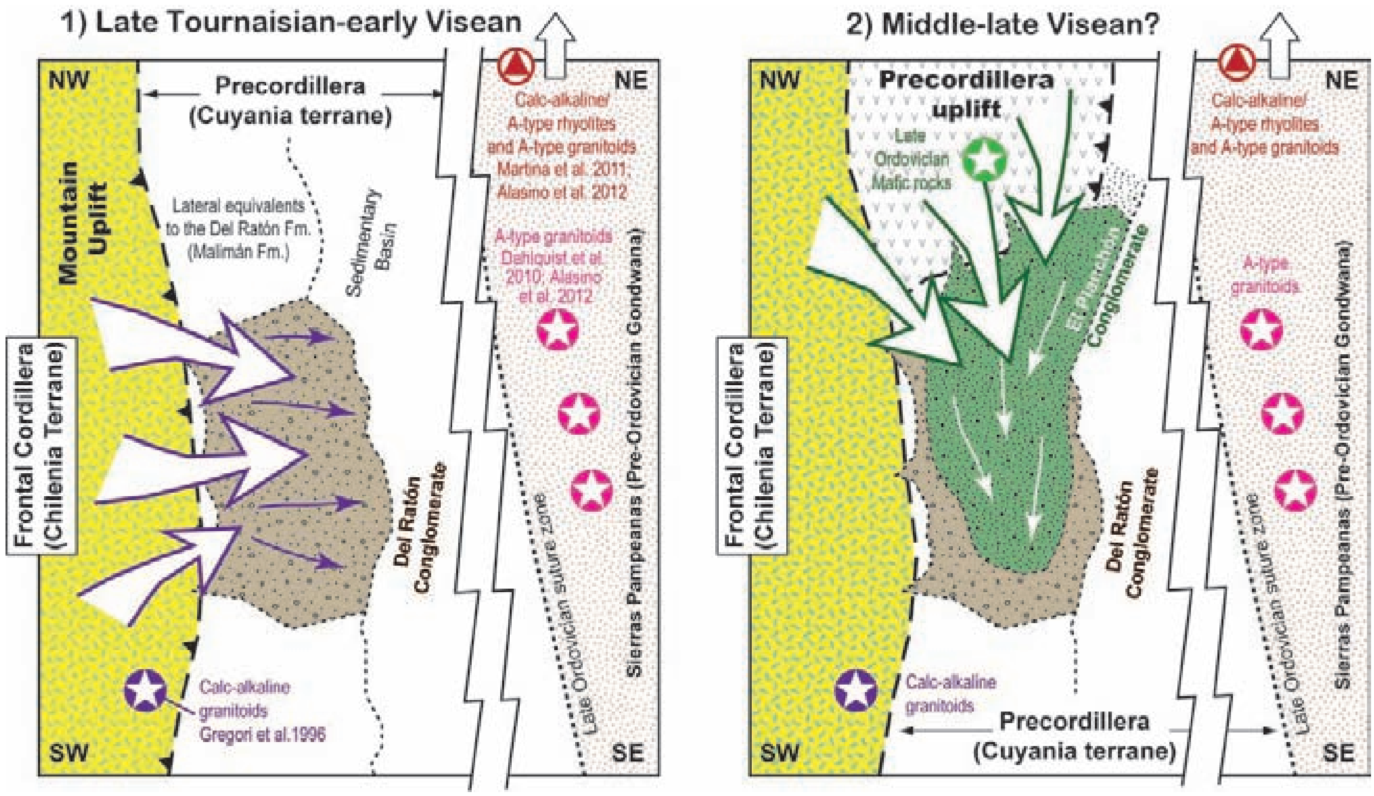

Fig. 11.- Schematic illustrations (no to scale) of the geological setting and possible sources of a) the Del Ratón conglomerates (late Tournaisian-early Visean) and b) the El Planchón conglomerates (middle-late Visean?). During the late Tournaisian-early Visean (a), the Frontal Cordillera (Chilenia terrane) was uplifted due to its collision with the Precordillera (Cuyania terrane). The Frontal Cordillera was composed at this time by calc-alkaline igneous rocks formed during a previous subduction event. Erosion of these igneous rocks and eastward sediment delivery generated the Del Ratón conglomerates (western provenance). Lateral equivalent facies of the Del Ratón Formation are the Malimán Formation to the north. This erosion processes probably removed many of the calc-alkaline igneous complexes and only south-southwest domains of the Frontal Cordillera still preserved the original calc-alkaline igneous rocks. Deformation was probably transferred eastwards, in the northern domains, causing uplift of a Precordillera basement block (Proto-Precodillera). Further erosion of this block produced the main sediment delivery towards the south and formed the El Planchón conglomerate (northern provenance).

11). However, their compositions (Fig. 10b, c) differ from those of the Del Ratón clats. The stratigraphic constraints of provenance from the W and NW (Colombo *et al.*, 2012) also preclude such rocks as the source.

The petrography and geochemistry indicates that the sources of the El Planchón basic clasts are the Late Ordovician sedimentary formations (Alcaparrosa-Yerba Loca Formation) that according to Haller and Ramos (1984), Kay *et al.* (1984), Davis *et al.* (2000), and Ramos *et al.* (2000) host a significant volume of interlayered mafic volcanics and sills. This would indicate a provenance either from the north or south (in present coordinates). Possible source areas with the suitable basaltic compositions occur within 50 km (to both north and south). Northern provenance of these clasts (Fig. 11b) is the preferred hypothesis because it agrees with recent palaeocurrent studies (Colombo *et al.*, 2012). Nevertheless, tholeiitic rocks of early Carboniferous age occur in southern locations of the Frontal Cordillera of Mendoza (Gregori *et al.*, 1996). These rocks have similarities in composition to the El Planchón basic clasts and also to the Late Ordovician Precordillera mafic rocks and therefore cannot be discarded as possible sources once located along the Frontal Cordillera (Fig. 11b).

The fact that the El Planchón conglomerate contains much older clasts (probably Late Ordovician) compared to the ones from the Del Ratón (early Carboniferous) has further significance since the Del Ratón Formation underlies the El Planchón Formation (Quartino et al., 1971; Alonso *et al.*, 2005; Colombo *et al.*, 2012). The fact that the older conglomerate (Del Ratón) includes younger clasts than the younger conglomerate (El Planchón) suggests that the first reliefs uplifted and eroded in the early Carboniferous (~348 Ma) where those of the Frontal Cordillera (Fig. 11a) as also indicated by Colombo et al. (2012). These clasts were transported eastwards and were deposited in the locations where the Del Ratón Formation presently outcrops (i.e., western provenance). Afterwards, this sedimentary flux from the Frontal Cordillera was partially shut off, orogenic deformation was transferred towards the east (in the northern domains) and the Precordillera was probably uplifted (Proto-Precordillera block; Fig. 11b). The partial erosion of its early Palaeozoic formations produced the main clastic component delivery towards the south that formed the El Planchón conglomerate (northern provenance). This scenario suggests that the main uplift of the Frontal Cordillera domain was followed by uplifts farther east during the early to late Carboniferous period.

8. Conclusions

The Del Ratón conglomerate igneous clasts are basic, intermediate and acid rocks with calc-alkaline geochemical signatures. Laser ablation has yielded a U-Pb zircon age of 348±2 Ma (late Tournaisian), interpreted as the maximum deposition age of this conglomerate formation. The Del Ratón clasts are similar in petrography and geochemistry to some early Carboniferous calc-alkaline complexes of the Frontal Cordillera suggesting provenance from the west or northwest. Frontal cordillera sources could have had one source location (a single igneous batholithic complex accounting for basic-intermediate-acid clasts) or varied ones (accounting for the basic clasts and for the intermediate-acid clasts).

The basic igneous clasts from the El Planchón conglomerate are different from those of the Del Ratón. Their petrology and geochemistry is that of tholeiites from extensional continent-oceanic transition or intraplate settings without any arc signature. The similarities with Late Ordovician mafic igneous rocks of the western Precordillera suggest a provenance from the erosion of early Palaeozoic formations that outcrop in the Argentine Precordillera (north provenance). These formations usually contain abundant mafic volcanic and subvolcanic rocks (i.e. Late Ordovician Alcaparrosa-Yerba Loca Formation). Other possible sources along the Frontal Cordillera cannot be discarded but their clastic input was probably minor.

The erosional events that delivered the clasts of the Del Ratón and El Planchón formations were probably related to mountain range uplift episodes during the early (~348 Ma) Carboniferous period. Uplift seems to have migrated from the Frontal Cordillera domain (producing clasts transported eastwards to generate the Del Ratón conglomerate) eastwards to the Precordillera (shifting to clasts transported mainly from the north, generating the El Planchón conglomerates).

Acknowledgments

We greatly appreciate the review of R.J. Pankhurst for their constructive comments, and English corrections, which have improved the original manuscript. We thank C.O. Limarino, S.N. Césari, F. Colombo, N. Heredia and an anonymous reviewer for their suggestions. Catalina Suárez is thanked for producing maps figures. Financial support was provided by CGL2006-12415-C03 and CGL2009-13706-C03 projects (I+D+i Spanish Programmes) and FEDER Funds of the EU.

References

Alasino, P.H., Dahlquist, J.A., Pankhurst, R.J., Galindo, C., Casquet, C., Rapela, C.W. (2012): Early Carboniferous sub- to mid-alkaline magmatism in the Eastern Sierras Pampeanas, NW Argentina: A record of crustal growth by the incorporation of mantle-derived material in an extensional setting. *Gondwana Research* 22(3-4), 992-1008. doi: 10.1016/j.gr. 2011.12.011.

Alonso, J.L., Farias, P., Rodríguez Fernández, L.R., Heredia, N., García-Sansegundo J. (2005): Stratigraphic location of the Planchón Conglomerates (Western Argentine Precordillera, San Juan river). *Abstracts Gondwana 12: Geological and Biological Heritage of Gondwana*. Academia Nacional de Ciencias de Argentina (R.J. Pankhurst, G.D. Veiga, eds.), Mendoza, Argentina: p. 41.

Alonso, J.L., Gallastegui, J., García-Sansegundo J., Farias, P., Rodríguez Fernández, L.R., Ramos V.A. (2008): Extensional tectonics and gravitational collapse in an Ordovician passive margin: The Western Argentine Precordillera. *Gondwana Research* 13(2), 204-215. doi: 10.1016/j.gr. 2007.05.014.

Amenábar, C.R., di Pasquo, M. (2008): Nuevos aportes a la palinología, cronología y paleoambiente de la Precordillera occidental de Argentina: formaciones El Planchón, Codo (Devónico) y El Ratón (Mississippiano). *Acta Geológica Lilloana* 21(1), 3-20.

Astini, R.A. (1997): Las unidades calcáreas del Ordovícico Medio y Superior de la Precordillera Argentina como indicadores de una etapa extensional. *Actas II Jornadas de Geología de Precordillera*. San Juan, Argentina: 8-14.

Astini, R.A., Benedetto, J.L., Vaccari, N.E. (1995): The early Paleozoic evolution of the Argentine Precordillera as a Laurentia rifted, drifted and collided terrane: a geodynamic model. *Geological Society of America Bulletin* 107(3), 253-273. doi: 10.1130/0016-7606(1995)107<0253:TEPEOT>2.3.CO;2.

Astini, R.A., Martina, F., Dávila, F.D. (2011): La Formación Los Llantares en la Precordillera de Jagüe (La Rioja) y la identificación de un episodio de extension en la evolución temprana de las cuencas del Paleozoico superior en el oeste Argentino. *Andean Geology* 38(2), 245-267. doi: 10.5027/andgeoV38n2-a01.

Azcuy, C.L., Césari, S.N., Longobucco, M.I. (1981): Las plantas fósiles de la Formación El Ratón (Provincia de San Juan). *Ameghiniana* 18, 11-28.

Azcuy, C.L., Carrizo, H.A., Caminos, R. (2000): Carbonífero y Pérmico en las Sierras Pampeanas, Famatina, Precordillera, Cordillera Frontal y Bloque San Rafael. In: R. Caminos (ed.), *Geología Argentina*. Instituto de Geología y Recursos Minerales, Buenos Aires, Anales 29: 261-318.

Azcuy, C.A., Beri, A., Bernardes-de-Oliveira, M.E.C., Carrizo, H.A., di Pasquo, M.M., Díaz Saravia, P., González, C., Iannuzzi, R., Lemos, V.B., Melo, J.H.G., Pagani, A., Rohn, R., Rodríguez Amenábar, C., Sabattini, N., Souza, P.A., Taboada, A., Vergel, M.M. (2007): Bioestratigrafía del Paleozoico Superior de América del Sur: primera etapa de trabajo hacia una nueva propuesta cronoestratigráfica. *Asociación Geológica Argentina, Serie D, Publicación Especial* No 11: 9-65.

Baldis, B.A., Chebli, G. (1969): Estructura profunda del área central de la Precordillera sanjuanina. Cuartas Jornadas Geológicas Argentinas, 1, 47-66.

Barker, F. (1979): Trondjemite: Definition, enviroment, and hypotesis of origin. In: F. Barker (ed.), *Trondjemites, dacites and related Rocks*, Elsevier, Amsterdam: 1-12.

Bea, F. (1996): Residence of REE, Y, Th and U in granites and crustal protoliths; implications for the chemistry of crustal melts. *Journal of Petrology* 37(3), 521-552. doi:10.1093/petrology/37.6.1601.

Bordonaro, O. (1999): Cámbrico y Ordovícico de la Precordillera y Bloque de San Rafael. In: R. Caminos (ed.), *Geología de Argentina*.

Subsecretaría de minería de la Nación, Instituto de Geología y Recursos Minerales. Anales 29(8): 189-204.

Boynton, W.V. (1984): Geochemistry of rare earth elements: Meteorite studies. In: P. Henderson (ed.), *Rare Earth Element Geochemistry*, Elsevier, New York: 63-114.

Bracaccini, O. (1946): Contribución al conocimiento geológico de la Precordillera Sanjuanina-Mendocina. *Boletín de Informaciones petroleras, Buenos Aires,* 258: 16-17.

Caminos, R., Cordani, U.G., Linares, E. (1979): Geología y geocronología de las rocas metamórficas y eruptivas de la Precordillera y Cordillera Frontal de Mendoza, República Argentina. *Actas 1, Segundo Congreso Geológico Chileno*, Arica, Chile: 43-61.

Césari, S.N., Gutiérrez, P.R. (2001): Palynostratigraphic study of the Upper Paleozoic central-western Argentinian sequences. *Palynology* 24, 113-146. doi: 10.2113/0240113.

Césari, S.N., Limarino, C.O., Gulbranson, E.L. (2011): An Upper Paleozoic bio-chronostratigraphic scheme for the western margin of Gondwana. *Earth-Science Reviews* 106, 149-160. doi.org/10.1016/j.earscirev.2011.01.012.

Colombo, F., Limarino, C.O., Spalletti, L.A., Cardó, R., Busquets, P., Méndez Bedia, I., Heredia, N. (2012): Unidades neopaleozoicas de la Precordillera de San Juan, Argentina. Características de las formaciones Ratón, Planchón y Salto. *Resúmenes extendidos del VIII Congreso Geológico de España.* CD anexo a Geo-Temas 13 (L.P. Fernández, A. Fernández , A. Cuesta, J.R. Bahamonde, eds.), Oviedo: 1863-1866.

Dahlquist, J.A., Alasino, P.H., Eby, G.N., Galindo, C., Casquet, C. (2010): Fault controlled Carboniferous A-Type magmatism in the proto-Andean foreland (Sierras Pampeanas, Argentina): geochemical constraints and petrogenesis. *Lithos* 115, 65-81. doi: 10.1016/j.lithos.2009.11.006.

Dahlquist, J.A., Pankhurst, R.J., Rapela, C.W., Casquet, C., Fanning, C.M., Alasino, P., Baez, M. (2006): The San Blas Pluton: An Exemple of Carboniferous plutonismo in the Sierras Pampeanas, Argentina. *Journal of South American Earth Sciences* 20, 341-350. doi:10.1016/j.jsames.2005.08.006.

Dalziel, I.W.D. (1997): Neoproterozoic-Paleozoic geography and tectonics: Review, hypothesis, environmental speculation. *Geological society of America Bulletin* 109(1), 16-42. doi: 10.1130/0016-7606(1997)109<0016:ONPGAT>2.3.CO;2.

Davis, J.S., Roeske, S.M., McClelland, W.C., Kay, S.M. (2000): Mafic and ultramfic crustal fragments of the southwestern Precordillera terrane and their bearing on tectonic models of the early Paleozoic in western Argentina. *Geology* 28 (2), 171-174. doi: 10.1130/0091-7613(2000)28<171:MAUCFO>2.0.CO;2.

Davydov, V.I., Crowley, J.L., Schmitz, M.D., Poletaev, V.I. (2010): High-precision U-Pb zircon age calibration of the global Carbonifeous time scale and Milankovitch band cyclicity in the Donets basin, eastern Ukraine. *Geochemistry, Geophysics, Geosystems* 11(2), 1-22. doi:10.1029/2009GC002736.

De Rosa, L.A. (1983): Sedimentitas continentales del Carbónico inferior del flanco occidental de la Precordillera, Dto. Calingasta-Pcia. de San Juan. *Revista de la Asociación Argentina de Mineralogía, Petrología y Sedimentología* 14, 51-59.

Debon, F., Le Fort, P. (1983): A chemical-mineralogical classification of common plutonic rocks and associations. *Trans. R. Soc. Edinburgh: Earth Sci.* 73, 135-149.

Dessanti, R., Caminos, R. (1967): Edades potasio-argón y posición estratigráfica de algunas rocas ígneas y metamórficas de la Precordillera, Cordillera Frontal y Sierras de San Rafael, provincia de Mendoza. *Revista de la Asociación Geológica Argentina* 22(2), 135-162.

Dickin, A.P., Brown, J.L., Thompson, R.N., Halliday, A.N., Morrison, M.A., Hutchinson, R., O'hara, M.J. (1984): Crustal contamination and granite problem in the British Tertiary Volcanic Province. *Philosophical Transactions of the Royal Society of London*, Series A310: 755-780.

Finney, S.C. (2007): The parautochthonous Gondwanan origin of the Cuyania (greater Precordillera) terrane of Argentine: A re-evaluation of evidence used to support an allochthonous Laurentia origin. *Geologica Acta* 5(2), 127-158. doi: 10.1344/105.000000300.

Frost, B.R., Barnes, C.G., Collins, W.J., Arculus, R.J., Ellis, D.J., Frost, C.D. (2001): A geochemical classification for granitic rocks. *Journal of Petrology* 42, 2033-2048. doi:10.1093/petrology/42.11.2033

Furque, G. (1956): Nuevos depósitos devónicos y carbónicos en la Precordillera sanjuanina. *Revista de la Asociación Geológica Argentina* 11(1), 46-71.

Furque, G. (1979): Descripción geológica de la Hoja 18c, Jáchal, Provincia de San Juan. *Carta Geológico-Económica de la República Argentina, Escala 1:200.000*. Servicio Geológico Nacional, Buenos Aires, Boletín 164: 79 p.

García de Madinabeitia, S., Sánchez Lorda, M.E., Gil Ibarguchi, J.I. (2008): Simultaneous determination of major to ultratrace elements in geological samples by fusion-dissolution and inductively coupled plasma mass spectrometry techniques. *Analytica Chimica Acta* 625(2), 117-130. doi.org/10.1016/j.aca.2008.07.024.

Gerdes, A., Zeh, A. (2006): Combined U-Pb and Hf isotope LA-(MC-) ICP-MS analyses of detrital zircons: Comparison with SHRIMP and new constraints for the provenance and age of an Armorican metasediment in Central Germany. *Earth and Planetary Science Letters* 249(1-2), 47-62. doi: 10.1016/j.epsl.2006.06.039.

Gerdes, A., Zeh, A. (2009): Zircon formation versus zircon alteration – new insights from combined U–Pb and Lu–Hf in situ LA-ICP-MS analyses, and consequences for the interpretation of Archean zircon from the Central Zone of the Limpopo Belt. *Chemical Geology* 261(3-4), 230-243. doi: 10.1016/j.chemgeo.2008.03.005.

Gill, J.B. (1981): *Orogenic Andesites and Plate Tectonics*. Springer-Verlag, Berlin: 380 p.

González-Menéndez, L., Gallastegui, G., Cuesta, A., Heredia, N., Rubio-Ordóñez, A. (2013): Petrogenesis of Early Paleozoic basalts and gabbros in the western Cuyania terrane: Constraints on the tectonic setting of the southwestern Gondwana margin (Sierra del Tigre, Andean Argentine Precordillera). *Gondwana Research* 24(1), 359-376. doi: 10.1016/j.gr. 2012. 09. 011.

Gosen, W. von (1997): Early Paleozoic and Andean structural evolution in the Río Jáchal section of the Argentine Precordillera. *Journal of South American Earth Sciences* 10(5-6), 361-388. doi.org/10.1016/S0895-9811(97)00029-1.

Gregori, D.A., Fernández-Turiel, J.L., López-Soler, A., Petford, N. (1996): Geochemistry of Upper Palaeozoic-Lower Triassic granitoids of the Central Frontal Cordillera (33º 10-33º 45), Argentina. *Journal of South American Earth Sciences* 9(1-2), 141-151. doi.org/10.1016/0895-9811(96)00034-X.

Grosse, P., Söllner, F., Báez, M.A., Toselli, A.J., Rossi, J.N., de la Rosa, J.D. (2009): Lower Carboniferous post-orogenic granites in central-eastern Sierra de Velasco, Sierras Pampeanas, Argentina: U-Pb monazite geochronology, geochemistry and Sr-Nd isotopes. *International Journal of Earth Science (Geol Rundsch)* 98, 1001-1025. doi: 10.1007/s00531-007-0297-5.

Guerstein, M., Laya, H., Pezutti, N. (1965): Bosquejo fotogeológico de la zona de "Las Juntas" (Dto. Calingasta, provincia de San Juan). *Acta Geológica Lilloana* 7, 231-242.

Haller, M.A., Ramos, V.A. (1984): Las ofiolitas famatinianas (Eopaleozoico) de las provincias de San Juan y Mendoza. *Actas 2, 9º Congreso Geológico Argentino*, Bariloche, Argentina: 66-83.

Hawkesworth, C.J., Kemp, A.I.S. (2006): The differentiation and rates of generation of the continental crust. *Chemical Geology* 226, 134-143. doi: 10.1016/j.chemgeo.2005.09.017.

Heim, A. (1952): Estudios tectónicos en la Precordillera de San Juan, en los ríos San Juan, Jáchal y Huaco. *Revista de la Asociación Geológica Argentina* 7, 11-70.

Heredia, N., Farias, P., García-Sansegundo, J., Giambiagi, L. (2012): The basement of the Frontal Cordillera in the Cordón del Plata (Mendoza, Argentina): Geodynamic Evolution. *Andean Geology* 39(2), 242-257. doi: 10.5027/andgeoV39n2-a03.

Jackson, S.E., Pearson, N.J., Griffin, W.L., Belousova, E.A., (2004): The application of laser ablation-inductively coupled plasma-mass spectrometry to in situ U-Pb zircon geochronology. *Chemical Geology* 211(1-2), 47-69. doi: 10.1016/j.chemgeo.2004.06.017.

Janoušek, V., Gerdes, A., Vrána, S., Finger, F., Erban, V., Friedl, G., Braithwaite, C.J.R. (2006): Low-pressure Granulites of the Lišov Massif, Southern Bohemia: Viséan Metamorphism of Late Devonian Plutonic Arc Rocks. *Journal of Petrology* 47, 705-744. doi:10.1093/petrology/egi091.

Kay, S.M., Ramos, V.A., Kay, R. (1984): Elementos mayoritarios y trazas en las vulcanitas ordovícicas en la Precordillera Occidental: Basaltos de rift oceánico temprano (?) próximos al margen continental. *Actas 2, 9º Congreso Geológico Argentino*, Bariloche: p. 48-65.

Keller, M. (1999): Argentine Precordillera: sedimentary and plate tectonic history of a Laurentia crustal fragment in South America. *Geological Society of America Special Paper* 341, 1-131. doi:10.1130/0-8137-2341-8.1

Keller, M., Lenhnert, O., Buggisch, W. (1993): The transition from diagenesis to low-grade metamorphism in the Argentine Precordillera: An application of the conodont colour alteration index. *Actas 1, XII Congreso geológico Argentino y II Congreso de Exploración de Hidrocarburos*: 294-299.

Kerlleñevich, S.C. (1967): Hallazgo del Devónico marino en la zona de Calingasta, provincia de San Juan. *Revista de la Asociación Geológica Argentina* 22, 291-294.

Llambías, E.J., Sato, A.M. (1990): El Batolito de Colangüil (29º-31ºS), Cordillera Frontal, Argentina: Estructura y marco tectónico. *Revista Geológica de Chile* 17(1), 89-108.

Llambías, E.J., Sato, A.M. (1995): El Batolito de Colangüil: transición entre orogénesis y anorogénesis. *Revista de la Asociación Geológica Argentina* 50(1-4), 111-131.

Llambías, E.J., Quenardelle, S., Montenegro, T. (2003): The Choiyoi Group fron central Argentina: a subalkaline transitional to alkaline association in the craton adjacent to the active margin of the Gondwana continent. *Journal of South American Earth Science* 16, 243-275. doi:10.1016/S0895-9811(03)00070-1.

Limarino, C.O., Césari, S.N. (1993): Reubicación estratigráfica de la Formación Cortaderas y definición del Grupo Angualasto (Carbonífero inferior, Precordillera de San Juan). *Revista de la Asociación Geológica Argentina* 47(1), 61-72.

Limarino, C.O., Spalletti, L.A. (2006): Paleogeography of the upper Paleozoic basins of southern South America: An overview. *Journal of South American Earth Science* 22, 134-155. doi:10.1016/j.jsames.2006.09.011.

Limarino, C.O., Tripaldi, A., Marenssi, S., Fauqué, L. (2006): Tectonic, sea-level, and climatic controls on Late Paleozoic sedimentation in the western basins of Argentina. *Journal of South American Earth Science* 22, 205-226. doi:10.1016/j.jsames.2006.09.009.

Limarino, C.O., Colombo, F., Busquets, P., Spalletti, L., Méndez-Bedia, I., Cardó, R. (2012): Aportes estratigráficos al conocimiento de la estructuración preandina entre los 29º y 32º de latitud sur, oeste argentino. *Resúmenes extendidos del VIII Congreso Geológico de España.* CD anexo a Geo-Temas 13 (Fernández, L.P., Fernández, A., Cuesta, A. y Bahamonde, J.R., eds.), Oviedo: 1891-1894.

López Gamundi, O.R., Rossello, E.A. (1993): Devonian-Carboniferous unconformity in Argentine and its relation to the Eo-Hercynian orogeny in southern South America. *Geologische Rundschau* 82(1), 136-147. doi: 10.1007/BF00563276.

López Gamundi, O., Azcuy, C., Cuerda, A., Valencio, D., Vilas, J. (1987): Cuencas Río Blanco y Calingasta-Uspallata. In: S. Archangeisky (ed.), *El sistema Carbonífero en la República Argentina*, Academia Nacional de Ciencias, Córdoba, Argentina: 281-291.

Martina, F., Viramonte, J.M., Astini, R.A., Pimentel, M.M., Dantas, E. (2011): Mississippian volcanism in the south-central Andes: New U-Pb SHRIMP zircon geochronology and whole-rock geochemistry. *Gondwana Research* 19(2), 524-534. doi:10.1016/j.gr.2010.07.004.

O'Connor, J.T. (1965): A classification for quartz-rich igneous rocks based on feldspar ratios. *U.S. Geological Survey Professional Paper* 525B: B79-B84.

Polanski, J. (1972): *Descripción Geológica de la Hoja 24 a-b, Cerro Tupungato, (Provincia de Mendoza)*. Boletín 165. Servicio Geológico Nacional, Secretaría de Estado de Minería: 117 p.

Pupin, J.P., Turco, G. (1972): Une typologie originale du zircon accessoire. *Bulletin de la Société Française du Cristallografie* 95, 348-59.

Quartino, B.J., Zardini, R.A., Amos, A. (1971): Estudio y exploración geológica de la region Barreal-Calingasta, Provincia de San Juan. *Revista de la Asociación Geológica Argentina*, Monografía 1: 184 p.

Ragland, P.C. (1989): *Basic Analytical Petrology*. Oxford University Press. New York.

Ramos, V.A. (1988): The tectonics of the Central Andes: 30º to 33º S latitude. In: S. Clark and D. Burchfield (eds.), *Processes in Continental Lithospheric Deformation*. Geological Society of America Special Paper 218, 31-54.

Ramos, V.A., Folguera, A. (2009): Andean flat-slab subduction through time. *Geological Society, London, Special Publications* 327, 31-54. DOI: 10.1144/SP327.3.

Ramos, V.A., Escayola, M., Mutti, D.I., Vujovich, G.I. (2000): Proterozoic-early Paleozoic ophiolites of the Andean basement of South America. *Geological Society of America Special Paper* 349, 331-349. doi:10.1130/0-8137-2349-3.331.

Ramos, V.A., Jordan, T.E., Allmendinger, R.W., Kay, S.M., Cortés, J.M., Palma, M.A. (1984): Chilenia: un terreno alóctono en la evolución Paleozoica de los Andes Centrales. *Actas 2. 9º Congreso Geológico Argentino*, Bariloche, Argentina: 84-106.

Ramos, V.A., Jordan, T.E., Allmendinger, R.W., Mpodozis, C., Kay, S.M., Cortés, J.M., Palma, M.A. (1986): Paleozoic Terranes of the Central Argentine-Chilean Andes. *Tectonics* 5(6), 855-880. doi: 10.1029/TC005i006p00855.

Rollingson, H. (1993): *Using Geochemical Data: evaluation, presentation and interpretation*. Longman: 352 p.

Sato, A.M., Llambías, E.J (1993): El grupo Choiyoi, provincia de San Juan: equivalente efusivo del batolito de Colangüil. *Actas IV, XII Congreso Geológico Argentino, II Congreso de Exploración de Hidrocarburos*: 156-165.

Sato, A.M., Llambías, E.J., Shaw, S.E., Castro, C.E. (1990): El Batolito de Colangüil: modelo del magmatismo neopaleozoico de la Provincia de San Juan. In: Relatorio de Geología y Recursos Naturales de la Provincia de San Juan. *XI Congeso Geológico Argentino,* Asociación Geológica Argentina: 100-123.

Scalabrini Ortiz, J. (1973): El Carbónico en el sector septentrional de la Precordillera sanjuanina. *Revista de la Asociación Geológica Argentina* 27(4), 351-377.

Sessarego, H.L.F. (1983): La posición estratigráfica y edad del conglomerado atribuido a la Formación del Salto. Río San Juan, Provincia de San Juan. *Revista de la Asociación Geológica Argentina* 38, 494-497.

Sessarego, H.L.F. (1988): *Estratigrafía de las secuencias epiclásticas devónicas a triásicas aflorantes al norte del río San Juan y al oeste de las Sierras del Tigre, provincia de San Juan*. PhD Thesis, Universidad de Buenos Aires, (unpublished).

Sessarego, H.L.F., Césari, S.N. (1986): La zona (de conjunto) Archaeosigillaria-Lepidodendropsis del carbonífero temprano de Argentina. *Abstract Annual meeting Project 21 1-IGCP*, Córdoba, Argentina:

69-70.

Sessarego, H.L.F., Césari, S.N. (1988): An Early Carboniferous Flora from Argentina. Biostratigraphic implications. *Rewiev of Palaeobotany and Palynology* 57(3-4), 247-264. doi.org/10.1016/0034-6667(89)90023-7.

Sessarego, H.L.F., Amos, A.J., Teixeira, W., Kawashita, K., Remesal, M.A. (1990): Diques Eocarbónicos en la Precordillera Occidental, margen oeste de las Sierras del Tigre. Provincia de San Juan. *Revista de la Asociación Geológica Argentina* 45, 98-106.

Spalletti, L.A., Cingolani, C., Varela, R., Cuerda, A. (1989): Sediment gravity flow deposits of an Ordovician deep-sea fan system (western Precordillera, Argentina). *Sedimentary Geology* 61(3-4), 287-301. doi: 10.1016/0037-0738(89)90063-8.

Sun, S.-s., McDonough, W.F. (1989): Chemical and isotopic systematic of oceanic basalts: implications for mantle composition and processes. In: A.D. Saunders and M.J. Norry (eds), *Magmatism and Ocean Basins*, Geological Society, London, Special Publications 42, 313-345. doi:10.1144/GSL.SP.1989.042.01.19.

Thomas, W.A., Astini, R.A. (2003): Ordovician accretion of the Argentine Precordillera terrane to Gondwana: a review. *Journal of South American Earth Sciences* 16, 67-79. doi:10.1016/S0895-9811(03)00019-1.

Thomas, W.A., Astini, R.A., Bayona, G. (2002): Ordovician collision of the Argentine Precordillera with Gondwana, independent of Laurentian Taconic orogeny. *Tectonophysics* 345, 131-152. doi: 10.1016/S0040-1951(01)00210-4.

Tickyj, H. (2011): Granitoides calcoalcalinos Tardío-Famatinianos en el Cordón del Carrizalito, Cordillera Frontal, Mendoza. *Actas CD, I.G. Petrología Ígnea y Metamórfica, Congreso Geológico Argentino*, No 18, Neuquén, Argentina: 2 p.

Tickyj, H., Fernández, M.A., Chemale Jr., F. y Cingonali, C. (2009): Granodiorita Pampa de los Avestruces, Cordillera Frontal, Mendoza: un intrusivo sintectónico de edad Devónica inferior. *Libro de Resúmenes 27*, XIV Reunión de Tectónica. Río Cuarto, Córdoba, Argentina.

Tófalo, O.R., De Rosa, L., Turco Greco, E., Forzinetti, M.E., Asaro, M. (1985): Análisis estadístico de los rodados de la Formación del Ratón (Carbónico), en Calingasta, San Juan. *Bol. Sedimentológico* 2-3, 49-65.

Walker, J.D., Geissman, J.W., Bowring, S.A., Babcock, L.E. (2012): The Geological Society of America Geologic Time Scale. *Geological Society of America*. doi: 10.1130/B30712.1.

Whalen, J.B., Currie, K.L., Chappell, B.W. (1987): A-type granites: Geochemical characteristics, discrimination and petrogenesis: *Contributions to Mineralogy and Petrology* 95, 407-419. DOI: 10.1007/BF00402202.

Whitney, D., Evans, B. (2010): Abbreviations for names of rock-forming minerals. *American Mineralogist* 95, 185-187. doi: 10.2138/am.2010.3371.

Winchester, J.H., Floyd, P.A. (1977): Geochemical discrimination of different magma series and their differentiation products using immobile elements. *Chemical Geology* 20, 325-343. doi: 10.1016/0009-2541(77)90057-2.