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Petrology of continental pyroclastic and epiclastic sequences in the Chubut Group (Cretaceous): Los Altares-Las Plumas area, Chubut, Patagonia Argentina

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ABSTRACT

The volcaniclastic successions of the Cerro Barcino Formation (Chubut Group), of Aptian-Cenomanian age, crop out on both margins of the Chubut River with a thickness of 200 m. The Middle Member Cerro Castaño (syneruptive, 90 m) and the Upper Member, Las Plumas (intereruptive, 110 m) are described on the basis of photogeological mapping, sections, and mineralogical, petrographical and geochemical analysis. Paleocurrents are directed to the northeast (Cerro Castaño) or north (Las Plumas). An erosive boundary, located at the base of the Las Plumas Member, is reported for the first time in this contribution The pyroclastic rocks are composed, of planar, curviplanar, branching, Y-shaped shards and fibrous pumice fragments. The volcanogenic sedimentary deposits also include, vitric fragments with hematitic pigmentation (Las Plumas). Due to diagenetic processes, the glass fragments are replaced by clay minerals (smectites and scarce illite) and zeolites which also appear as cementing material. Within the Cerro Castaño Member, analcime prevails assembled with less clinoptilolite, while in the Las Plumas Member, the abundant clinoptilolite is assembled with scarce analcime and mordenite. Pyroclastic sediments (ash-fall) covered extended flat or slightly undulated plains, where discrete sandy rivers flowed. The presence of gravels and sandstones at the base of the Las Plumas Member and wide and shallow braided river channels are associated to tectonic events and seasonability. Eruptions were highly explosive derived from viscous and volatile-rich magmas. The abundance of fine planar and cuspate shards in the tuff suggest that the explosive center was located approximately 500 km probably to the west.

Key words: Petrology of pyroclastic and volcaniclastic rocks, Stratigraphical correlation,Syneruptive and intereruptive deposits.

RESUMEN

La petrología de secuencias piroclásticas y epiclásticas en el Grupo Chubut (Cretácico): área de Los Altares-Las Plumas, Patagonia Argentina. Las sucesiones volcaniclásticas de la Formación Cerro Barcino (Grupo Chubut, Aptiano-Cenomaniano), afloran en ambas márgenes del río Chubut con

200 m de espesor. Los miembros medio: Cerro Castaño (sineruptivo, 90 m) y superior, Las Plumas (intereruptivo, 110 m) son descritos con el mapeo fotogeológico, estudios de campo y laboratorio (mineralógico, petrográfico y geoquímico). Las paleocorrientes se orientan hacia el noreste (Cerro Castaño) y hacia el norte (Las Plumas). Se ha reconocido, por primera vez, un límite erosivo en la base del Miembro Las Plumas. Las rocas piroclásticas presentan vitroclastos planares, curviplanares, ramificados y en forma de Y, y pumicitas fibrosas. Los depósitos epiclásticos incluyen fragmentos de tobas vítreas, con pigmentación hematítica (Las Plumas). Los vitroclastos están alterados, por procesos diagenéticos, a arcillas (esmectita y rara illita) o a zeolitas. En el Miembro Cerro Castaño predomina analcima, asociada a clinoptilolita, mientras que en el Miembro Las Plumas la clinoptilolita se asocia a analcima y mordenita. La sedimentación piroclástica (lluvias de cenizas) ocurrió en extensas llanuras onduladas, donde había discretos canales arenosos. En la base del Miembro Las Plumas, la aparición de valles amplios poco profundos, por los cuales corrieron ríos entrelazados que depositaron conglomerados y areniscas, está relacionada a actividad tectónica-climática. Las erupciones fueron del tipo magmático explosivo y los intensos procesos de fragmentación estuvieron relacionados a magmas viscosos, ricos en volátiles de composición riolítica-dacítica. La abundancia de vitroclastos planares, curviplanares y ramificados finos, sugieren que el centro explosivo se localizaba a una distancia aproximada de 500 km probablemente hacia el oeste.

Palabras claves: Petrología de rocas piroclásticas y volcaniclásticas, Correlación estratigráfica, Depósitos sineruptivos e intereruptivos.

INTRODUCTION

The aim of this contribution is to provide new stratigraphical, sedimentological and mineralogical data on the pyroclastic and epiclastic sequences of the middle and upper members, Cerro Barcino Formation (Chubut Group).

The study area is located downstream of the Río Chubut, which flows from the Andean Cordillera to the Atlantic Ocean throughout the Province of Chubut (Fig 1). The Cretaceous sediments of the Chubut Group exposed along the Chubut Valley have been described by Volkheimer (1969), Robbiano (1971), Musacchio and Chebli (1975), Chebli *et al.* (1976), Codignotto *et al.* (1978) and Manassero *et al.* (1998) among others, giving a complete field description of lithofacies and stratigraphic correlations. In this contribution, the authors followed the stratigraphic scheme of Codignotto *et al.* (1978) due to simplicity and the clear description of the units; yet, some modifications were introduced in this scheme in order to explain the geological evolution of the area.

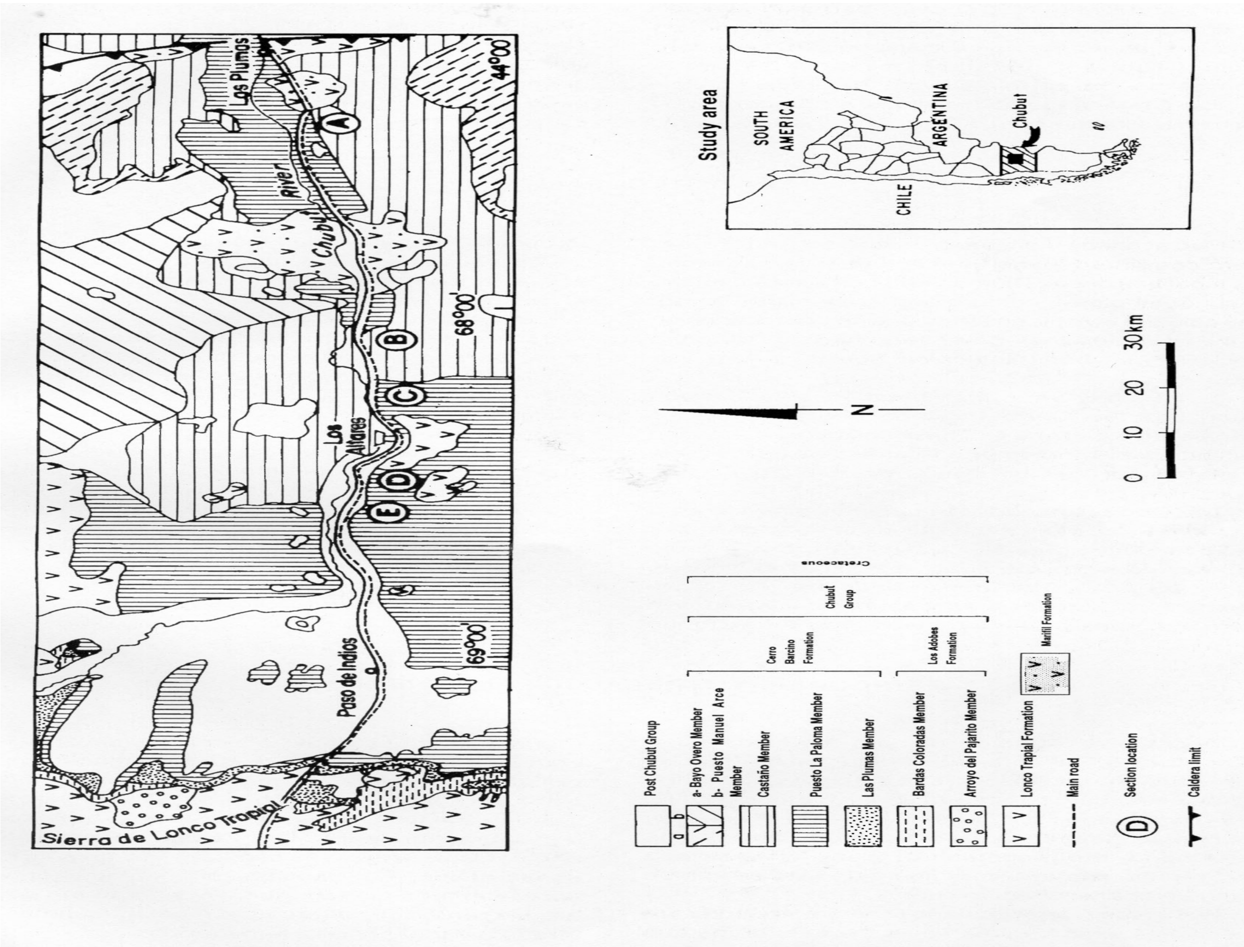

FIG. 1. Geological map with location of studied section and simplified stratigraphic scheme (adapted from Codignotto *et al.*, 1978).

The recognised and mapped units of the Chubut Group (1000 m thick) studied by Lesta and Ferello (1972) and Chebli *et al.* (1976) among others, comprise from bottom to top (Fig. 1) the Los Adobes Formation and the Cerro Barcino Formation. The Los Adobes Formation is composed of the Arroyo del Pajarito Member (conglomerates) and Bardas Coloradas Member (sandstone and argillaceous rocks). The Cerro Barcino Formation is composed of four volcaniclastic members, from bottom to top: La Paloma, Cerro Castaño, Las Plumas and Puesto Manuel Arce. The La Paloma Member (40 m) is composed of green homogeneous stratified tuffs, and the Puesto Manuel Arce Member (45 m), cropping out to the south of Las Plumas town, is composed of yellowish tuffs with intercalations of gray shales. The Cerro Castaño and Las Plumas Members are the most areally widespread members along the río Chubut Middle Valley and they are the objects of this study.

The succession appears as an homoclinal, which is tilted with low angle to the east, so the oldest units are exposed to the west of Paso de Indios locality (Fig. 1).

For the study area, the age of the Chubut Group is assigned to the Cretaceous (Barremian-Cenomanian) based on available bioestratigraphical data from charofites and ostrachoda (Musacchio, 1972; Musacchio and Chebli, 1975). The upper part of this Group has been regionally correlated by Codignotto *et al.* (1978) and Manassero (1997) with the Angostura Colorada Formation (Coniacian-Campanian) cropping out 300 km to the northwest of the study area. For the depositional basin Ramos (1979) and Ramos and Drake (1987) described the main volcanic event during Barremian-Aptian time. According to these authors, the rhyolitic and dacitic Divisadero Group (Niemeyer, 1975), cropping out 350 km to the west can be correlated with the studied units.

The Cretaceous successions are underlain by ignimbrites of the Marifil Complex, these volcanic

rocks belong to a Middle Jurassic igneous cycle related to extensional processes (Haller and Lapido, 1982; Rapela *et al.* 1992; Page and Page, 1993). This unit is part of one of the most extensive silicic volcanic intraplate associations, temporally and genetically related to crustal extension throughout early stages of the Gondwana rifting (Rapela and Pankhurst, 1993).

STRATIGRAPHY

Five sections have been described, and three of them correlated along the Chubut River, between the localities of Las Plumas and Los Altares, on the basis of lithology, colours and grain size (Fig. 2). The colours have diagnostic value for unit recognition in the field, and they have been typified using the Rock Colour Chart (Geological Society of America, 1999).

FIG. 2. Stratigraphy, lithofacies and reference level for the studied sections.

In the study area, the Cretaceous succession comprises the Cerro Castaño and Las Plumas members (Figs. 3 and4). These units were correlated using the first conglomerate-sandstone fluvial cycle at the base of the Las Plumas Member (Figs. 2 and 5).

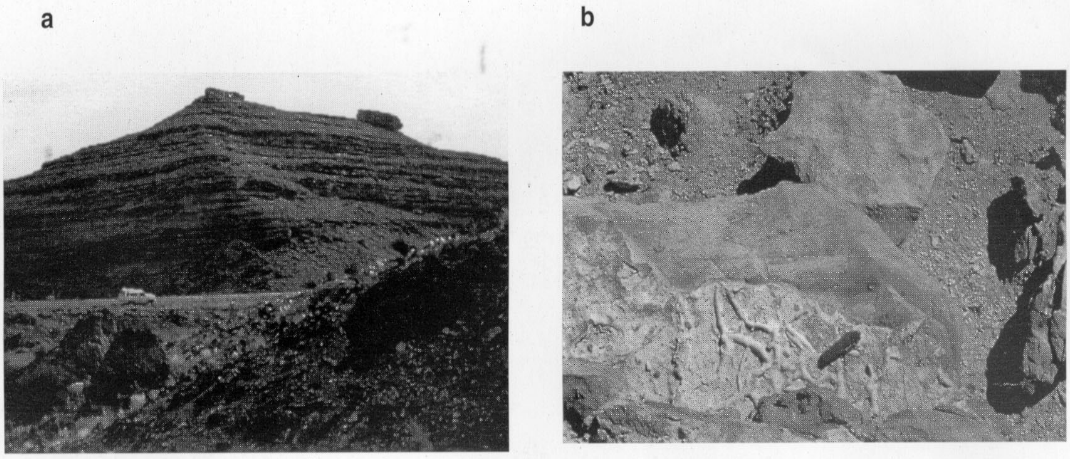

FIG. 3. Cerro Castaño Member: **a-** general view of the unit in section E; **b-** trace fossils (Palaeophycus) in section B.

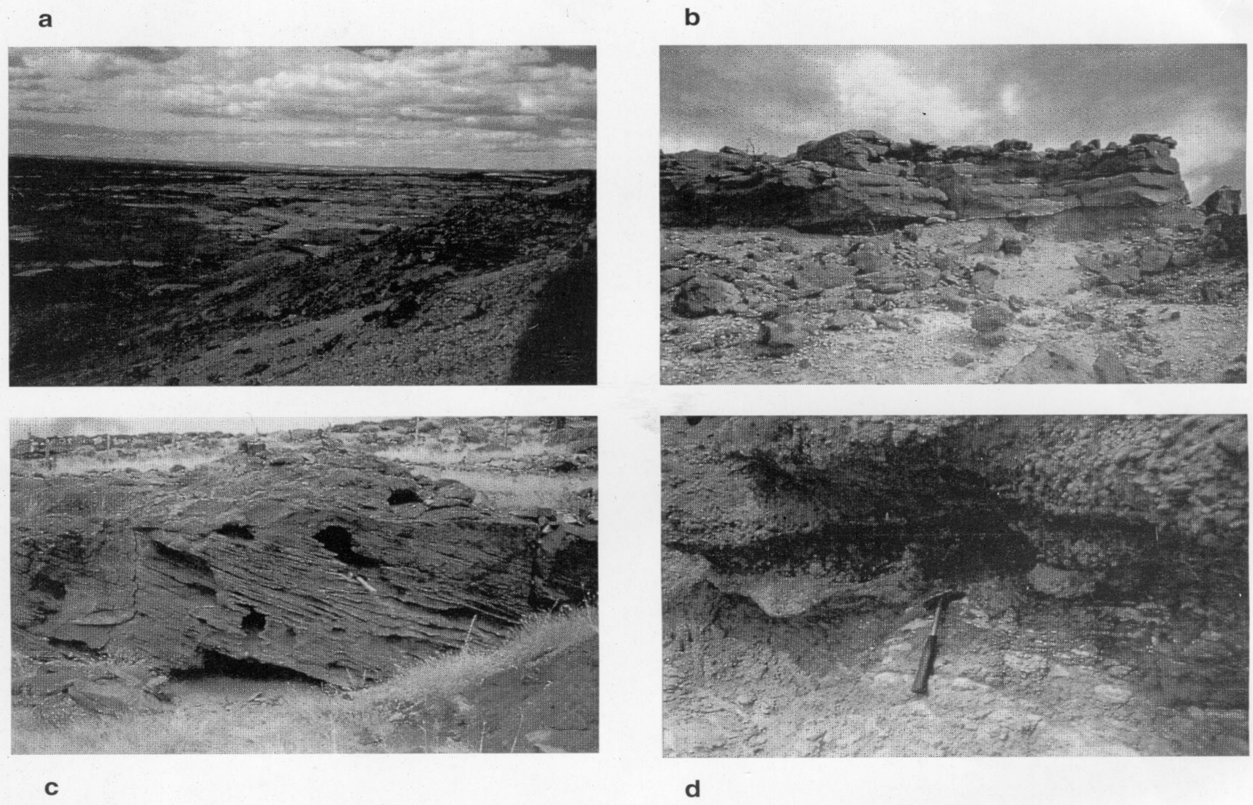

FIG. 4. Las Plumas Member; **a-** general view of this unit in section A; **b-** amalgamated coarse sandstones in section A; **c-** Planar cross bedded sandslones in section B; **d-** channels with well-sorted and clast-supported conglomerates in section A.

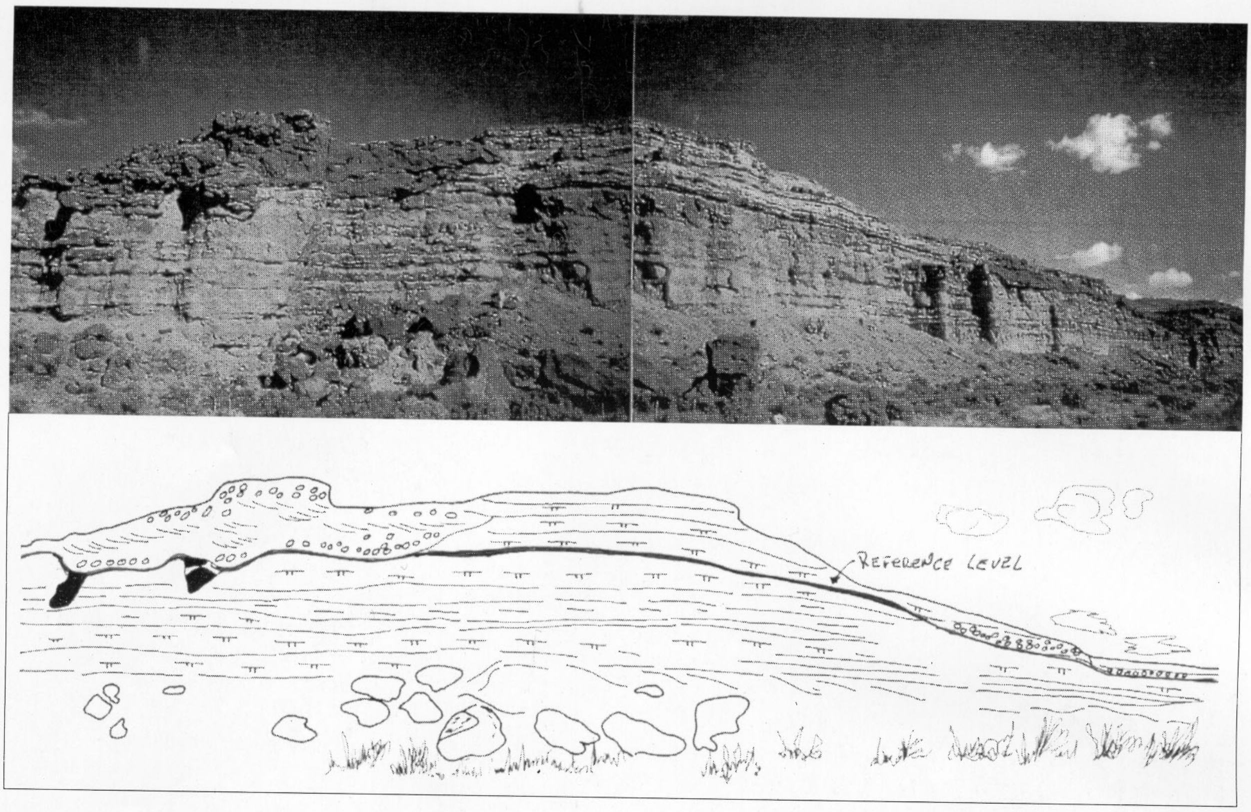

FIG. 5. Erosive surface at the base of the Las Plumas Member. Outcrop view of secion B (Fig. 2), amalgamated and tabular conglomerates intercalated with the tuffs.

The Cerro Castaño Member shows a wide area of outcrops between the localities of Paso de Indios and Los Altares (Fig. 1). Pale yellow-brown colours are dominant and the strata are exposed in steep ridges

(Fig. 3a). The tabular beds are one to two meters thick and with sharp basal contacts, many of them are massive. Fine grained vitric tuffs are the dominant lithotype within the sections.

On the other hand, the Las Plumas Member shows a number of different characteristics (Table 1), such as dominant red-white-yellow colours and smooth slopes of the outcrops (Fig. 4a) although reworked ash-fall deposits are still abundant. At least, four conglomerate and sandstone fluvial cycles reaching more than two meters thick are interbedded within the sequence (Fig. 2). These layers are either lenticular or tabular (Fig. 4b) showing well developed planar cross bedding in the sandstones (Fig. 4c) and amalgamated clast supported conglomerates, in channels three to four meters wide (Figs. 4d and 5). The gravels are composed of fine to medium rounded pebbles, cobbles (2-3 cm) of rhyolites, volcanic quartz and older tuffs. The sandstones are lithic (Fig. 6) and also have euhedral quartz and feldspars (sanidine, oligoclase).

The clast imbrication along the channel axes suggests a northward paleocurrent.

TABLE 1. COMPARATIVE CHARACTERISTICS OF THE CERRO CASTAÑO AND LAS PLUMAS MEMBERS.

Characteristics	**Cerro Castaño Member**	**Las Plumas Member**
Dominant colours	Pale brown-vellow	White-red
Outcrops	Steep slopes	Low angle slopes
Stratification	Tabular bedding with sharp contacts in	Tabular and lenticular
	tuffs, scarce small scale sandy	(amalgamated)
	paleochannels	
Sedimentary	Massive-lamination	Massive and cross bedding
structures		(trough) and imbrication
		(conglomerates)
Ichnofosils	Palaeophycus to the top of the unit	Traces of worm and root activity
		(organic voids)
Depositional	Ash fall in wide plains and poor	Intermittent ash fall, and reworking
Processes	developed drainage basins	of the pyroclastic deposits
		by braided fluvial systems
Magmatism and	Dominant sineruptive facies	Dominant intereruptive facies
Sedimentation		
Petrography	Fine vitric tuff and scarce lithic arenites	Tuff, and epiclastic deposits with at least four intercalated
		fluvial cycles of conglomerates and sandstones
Zeolite assemblage	Predominant analcime with scarce	Predominant clinoptilolite
	clinoptolite	and scarce mordenite
Paleocurrents	To the northeast	To the north
Paleogeography	Wide plains with isolated channels and	Onduiated and wide plains
	small -shallow water bodies	with shallow fluvial channels and incipient soil development

PETROGRAPHY, MINERALOGY AND CHEMISTRY

Twenty-five samples of both members have been studied, -18 tuffs and 7 sandstones- (Fig. 6). Three hundred points were counted in each of the sandstones using the traditional method (Zuffa, 1984) where the rock fragments are recognised by their origin independently of the grain size. On the other hand, the proportion of glass, crystals and lithics in the fine and very fine tuffs was estimated using comparison visual charts.

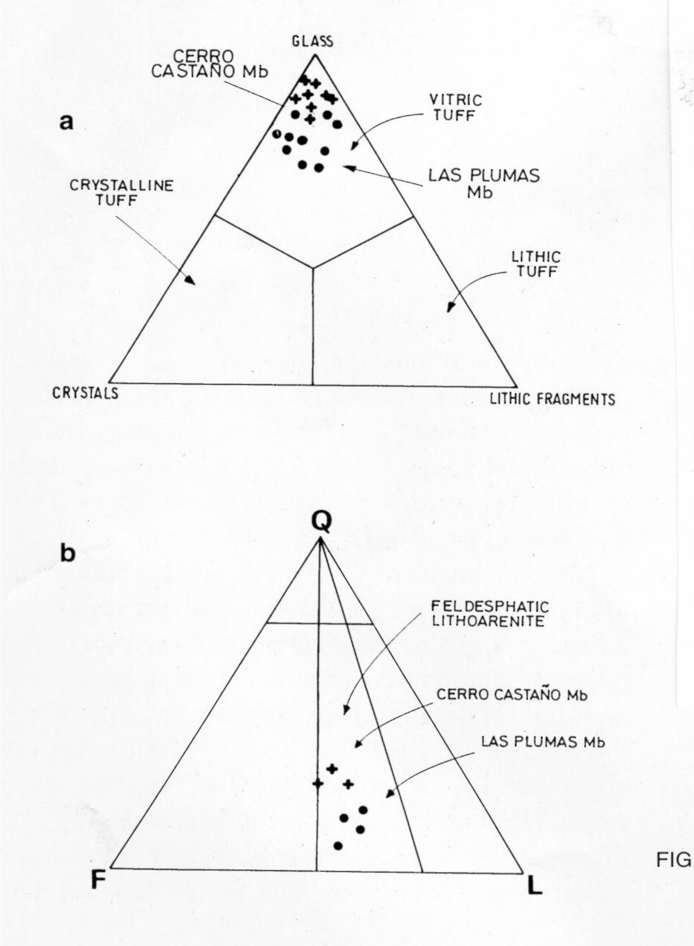

FIG. 6. Triangular diagram for tuffs (Pettijohn *et al.*, 1987) and QFL diagram for sandstones (Folk *et al.*, 1970).

Within the Cerro Castaño Member, the tuffs are mainly fine vitric (Fig. 6), while the tuffs of the Las Plumas Member show a greater input of lithic components. Planar and cuspate glass shards predominate (Fig. 7) and less Y-shaped shards, while fibrous pumice fragments are very scarce. The volcanogenic (McPhie, *et al.*, 1993) sedimentary deposits, abundant in Las Plumas Member, have angular lithic fragments of older vitric-tuffs as mentioned above. The hematitic pigmentation is widespread in tuffs and conglomerates and the shards are diagenetically altered to smectite (scarce illite) and to a variety of zeolite minerals.

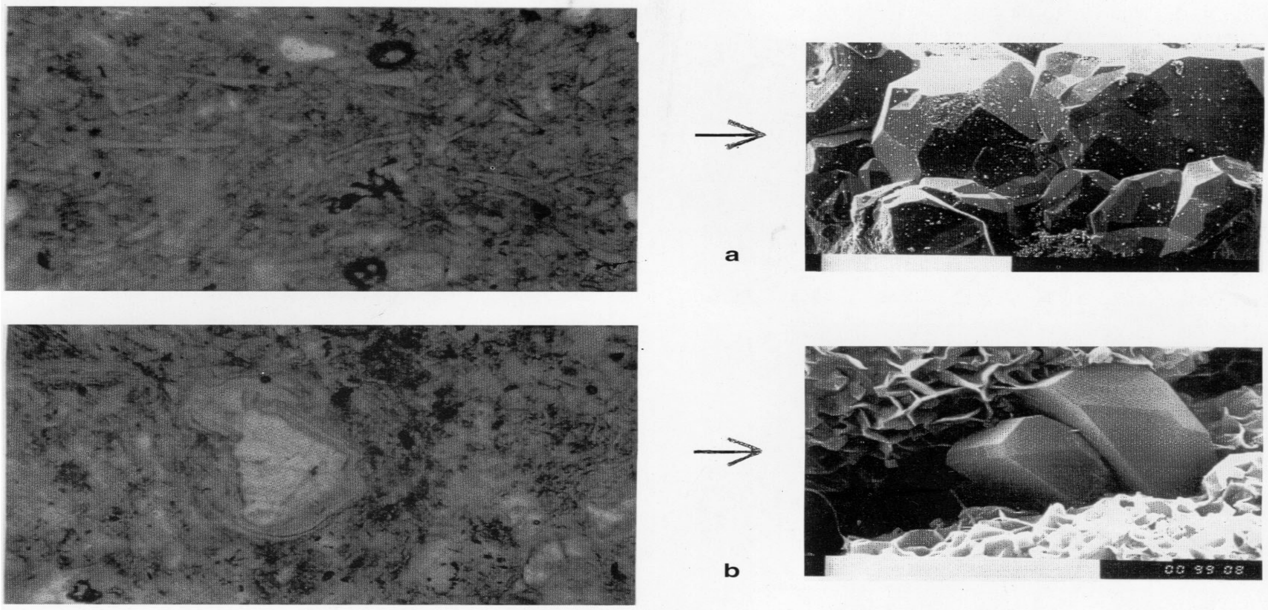

FIG. 7. Optical and SEM pyroclastic petrography; **a-** vitric-tuff with platy and cuspate shards (sample A15) of the Cerro Castaño Member and analcime crystals. **b-** Vitric-tuff (sample A50) of the Las Plumas Member showing a void successively infilled by smectite-clinoptilolite-mordenite.

All the pyroclastic rocks plot in the vitric tuff field of figure 6a (adapted from Fisher and Schmincke, 1984), but the Las Plumas Member always shows more than 5% of lithics as accessory fragments (Fig. 8).

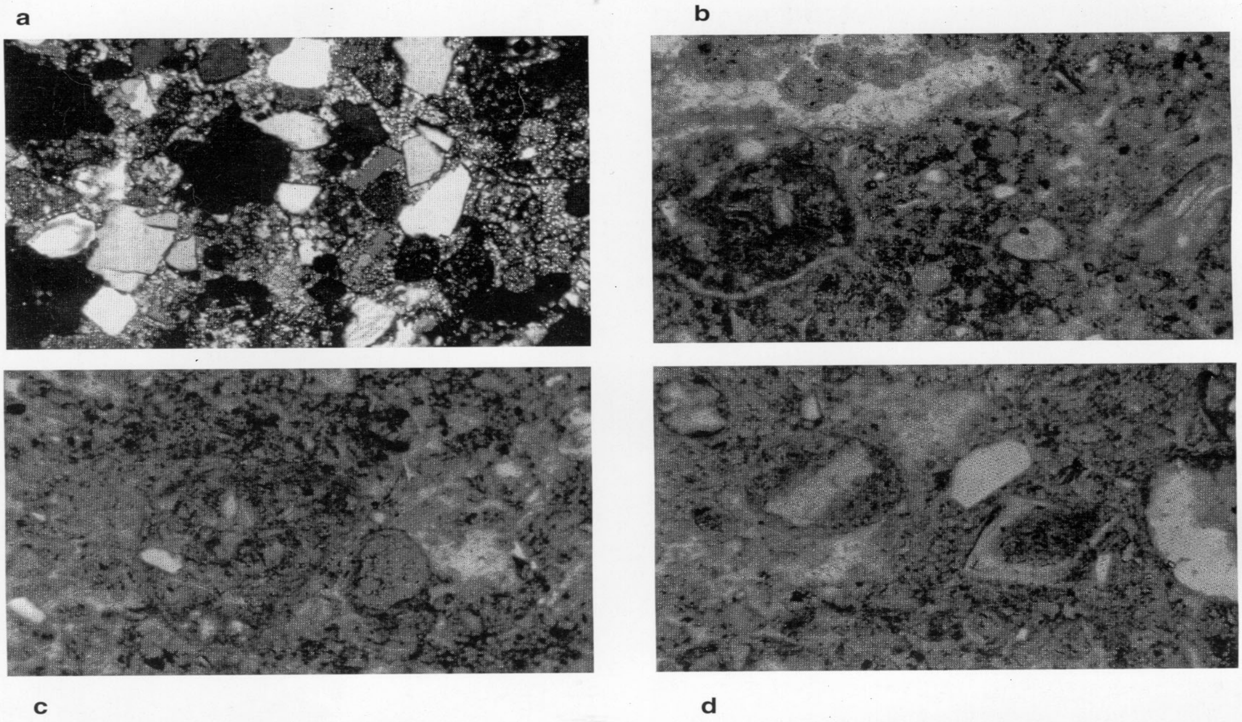

FIG. 8. Las Plumas volcaniclastic lithofacies; **a-** coarse sandstone with sanidine, quartz and volcanic rock fragments; **b-** reworked andesitic fragment and veins infilled with zeolite (sample A45'); **c-** clay rims (cutans) around volcanic rock fragments (sample A 45); **d-** Diagenetic alteration of detrital plagioclase to clay minerals and lithic fragments (sample A45).

The composition of the fluvial interbedded sandstones has been also plotted in a ternary diagram (Folk *et al.*, 1970), showing dominant grouping within the field of feldsphatic lithoarenites. The samples of the Cerro Castaño Member show a comparative rich quartz-feldspar composition, related to the input of rhyolitic material derived from the erosion in the margin of the basin, of the underlying Marifil Formation.

The components recorded both in the sandstones and tuffs, are monocrystalline, euhedral quartz with embayments and attached aphanitic glassy blebs, K-feldspar (sanidine), plagioclase (An 25%), volcanic rock fragments (felsic and silicified rhyolites, tuff, and andesites) and sedimentary rock fragments. The typical volcanic rock fragments are felsic lava.

The chemical composition of these tuffs reflects the composition of the parental rhyolitic-dacitic magma (Table 2 and Fig. 9), although, in this case the intense diagenetic silicification hampers the precise identification of the source. This silicification process causes a displacement of the sample plotting towards the right (higher SiO_2) in figure 9.

TABLE 2. CHEMICAL ANALYSIS OF FALLOUT TEPHRA. CERRO CASTAÑO MEMBER SAMPLES UNDERLINED. THE REST BELONG TO THE LAS PLUMAS MEMBER.

Sample	SiO2	Al2O3	Fe2O3	MnO	MgO	CaO	Na2O	K2O	TiO2	P2O5	Loi	Total	Ba	Sr	Y	Zr	Be	V
No.	%	%	%	%	%	%	%	%	%	%	%		ppm	ppm	ppm	ppm	ppm	ppm
A30	77.36	8.57	0.18	-0.01	0.09	1.08	3.38	0.81	0.1	0.04	8.82	100.43	298	374	15	61	1	10
A40	74.47	9.61	1.79	0.04	1.22	0.9	2.13	0.8	0.17	0.03	9.23	100.39	145	117	28	89	2	131
NB6	69.02	10.91	0.87	0.05	0.15	1.8	4.68	1.41	0.2	0.13	11.47	100.68	975	645	18	56	1	10
N6	75.84	9.14	2.65	0.02	0.82	1	1.41	3.81	0.25	0.04	5.63	100.6	218	77	22	144	3	25
L8	77.5	9.81	1.18	0.02	0.43	1.57	3.1	2.83	0.19	0.05	4.29	100.96	211	83	18	97	1	10
L10	68.57	12.55	1.88	0.05	0.89	1.3	5.9	2.08	0.22	0.05	7.07	100.56	407	144	20	121	1	27
L12	81.69	7.25	0.96	0.02	0.47	0.84	2.2	1.73	0.09	0.05	5.33	100.63	672	69	31	86	1	11

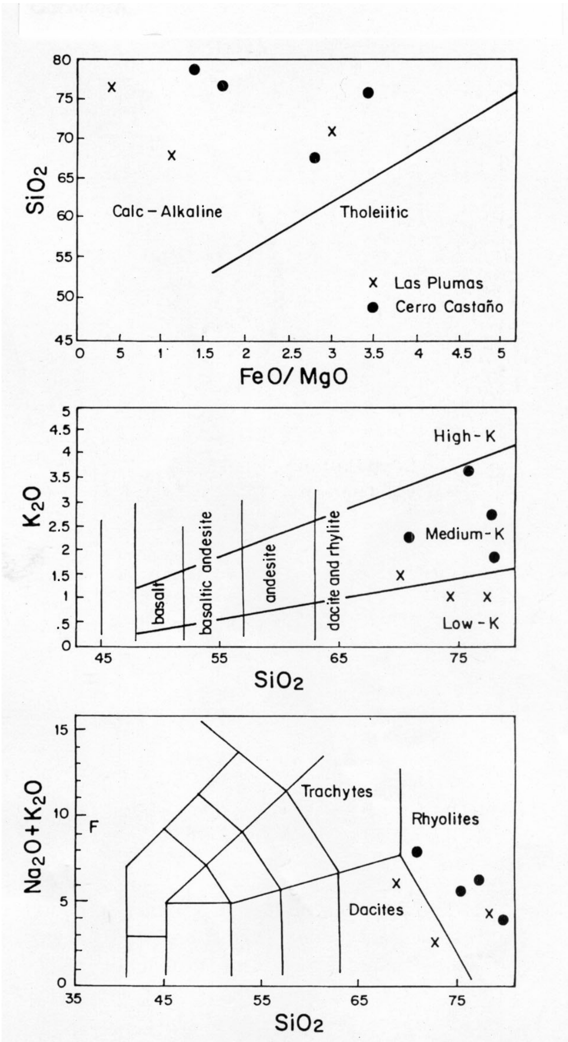

FIG. 9. Discrimination diagrams from Le Maitre *et al.* (1997). Oxides in weight %. ● = Cerro Castaño Member; x= Las Plumas Member.

The samples have been plotted in a Na-K *versus* SiO_2 diagram for volcanic rocks, from Le Maitre *et al.* (1997), and they are interpreted as sourced in rhyolites- dacites, The Cerro Castaño samples show medium K content while the Las Plumas samples show low K content. The calc-alkaline association for both members is proposed on the basis of the FeO/MgO *versus* SiO_2 diagram.

On the basis of X ray diffraction, differential thermal and thermogravimetric analysis, chemistry and scanning electron microscope analysis on the tuffs, two different diagenetic zeolite assemblages have been detected for each of the studied members (Iñiguez *et al.*, 1987; Zalba *et al.*, 1998). For the lower member, an analcime dominant association with sodic affinity, fills regular and extra-sized pores produced either by worm or root activity. In some cases the analcime also replaces feldspar and lithic framework grains and it is recognised by its characteristic cubo-octahedral and trapezoedral habits (Fig. 7A). For the upper member, a clinoptilolite dominant association (and occasionally mordenite) was recognised. Idiomorphic clinoptilolite shows monoclinic habit and coffin-shaped crystals and appears replacing cuspate shards and filling cavities. Mordenite appears as thin threads of a second phase and criss-crosses the clinoptilolite plates. It is always a minor component (less than 10%) and was recognised in the scanning electron microscope (Fig. 7B).

The origin of these zeolites is related to substitution of shards and to the alteration of glass to smectite, previous to zeolite generation. Besides, there are also some considerations about the possible setting and conditions with intense phreatic activity that affected the glass components. The requirements for large-scale zeolitization (Hall, 1998) are high proportion of glassy particles, high permeability and favourable hydrological conditions. This author also underlines the high proportion of zeolitized rocks in the geologic record for which the conditions of deposition are epiclastic. In general terms, the authors assume these conditions associated to depositional systems like: ash falls in wide plains and reworking by ephemerous rivers and braided systems on these plains.

PALEOGEOGRAPHY AND DEPOSITIONAL EVENTS

The substrate of the Chubut Group is a huge rhyolitic caldera and ignimbritic plateau of Jurassic age (Bajocian) mapped as the Marifil Formation (Rapela and Pankhurst, 1993; Aragón *et al.*, 1996) shown in figure 1. The edge of this large and roughly circular depression is the steep wall of silicic volcanic rocks, which crop out near the locality of Las Plumas (Fig. 1).

The depositional characteristics of the pyroclastic and epiclastic deposits from the Cerro Barcino Formation are analysed on the basis of sedimentary structures and compositional criteria. Ash-fall processes on wide plains generated the tuffs within the Cerro Castaño and the Las Plumas Members. Later, ephemeral water courses, as poorly developed drainage systems that partially reworked the former sediments, formed volcanogenic sedimentary deposits. Mixed with these rocks, epiclastic sandy rhyolitic material was provided to the basin by streams and rivers from the older Marifil Formation. Paleocurrents show a general trend to the north. It is important to stress the fact that the abundance of trace fossils like *Paleophycus* to the top of the Cerro Castaño Member is also indicative of low energy and shallow water environments.

During the deposition of the Las Plumas Member, ephemeral, distal gravel and sandy braided fluvial systems were widespread in shallow and wide channels associated to periodical ash-fall deposition. The dominance of coarse detritus to the base of each fluvial cycle is interpreted either as tectonic reactivation within the source areas to the south and/or as meteorological changes due to intense rain (Fig. 2).

Both units offer a good example of the importance of sediment aggradation in flat plains dominated by volcanic events (Smith, 1991). Following this scheme (Fig. 10), the Cerro Castaño Member is defined as the Type 1 kind of syneruptive pyroclastic and sandy volcaniclastic facies, with active explosive volcanism synchronic with the sedimentation. The resultant stratigraphy is an event stratigraphy with time planes essentially parallel to bedding surfaces (Orton, 1995, 1996). High eruption frequencies and large eruptions allow little or no depositional record of intereruptive periods within this unit. Weak channel incision may occur between volcanic events and the absence of erosion surfaces makes distinction between inter and syneruptive sedimentary deposits difficult (Smith, 1991). Syneruptive facies are strongly aggradational and have high preservation potential, because they are relatively thick and laterally extensive, and also, the volcanic eruption often creates accommodation space by growing higher or driving basin subsidence (Orton, 1996).

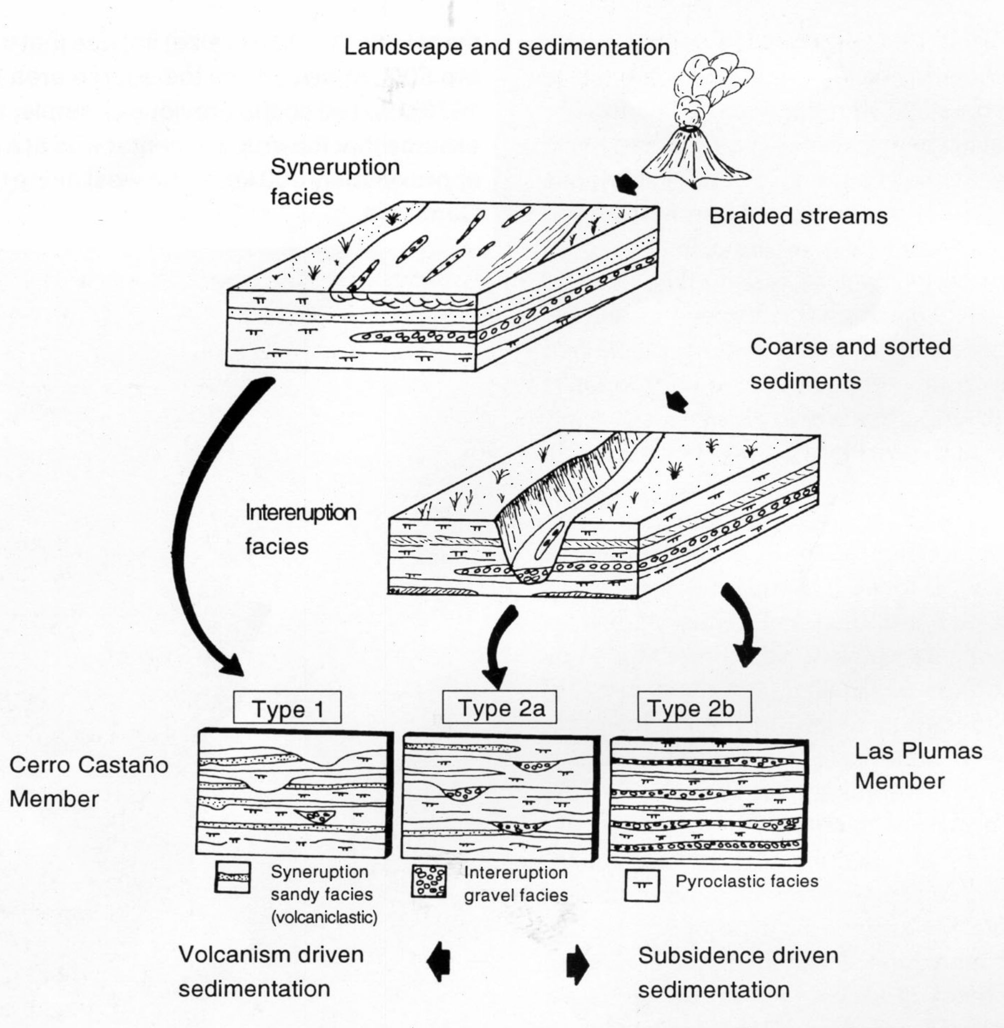

FIG. 10. Block diagrams showing intereruption and syneruption facies within Cerro Castaño and Las Plumas members, adapted from G. Smith (1991).

On the other hand, the Las Plumas Member is interpreted as intereruptive facies characterised by Types 2a and 2b of Smith (1991) in figure 10, showing ash-fall deposits with thick intercalations of epiclastic coarse detritus. Processes like erosion and channel incision dominate in this unit, while fast agraddation and climatic changes like intense rain seem to be the main control in the sedimentation. The overall geometry of this succession is controlled by the relative importance of syneruptive *versus* intereruptive conditions, which in turn, is controlled by the frequency and magnitude of explosive eruptions, rate of tectonic or volcanic subsidence, rate of erosion and position with respect to the the volcano (Orton, 1996).

In the tuffs, planar and cuspate shards are dominant, with lesser proportions of Y-shaped shards and scarce pumice fragments, with a high fragmentation index, suggesting highly explosive eruptions of a viscous volatile rich rhyolitic-dacitic magma (Mazzoni, 1985, 1989; Sparks *et al.*, 1997). These well-sorted ash-fall deposits, with sharp contact bedding, are composed of fine to very fine platy and cuspate shards.

Related to the distance of the eruptive center, Heiken and Wohletz (1992) in their study of the glass components of the Mazama Volcano (Washington State, U.S.A.) suggested that the presence of Y-shaped, flat and curve shards and small pumice pyroclasts (1-100 µ in size) implies that the deposits are 500 km away from the source area (Kittleman, 1973). Based on the previous example, the authors assume that the eruptive center was at a distance of approximately 500 km to the west along the Andean Cordillera.

FIG. 9. Discrimination diagrams from Le Maitre *et al.* (1997). Oxides in weight %.• = Cerro Castaño Member; x= Las Plumas Member.

CONCLUSIONS

• The Cerro Castaño and the Las Plumas Members are the most areally widespread of the Cerro Barcino Formation (Chubut Group) in the Río Chubut Valley, reaching 200 m thick and composed of pyroclastic rocks with minor intercalations of alluvial conglomerates and sandstones.

• The Cerro Castaño Member, with dominant pale-brown, yellow and grey colours is composed of fine vitric-tuff (mostly tabular ash-fall deposits) evidenced by outcrops with high angle slopes. These beds, reaching 2 m thick show sharp and planar contacts and have small-scale channels with reworked sandy rhyolite and tephra sourced in the Marifil Formation. This unit is interpreted as the product of syneruptive ash-fall deposits on plains, with shallow ponds and poorly developed drainage systems flowing to the north-northeast.

• The intereruptive facies of the Las Plumas Member, have red-white-yellow dominant colours, and are composed of lesser proportions of pyroclastic rocks (ash-fall deposits) but abundant resedimented tephra with, at least, four intercalated cycles of clast-supported conglomerates and sandstones. The latter braided fluvial facies show well-developed incision features, tabular bedding, cross-bedding, amalgamation of beds and imbrication of clasts (paleocurrents oriented to the north). The volcanogenic sedimentary deposits are interpreted as the product of the reworking of previous ash-fall deposits by permanent rivers with climatic regime.

• The first fluvial clast-supported conglomerate bed of the Las Plumas Member is defined as the base of this unit and it is also considered as an important correlation surface (marker) within the basin.

• Two different diagenetic zeolite assemblages are described; **a-**dominant analcime association for the Cerro Castaño Member, and **b-** dominant clinoptilolite-mordenite association for the Las Plumas Member. These zeolites show idiomorphic crystals filling organic voids, or in some cases, replacing shards. The observed diagenetic sequence of pore filling events is: altered glass-smectite-well crystallized zeolites.

• The geochemistry of selected pyroclastic samples shows a trend to a rhyolite-dacite parental magma. All the samples show calc-alkaline affinities with medium to low potassium content.

• The nature and grain size of the shards, bedding, sharp contacts, and abundance of ash-fall deposits with high fragmentation index suggest a volcanic source located approximately 500 km to the west of the study area, assigned to the Divisadero Group.

• These contribution underlines the importance and high preservation potential of fast agradational-pyroclastic depositional processes in wide plain environments.

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