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CERRO BLANCO 4.2 ka VOLCANIC ASH DEPOSIT AT CERRO COLORADO (CÓRDOBA PROVINCE, ARGENTINA)

Abstract: Boretto G., Zanchetta G., Bini M., Cioccale M., Carignano C., Gordillo S., Giaccio B., Fernandez-Turiel J.-L., Arienzo I. & Isola I., *Cerro Blanco 4.2 ka volcanic ash deposit at Cerro Colorado (Córdoba Province, Argentina).* (IT ISSN 0391-9838, 2021).

A tephra layer was recovered within the Holocene fluvial succession of the Cerro Colorado Cultural and Natural Reserve in the Córdoba Province (Argentina). Radiocarbon dating on organic matter preserved within the paleosoil beneath the tephra layer indicate that the ash layer is younger than ca. 4700 cal yr BP. Radiocarbon ages, Sr and Nd isotope data on the bulk rock, and microanalytical data on glass shards allow us to identify the Andean Central Volcanic Zone as the possible source area of the analyzed tephra. Our data highlight that the tephra layer recovered in the Córdoba Province was produced by volcanoes of the southern fringe of the Andean Central Volcanic Zone and that it can be confidently correlated with the Cerro Blanco 4200 cal yr BP eruption. These findings are also coherent with the known dispersion axis of the products of this eruption and allow further constraining their dispersion. This latter is extremely important for any attempt in volcanic hazard assessment.

Key Words: Tephra, Holocene, Cerro Colorado, Cerro Blanco, Argentina.

Resumen: Boretto G., Zanchetta G., Bini M., Cioccale M., Carignano C., Gordillo S., Giaccio B., Fernandez-Turiel J.-L., Arienzo I. & Isola I., *Cenizas volcánicas de Cerro Blanco datadas en 4,2 ka identificadas en Cerro Colorado (Provincia de Córdoba, Argentina).* (IT ISSN 0391-9838, 2021).

Una capa de tefra ha sido identificada dentro de la sucesión fluvial holocena en la Reserva Cultural y Natural Cerro Colorado de la Provincia de Córdoba (Argentina). Por debajo de esta capa se observa un paleosuelo que preserva restos de materia orgánica la cual ha sido datada mediante método radiocarbónico. Los resultados obtenidos indican que las cenizas presentan una edad menor a ca. 4700 cal años AP. En este sentido, las edades radiocarbónicas, los datos isotópicos de Sr y Nd en la roca y los datos microanalíticos en fragmentos de vidrio volcánico nos permiten reconocer a la Zona Volcánica Central Andina como la posible área de origen de la tefra analizada. Nuestros datos sugieren que esta capa de tefra fue producida por volcanes de la franja sur de la Zona Volcánica Central Andina, y pueden correlacionarse con la erupción de Cerro Blanco datada en 4200 cal años AP. Estos hallazgos también son coherentes con el eje de dispersión conocido de los productos de esta erupción y permiten restringir aún más su diseminación. Se resalta este último aspecto como extremadamente importante ya que sirve de base para cualquier evaluación del peligro volcánico.

Palabras Claves: Tefra, Holoceno, Cerro Colorado, Cerro Blanco, Argentina.

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INTRODUCTION

The Andean volcanic arc includes more than 200 potentially active Quaternary volcanoes (Stern, 2004; Tilling 2009), and volcanic hazard is a real and immanent risk for the local populations (e.g. Tilling, 2009), represented by pyroclastic flow, tephra fall, and remobilization of the volcanic material by water (the so-called "lahars"). The active volcanism occurs in four separate segments (e.g. Stern, 2004): the Northern, Central, Southern, and Austral Volcanic Zones, respectively (NVZ, CVZ, SVZ, and AVZ, fig. 1). Being located downwind to the CVZ, SVC and AVZ, Argentina is potentially largely interested by tephra fall hazard. Indeed, the pyroclastic fallout of two with the higher magnitude, historical explosive eruptions of the Andean volcanic system extensively affected the Argentina territory, owing to the general wind circulation dominated by south westerlies wind system: the eruption of the Quizapu (Cerro Azul) in 1932 (Hildreth & Drake, 1992) and Cerro Hudson in 1991 (Naranjo & *alii*, 1993).

The study of distal tephra layers (i.e. far from the volcanic center) is therefore of paramount importance in order to reconstruct frequency, dispersion, volume, and potential impact of explosive eruptions (e.g. Daga & *alii*, 2010, 2014; Naranjo & *alii*, 2017; Sulpizio & *alii*, 2014). Moreover, tephra can represent a valuable tool for correlating and synchronizing different sedimentary archives and dating them independently (e.g. Lowe, 2011; Prieto & *alii*, 2013; Zanchetta & *alii*, 2018a). Under these promises, distal tephrostratigraphic studies in southernmost South America are in tumultuous development as witnessed by a significant increasing number of specific studies with different aims (e.g. Stern 1991, 2008; Hermanns & Schellenberger 2008; Daga & *alii*, 2010, 2014; Fontijn & *alii*, 2014; Prieto & *alii*, 2013; Del Carlo & *alii*, 2018; Zanchetta & *alii*, 2018b, 2021). However, more data are vital to produce a correct volcanic hazard assessment in a distal setting and build a tephrostratigraphic lattice to support Quaternary stratigraphy, chronology, archaeology, and paleoclimatology (Lowe & *alii*, 2015). Moreover, the role of volcanic activity in controlling (or triggering) climatic changes at different scales during the Last Glacial and Holocene has found renewed interest, and this adds a new value in the stratigraphic and volcanological study of the large scale – Plinian – eruptions (e.g. Sigl & *alii*, 2014, 2015; Svensson & *alii*, 2020; Mann & *alii*, 2021).

In this work, we present new data on a tephra layer identified within the Cerro Colorado Holocene succession in the Córdoba province (fig. 1), which improves the dispersion of one of the largest explosive eruptions of the CVZ, ejected by the Cerro Blanco Volcanic Complex.

GEOLOGICAL AND CLIMATOLOGICAL SETTING

The Cerro Colorado Cultural and Natural Reserve is located around the coordinates 30° 05' S and 63° 55' W, at the north-eastern slope of the Sierras Pampeanas, in the province of Córdoba, Argentina (fig. 1). The study area preserves a unique landscape produced by impressive sculptured outcrops of red sandstone. The natural reserve contains an important archaeological legacy recorded in rock paintings preserved inside caverns and rock shelters (Gadner, 1931; Recalde, 2016, 2018).

This region belongs to the Sierra Norte area, which corresponds to the northern sector of the Sierras Pampeanas Orientales (Lucero Michaut, 1979). Its igneous-metamorphic basement is Proterozoic to Middle Cambrian in age and is composed of granodiorite and monzogranite batholiths with sub-volcanic porphyric facies, surrounded by isolated remnants of low to medium degree metamorphic rocks, with intrusions of Ordovician-Devonian granitoids (Candiani & *alii*, 2001; Miró, 2000). The most representative unit of the area corresponds to the Cerro Colorado Formation sandstones and conglomerates (Methol, 1958; Polanski, 1970). The age of these outcrops is a source of controversy for some authors; Pastore (1932), Gutiérrez & *alii* (2006), and Candiani (2008) interpreted them as Mesozoic, while Lucero Michaut (1979) and Astini & Del Papa (2014) interpreted them as belonging to the Carboniferous-Permian.

The Mesozoic record has little development in the area and would be represented by Cretaceous sandstones and conglomerates (Miró, 2000), on which lie Avellaneda calcretes (Carignano, 1997a; Candiani, 2008) associated with the pelitic marine-coastal facies corresponding to the Miocene Atlantic transgression (Bertolino & *alii*, 2000; Miró, 2000; Candiani & *alii*, 2001, 2010).

Although the Sierra Norte was affected by the Andean orogeny, it does not have the characteristic asymmetric profile of the Sierras Pampeanas Orientales reverse fault blocks, except in its extreme southwest (Sierra de Sauce Punco), where abrupt escarpments of eroded faults are located (Carignano & *alii*, 2014). During the Cenozoic, processes associated with the filling and subsequent terracing of the intracratonic basin would have occurred (Strelin, 1995; Carignano, 1996, 1997a, 1997b, 1999; Herrero, 1999, 2000; Iriondo, 2010; Kröhling & Carignano, 2014).

The Quaternary deposits are represented mainly by fluvial-aeolian sediments on hills and within valleys and have been studied by Carignano (1999), Carignano & *alii* (2014), and Kröhling & Carignano, 2014. However, detailed stratigraphy of the local successions and their cartography is not yet available.

Cerro Colorado presents a variety of sandstone morphologies at different scales, such as cliffs, cavernous forms, tafoni, balanced rocks, flared slopes, pavements, domes, tors, among others (Boretto & *alii*, 2021). The particular sandstone geomorphology allowed the pre-Hispanic development of populations in the area during the Holocene, whose presence is registered mainly by the spectacular rock painting preserved in the cavernous forms (Boretto & *alii*, 2021).

This region is characterized by a semi-arid climate (Capitanelli, 1979), with an average annual rainfall of 600 mm, concentrated mainly during the wetter spring-summer season (October to March). It has a long intermediate season with average temperatures of 10 °C, and frosts reaching -5 °C during the winter. Wide temperature ranges between day and night are characteristic of the area (Capitanelli, 1979). The dominant vegetation type is Chaco woodland, in an ecotone between the Serrano and Chacopampeano districts (Sanabria & *alii*, 1996). In general, the soils of the area present little development and thickness, although differences can be found depending on the orientation and exposure of the slopes (Sanabria & *alii*, 1996).

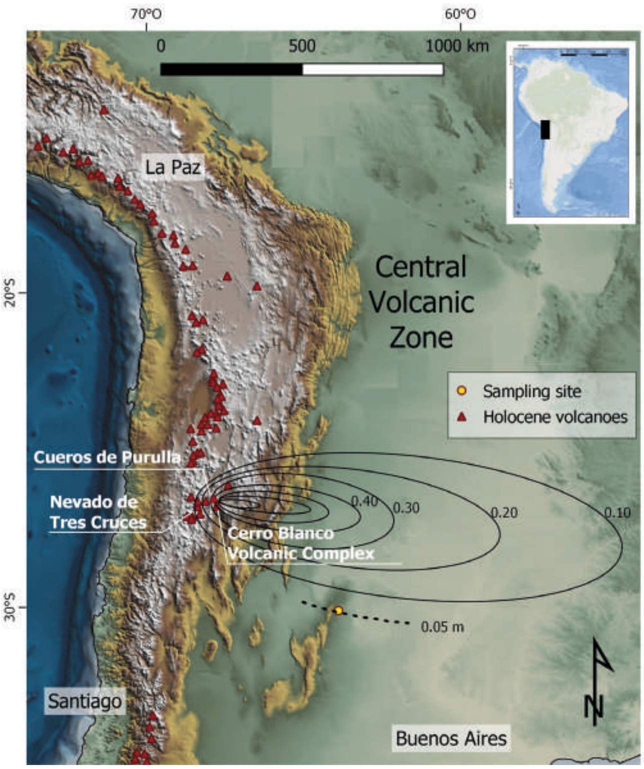

FIG. 1 - Location map of the sites cited within the text. Black lines isopachs (in m) of Cerro Blanco eruption (after Fernández-Turiel & *alii* 2019). Dashed line: reconstructed isopach from Cerro Colorado outcrop. Holocene volcanoes after Tilling 2009. The isopach reported in fig. 1 are both the results from field measurement and modelling of the paroxysmal phase of the Cierro Blanco eruption (Turiel & *alii* 2019).

MATERIAL AND METHODS

The main studied section outcrops along the flanks of a small valley where the local continental succession is exposed at 30° 6' 16.70" S and 63° 53' 12.20" W. The section was described and sampled for tephra analyses and radiocarbon dating. The samples were dried in an oven for 48 h at the laboratory of Palaeoclimatology and Geoarcheology of the University of Pisa.

Soil samples for radiocarbon dating were sieved at 1 mm (Phi scale 0 -ϕ-), and the finer fraction was manually cleaned by possible young contaminants like roots and insects. An additional sample for radiocarbon dating was collected in the lower part of the section, represented by an individual of the land snail *Megalobulimus lorentzianus* (Doering 1876). This sample was cleaned in deionized water in an ultrasonic bath before being sent out for radiocarbon measurements.

Radiocarbon measurements were carried out at the CIRCE laboratory of Caserta, Italy (Terrasi & *alii*, 2007, 2008) and the Arizona AMS Laboratory. The resulting conventional ^{14}C ages (^{14}C yr BP) were calibrated to calendar years (cal yr BP) with the Calib8.2 program (Stuiver & *alii*, 2021) using the SHCal20 calibration curve (Hogg & *alii*, 2020). Tab. 1 shows the radiocarbon results.

A portion of the sample of the tephra layer was embedded in epoxy resin, polished and coated with graphite, and analyzed at the Istituto di Geologia Ambientale e Geoingegneria of the Italian National Research Council (IGAG-CNR) (Rome, Italy) using a Cameca SX50 electron microprobe equipped with five wavelength-dispersive spectrometers. Operating conditions were set to 15 kV accelerating voltage; 15 nA beam current; 10-15 mm beam diameter; 20 s per element counting time; Wollastonite (Si and Ca), corundum (Al), diopside (Mg), andradite (Fe), rutile (Ti), orthoclase (K), jadeite (Na), phlogopite (F), potassium chloride (Cl), barite (S), and metals (Mn) were used as standards. The Ti content was corrected for the overlap of Ti-Ka peaks. In order to evaluate the accuracy of the electron microprobe analyses, three secondary standard reference materials (Kakanui augite and rhyolite RLS132 glasses from the United States Geological Survey) were measured prior to each analytic run. Supplementary tab. S1 shows the data, whereas supplementary tab. S2 shows the test on the standards.

The Sr and Nd isotope compositions were determined on a "bulk" sample by thermal ionization mass spectrometry at the Istituto Nazionale di Geofisica e Vulcanologia, Osservatorio Vesuviano (INGV, Naples, Italy), using a ThermoFinnigan Triton TI multicollector mass spectrometer, in static mode, on an aliquot of the powdered sample. A 0.1 g of sample was directly dissolved with high purity acids before Sr and Nd extraction. To consider the possible presence of a "exotic" contamination of terrigenous material in the bulk sample, two different aliquots of the same sample powder were at first leached 4-5 times with cold 6 N HCl for 10 min and then rinsed in MilliQ® deionized water and then dissolved with high purity acids. After dissolution, Sr and Nd were separated by conventional ion-exchange chromatographic techniques. The Sr blank was less than 0.2 ng during the analytical process. Measured $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ isotope ratios were normalized for within-run isotopic fractionation to $^{86}Sr/^{88}Sr = 0.1194$ and $^{146}Nd/^{144}Nd = 0.7219$, respectively. The mean of measured values of $^{87}Sr/^{86}Sr$ for NIST-SRM 987 was 0.710220 ± 0.000019 (2σ) and 0.511845 ± 0.000010 (2σ). The external reproducibility (2σ) is calculated according to Goldstein & *alii*, (2003). The Sr and Nd isotope ratios were normalized to the recommended values of NIST SRM 987 ($^{87}Sr/^{86}Sr = 0.71025$) standard and La Jolla ($^{143}Nd/^{144}Nd = 0.51185$) standards, respectively.

RESULTS

Fig. 2 shows the stratigraphy of the section, which consists of two distinct phases of fluvial aggradation and soil formation. The radiocarbon dating suggests that this succession developed during the Holocene, representing two phases of aggradation of the local fluvial network, possibly connected to changes in the local climate (e.g. Carignano, 1999). The bulk organic matter of the upper paleosoil yielded an age of 4207 ± 22 yr BP (4833-4579 cal yr BP), whereas the radiocarbon dating of the lower fluvial phase yielded an age of 5750 ± 30 yr BP (6627-6443 cal yr BP) (tab. 1).

TABLE 1 - Radiocarbon dating from Cerro Colorado section. Calibration was performed with the Calib8.2 program (Stuiver & *alii*, 2021) and the SHCal20 calibration curve (Hogg & *alii*, 2020).

Sample ID	Field Label	Material	^{14}C yr BP	^{14}C cal yr BP (2σ) (median probability)
DSH9532_SD[1]	CORD-15	soil organic material	4207 ± 22	4833-4579(4713)
AA 112368[2]	BPyV	land snail shell *Megalobulimus lorentzianus* (Doering 1876)	5750 ± 30	6627-6443(6502)

[1] CIRCE Laboratory, Caserta; [2] Arizona AMS Laboratory.

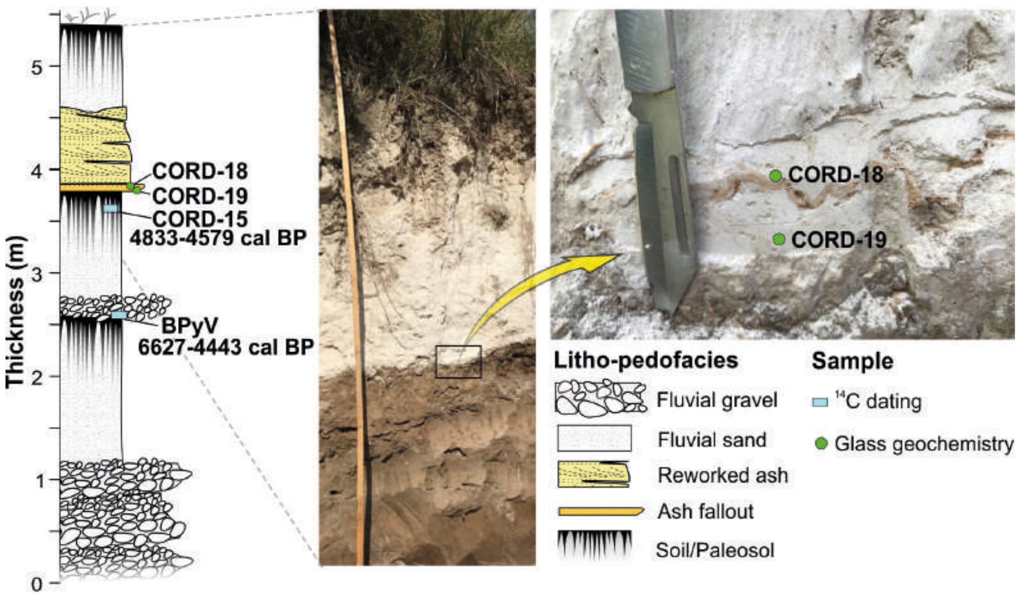

FIG. 2 - General stratigraphy of the Cerro Colorado section discussed in the text. Left) Synthetic stratigraphic profile; central) section showing the volcanic ash deposits overlying a paleosol; right) detail of the basis of the volcanic ash deposits.

The tephra shows a medium to fine ash grain size. The first ca. 5-6 cm are represented by massive whitish ash covered by a thin (2-4 mm) pinkish ash layer (fig. 2). This pinkish layer is observed more or less continuously throughout the area where the tephra outcrops. The layer shows evident deformation probably derived by local sliding and deformation on gentle slopes. Above this layer, lenses of coarse ash alternate with thin fine ash, clearly indicating water reworking on the slope and resembling "scour-and-fill" structures described, for instance, by Smith (1987) and Zanchetta & *alii* (2004).

The whitish basal layer and the pinkish one were analyzed separately, but they did not show appreciable differences and are, therefore, considered together. Glass shards are the dominant fraction, with rare crystals, and have a rhyolitic composition (e.g. SiO_2: 78.02 ± 0,21%, $Na_2O + K_2O$: 8.06 ± 0.21%; fig. 3) in the Total – Alkali – SiO_2 diagram (Le Bas & *alii*, 1986), with a ratio $K_2O/Na_2O > 1$ (1.22 ± 0.04). They lie below the Irvine & Baragard (1971) line and, considering the K_2O – SiO_2 diagram, are in the field of the high-K calc-alkaline series (Peccerillo & Taylor, 1976). The unleached fraction's $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ ratios are 0.70932 and 0.51240 for sample CORD-19, respectively whilst the Sr isotopic compositions of the leached fractions are 0.70820 and 0.70807 with Nd isotopes of 0.51243 and 0.51241, respectively (tab. 1).

DISCUSSION

The section analyzed suggests two main phases of fluvial aggradation separated by buried soil/paleosols indicating the local surface stability favoring pedogenesis (Retallack, 1990). The lowermost soil is generically older than 6627-6443 cal yr BP, whereas the following phase of pedogenesis occurred ca. 1600-2000 yr later, at around 4833-4579 cal yr BP, and terminated with the tephra deposition. The radiocarbon age obtained in this paper for organic material just below the ash layer (precisely it exposed 30° 6' 16.43" S and 63° 53' 12.12" W) is confirmed by an unpublished age of 4250 ± 40 ^{14}C yr BP (4860-4580 cal yr BP) below a tephra layer from a close outcrop studied by Herrero (2000). Herrero (2000) indicated for the ash layer a tabular geometry with variable thickness between 15 and 25 cm and longitudinal continuity along tens of meters; besides, the contact between the tephra and the overlying paleosol is sharp. This age indicates that the tephra is younger than ca. 4800-4700 cal yr BP. This succession would be consistent with the general climate evolution of the area reconstructed by Cioccale (1999) and Carignano (1999) with a first phase of the Holocene characterized by wetter conditions, separated by a second part of the Holocene much drier. However, more data need to be collected to improve the local geological and geomorphological evolution, which will be the target of future studies.

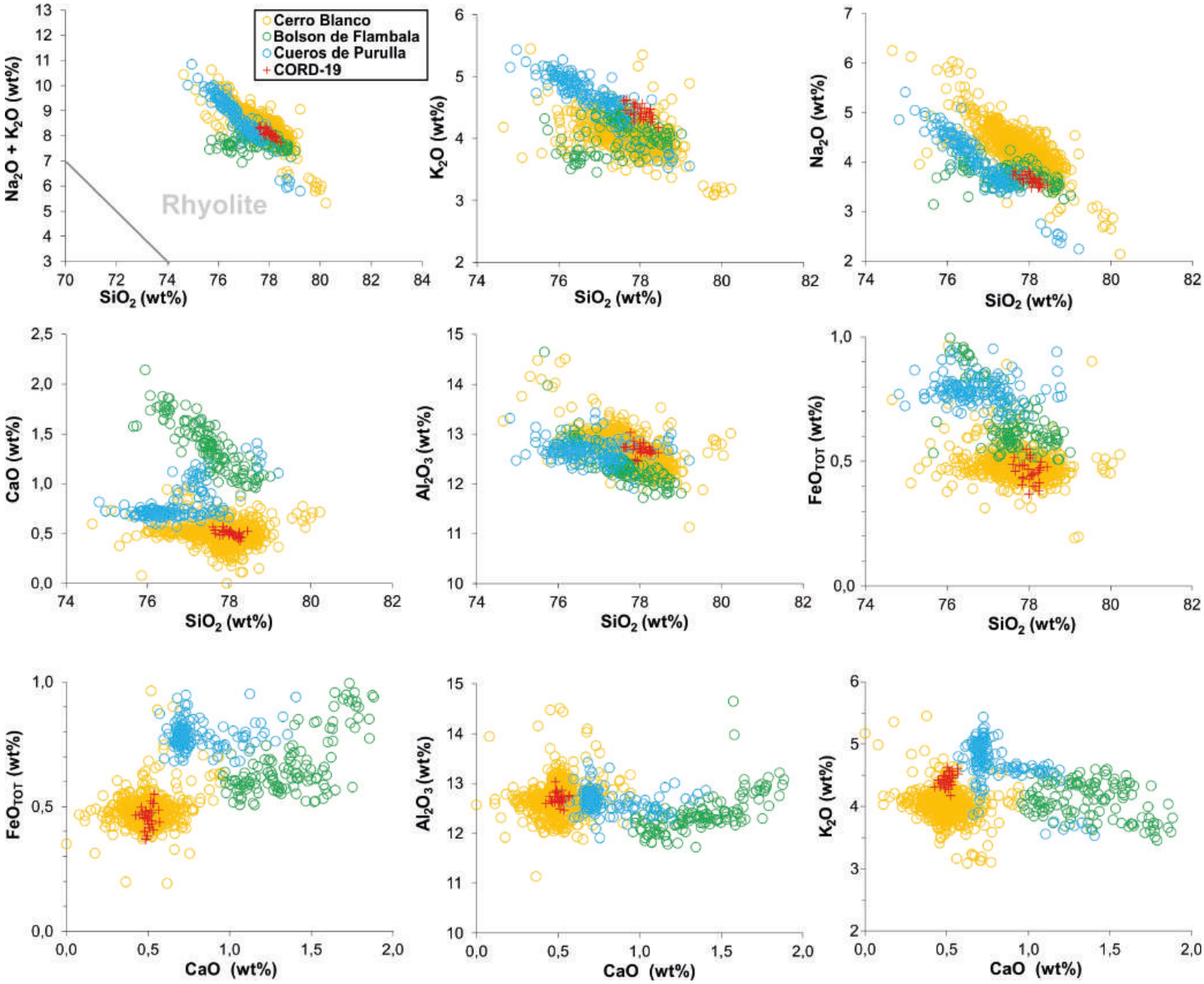

FIG. 3 - Bi-plots of the major chemical compositions of glass shards of the Cerro Colorado ash layer (CORD-19). In the graphs data from Cerro Blanco, Bolsón de Flambalá, and Cueros de Porulla volcanic eruptions are shown for comparison (data after Fernández-Turiel & *alii,* 2019). Compositional field divisions in the SiO_2 vs. $Na_2O + K_2O$ plot according to the Total – Alkali – SiO_2 diagram (Le Bas & *alii*, 1986).

The origin of the recovered tephra layer deserves detailed investigation. Considering the geographical location of the outcrop, it is highly probable that its origin should be found in the southern sector of the CVZ. This origin is consistent with the $^{143}Nd/^{144}Nd$ and to less extent with the $^{87}Sr/^{86}Sr$ ratios (fig. 4), which appear more radiogenic but still within the range of values featuring the Neogene-Quaternary ignimbrites from the CVZ (Siebel & *alii*, 2001) and more in general of the products of the CVZ (Scott & *alii*, 2018). Much more similar to the Sr isotope composition of the proximal CVZ volcanic products is the $^{87}Sr/^{86}Sr$ of the leached fraction. However, we cannot rule out entirely that also the $^{87}Sr/^{86}Sr$ ratio of the leached fractions is affected by the contribution of some external Sr, in particular taking into account the high evolved nature of this tephra and, in turn, its relatively low Sr content (de Silva & *alii*, 2022; Fernandez-Turiel & *alii*, 2021). The effect introduced by the leaching is indicated in fig. 4 by an arrow, which shows how $^{87}Sr/^{86}Sr$ is more affected by leaching operation moving the values toward less radiogenic composition, but has very minor effects on $^{143}Nd/^{144}Nd$ ratio. For instance, Sr-isotopes have been demonstrated as a valuable tool in the SVZ to distinguish among different sources and, within the same volcanic edifice, different eruptions (Naranjo and Stern 1998; Stern, 2008; Weller & *alii*, 2014; Zanchetta & *alii*, 2021). Conversely, Nd isotopes are much more stable irrespective of the leaching procedure. These results demonstrate the stability of $^{143}Nd/^{144}Nd$ with respect to Sr isotopes, being Nd a less fluid mobile element.

On the other hand, there are insufficient geochemical data on glass shards on the explosive volcanic activity for most CVZ for fingerprinting volcanic sources of distal tephra layers. In addition, geochemical data have been obtained with different methods making correlation complex (e.g. Hermanns & *alii*, 2000; Hermanns & Schellenberger. 2008; Sampietro-Vattuone & *alii*, 2020). Recently, Fernán-

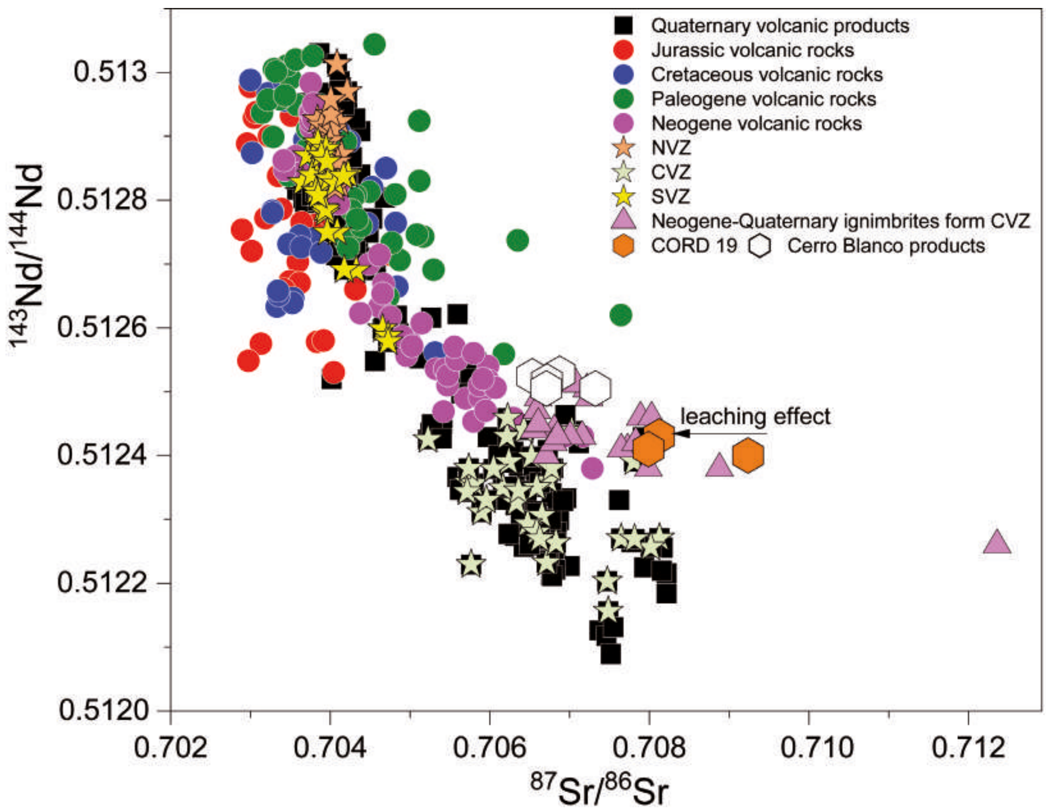

FIG. 4 - Comparison of $^{87}Sr/^{86}Sr$ vs. $^{143}Nd/^{144}Nd$ for Cerro Colorado sample compared with literature data for Andean volcanism (data after de Silva & *alii*, 2022; Scott & *alii*, 2018; Siebel & *alii*, 2001). The arrow indicates the compositional shift $^{87}Sr/^{86}Sr$ and $^{144}Nd/^{143}Nd$ of the leached samples. The $^{87}Sr/^{86}Sr$ ratio move towards less radiogenic composition, whereas the $^{144}Nd/^{143}Nd$ is more stable, indicating the stability of $^{143}Nd/^{144}Nd$ with respect to Sr isotopes, being Nd a less fluid mobile element. NVZ: Northern Volcanic Zone; CVZ: Central Volcanic Zone; SVZ: Southern Volcanic Zone.

dez-Turiel & *alii* (2019) reported detailed major and minor chemical elements of volcanic activity of comparable ages for the volcanoes in the southern edges of the CVZ (Cueros de Purulla, Nevado de Tres Cruces; Cerro Blanco Volcanic Complex). In different diagrams (e.g. alkali vs. SiO_2, K_2O vs. SiO_2, Na_2O vs. SiO_2; fig. 4), there is a general overlap between the Cerro Colorado tephra and the different eruptions close in age, whereas in others (CaO vs. SiO_2, FeO vs. SiO_2, and in particular FeO, Al_2O_3 and K_2O vs. CaO; fig. 3) the correlation between our tephra and the products of the Cerro Blanco eruption occurring at ca. 4200 cal yr BP is unquestionable. This correlation is strengthened by the radiocarbon ages obtained in this study and the study by Fernández-Turiel & *alii* (2019).

According to Fernández-Turiel & *alii* (2019), the eruption of the Cerro Blanco Volcanic Complex is dated at 4410-4150 cal yr BP and spread volcanic deposits over an area of ~500,000 km^2, accumulating >100 km^3 of tephra (bulk volume). Ash-fall deposits mantled the region at distances >400 km from the source, and thick pyroclastic-flow deposits filled neighboring valleys as far as 35 km from the source. This eruption is the largest documented during the past five millennia in the CVZ of the Andes and is probably one of the largest Holocene explosive eruptions in the world, with an estimated Volcanic Explosive Index (VEI) of 7 (Fernández-Turiel & *alii* 2019; Báez & *alii* 2020). The isopach reported in fig. 1, from Fernández-Turiel & *alii* (2019), are both the results from field measurement and modelling of the paroxysmal phase of the Cierro Blanco eruption. Considering the thickness of the tephra below the pinkish layer, that is what can be reasonably considering not reworked, the area is consistent with an isopach of ca. 5 cm (fig. 1), allowing to refine the dispersion of this eruption, but also helping to define where this eruption can be potentially encountered.

The improvement of chronology, volume, and dispersion of large eruptions is also relevant for constraining the origin of climatic changes during the Holocene (e.g. Sigl & *alii*, 2015, Svensson & *alii*, 2020; Mann & *alii*, 2021). In particular, the age of the Cerro Blanco eruption is close to the so-called 4200-year event (Weiss, 2015), a climatic event that affected the climate of the Northern Hemisphere for some centuries (e.g. Weiss, 2015; Bini & *alii*, 2019), but which possibly had a global effect. Therefore, the Cerro Blanco eruption can be a good marker to search for the expression of this event in the Southern Hemisphere, as similarly tephra layers are used at regional scale in the Northern Hemisphere (Zanchetta & *alii*, 2011, 2019).

CONCLUDING REMARKS

The studied section indicates two main phases of fluvial aggradation during middle-to-late Holocene separated by phases of soil development in the area of the Cerro Colorado. The first phase is older than ca. 6500 cal yr BP, as indicated by the radiocarbon dated snail, but it is terminated before ca. 4700 cal yr BP as indicated by the age of the organic matter of paleosol. The phases of fluvial aggradation suggest two main "wetter" periods separated by episodes of pedogenesis. Radiocarbon dating and microanalytical data allow us to precisely correlate the tephra layer find embedded in the local Holocene succession of the Cerro Colorado with the large eruption that occurred at the Cerro Blanco Volcanic Complex at ca. 4.2 cal ka BP. Moreover, this finding also improves our knowledge of the dispersion of this eruption. These results can, in the future, improve the chronological and the stratigraphical constraints of the rich archeological remains of the area and, more in general, on the Quaternary stratigraphy of the region.

REFERENCES

Astini R.A. & Del Papa C.E. (2014) - *Cubierta sedimentaria paleozoica superior.* In: Martino R.D. & Guereschi A.B. (Eds.), Geología y Recursos Naturales de la Provincia de Córdoba, Relatorio del 19º Congreso Geológico Argentino, Córdoba.

Báez W., Bustos E., Chiodi A., Reckziegel F., Arnosio M., de Silva S., Giordano G., Viramonte J.G., Sampietro-Vattuone M.M. & Peña-Monné J.L. (2020) - *Eruptive style and flow dynamics of the pyroclastic density currents related to the Holocene Cerro Blanco eruption (Southern Puna plateau, Argentina).* Journal of South American Earth Sciences, 98, 102482.

Bertolino S.R., Poire D.G. & Carignano C. (2000) - *Primer registro de sedimentitas marinas terciarias aflorantes en las Sierras Pampeanas de Córdoba, Argentina.* Revista de la Asociación Geológica Argentina, 55, 121-124.

Bini M., Zanchetta G., Perşoiu A., Cartier, R., Català A., Cacho I., Dean J.R., Di Rita F., Drysdale R.N., Finnè M., Isola I., Jalali B., Lirer F., Magri D., Masi A., Marks L., Mercuri A.M., Peyron O., Sadori L., Sicre M.A., Welc F., Zielhofer C. & Brisset E. (2019) - *The 4.2 ka BP Event in the Mediterranean Region: an overview.* Climate of the Past, 15, 555-577.

Boretto G.M., Cioccale M., Carignano C., Gordillo S., Recalde A. & Tissera L. (2021) - *Sandstone Geomorphology: Cerro Colorado, Sierras Pampeanas, Córdoba, Argentina.* In: Advances in Geomorphology and Quaternary Studies in Argentina, Springer, Cham, 30-52.

Candiani J.C. (2008) - *Cerro Colorado Cuando la pintura se apodera de la piedra.* Anales Servicio Geológico Minero Argentino (SEGEMAR), 46, 349-356.

Candiani J.C., Carignano C., Stuart-Smith P., Lyons P., Miró R. & López H. (2001) - *Hoja Geológica 3166-II Cruz del Eje, Provincias de Córdoba, La Rioja y Catamarca.* Servicio Geológico Minero Argentino Instituto De Geología Y Recursos Minerales, Boletín 249, Buenos Aires, 77 pp.

Candiani J.C., Gaido F., Miró R., Carignano C., & López H. (2010) - *Hoja geológica 3163-I Jesús María, Provincia de Córdoba.* Instituto de Geología y Recursos Minerales, SEGEMAR. Boletín 314. Buenos Aires.

Capitanelli R.G. (1979) - *III Clima.* In: Vázquez J.B., Miatello R.A. & Roqué M.E., Geografía física de la provincia de Córdoba. Buenos Aires, 45-138.

Carignano C.A. (1996) - *Evolución geomorfológica de las planicies en la provincia de Córdoba durante el Pleistoceno Superior.* Revista del Instituto de Geología y Minería, 11, 7-26.

Carignano C.A. (1997a) - *Caracterización y evolución durante el Cuaternario Superior, de los ambientes geomorfológicos extraserranos en el noroeste de la provincia de Córdoba*, Universidad Nacional de Córdoba, Tesis doctoral.

Carignano C.A. (1997b) - *El Holoceno en la provincia de Córdoba (Argentina).* Revista del Instituto de Geología y Minería, 11, 1-20.

Carignano C.A. (1999) - *Late Pleistocene to recent climate change in Córdoba Province, Argentina: Geomorphological evidence.* Quaternary International, 57/58, 117-134.

Carignano C.A., Kröhling D., Degiovanni S. & Cioccale M. (2014) - *Geomorfología.* In: Martino, R., Guereschi, A. (Eds.), Relatorio XIX Congreso Geológico Argentino: Geología y Recursos Naturales de la Provincia de Córdoba. Córdoba, Asociación Geológica Argentina, 747-82.

Cioccale M.A. (1999) - *Climatic fluctuations in the Central Region of Argentina in the last 1000 years.* Quaternary International, 62, 35-47.

Daga R.; Guevara S.R., Sañchez M.L. & Arribére M. (2010) - *Tephrochronology of recent events in the Andean Range (northern Patagonia): spatial distribution and provenance of lacustrine ash layers in the Nahuel Huapi National Park.* Journal of Quaternary Science, 25 (7), 1113-1123.

Daga R., Guevara S.R., Poire D.G. & Arribére M. (2014) - *Characterization of tephras dispersed by the recent eruptions of volcanoes Calbuco (1961), Chaitén (2008) and Cordón Caulle Complex (1960 and 2011), in Northern Patagonia.* Journal of South American Earth Sciences, 49, 1-14.

Del Carlo P., Di Roberto A., D'Orazio M., Petrelli M., Angioletti A., Zanchetta G., Maggi V., Daga R., Nazzari M. & Rocchi S. (2018) - *Late Glacial-Holocene tephra from southern Patagonia and Tierra del Fuego (Argentina, Chile): A complete textural and geochemical fingerprinting for distal correlations in the Southern Hemisphere.* Quaternary Science Reviews, 195, 153-170.

de Silva S.L., Roberge J., L. Bardelli, Báez W., Ortiz A., Viramonte J.G, Arnosio J.M., & Becchio R. (2022) - *Magmatic evolution and architecture of an arc-related, rhyolitic caldera complex: The late Pleistocene to Holocene Cerro Blanco volcanic complex, southern Puna, Argentina.* Geosphere 2022. doi: https://doi.org/10.1130/GES02294.1

Fernández-Turiel J.L., Perez–Torrado F.J., Rodriguez-Gonzalez A., Saavedra J., Carracedo J.C., Rejas M., Lobo A., Osterrieth M., Carrizo J.I., Esteban G., Gallardo J., & Ratto N. (2019) - *The large eruption 4.2 ka cal BP in Cerro Blanco, Central Volcanic Zone, Andes: Insights to the Holocene eruptive deposits in the southern Puna and adjacent regions.* Estudio Geológicos, 75 (1), e088.

Fernandez-Turiel J.L., Rejas M., Perez-Torrado F.J. & Rodriguez-Gonzalez A. (2021) - *Dataset of whole rock analysis of Holocene volcanic ashes and lava domes of 4.2 ka Cerro Blanco eruption, NW Argentina [Excel file].* DIGITAL.CSIC. doi: 10.20350/DIGITALCSIC/14151

Fontijn K., Lachowycz S.M., Rawson H., Pyle D.M., Mather T.A., Naranjo J.A., & Moreno-Roa H. (2014) - *Late Quaternary tephrostratigraphy of southern Chile and Argentina.* Quaternary Science Reviews, 89, 70-84.

Gardner G. (1931) - *Rock paintings of North-West Córdoba.* Oxford, Clarendon Press.

Goldstein S.L., Deines P., Oelkers E.H., Rudnick R.L & Walter L.M. (2003) - *Standards for publication of isotope ratio and chemical data in Chemical Geology.* Chemical Geology, 202, 1-4.

Gutiérrez P.R., Ottone E.G. & Japas S.M. (2006) - Léxico Estratigráfico de la Argentina, Volumen VII. Pérmico. Asociación Geológica Argentina, Serie B 28 y Servicio Geológico Minero Argentino, Buenos Aires 167, 368.

Hermanns R.L. & Schellenberger A. (2008) - *Quaternary tephrochronology helps define conditioning factors and triggering mechanisms of rock avalanches in NW Argentina.* Quaternary International, 178, 261-275.

Hermanns R.L., Trauth M.H., Niedermann S., McWilliams M. & Strecker M.R. (2000) - *Tephrochronologic Constraints on Temporal Distribution of Large Landslides in Northwest Argentina.* The Journal of Geology, 108, 35-52.

Herrero S. (1999) - *Tafonización en las areniscas del Cerro Colorado (Sierra Norte, provincia de Córdoba), con especial referencia a los aleros con pinturas rupestres.* Revista de la Asociación Geológica Argentina, 54, 123-131.

Herrero S. (2000) - *Procesos sedimentarios holocenos en la cuenca del río Los Tártagos (Sierra Norte, Provincia de Córdoba): Implicancias paleoclimáticas y geomorfológicas*. Universidad Nacional de Córdoba, Tesis doctoral.

Hildreth W. & Drake R.E. (1992) - *Volcán Quizapu, Chilean Andes*. Bulletin of Volcanology, 54, 93-125.

Hogg A.G., Heaton T.J., Hua Q., Palmer J.G., Turney C.S.M., Southon J., Bayliss A., Blackwe Boswijk G., Bronk Ramsey C., Pearson C., Petchey F., Reimer P., Reimer R. & Wacker L. (2020) - *SHCal20 Southern Hemisphere calibration, 0-55,000 years cal BP*. Radiocarbon, 62. doi: 10.1017/RDC.2020.59

Iriondo M. (2010) - *Geología del Cuaternario en la Argentina*. Museo Provincial de Ciencias Naturales Florentino Ameghino, Santa Fe, 347.

Irvine T.N. & Baragar W.R.A. (1971) - *A guide to the chemical classification of the common volcanic rocks*. Canadian Journal of Earth Science, 8, 523-548.

Kröhling D. & Carignano C.A. (2014) - *La estratigrafía de los depósitos sedimentarios cuaternarios*. Relatorio del XIX Congreso Geológico Argentino, Asociación Geológica Argentina, 663-684.

Le Bas M.J., Le Maitre R.W., Streckheisen A. & Zanettin B. (1986) - *Chemical classification of volcanic rocks based on the total alkali-silica diagram*. Journal of Petrology, 27, 745-750.

Lowe D.L. (2011) - *Tephrochronology and its application: a review*. Quaternary Geochronology, 6, 107-153.

Lowe J.J., Bronk Ramsey C., Housley R.A., Lane C.S. Tomlison E.L., & RESET Team, RESET Associates (2015) - *The RESET project: constructing a European tephra lattice for refined synchronisation of environmental and archaeological events during the last c. 100 ka*. Quaternary Science Reviews, 118, 1-17.

Lucero Michaut H.N. (1979) - *Sierras Pampeanas del norte de Córdoba, sur de Santaigo del Estero borde oriental de Catamarca y sudeste de Tucumán*. 2º Simposio Geología Regional Argentina, Academia Nacional de Ciencias, 1, Córdoba, 293-347.

Mann M.E., Steinman B.A., Brouillette D.J. & Miller S.K. (2021) - *Multidecadal climate oscillations during the past millennium driven by volcanic forcing*. Science, 371 (6533), 1014-1019.

Methol E.J. (1958) - *Descripción Geológica de la Hoja 18I. Deán Funes, Tulumba (Córdoba).* Dirección Nacional de Geología y Minería, Boletín 88, 32-34.

Miró C.R. (2000) *Hoja Geológica 1:250.000, Villa Ojo de Agua, Santiago del Estero y Córdoba*. IGRM, Servicio Geológico Minero Argentino.

Naranjo J.A. & Stern C.A. (1998) - *Holocene explosive activity of Hudson volcano, southern Andes*. Bulletin of Volcanology, 59, 291-306.

Naranjo J.A., Moreno H. & Banks N.G. (1993) - *La erupción del volcán Hudson en 1991 (46°S), Región XI, Aisén, Chile*. Servicio Nacional de Geología y Minería de Chile Boletín, 44, 1-50.

Naranjo J.A, Singer B.S., Jicha B.R., Moreno H. & Lara L.E. (2017) - *Holocene tephra succession of Puyehue-Cordón Caulle and Antillanca/Casablanca volcanic complexes, southern Andes (40-41°S).* Journal of Volcanology and Geothermal Research, 332, 109-128.

Pastore F. (1932) - *Hoja 20i del Mapa Geológico de la Argentina. Región oriental media de la Sierra de Córdoba. Relevamiento geológico y explicación*. Boletín de la Dirección de Minas y Geología 36, Buenos Aires, 1-67.

Peccerillo A & Taylor S.R. (1976) - *Geochemistry of Eocene Calc-Alkaline Volcanic Rocks from the Kastamonu Area, Northern Turkey.* Contributions to Mineralogy and Petrology, 58, 63-81.

Polanski J. (1970) - *Carbónico y Pérmico de la Argentina*. EUDEBA, Manuales, 149-150.

Prieto A., Stern C.R. & Estévez J.E. (2013) - *The peopling of the Fuego-Patagonian fjords by littoral hunter-gatherers after the mid-Holocene H1 eruption of Hudson Volcano*. Quaternary International, 317, 3-13.

Recalde A.M. (2016) - *Paisaje rupestre en el norte de Córdoba*. Anales de arqueología y etnología, 70-71.

Recalde M.A. (2018) - *Memory in the stone: Rock art landscape at Cerro Colorado as a negotiation space for social memory.* In: Archaeologies of Rock Art. Routledge, London, 106-129.

Retallack G.J. (1990) - *Soils of the Past: An Introduction to Paleopedology*. Unwin Hyman, London, 520 pp.

Sampietro-Vattuone M.S., Báezc W.A., Peña-Monné J.L. & Sola A. (2020) - *Chronological and geomorphological approach to the Holocene tephras from Tafí and Santa María valleys, NW Argentina*. Quaternary Research, 94, 14-30. doi: 10.1017/qua.2019.78

Sanabria J.A., Leguizamón R.R., Tauber A.A., Manzur A., Piovano E.L., Barbeito O., Argüello G., & Balbis A. (1996) - *Guía de campo*. Actas de la 8º Reunión de campo del Cuaternario, Córdoba. Cadincua, 1-41.

Scott E.M., Allen M.B., Macpherson C.G., McCaffrey K.J.W., Davidson J.P., Saville C., Mihai N. & Ducea M.N. (2018) - *Andean surface uplift constrained by radiogenic isotopes of arc lavas*. Nature Communication, 9, 969. doi: 10.1038/s41467-018-03173-4

Siebel W., Schnurr W.B.W, Knut Hahne, Kraemer B., Trumbull R.B., van den Bogaard P. & Emmermann R. (2001) - *Geochemistry and isotope systematics of small- to medium-volume Neogene-Quaternary ignimbrites in the southern central Andes: evidence for derivation from andesitic magma sources*. Chemical Geology 171, 213-237.

Sigl M., McConnell J.R., Toohey M., Curran M., Das S.B., Edwards R., Isaksson E., Kawamura K., Kipfstuhl S., Kruger K., Layman L., Maselli O.J., Motizuki Y., Motoyama H., Pasteris D.R. & Severi M. (2014) - *Insights from Antarctica on volcanic forcing during the Common Era*. Nature Climate Change, 4, 693-697.

Sigl M., Winstrup M., McConnell J.R., Welten K.C., Plunkett, G., Ludlow F., Büntgen U., Caffee M., Chellman N., Dahl-Jensen D., Fischer H., Kipfstuhl S., Kostick C., Maselli O.J., Mekhaldi F., Mulvaney R., Muscheler R., Pasteris D.R., Pilcher J.R., Salzer M., Schupbach S., Steffensen J.P., Vinther B.M. & Woodruff T.E. (2015) - *Timing and climate forcing of volcanic eruptions for the past 2,500 years*. Nature 523, 543-549.

Smith G.A. (1987) - *The influence of explosive volcanism on fluvial sedimentation: the Deschutes formation (Neogene) in central Oregon*. Journal of Sedimentary Petrolology, 57, 613-629.

Stern C.H. (1991) - *Mid-Holocene tephra on Tierra del Fuego (54° S) derived from the Hudson volcano (46° S): evidence for a large explosive eruption*. Revista Geologica de Chile, 18, 139-146.

Stern C.R. (2004) - *Active Andean volcanism: Its geologic and tectonic setting*. Revista Geologica de Chile, 31, 161-206.

Stern C.R. (2008) - *Holocene tephrochronology record of large explosive eruptions in the southernmost Patagonian Andes*. Bulletin of Volcanology, 70, 435-454.

Stuiver M., Reimer P.J., & Reimer R.W. (2021) - CALIB 8.2 [WWW program] at http://calib.org, accessed 2021-4-3

Strelin J.A. (1995) - *Geomorfología de Cerro Colorado*. Seminario de Investigaciones sobre Epidemiología Psiquiátrica, 19, 42-69.

Sulpizio R., Zanchetta G., Caron B., Dellino P., Mele, D., Giaccio G.; Insinga D., Paterne M., Siani G., Costa G., Macedonio G. & Santacroce R. (2014) - *Volcanic ash hazard in the Central Mediterranean assessed from geological data*. Bulletin of Volcanology, 76, 866.

Svensson A., Dahl-Jensen D., Steffensen J.P., Blunier T., Rasmussen S.O., Vinther B.M., Vallelonga P., Capron E., Gkinis V., Cook E., Kjær H.A., Muscheler R., Kipfstuhl, S., Wilhelms F., Stocker T.F., Fischer H., Adolphi F., Erhardt T., Sigl M., Landais A., Parrenin F., Buizert C., McConnell J.R., Severi M., Mulvaney R. & Bigler M. (2020) - *Bipolar volcanic synchronization of abrupt climate change in Greenland and Antarctic ice cores during the last glacial period*. Climate of the Past, 16, 1565-1580.

Terrasi F., Rogalla D., De Cesare N. & *alii.* (2007) - *A new AMS facility in Caserta/Italy.* Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, 259, 14-17.

Terrasi F., De Cesare N., D'Onofrio A. & *alii* (2008) - *High precision ^{14}C AMS at CIRCE*. Nuclear Instruments and Methods in Physics Research, 266, 2221-2224.

Tilling R.I. (2009) - *Volcanism and associated hazard: The Andean perpesctive.* Advances in Geosciences, 22, 125-137.

Weiss H. (2015) - *Megadrought, collapse, and resilience in late 3rd millennium BC Mesopotamia, in 2200 BC.* In: Meller H., Arz H.W., Jung R. & Risch R., A Climatic Breakdown as a Cause for the Collapse of the Old World?, Landesmuseum fur Vorgeschichte, 35-52.

Weller D., Miranda C.G., Villa-Martínez R. & Stern C.R. (2014) - *The large lateglacial H0 eruption of the Hudson volcano, southern Chile.* Bulletin of Volcanology, 76, 831-850.

Zanchetta G., Sulpizio R.,& Di Vito M.A. (2004) - *Genesis and evolution of volcaniclastic alluvial fans in the southern Campania (Italy): relationships with volcanic activity and climate.* Sedimentary Geology, 168, 249-280.

Zanchetta G., Sulpizio R., Roberts N., Cioni R., Eastwood W.J., Siani G. Caron B., Paterne M., & Santacroce R. (2011) - *Tephrostratigraphy, chronology and climatic events of the Mediterranean basin during the Holocene: An overview.* The Holocene, 21, 33-52.

Zanchetta G., Giaccio B., Bini M. & Sarti L. (2018a) - *Tephrostratigraphy of Grotta del Cavallo, Southern Italy: insights on the chronology of Middle to Upper Palaeolithic transition in the Mediterranean.* Quaternary Science Reviews, 182, 65-77.

Zanchetta G., Ribolini A., Ferrari M., Bini M., Isola I., Lezzerini M., Baroni C., Salvatore M.C., Pappalardo M., Fucks E. & Boretto G. (2018b) - *Geochemical characteristics of the infilling of ground wedges at Puerto Deseado (Santa Cruz, Argentina): Palaeoenvironmental and chronological implications.* Andean Geology, 45, 130-144.

Zanchetta G., Bini M., Di Vito M.A., Sulpizio R. & Sadori L. (2019) - *Tephrostratigraphy of paleoclimatic archives in central Mediterranean during the Bronze Age.* Quaternary International, 499, 186-194.

Zanchetta G., Pappalardo M., Di Roberto A., Bini M., Arienzo I., Isola I., Ribolini A., Boretto G., Fucks E., Mele D., D'Orazio M., Marzaioli F. & Passariello I. (2021) - *A Holocene tephra layer within coastal aeolian deposits north of Caleta Olivia (Santa Cruz Province, Argentina).* Andean Geology, 48, 267-280.

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