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OVERVIEW OF THE CERRO CHIVO VOLCANIC FIELD (CCVF), CHUBUT PROVINCE, ARGENTINA: BASALT SHEETS, ROOT ZONES, DIATREMES AND 'PLUGS'

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RESUMEN

El Campo Volcánico del Cerro Chivo (CVCC), provincial del Chubut, Argentina: filones capa, zonas de raíz, diatremas y "cuellos volcánicos". El Campo Volcánico Cerro Chivo (CVCC), de edad terciario temprana, expone en la superficie manifestaciones de volcanes basálticos monogenéticos, la mayoría del tipo maar-diatrema. Los rasgos reconocidos incluyen diques; filones capa; zonas de raíz, donde los diques y la roca de caja están fragmentados; diatremas freatomagmáticas que incluyen rocas piroclásticas; diatremas "freato-strombolianas" poco comunes; y grandes macizos verticales de basalto coherente (cuellos volcánicos) que pudieron haberse originado como diatremas freatomagmáticas. Estudios volcanológicos más detallados del CVCC permitirán un avance significativo de la comprensión de los volcanes tipo maar-diatrema.

Palabras clave: Maares, diatremas, zonas de raíz, freatomagmatismo, peperita.

ABSTRACT

The Cerro Chivo Volcanic Field (CCVF) in Chubut Province dates from the early Tertiary and exposes the subsurface manifestations of basaltic monogenetic volcanoes, mostly of the maar-diatreme type. Documented features include unfragmentated basalt sheets; root zones, where the dikes and/or the country rocks are fragmented, and which may have fed diatremes; phreatomagmatic diatremes including bedded pyroclastic rocks; unusual "phreato-strombolian" diatremes; and large coherent basalt massifs ("plugs") that may have originated as phreatomagmatic diatremes. The CCVF offers numerous opportunities for more detailed volcanological studies which have the potential to significantly improve our understanding of maar-diatreme volcanoes.

Keywords: Maar, diatreme, root zone, phreatomagmatic, peperite.

INTRODUCCIÓN

Maar-diatremes are small explosively erupting subaerial volcanoes that pose hazards in active volcanic fields (e.g. Lorenz 2007), and can carry diamonds in kimberlitic ones. They comprise a crater cut into the original ground surface, underlain by a diatreme (White 1991; Lefebvre *et al*. 2013) and surrounded by an ejecta ring (Fig. 1). The diatreme grades downward into a root zone, and eventually into a coherent (unfragmented) dike. Many young ejecta rings have been studied (*e.g*. references cited in White and Ross 2011), but fewer diatremes and root zones. For these deeper parts, partially eroded Tertiary fields such as the Cerro Chivo Volcanic Field (CCVF) in Chubut Province are ideal. The objective of this expanded abstract is to outline the features of the volcanic plumbing system and the shallow intrusion mechanisms of the CCVF.

GEOLOGICAL CONTEXT AND OVERVIEW OF THE CCVF

The CCVF was emplaced within the Cretaceous Chubut Group continental sediments (Fig. 2). Underneath are rocks of the Triassic-Jurassic Chon Aike Siliceous Large Igneous Province and then a crystalline basement. Mafic volcanism in Patagonia started in Paleocene times (Alric *et al*. 2002) and continued until the Pleistocene. The basaltic volcanoes of the CCVF are Pa-

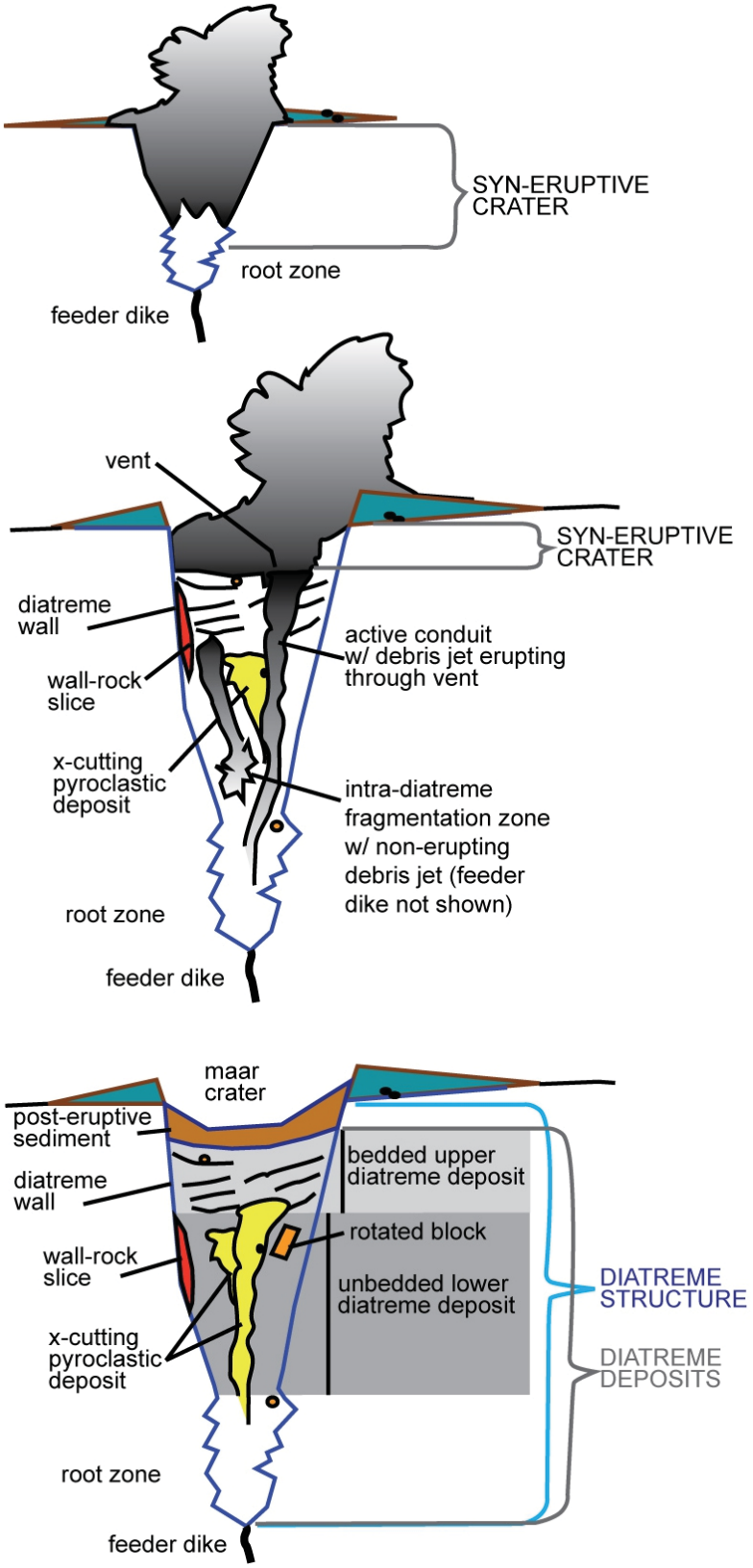

Figure 1. Schematic cross-section of a maar-diatreme volcano, after White and Ross (2011).

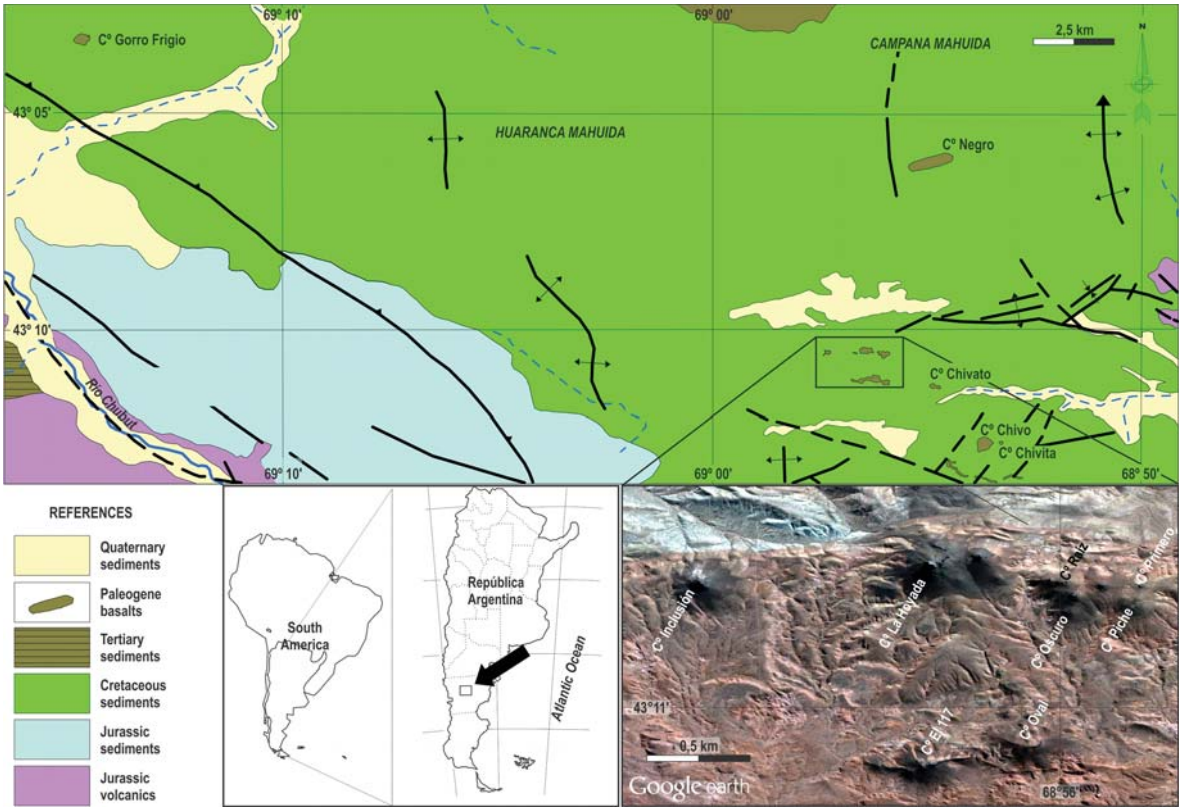

Figure 2. Simplified geological map of the Cerro Chivo Volcanic Field modified from Silva Nieto (2005) and Anselmi *et al*. (2004). The Google Earth™ image in the lower right shows a number of interesting volcanic vents (mostly black rocks on the image).

leocene - Eocene (Alric *et al*. 1996), and so are older – and generally occur to the south of – Oligocene-Miocene flood lavas of the Somuncura Plateau (Kay *et al*. 2007).Eighteen CCVF vents have been recognized so far in an area of 130 km^2. We estimate the minimum depth of erosion as ~0.5 km for the CCVF, based onDEM data that show the top of Cerro Chivo, which intrudes Cretaceous sediments, at 1130 m a.s.l. andthe lowest Cretaceous sediment outcrops at 615 m a.s.l. Initial studies on the CCVF were carried out by Németh *et al*. (2007) and Haller and Németh (2009).

INTRUSIVE SHEETS IN COUNTRY ROCK

Intrusive sheets of basalt in the CCVF range from well-defined dikes and sills, through a range of simple inclined sheets to complex sheets tangled with host material that in places produced domains of basalt within disturbed host materials (interpreted as peperites, see Skilling *et al*. 2002). Typical simple dikes and sills in country rock are 0.5-1.0 m thick with chilled margins and common columnar jointing. There is *en-echelon* segmentation of dikes, and development of horns and bridges in sills. Both dikes and sills have in many places significant inclined sheets that connect segments together, or accommodate transitions from dike to sill or *vice versa*. In the area of Cerro Chivo (Fig. 2), including between it and Cerro Chivita, sills traverse lateral distances exceeding 1 km in the layered mudrock and sandstone host. The total area of these thin sills probably exceeds 1 km^2. Near Cerro Chivo they show hook and horn steps and local bifurcations and rotations (Fig. 3a). Thin dikes, less than 0.5 m and locally thinning to a few centimeters, wind through the country rock and strike toward the massif of the volcanic plugs. Vesicular zones define layers parallel to the dike walls.

ROOT ZONES

Several structures are interpreted as root zones in the CCVF. **Cerro Raíz** is an elongate structure oriented about N100°, exposed over an area about 100 m by 20 m, and which lines up with the La Hoyada diatreme further west. A common rock type at Cerro Raíz consists of well mixed blocks of muddy to silty sedimentary country rock in a matrix of gravelly sand (Fig. 3b). Sparse juvenile fragments are also present. Locally, there is less mixing and large domains of country rocks, up to several meters across, are incipiently disaggregated, with irregular margins and locally injected by other sediments. These rocks are cut by coherent basalt sheets (mostly dikes) and pods commonly having marginal basalt-sediment peperite.

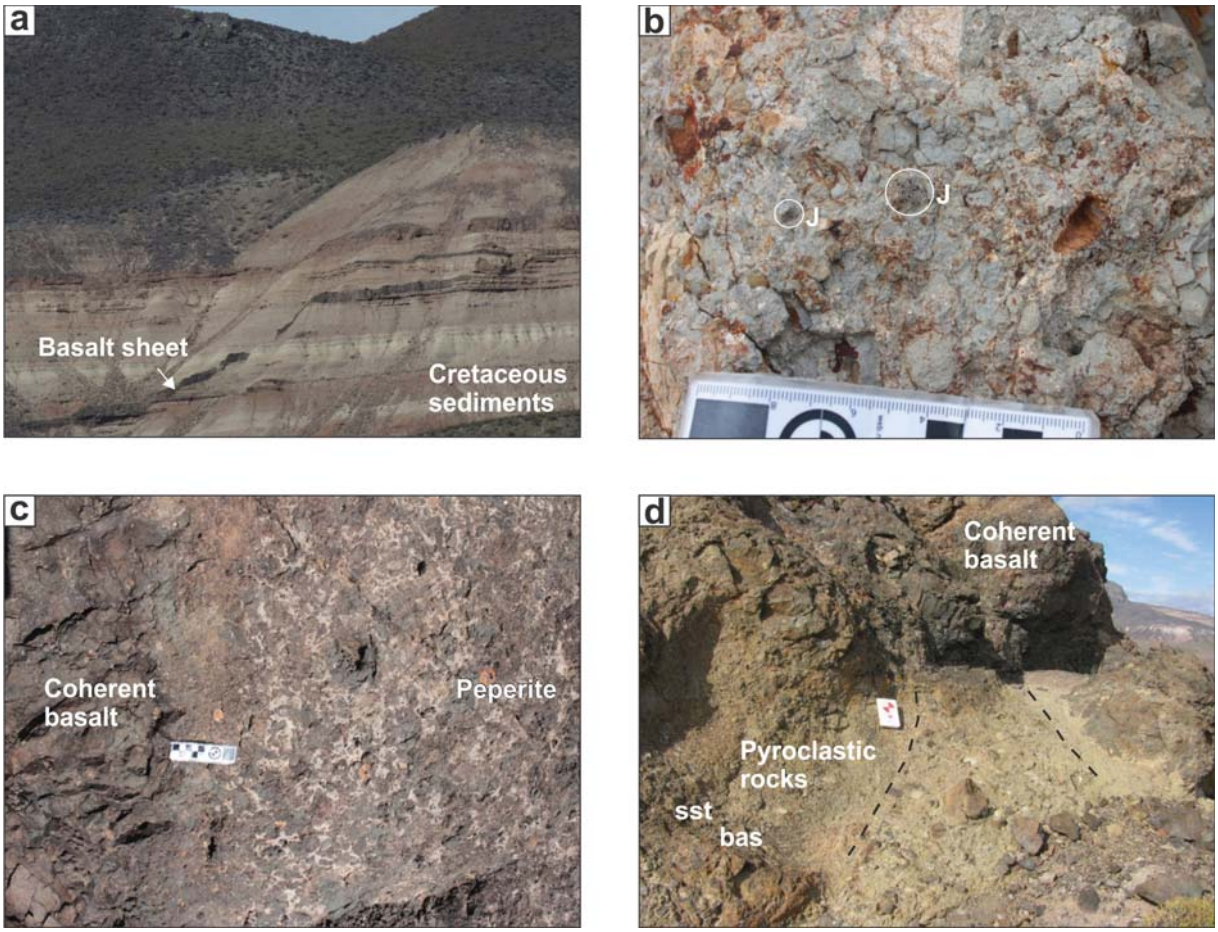

Figure 3. Photos of basalt sheets (a) and root zones (b-d). (a) Thin (0.5-1 m) sills in mudrock-sandstone sediment in places become inclined sheets or dikes connecting different sill levels. The Cerro Chivo massif lies to the right and above this image. (b) Volcaniclastic rock dominated by lithic (sedimentary) clasts of various types in the lapilli and ash size fractions, with minor proportions of juvenile (J) clasts, at Cerro Raíz. (c) Coherent basalt sheet grading into juvenile-rich fluidal peperite with both a light brown clastic and white carbonate cement matrix at Cerro El 117 (scale = 10 cm). (d) Steeply-dipping tuff breccia and lapilli tuff bedded domain from Cerro El 117 central segment. Contact between beds shown by dashed lines.

Cerro El 117 (Fig. 2) isa 900 m-long segmented structure oriented generally N095°, which comprises several linear segments. The eastern half and the westernmost part consist of several dike segments with overall thickness up to ~1.5 m. The western half has distinct western and central segments, 38 m and up to 60 m thick, respectively. The rocks in the widened portions are partly similar to those at Cerro Raíz, in that they include country rock breccias, juvenile-bearing volcaniclastic rocks of uncertain origin, and sheets of coherent basalts with variably extensive peperite (Fig. 3c). In addition, Cerro El 117 includes moderately to vertically dipping, dm-thick beds of tuff, lapilli tuff and tuff breccia (Fig. 3d) which are similar in appearance to the main infill of La Hoyada diatreme.

BEDDED (UPPER?) DIATREME

Cerro La Hoyada, an approximately circular structure about 0.25 km in diameter exposes mostly bedded lapilli tuffs, with minor lapillistones, tuff breccias and tuffs (Figs 4a, 4b). These are interpreted to fill a phreatomagmatic diatreme. Pyroclastic beds are typically several dm thick and seem to have concentric inward dips. In the summit area bedding is absent, and there is a presumably steep contact between bedded and non-bedded pyroclastic rocks,both bedded and non-bedded pyroclastic rocks are generally juvenile-rich. The diatreme is cut by basalt dikes up to several meters thick, many of which have peperitic contacts with their pyroclastic host. The summit area is partly occupied by a coherent basalt plugand thick basalt dikes.

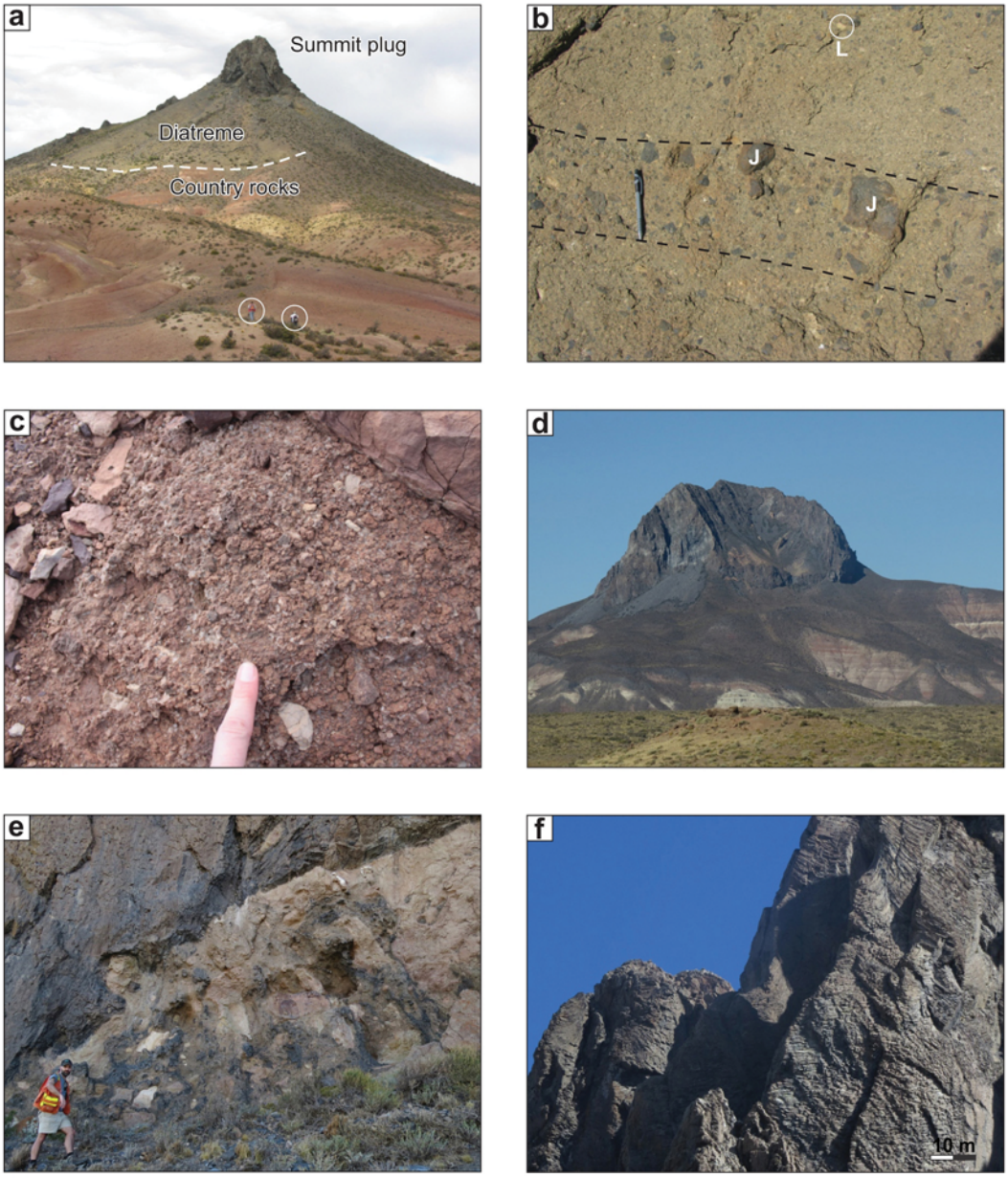

Figure 4. Photos of diatremes (a-c) and basalt massifs (d-f). (a) Overview of the Cerro La Hoyada diatreme, looking eastward. People (circled) for scale. (b) Close-up view of bedded juvenile (J)-rich and lithic (L)-poor pyroclastic rocks at Cerro La Hoyada. (c) Juvenile-rich lapilli tuff from Cerro Chivita. (d) Overview of Cerro Chivo. (e) Domains with basalt mingled into sandy sediment with country rock blocks comprise peperite along the eastern basal outcrops of Cerro Chivo. (f) Complex sets of curved basalt columns at Cerro Gorro Frigio meet at steep-dipping master joints in an entablature arrangement suggesting water cooling.

PHREATO-STROMBOLIAN DIATREME

While classic diatremes are mostly phreatomagmatic in origin, we also found some unusual deposits in what may perhaps be called a phreato-strombolian (?) diatreme (?).**Cerro Chivita** is a small ellipsoidal-shaped structure (~70 m x ~130 m) that cross-cuts the Cretaceous sediments. The dominant infill is amoderately sorted, framework-supported, structureless, juvenile-rich lapilli tuff (Fig. 4c).Juvenile pyroclasts are typically fine to medium lapilli in size, ovoid in shape with rough surfaces and poorly vesicular. Locally, the lapilli tuff exhibits welding. Country rock clast content is generally low (~5-15%) except for local regions of country rock breccia and rare country rock-rich (up to 90%) lapilli tuff domains.

BASALT MASSIFS (LARGE "PLUGS")

A prominent feature of the CCVF are the large massifs ("plugs") of Cerro Chivo itself (Fig. 4d), and Cerro Gorro Frigio. These large bodies of coherent basalt stand

hundreds of meters above their surroundings and have diameters of half a km. Multiple injections are apparent from a variety of steeply crosscutting contacts within the basalt masses, particularly near their margins where some dikes, sills and inclined sheets cross the boundaries between country rock and the basalt masses (Fig. 4e). Each has internal and/or peripheral bodies of pyroclastic lapilli tuff and tuff breccia, which suggests that these volcanoes originated as phreatomagmatic diatremes. Coherent basalt at **Cerro Chivo** is mostly characterized by platy joints, which have varied orientations and define complex curving sheets 1-3 dm thick that are cut by anastomosing secondary joints. In places the platy joints broadly parallel the basalt-country rock contact at the massif margins, but also common are joint sets that reach the cliff faces at nearly normal angles. In contrast, **Cerro Gorro Frigio** shows pervasive and well-developed columnar jointing, with typical columns 0.5 m in diameter. Some zones are characterized by master joints from which columns extend at right angles (Fig. 4f), stacked sets of columnar joints, and single sets of columnar joints defining shallow-plunging basalt columns that are tens of meters long.

DISCUSSION AND CONCLUSIONS

The Cerro Chivo Volcanic Field (CCVF) of northern Patagonia is a basaltic, monogenetic volcanic field where the current level of erosion is, in places, at least 0.5 km below the original ground surface. The CCFV shows a range of interesting features, such as the plumbing system (basalt sheets of various types), root zones, diatremes, and large basaltic plugs. Peperite is exposed in nearly every site visited and is inferred to have been formed when basalts intruded into wet, non-consolidated to poorly consolidated hosts, including country rocks and existing diatreme infills. The CCVF offers numerous opportunities for more detailed volcanological studies.

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