Caldera evolution of the Colima Volcanic Complex, México, based on 3D elevation models

Szabolcs Kósik[1,2,]Ê, Nicholas R. Varley[2], Dávid Karátson[1]

1. Department of Physical Geography, Eötvös Loránd University, 1117, Pázmány P. sétány. 1/C, Budapest, Hungary
2. Centro de Intercambio e Investigación en Vulcanología, Facultad de Ciencias, Universidad de Colima, Colima, México

Ê *corresponding author: Szabolcs Kósik: kosiksz@eotvos.elte.hu*

INTRODUCTION

One of North America's most active volcano, **Volcán de Colima (Volcán de Fuego)** is the southern-most member of **Colima Volcanic Complex (CVC)**, where several lateral collapses have occurred possibly with blast-like Mt. St. Helens eruption. The last of these was the **Paleofuego** caldera-forming event ~4300 yr. B.P. **(Robin et al. 1987)**. Besides frequent **Plinian-type** eruptions, the sector collapses-linked **debris avalanches** are the greatest risk to the surroundings.

The CVC shows a southern migration of activity, the oldest edifices being at the **El Cántaro** volcano, which was active between 1.6 and 1 million years B.P. **(Allan 1986)**. Subsequently volcanism moved south to the territory of **Nevado de Colima**, and more recently to its current location, further 6 km to the south (Fig.1). Apart from the multiple dome complexes, **eleven alkaline cinder cones** and associated lava flows were formed, most of them between 240 and 60 ka **(Charmichael et al. 2006)**.

The last comprehensive works on geologic history and volcanic geomorphology of the CVC **(Robin et al. 1987, *Rodríguez-Elizarrarás* 1995** and **Cortés et al. 2005)** had no or little opportunity to apply GIS techniques. The latest work **(Cortés et al. 2010)** reports the usage of GIS methods, but no direct evidence to volcanic geomorphology is presented.

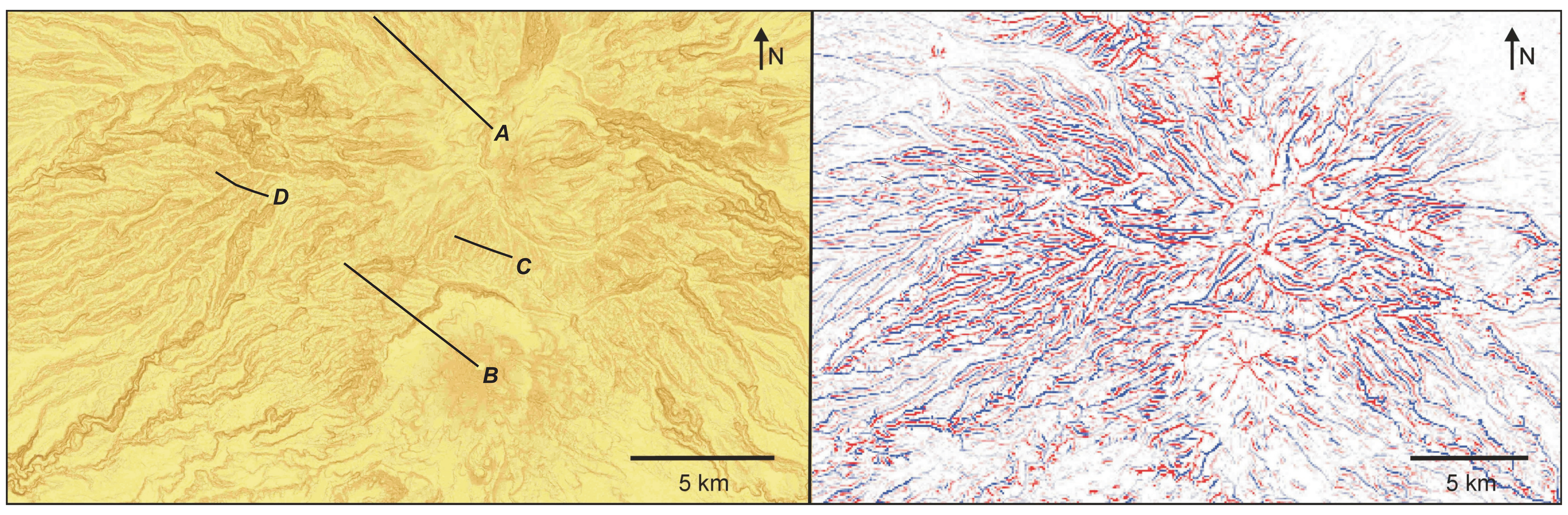

Fig. 2: Slope map and ridge (red) and valley (blue) map of the study area. Inside the Paleofuego caldera and the highest parts of Nevado the erosion is less developed. A, B, C, D are the locations of the sections of Fig. 3.

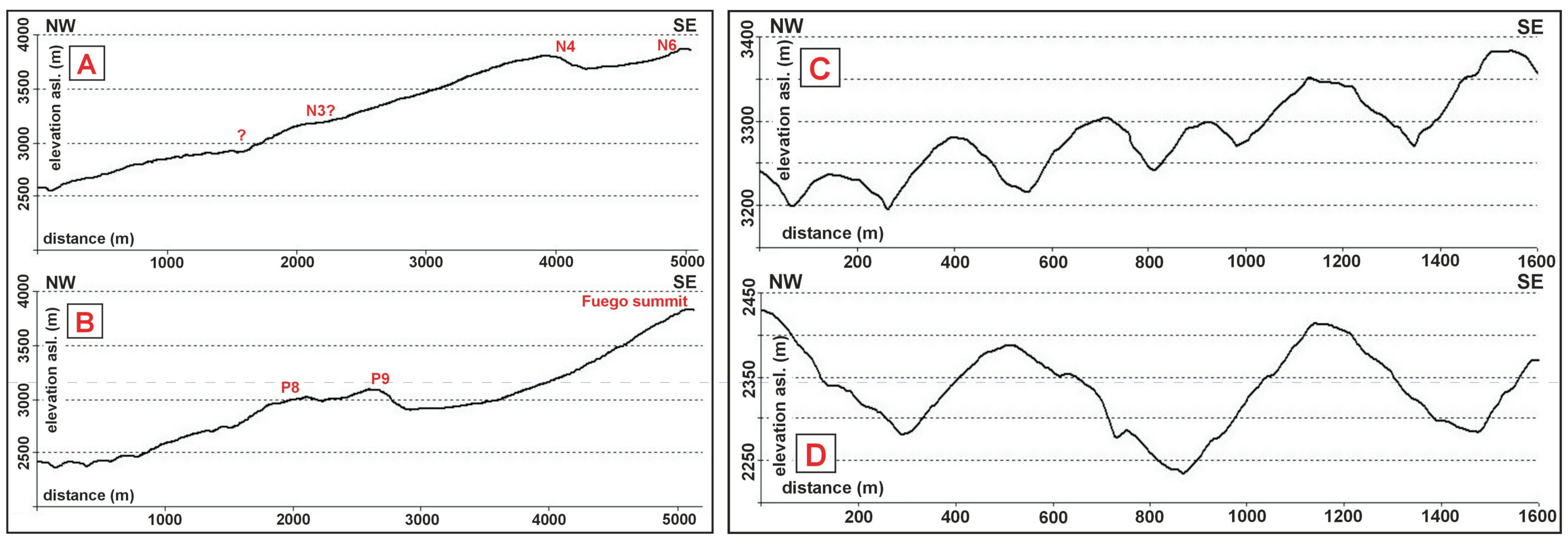

Fig. 3: Slope profiles of Nevado de Colima (A) and Fuego (B). Cross sections of the aspect at SW flank of Nevado (C) and south from the valley head of Telcruz (D). Both cross sections are measured 1 km away from the ridge (caldera rims; T2, and N4, N6) above them. For exact locations see slope map (Fig. 2).

DISCUSSION

We can observe significantly **higher ridge and valley density** on the outer slopes of Nevado, mainly **on the western flanks** (Fig. 2). This may imply an older (and more dissected) part of the edifice, which hypothesis is also **supported by the cross-sections** to the aspect (Fig. 3). Furthermore, the **drainage shows peculiar features** possibly **related to superimposed volcanic edifices and caldera rims.** Especially, surroundings the valley head of Telcruz, the outer slopes show a more or less radial divergent pattern. There, the southern side of Telcruz valley is bordered by a **high-altitude, arcuate, flat ridge that seems to represent an old caldera rim with radial ridges southward (T2)** (Fig. 5). We propose the **Telcruz valley head to represent an independentvolcanic centre** as part of the **early evolution of Nevado volcanism**. To the north, the picture is more disturbed, perhaps subsequent lavas of the growing Nevado edifice partially buried the Telcruz volcano, and later the **caldera interior has been excavated by fluvial erosion** (perhaps related to the first-order tectonic line cutting through this flank: Fig 1 & 5).

We assume **further primary structures on the slopes of Nevado de Colima and Fuego**. A few of them have already been mentioned wholly or partially but without exact location **(C1, N4, N5, N6, P8)**, however we have **distinguished unmentioned remnants, too (N3, N7, P9)** (Fig. 5).

The formation of the flank depressions may have chiefly controlled by the subsidence and other tectonic movements of Colima rift (Norini et al. 2010), creating horseshoe-shaped calderas breached to the east. We **could not confirm the existence of large calderas** (10-12 km wide) in any of the two volcanic systems. Firstly, such calderas should have associated high-volume ignimbrites from highly explosive eruptions, that we cannot detect in the area. Secondly, the existing and the **supposed caldera remnants are just 4-5 km wide**, **fitting to the average size of the horseshoe-shaped calderas worldwide** (Siebert 1984).

In conclusion, the evolution and the structure of CVC is **much more complex than previously thought** comprising a generation of calderas of probably debris-avalanche origin. It is very likely that **several scars have been completely buried by subsequent edifices**. Unfortunately, t here is no high-resolution DEM data about the northern flanks, which will be important for understanding the morphological relationship between the northern flanks of Nevado and El Cántaro volcano. A further disadvantage is that there are **no available radiometric dates on the above-outlined or previously known volcanic structures** (for the locality of dated samples, see the geologic map: Cortés et al. 2005), therefore the **age of the individual edifices is unknown**. For this reason, new dating campaigns in order to define the chronological evolution is inevitable.

REFERENCES

Allan, J. F. 1986, Geology of the northern Colima and Zacoalco grabens, southwest Mexico: Late Cenozoic rifting in the Mexican volcanic belt. Geological Society of America Bulletin 97, p. 473485

Carmichael, I. S. E., Frey, H. M., Lange, R. A., and Hall, C. M. 2006, The Pleistocene cinder cones surrounding Volcán Colima, Mexico re-visited: Eruption ages and volumes, oxidation states, and sulfur content. Bulletin of Volcanology 68, p. 407-419,

Cortés, A., Garduño, V. H., Navarro-Ochoa, C., Komorowski, J. C., Saucedo, R., Macías, J. L., and Gavilanes, J. C. 2005, Carta Geológica del Complejo Volcánico de Colima, con Geología del Complejo Volcánico de Colima. Universidad Nacional Autónoma de México, Instituto de Geología, Cartas Geológicas y Mineras, v. 10, scale 1:100,000, 1 sheet, 37 text.

Cortés, A., Garduño, V. H., Macias, J. L., Navarro-Ochoa, C., Komorowski, J. C., Saucedo, R., Gavilanes, J. C. 2010, Geologic mapping of the Colima volcanic complex (Mexico) and implications for hazard assessment. In: Groppelli, G., Viereck-Goette, L. (Eds.), Stratigraphy and Geology of Volcanic Areas: Geological Society of America Special Paper 464, p. 116.

Karátson, D., Telbisz, T., Wörner, G. 2011, Erosion rates and erosion patterns of Neogene to Quaternary stratovolcanoes in the Western Cordillera of the Central Andes: An SRTM DEM based analysis. Geomorphology 139-140, p. 122-135.

Kósik, Sz., Nagy, T., Kaproncai, M., Karátson, D., Németh, K. 2011, Geomorphology and paleogeography of lava-capped buttes in the Tapolca Basin (Hungary) as reflected by 3D elevation models. 4th Maar Conference, Abstract Volume, p. 121-122.

Luhr, J.F., and Prestegaard, K. L. 1988, Caldera formation at Volcán de Colima, Mexico, by a large Holocene volcanic debris avalanche. Journal of Volcanology and Geothermal Research 35, p. 335348,

Norini, G., Capra, L., Groppelli, G., Agliardi, F., Pola, A. Cortes, A. 2010, Structural architecture of the Colima Volcanic Complex. Journal of Geophysical Research 115, B12209, 20 PP.

Robin, J., Mossand, P., Camus, G., Cantagrel, J. M., Gourgaud, A., and Vincent, P. M. 1987, Eruptive history of the Colima volcanic complex (Mexico). Journal of Volcanology and Geothermal Research 31, p. 99113.

Rodríguez-Elizarrarás, S. R. 1995, Estratigrafía y estructura del Volcán de Colima, México. Revista Mexicana de Ciencias Geológicas, v. 12, p. 2246

Siebert, L. 1984, Large volcanic debris avalanches: characteristics of source areas, deposits, and associated eruptions. Journal of Volcanology and Geothermal Research 22, p. 163-197.

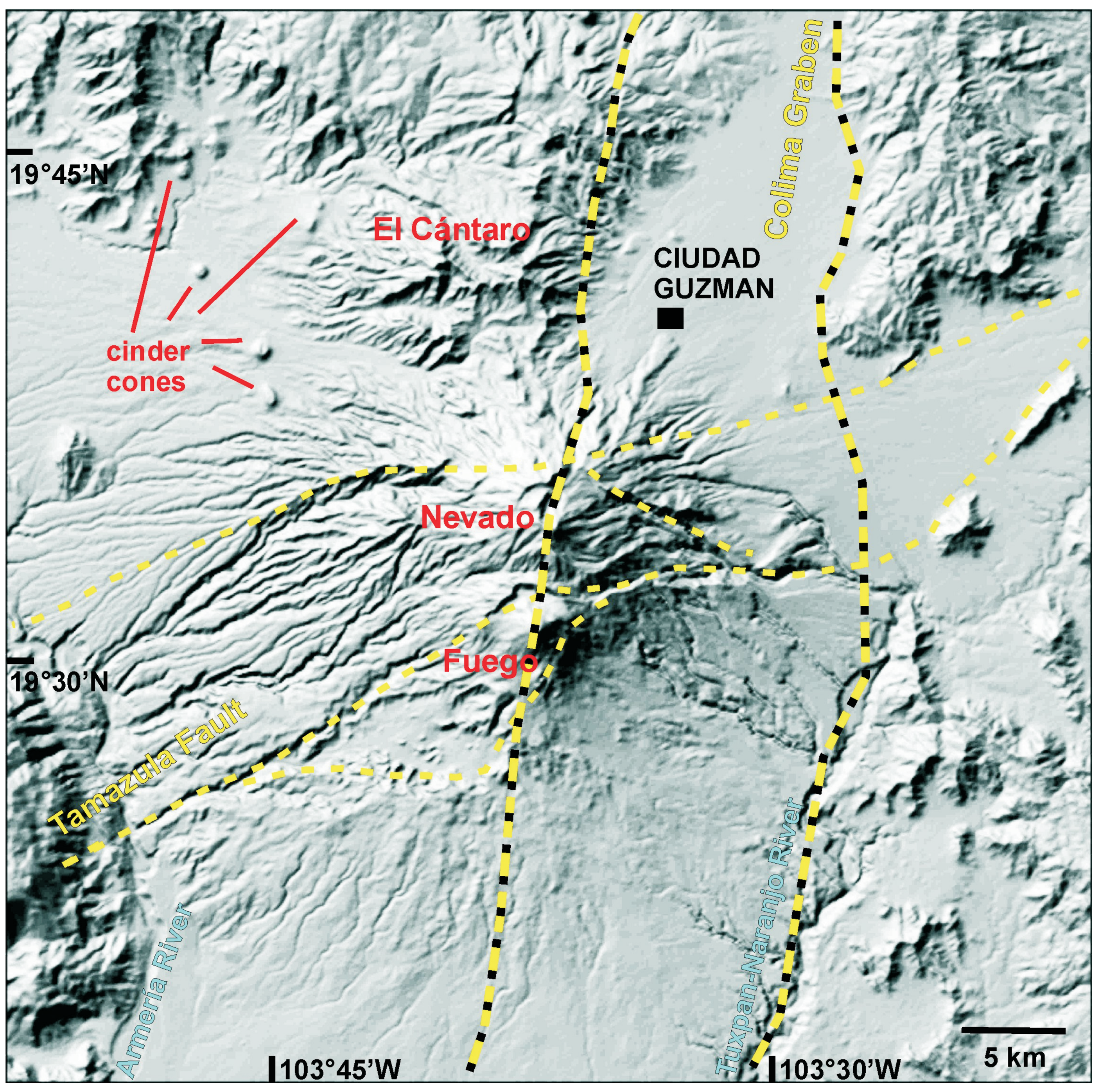

Fig. 1: Overview map of the CVC area showing major tectonic lines (after Allan 1996, Cortes et al. 2010, Norini et al. 2010).

METHODS

In our study, we assessed the **volcanic geomorphology** of CVC, focusing pieces of evidence for the remnants of previous structures in the territory of Nevado de Colima, by using **DEM** and **DEM derivates** (eg. **slope, aspect** and ridge maps) (Fig. 2). For the GIS analysis we used **ESRI ArcView 3.3** and Golden Software **Surfer 8** programs. The data sources were **SRTM 3"** (90 m spatial resolution) and a **5 m spatial resolution** national data set that enabled us to produce an optimally predicted **10x10 m grid**.

Based on the high-resolution DEM, we derived **slope profiles** along various azimuth directions starting in the highest parts of Nevado and Fuego. These slope profiles were used to **identify morphological breakpoints** that we assume to reveal contacts of rocks of different resistance and/or exposed edifice boundaries (Fig. 3). We also produced **cross section**s to **infer the rate of contrasting erosion** (Fig. 3 C, D): the **depth of valleys roughly correlates with the age of surface.**

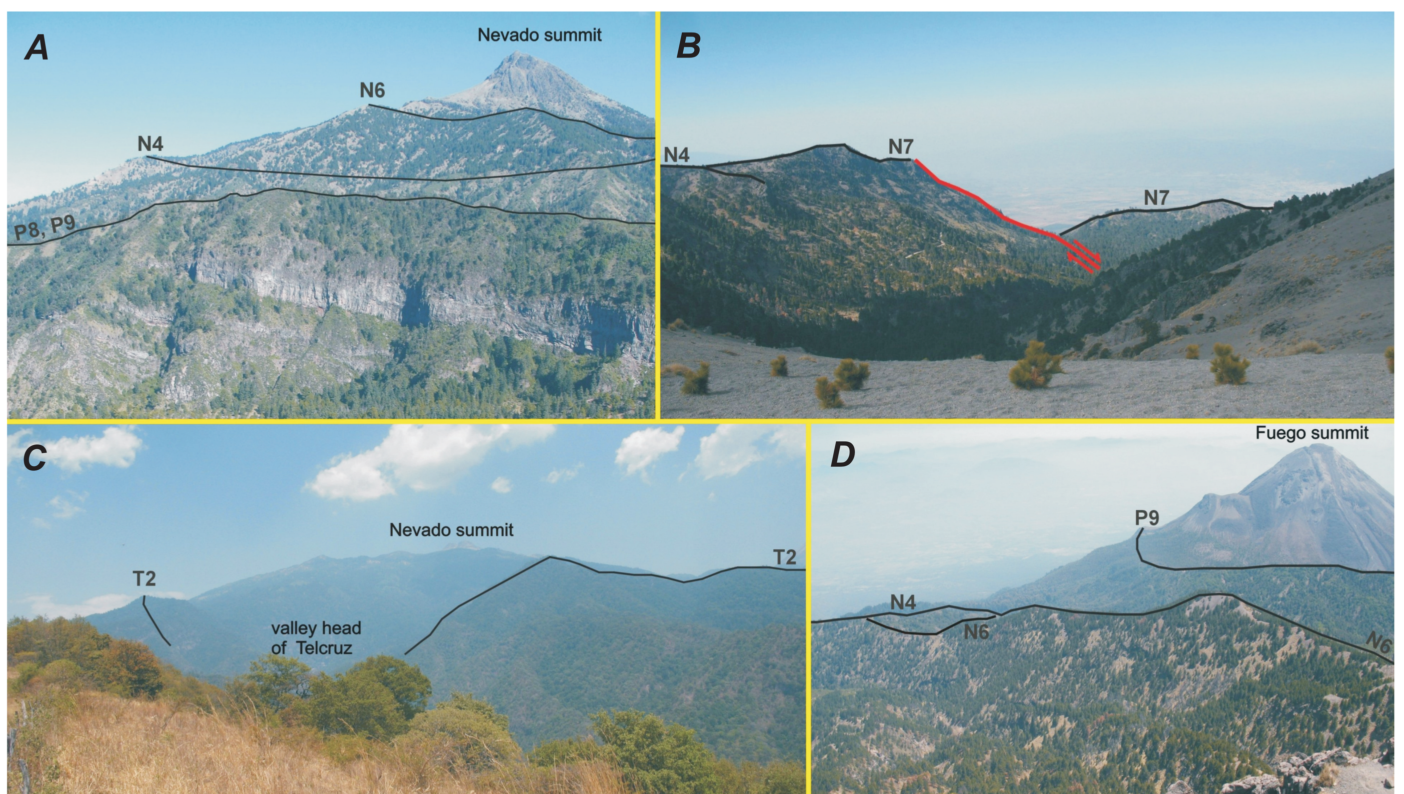

Fig. 4: Views to the caldera rims from different directions. A: view from the Fuego northern flank to the N-NW. B: view from the saddle of the Nevado summit and N5 caldera rim to the north. C: view from the right side ridge of the valley Telcruz to the east. D: view from the saddle of the Nevado summit and N5 caldera rim to the south.

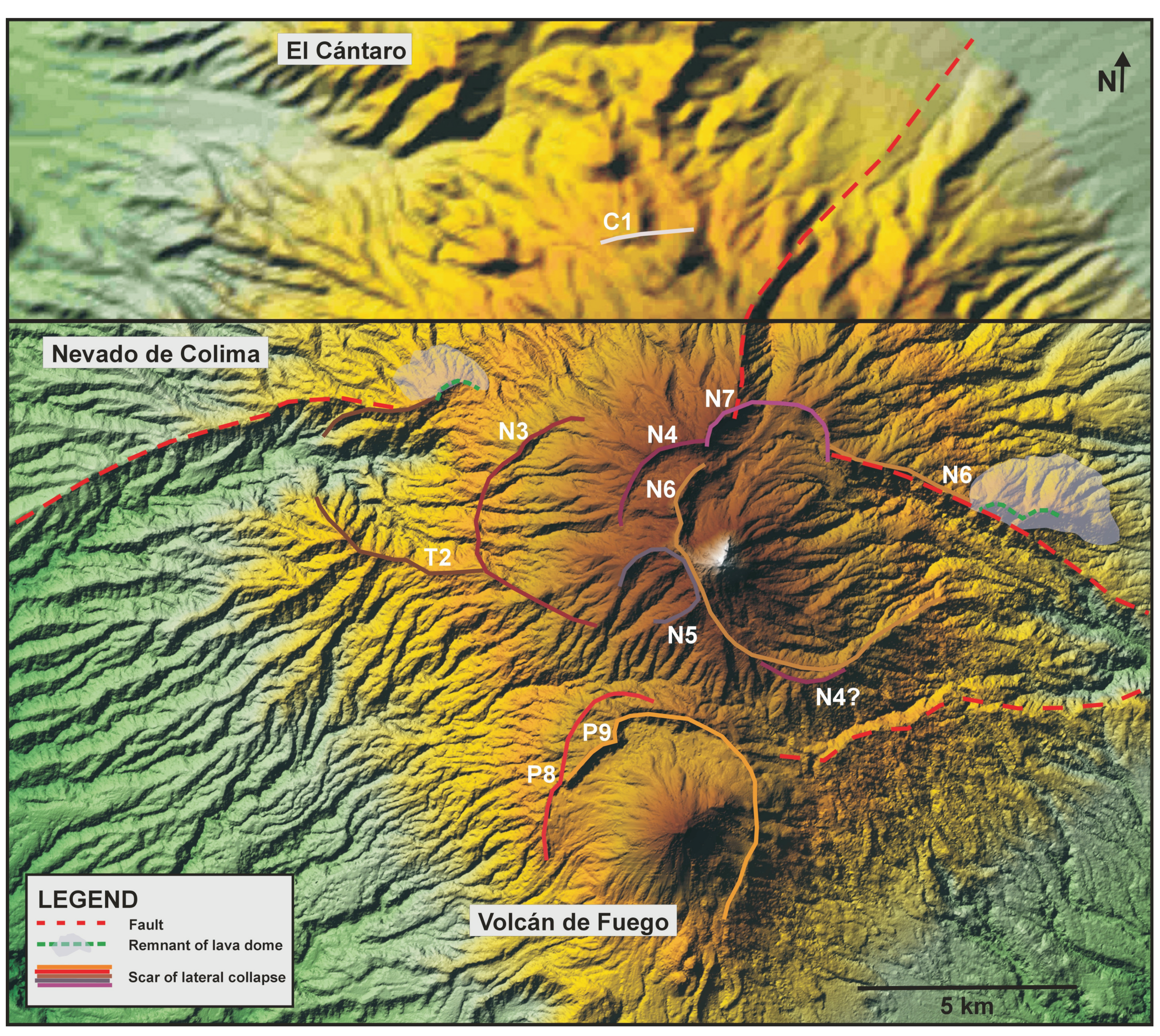

Fig. 5: Hypothesized caldera rims and satellite centres based on slope profiles, valley density and interpretation of DEM shaded relief image of CVC. Some faults indicated (cf. Norini et al. 2005 also controlled the morphology of the surrounding flanks.