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# Craters in the Telsen area, Chubut Province, Argentina: Satellite imagery digital processing techniques applied to surficial geology mapping

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**Resumen:** *CRÁTERES EN EL ÁREA DE TELSEN, PROVINCIA DE CHUBUT, ARGENTINA: TÉCNICAS DE PROCESAMIENTO DIGITAL DE IMÁGENES SATELITALES APLICADAS AL MAPEO GEOLÓGICO DE SUPERFICIE.* En cercanías de la localidad de Telsen, NE de Chubut, se reconocieron rasgos subcirculares, con morfología de cráteres, desarrollados en un contexto volcano-sedimentario con un diámetro que no superan los 2 km. Estas estructuras, rodeadas por rocas volcánicas tabulares con bajo buzamiento radial centrífugo de la Fm. Quiñelaf, presentan un anillo externo con niveles visuales oscuros que encierra en su interior altos topográficos caracterizados por niveles visuales mayoritariamente claros. Se desarrolló un mapeo de detalle, a escala 1:3.000, de una de las estructuras mayores reconocidas (S 42° 22' 55", W 66° 49' 15"), empleando imágenes satelitales y siguiendo las pautas propias de la fotointerpretación. Se utilizaron bandas de imágenes pancromática y multiespectral de Spot y ventanas de imágenes Google Earth de 0.5 m de resolución espacial. Los software Idrisi, Global Mapper, StitchMaps y Corel Draw fueron empleados para el tratamiento digital de las imágenes. Las referencias geológicas del área fueron consideradas a partir de la Hoja Geológica Telsen, georreferenciada con Global Mapper. Histogramas de distribución de frecuencias de ventanas de imágenes de los sectores mapeados, permitieron realizar distintos realces de contraste. Filtros direccionales del menú texture analysis de Idrisi facilitaron el reconocimiento de rasgos. Las imágenes así obtenidas, posibilitaron la delimitación de unidades homogéneas en términos de caracteres de observación directa, vinculadas con la etapa de fotoanálisis. El ajuste y asignación final de categoría de cada unidad homogénea (etapa de fotointerpretación final), se realizó con posteriores observaciones de campo. El mapa final se desarrolló con el software Corel Draw a partir de la imagen resultante de síntesis del procesamiento digital, georreferenciado posteriormente con Global Mapper. Se delimitaron afloramientos y fragmentos de basaltos que constituyen un anillo externo y encierran fragmentos de volcanitas de diferente composición, brechas y fragmentos del Grupo Chubut esparcidos en toda la superficie. En la parte centro-sur, se destacan afloramientos de volcanitas y fragmentos y estratos buzantes del Grupo Chubut cuyo rumbo tiende a acompañar al rumbo del anillo. Estudios geofísicos de detalle, permitieron reconocer dos anomalías magnéticas en el sector SE. Diversos mecanismos como magmatismo, freatomagmatismo y/o impacto de bólidos constituyen hipótesis relacionadas al probable origen de estas geoformas.

**Abstract:** Subcircular features, with crater morphology, developed in a volcano-sedimentary context, with diameters no greater than 2 km, were recognized in the vicinity of the Telsen locality, northeastern Chubut Province, Argentina. These structures are surrounded by tabular volcanic rocks of the Quiñelaf Formation with low radial-centrifugal dip, exhibit an external ring with dark visual levels enclosing topographic highs with mostly light visual levels. Surficial geological aspects of one of the larger structures in the area

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(S 42° 22' 55", W 66° 49' 15") were mapped from raster data at a scale of 1:3.000, following the stages of the photographic interpretation. Panchromatic and multispectral Spot images, and Google Earth image with 0.5 m. spatial resolution were used. Idrisi, Global Mapper, StitchMaps and Corel Draw software were used in the digital processing. The geological references of the area were obtained from the Telsen Geological map, herein georeferenced with Global Mapper. The frequency distribution histograms of the image windows of the different mapped sectors, allowed the generation of different contrast enhancements. Directional filters of the menu texture analysis of Idrisi permitted the identification of the oriented features. The images obtained herein, allowed the recognition of homogeneous units in terms of interpretation keys linked to the photo-analysis phase. Subsequent field observations contributed to the adjustment and to the final assignment of categories to each homogeneous unit (photo-interpretation last stage).The final map was compiled with the software Corel Draw, it was based on the synthesis image from the digital processing and referenced using Global Mapper. Deposits and fragments of basalt that constitutes the external ring of the crater along with different volcanic rocks, breccia and Chubut Group rocks fragments enclosed within the crater are mainly showed in this map. Also, deposits and dipping strata of the Chubut Group following the strike of the ring and outcrops of volcanic rocks in the central - south part of the mapped area were recognized. Detailed geophysical surveys detected magnetic anomalies in the SE part of the mapped crater. Several mechanisms such as magmatism, phreatomagmatism and/or bolide impacts constitute hypotheses related to the probable origin of these landforms.

**Key words:** Image processing. Craters. Geologic map. Telsen. Argentina.

**Palabras clave:** Procesamiento digital. Cráteres. Mapa geológico. Telsen. Argentina.

## Introduction

The study area is located near the Telsen locality, to the southeast of the Somún Curá massif in the northeastern margin of the Somuncurá-Cañadón Asfalto (S-CA) Basin (figura 1).

The sedimentary sequence that crops out in the study area and associated to the crater geoforms herein studied, includes a broad variety of reddish and greyish clastic rocks of the Chubut Group of Albian age (~106 Ma., Navarro *et al.*, 2015), displaying a record of lacus -

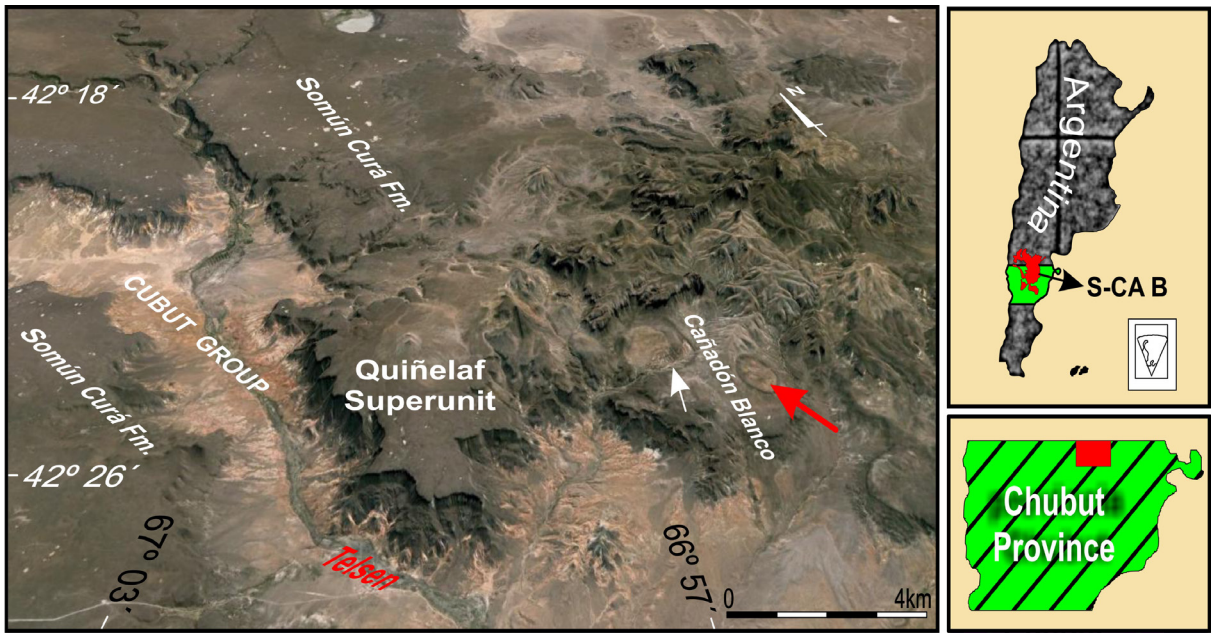


**Figure 1.** Location of the study area. Arrows point out the biggest crater structures near the Telsen locality. Red arrow points out the studied crater. S-CA B: Somuncurá - Cañadón Asfalto Basin. Image modified from Google Earth 2017. (For the color references in this figure, see the web version of this article). / **Figura 1.** *Localización del área de estudio. Las flechas señalan las dos estructuras mayores de cráteres en las cercanías de la localidad de Telsen. Flecha roja identifica al rasgo estudiado. S-CA B: Cuenca Somuncurá - Cañadón Asfalto. Imagen modificada de Google Earth 2017. (Para las referencias color de esta figura ver la versión web de este artículo).*

trine, alluvial and fluvial systems. The latter are overlain by lacustrine and shallow marine deposits of the La Colonia Formation of Maastrichtian-Paleocene age (Malumián, 1999; Nañez and Malumián, 2008; Guler *et al.*, 2014). In turn, the succession is overlain by the Late Oligocene (ca. 26 ± 2 Ma, Ardolino and Franchi, 1996) basaltic rocks of the Somún Curá Formation. Other regionally extensive tabular deposits of the Sarmiento Group and the Quiñelaf Superunit (Oligocene-Miocene, Ardolino and Franchi, 1996) complete the local stratigraphy. This succession overlies non-conformably rhyolitic rocks of the Marifil Formation (182 - 185 Ma, in the Telsen area, Navarro *et al.*, 2015).

Subcircular craters were recognized in northeastern Patagonia, in the Cañadón Blanco area, in the proximity of the Telsen locality (figure 1). These morphologic units have been related and mapped as annular dykes (Yllañez and Lema, 1979; Ardolino and Franchi, 1996) and even though they are associated to an igneous-sedimentary context, the mechanisms that would have originated them are still debatable. Signals of large-magnitude energy were observed in the area through the identification of brecciation related to over-pressurizing mechanisms (Navarro and Astini, 2010). Besides, impact craters were recognized in Bajada del Diablo (Acevedo *et al.*, 2009, among others), 100 km southward of Telsen. Hence, mechanisms like freatomagmatism, magmatism and bolide impacts or combination of these processes constitute hypothesis related to the probable origin of these geoforms. As part of a multidisciplinary approach and in the initial stage of the study of these features, a detailed-scale mapping was carried out using digital processing of high-resolution satellite imagery. The main objective is to identify the surficial

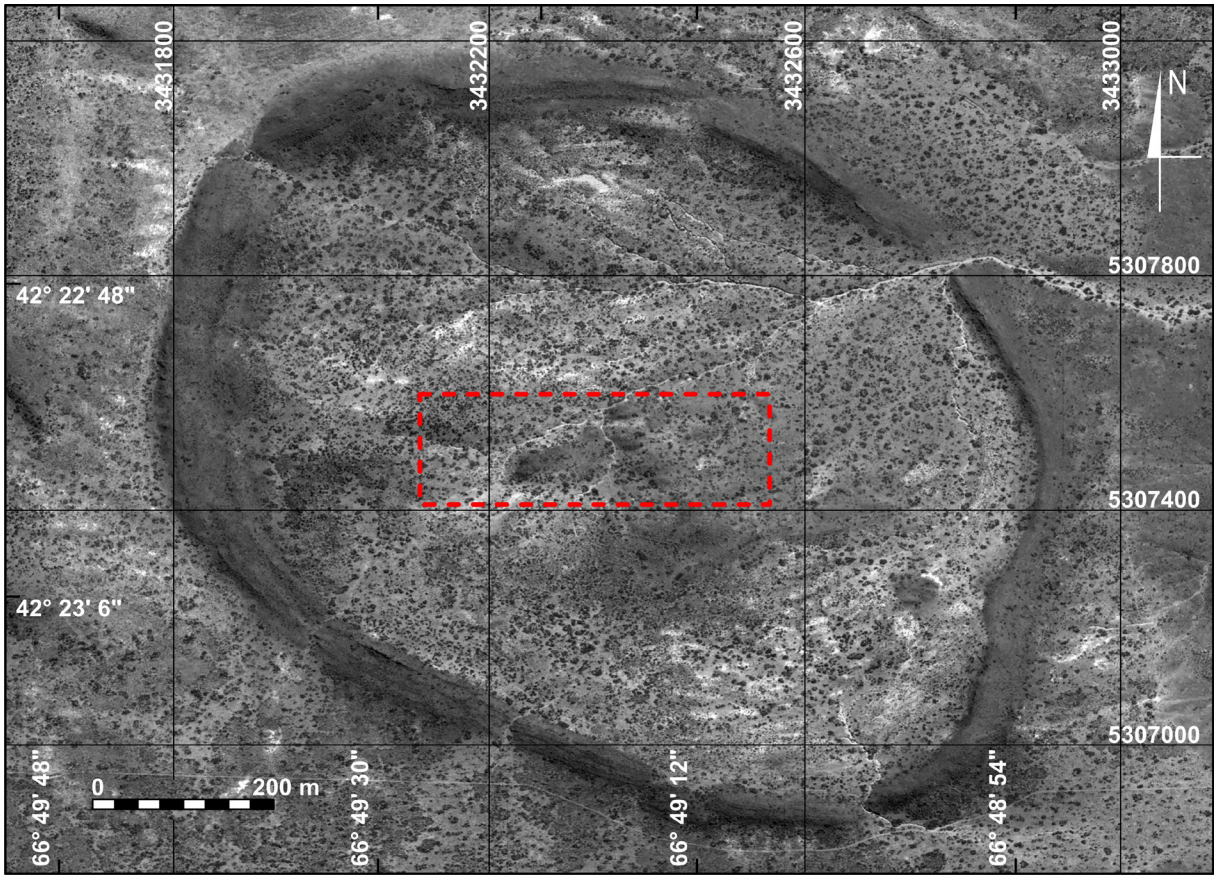


**Figure 2.** Panchromatic band window of Spot 6 (spatial resolution 1.5 m) used in the photo- analysis stage of the detailed mapping of the crater structure. Red dotted rectangle delimits the area associated to the principal component analysis image window shown in figure 4. (For the color references in this figure, see the web version of this article). / **Figura 2.** *Ventana de imagen de la banda pancromática de imagen Spot 6 (1.5 m de resolución espacial) empleada en la etapa de fotoanálisis del mapeo de detalle de la estructura de cráter. El recuadro rojo punteado delimita el sector asociada a la ventana de imagen de análisis de componentes principales de la figura 4. (Para las referencias color de esta figura ver la versión web de este artículo).*

geological aspects that characterize these circular structures, as well as the lithological types associated to the different stratigraphical units and their distribution either as in situ deposits or fragments of these rocks. Geomatics constitute a useful tool to be applied in this case, considering successful results obtained in previous regional geologic studies, where digital processing techniques were developed using different types of geographic information systems (GIS) (Navarro, 2012; Navarro and Astini, 2014).

## Materials and Methods

The detailed mapping was made following the stages of photo-interpretation proposed by the American Society of Photogrammetry (1960): *Photo-identification, Photo-analysis and Photo-interpretation*. The GISs used in all the stages were Idrisi Selva and Global Mapper 15 and the software Stitch Maps 2.61.

Previous studies in the area using digital processing technics are related to the palaeoenvironmental analysis of the Chubut Group and the stratigraphical interpretation in the northeastern S-CA Basin (Navarro, 2012; Navarro and Astini, 2014). For the 1:60000 scale map, Landsat 7 ETM+ band images, Path 229, row 89 and 90, acquired in June of 2009 (30 m of spatial resolution except band 8 and 6, with 15 and 120 m spatial resolution, respectively) and 3 spectral bands at the visible wavelengths of the Aster images (15 m spatial resolution) acquired in August of 2006, were used. Processing related to the principal component analysis, composite image, edge enhancement and filters, was also applied for the development of this map. The geological units correspond to the Hoja Geológica Telsen (Ardolino and Franchi, 1996), georeferenced using Global Mapper 15. The semi-detailed mapping facilitated the photo-identification of sub-circular features in the area, which reach less than 2 km of diameter; two of these structures were recognized 8.5 km to the east of the Telsen locality (figure 1). They are characterized by an external ring with dark brightness levels, whereas a dome inside them presents lighter brightness levels. The ring is surrounded by tabular volcanic rocks of the Quiñelaf Superunit. A low centrifugal radial dip, with regard to the centre of these structures, was determined using a digital elevation model (DEM) of the SHUTTLE RADAR TOPOGRAPHY MISSION (SRTM) of 90 m of spatial resolution.

A 1:3.000-scale photo-analysis was developed over one of the greater structures (S 42° 22' 55", W 66° 49' 15"). It is elongated in a NW-SE direction, the major axis reaches 1.5 km longitude, while the length of the minor axis is of approximately 1 km. The study was focused on the digital processing of spatial high-resolution image bands, particularly in the application of different enhancement techniques. The resulting products allowed the definition and combination of the interpretation keys that facilitated to demarcate homogeneous units in terms of brightness levels. For the development of this phase, panchromatic and multispectral image bands of Spot 6 acquired in June of 2015 with spatial resolutions of 1.5 m and 6 m respectively (figure 2) orthorectified at UTM projection based on WGS84 datum, were used. Google Earth image windows with spatial resolution of 0.5 m were captured using the software Stich Maps 2.61; this process complements in more detail the information of the Spot bands. In this stage, the mapping area was divided in nine sub-areas as individual units; and then, the image window processing techniques where applied to each of them. In the initial phase of this stage, the evaluation of the frequency distribution histograms of the Spot images windows allowed us to select the suitable enhancement techniques. The Google Earth windows were used not only because of their contribution to the spatial resolution, but also due to their support to the visual analysis. The contrast of tones between the different lithological types of the Chubut Group and also with the volcanic rocks, is highlighted due to the use of these windows.

Processing related to lineal stretching and histogram equalization techniques (Richards, 1995; Chuvieco, 2010), using the menu stretch of the Idrisi software allowed visually recogni -

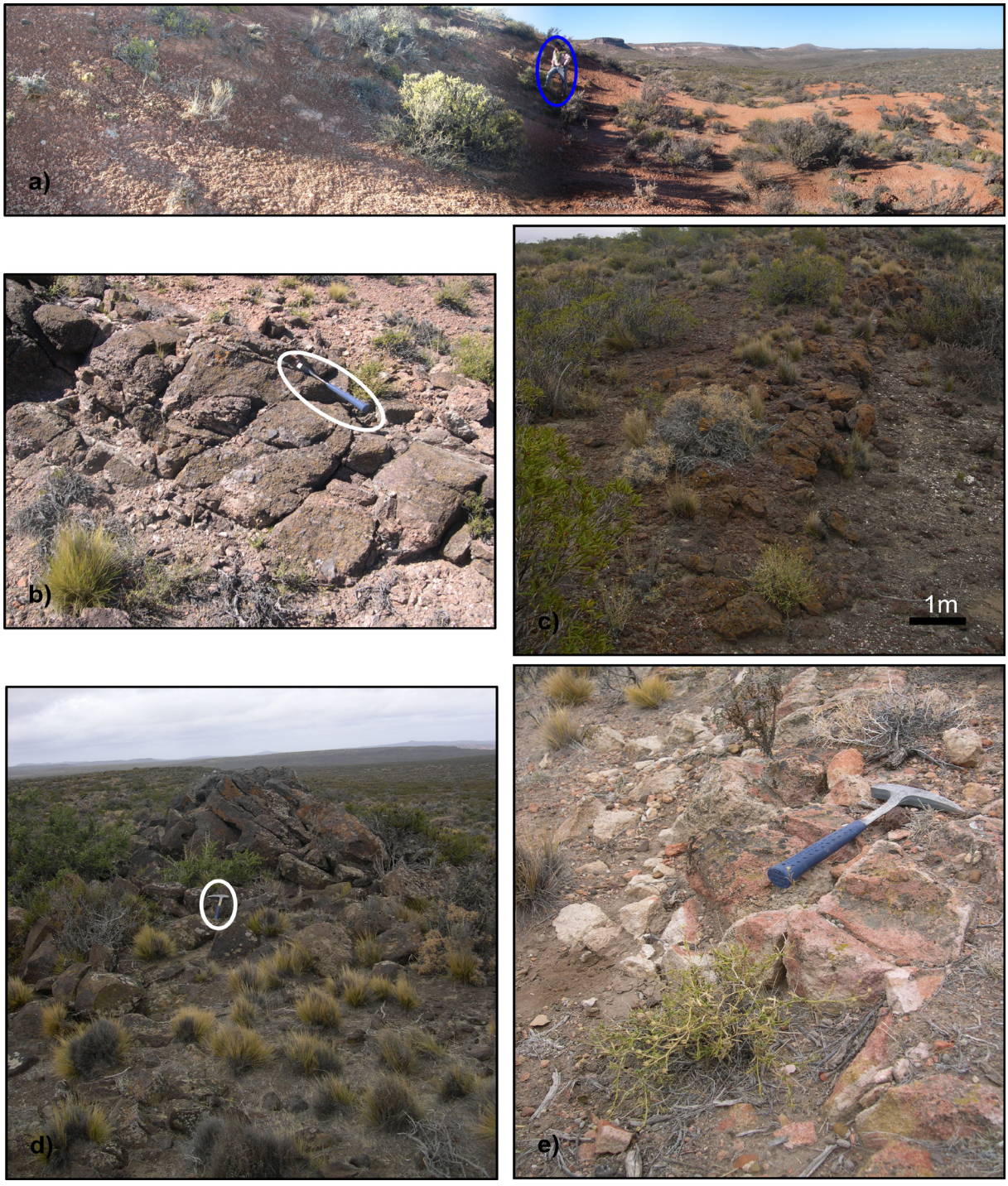


**Figure 3.** Lithologies and field geological features of the mapped crater: Reassignment stage of the photo-analysis units to field units. **A)** Reddish pelitic deposits of the Chubut Group outcropping in the northeastern sector. **B)** Conglomeratic deposits of the Chubut Group in the southern part of the crater dipping to the SW. **C)** Subhorizontal volcanic deposits in the central part of the crater. **D)** Volcanic rocks in the external rim. **E)** Sandstone deposits of the Chubut Group dipping to the SW. Scale: person in blue circle and hammer (0.30 m) in white circle. (For the color references in this figure, see the web version of this article). / **Figura 3.** *Litologías y aspectos geológicos de campo del cráter mapeado: Reasignación de las unidades homogéneas de la etapa fotoanálisis a unidades de campo.* **A)** *Pelitas rojizas del Grupo Chubut aflorantes en el sector NE.* **B)** *Depósitos conglomerádicos del Grupo Chubut en el sector sur del cráter, buzando al SO.* **C)** *Volcanitas subhorizontales en el sector central del cráter.* **D)** *Volcanitas en el anillo externo.* **E)** *Depósitos de areniscas del Grupo Chubut buzando al SO. Escala: persona en círculo azul y piqueta (0.30 m) en círculo blanco. (Para el color de las referencias de esta figura ver la versión web de este artículo).*

zing the different homogeneous units. Directional filters were used for the identification of elongated features (Richards, 1995; Chuvieco, 2010) using the texture analysis menu; the linear arrangement of the dark pixels linked to the feature shadows defined the filter direction.

Figure 4 illustrates with a screenshot, one of the enhancement techniques that contributed to the delimitation of the homogeneous units in this phase. The observed image resulted from the digital processing using principal component analysis (PCA) of the image windows (first principal component) obtained from Spot 6 multispectral and panchromatic bands and of an image window captured from Google Earth. To develop this process, the images were re-sampled to a spatial resolution of 1m by 1m. Since the number of windows is scarce (3) for this processing and nevertheless the variables are expressed in the same unit, for this mapping the correlation matrix was used. Thus, with the standarized digital levels, each window had the same statistical importance (Jollife, 2002). Each band has the same weight to obtain the principal component (Pla, 1986) and consequently, it is avoided that most of the information of any of the images be expressed by only one of the components.

Finally, in order to delimit the mapping units in the Photo-interpretation stage, those homogeneous units defined in the photo-analysis stage were adjusted and associated to the lithology and surficial geological features of the ground control points (figure 3). Moreover, geophysical studies indicated the existence of magnetic anomalies in the southeastern part of the mapped crater (figure 5). Those quantitative data non - mappable from the images, like strike

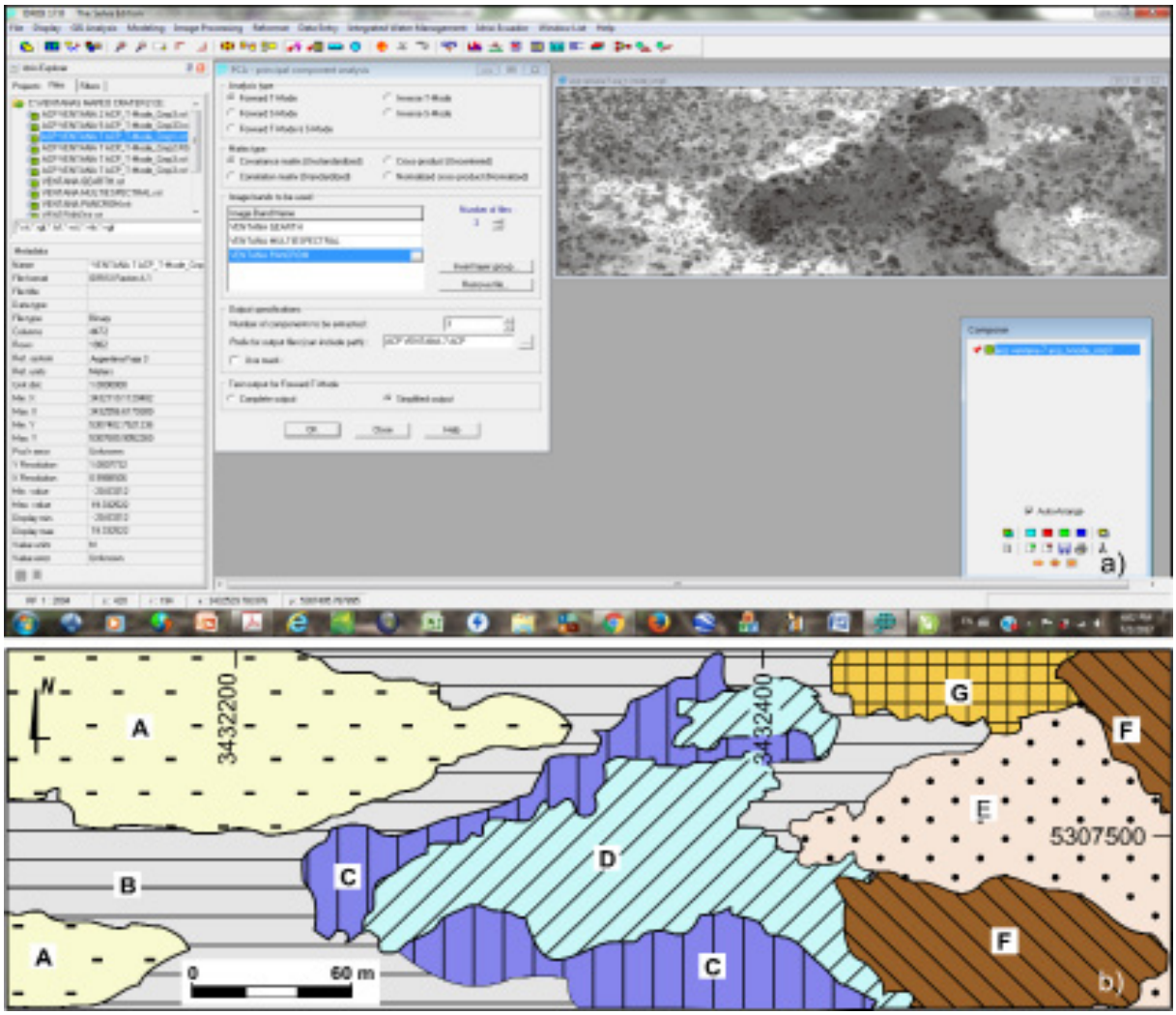


**Figure 4. A)** Photo-analysis stage. Screenshot: Image window associated to the first principal component. **B)** Photo-units related to the image window obtained in a): Homogeneous units created from keys of identification, particularly tone and mottled texture. (For the color of this figure, see the web version of this article). / **Figura 4. A)** *Etapa de fotoanálisis. Captura de pantalla: Ventana de imagen asociada al primer componente principal.* **B)** *Fotounidades asociadas a la imagen obtenida en a): Unidades homogéneas definidas por claves de identificación, particularmente tono y textura moteada. (Para el color de las figuras ver la versión web de este artículo).*

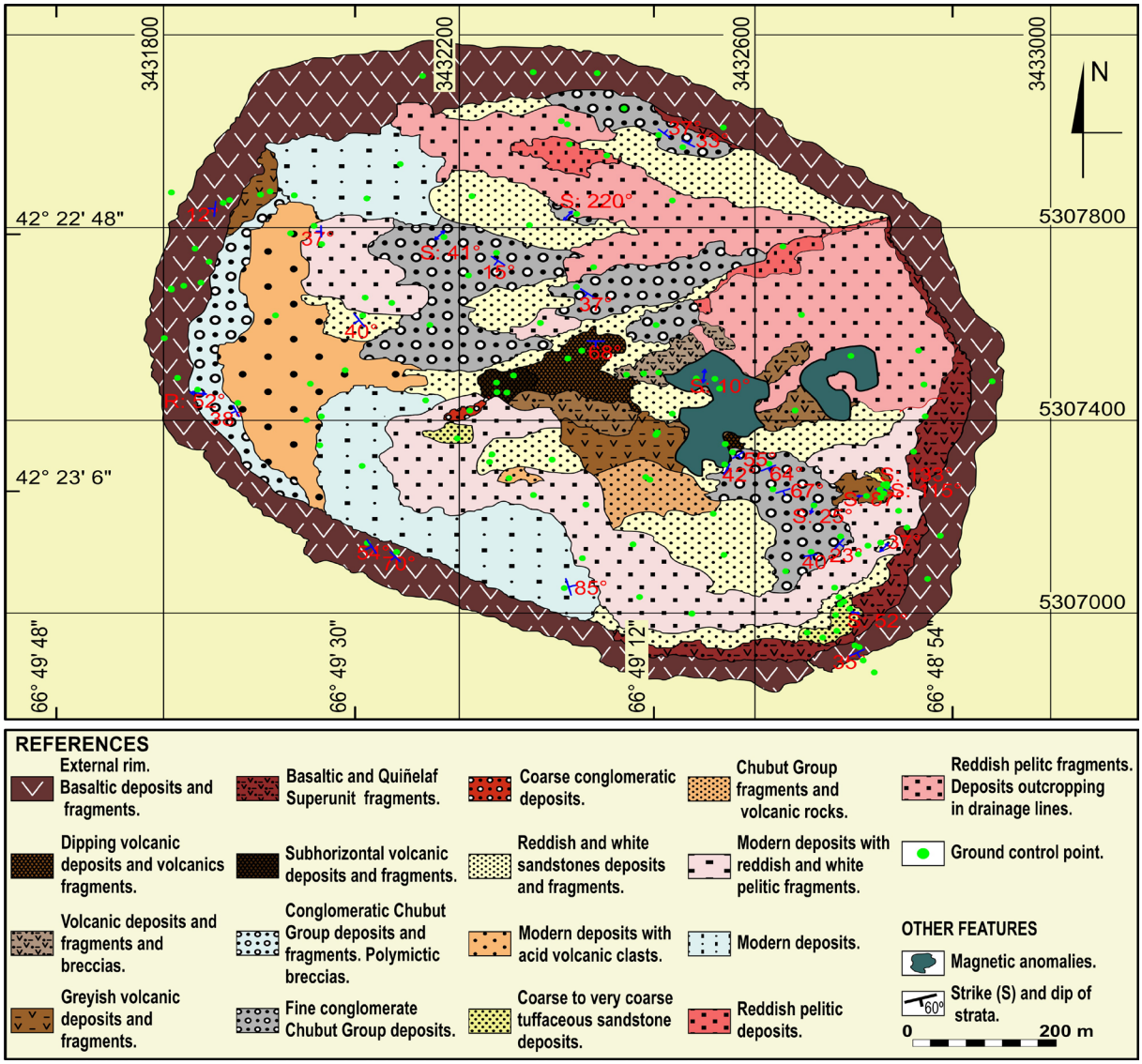


**Figure 5.** Detailed surficial geologic map of the crater structure in the Telsen area made using digital processing of satellite imagery. (For the color references in this figure, see the web version of this article). / **Figura 5.** *Mapa geológico superficial de detalle de la estructura de cráter en el área de Telsen elaborado a partir del procesamiento digital de imágenes satelitales. (Para las referencias color de esta figura ver la versión web de este artículo).*

and dip of the strata, were added in this stage.

The final map was made using Corel Draw 17 software, on the basis of the different digitally processed image windows and the field visual observations. To reach a spatial integration with other variables, the map was georeferenced using Global Mapper 15.

## Results and conclusions

A surficial geological map was obtained applying different digital processing techniques to satellite imagery (figure 5). The detailed map ping shows the arrangement and spatial distribution of some geological aspects (mainly dip and strike of the strata) and the lithological types associated with the subcircular morphological features of a crater exposed in Cañadón Blanco, in the proximity of the Telsen locality. The mapping exhibits:

- An external ring of basaltic rocks [Somún Curá Fm.] constitutes the most notable feature of this structure in the satellite imagery, presenting a centrifugal radial dip varying between 12º and 70º. The field observation allows determining that the inner slope is in general steeper than the outer one in cross section.

- Strata and fragments of the different stratigraphic units that crop out in the area, with the exception of the La Colonia Formation, are

represented in this map.

- Outcrops and disseminated fragments related to the conglomeratic, tuffaceous sandstones and fine-grained red facies of the Chubut Group are the main deposits identified within the limits of the ring. In particular, the conglomeratic strata develop elongated positive topographic reliefs up to 7 m high. The red fine-grained lithologies crop out in the northwestern area of the crater exhibiting low reliefs.

- The strike and dip of the sedimentary strata, particularly those next to the external ring, tend to follow the strike and dip of the ring, in some cases with slopes of approximately ~90º.

- Volcanic rocks are sub-horizontal and also present dips of up to 68º in the central part of the crater.

- Scattered fragments of breccia were recognized in the western and central-eastern parts of the mapped area.

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