Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

New Superficial Trace of the Los Humeros and Los Potreros Volcanic Calderas, Mexico

Fidel Cedillo-Rodríguez

Comisión Federal de Electricidad, Mexico

fedelecedillo@hotmail.com

Keywords: Gravimetric anomalies, resistivity anomalies, photo-geological interpretation, volcanic caldera, geothermal exploration.

ABSTRACT

A photo-geologic re-interpretation and new analyses of gravimetric and resistivity data of the Los Humeros geothermal field allows one to define the new superficial trace of the rim of the Quaternary volcanic calderas of Los Humeros and Los Potreros in the Mexican states of Puebla and Veracruz. The photo-geologic re-interpretation shows a volcanic arc in the northern portion not previously identified. This feature is used to trace a new rim of the Los Humeros Caldera (LHC) together with some other volcanoes and craters and another southern volcanic arc. The new trace of the Los Potreros Caldera (LPC) includes several volcanic edifices and craters, like the Maztaloya crater and the Arenas, Los Coyotes, San Antonio, Don Fidel, Sotoltepec and El Gato volcanoes. The Bouguer's anomaly map show a gravimetric minimum related to the LHC, which is coincident with the trace defined by the photo-geologic map. Some exploration geothermal wells were drilled in the past with the aim to intersect the deep trace of both calderas with no success. The new traces so defined imply new exploration targets in the Los Humeros geothermal field, which is one of the four fields in operation in Mexico.

1. INTRODUCTION

Altogether, Cerro Prieto, Los Azufres and Las Tres Vírgenes, Los Humeros is one of the four geothermal fields in operation in Mexico. The current geothermal power capacity installed is 94 MW, composed of two 26.7-MW condensing (flash) units and eight 5-MW each back-pressure units. Five of these 5-MW units are out of routine operation, and then the running capacity is 68.4 MW.

The geothermal field lies inside the Los Potreros Caldera (LPC), which is a Quaternary volcanic caldera formed some 100,000 years ago and is nested in the south-central portion of the older, larger Los Humeros Caldera (LHC). LHC was formed 0.460 Ma ago after a highly differentiated magmatic chamber that was emplaced into the Mesozoic calcareous basement, which was already partially metamorphized by the Laramide Orogeny and the Oligocene intrusions. The magmatic chamber produced a series of explosive eruptions with an equivalent magma volume estimated to be 115 cubic kilometers, which produced the Los Humeros Caldera, an oval collapse of 21 km per 15 km in diameters. After a resurgence process, a new gasification occurred in the chamber, whose pressure was also released by sudden explosive eruptions giving place to the LPC, with oval shape and 7-10 km in diameter (Gutiérrez-Negrín et al., 2010).

Based on a photo-geologic re-interpretation of the region where the Los Humeros geothermal field is located, some volcanic features like a couple of volcanic apparatus and structures were identified. These features went unnoticed in past surveys and studies in the area and together with new analyses of old geophysical data, mainly from gravimetric and resistivity surveys, have led to define a new trace for both calderas. It is noteworthy that the new rim of the LPC certainly enlarges the geothermal development area giving more chance of success for new wells to be drilled in the field.

2. GEOLOGICAL BACKGROUND

The first photo-interpretation of the Los Humeros region was made in 1978 (Pérez, 1978). The Figure 1 shows parts of the LHC southeastern rim. To define the trace Pérez (1978) took into account the annular fault of the southeast sector, but he just inferred the northern border with no volcanic evidences. To the west there are a couple of volcanic craters partially truncated (Fig. 2) that Pérez did not take into account to place the trace of the rim. He neither considered some volcanic edifices at the SW as parts of the LHC.

The trace of the LPC rim was interpreted by Pérez (1978) only based on topographic differences, with no further consideration of some volcanic features like the Maztaloya (Fig. 3) crater and structures like the normal faults of Maztaloya (Fig. 3) and Los Humeros. It is important to mention that when Pérez prepared his map there were no available aerial photos at appropriate scales covering the northern part of the Los Humeros region, which explains why some volcanic features, as the northern volcanic arc mentioned below, was unnoticed in his work.

Yáñez and Casique (1980) prepared the geological map of the Los Humeros geothermal field based on a detailed geologic survey. The trace of the LHC was mainly defined by photo-geologic interpretation and based on the prior work of Pérez (1978), but their map shows more relation to volcanic structures. They took into account the mentioned truncated craters and the southern volcanoes that Pérez (1978) did not, and they also used an isolated volcanic cone called Cerro Patata (Fig. 4) to close the LHC rim in an almost circular shape. They considered that the Maztaloya crater and the truncated craters were the result of phreatic or phreatic-magmatic eruptions.

Regarding the LPC rim, Yáñez and Casique (1980) defined the northern trace based on the Los Encinos volcano (Fig. 2) and continued the western rim with no volcanic control. They did not define the rim at the west and south, leaving it open.

Ferriz and Yáñez (1981) presented a geological map of Los Humeros. They inferred that the rims of both calderas are as follows. For the LHC they considered the rhyolite domes outcropping in the northwestern sector as part of the collapse. The NE and SW limits of the rim were defined with no volcanic structures, and the SE sector of the caldera was defined with no consideration of the topographic features.

To define the LPC, Ferriz and Yáñez (1981) considered more volcanic apparatus, including the Maztaloya crater, the truncated craters and some volcanoes as El Pájaro (Fig. 3) and the Sotoltepec volcano. The LPC rim was completely closed.

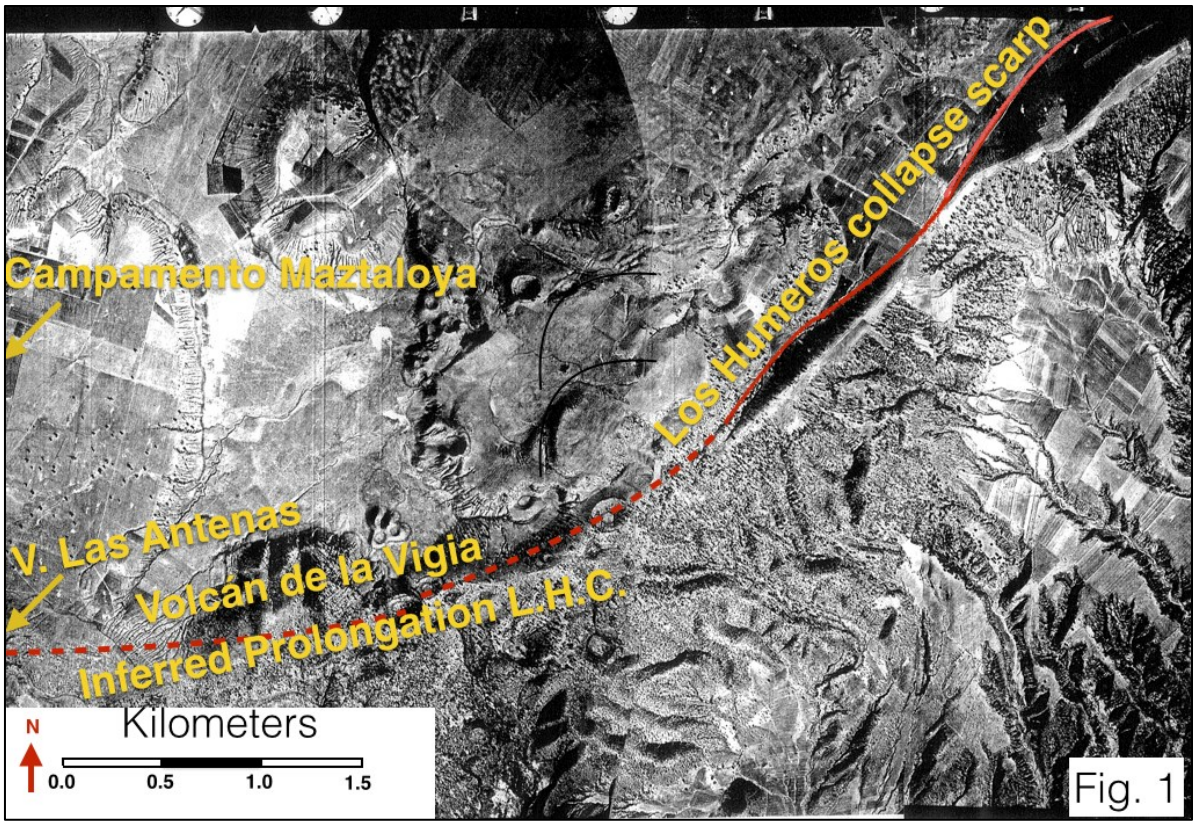

Figure 1. Aerial photo at 1:20,000 scale showing parts of the SE sector of the LHC.

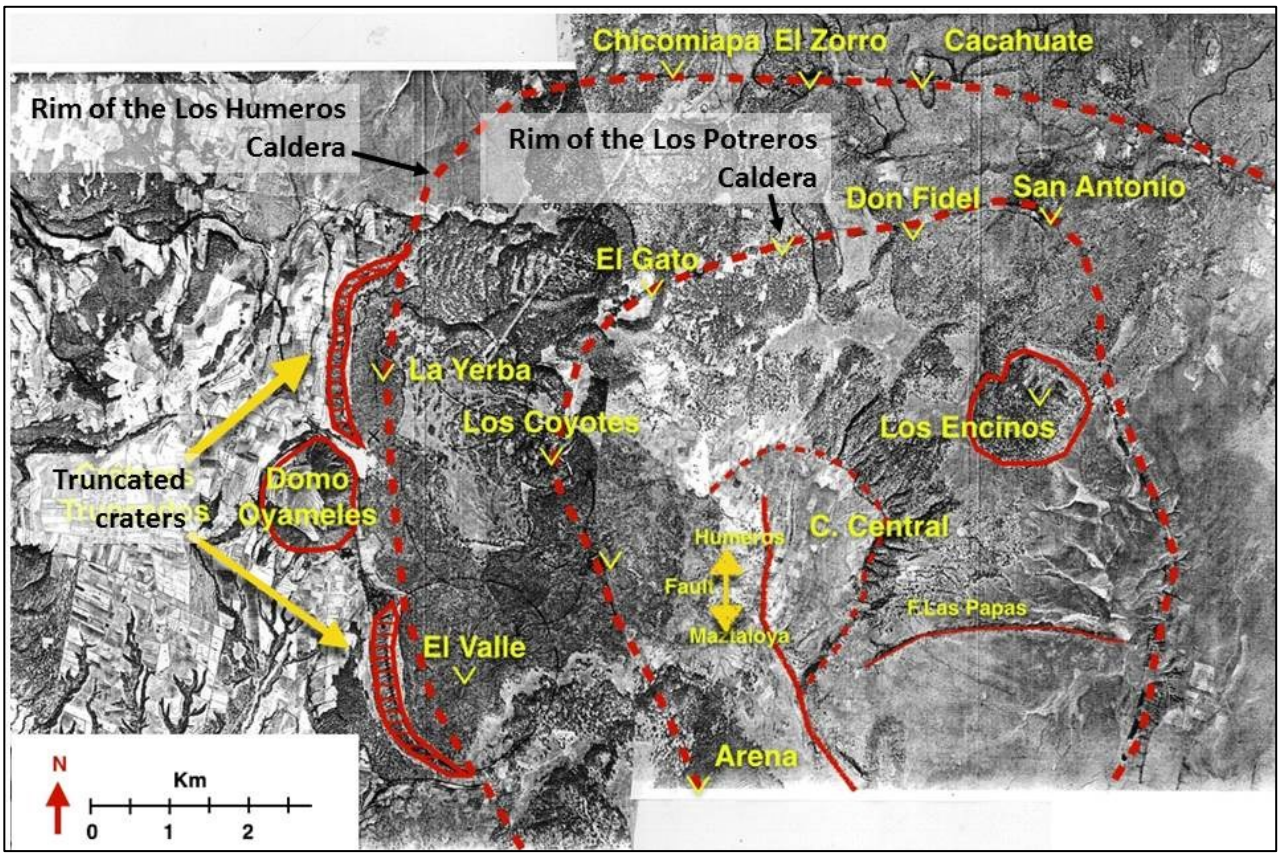

Figure 2. Photo composition showing parts of the LHC and LPC rims and some volcanic features, including two truncated craters located in the LHC rim.

The version of the LPC rim presented by Ferriz and Mahood (1984) was taken from that presented by Ferriz and Yáñez (1981). However, they did not take into account the Maztaloya crater or the volcanoes of the northern part to close the LPC rim.

A detailed geological and structural survey in the Los Humeros area made by De la Cruz (1983) concluded that there was a third caldera inside the LPC, called the Colapso Central (central collapse, see Fig. 2), as well as another phreatic-magmatic crater. He also mapped some lateral phreatic explosions in the San Antonio, El Jaral and Arenas volcanoes and an older volcano between the Arenas and El Pájaro volcanoes (Fig. 3).

De la Cruz (1983) defined the LHC rim based on volcanic features. Thus, the W and SW rim is defined by the Oyameles dome, the El Valle crater (Fig. 2), the El Pájaro and El Jaral volcanoes, and the lateral explosion of the Maztaloya crater (Fig. 3). The southeast border is marked by a volcanic lineament and the northern-northwestern limit is defined by the Ocotepec dome.

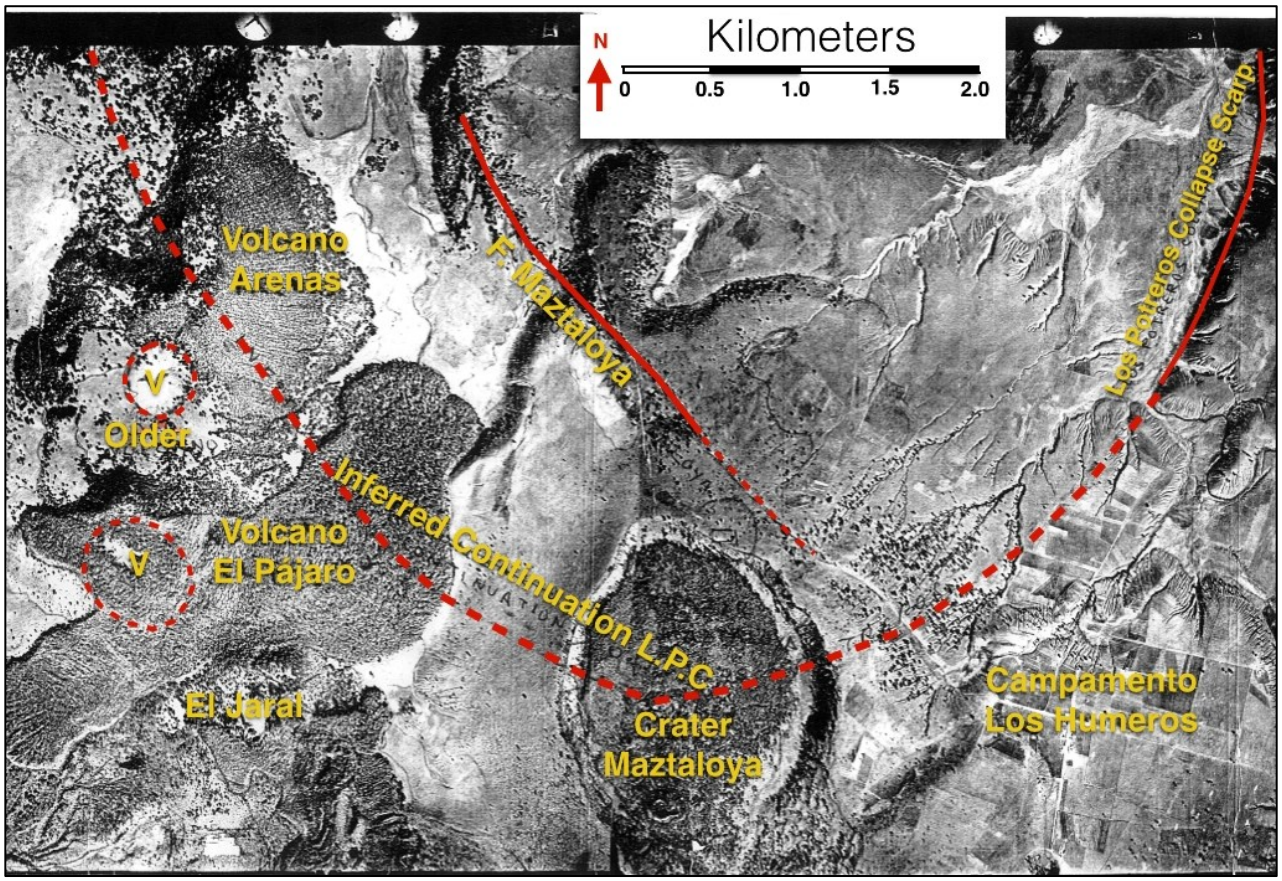

Figure 3. The Maztaloya crater, located at the southern rim of the LPC, and the Maztaloya normal fault.

Regarding the LPC, De la Cruz (1983) defined the rim mainly based on topographic features. He also proposed a normal fault as a part of the northern rim of this caldera, but actually the fault turned to be the unusually straight front of a lava flow from the San Antonio volcano. He used this feature to set part of the northern rim of the LPC and later some geothermal wells were located aiming to intersect this supposed structure to get more permeability and production –which was not the case.

In 2006, Cedillo started a revision of the previous works and proposed some changes in the superficial rims of the LHC and LPC, which are the base of this work.

Dávila and Carrasco (2014) made a detailed study of one of the volcanic members of the Los Humeros caldera, and included a map showing the LHC and LPC rims (Fig. 4). However, the traces are practically the same presented by Ferriz and Yáñez (1981).

3. GEOPHYSICAL BACKGROUND

Arredondo and Campos (1999) made a gravimetric survey in the Los Humeros area. They prepared a gravimetric map and a residual anomaly map, where a series of gravimetric maxima and minima are defined by iso-anomaly lines. It is remarkable a gravimetric maximum located in the western sector related to a structural high, and two concentric and extended gravimetric minima related to the LHC and LPC rims. Based on their gravimetric-structural analysis, Arredondo and Campos (1999) determined two systems of normal faults, one with NNW-SSE direction and dip to the east, and other with NNE-SSW trend and dip to the west. Both systems seem to affect only the sedimentary-metamorphic basement.

García Estrada (1992) prepared a regional map of the Bouguer anomaly in the zone. This map shows one gravimetric maximum enclosing the gravimetric minimum in the NE sector. Their traces are related to the NNE and SSE sectors of the LHC and LPC rims. In the north-central part of the gravimetric minimum it is observed an abnormal horizontal gradient, which defines the north portion of both calderas. He also prepared a profile of the gravimetric basement, where a depression is observed. This depression corresponds to the two caldera rims.

Palacios and García (1981) conducted an electric survey in the Los Humeros geothermal field and its surroundings, based on vertical electric sounds (VES) with Schlumberger arrangement. They carried out 220 VES distributed in 20 lines crossing the geothermal field and the main volcanic structures. The sections showing lines of the same apparent resistivity allow define in some parts the probable location of the LHC and LPC traces.

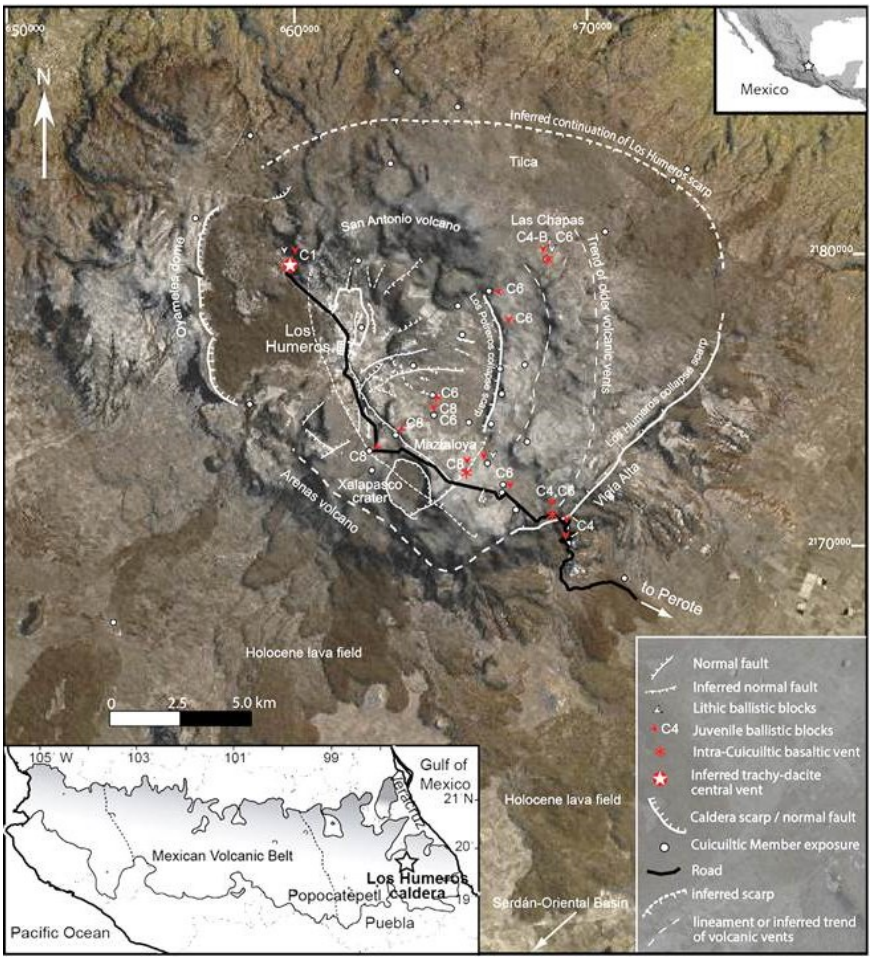

Figure 4. Volcanological map of Los Humeros, showing the LHC and LHC (taken from Dávila and Carrasco, 2014).

4. WORKING METHOD AND RESULTS

The re-definition of the rims of both calderas presented in this paper was mainly based on the photo-geological interpretation of aerial photos at 1:50,000, 1:20,000 and 1:10,000 scales. It was possibly to identify contacts of lava flows and pyroclastic deposits, structures and volcanic craters. It was also possible define the type of volcano and the relative age of each one. Some volcanoes that had gone unnoticed before were identified and related to the traces of the LHC and LPC. One of these volcanoes is Don Fidel, which seems to be part of a volcanic arc and of the LPC trace (see Fig. 2).

In order to verify and check the new rims of LHC and LPC so defined, all the available geophysical information was re-examined, including the Bouguer anomaly and residual anomalies maps and several sections of apparent iso-resistivity. In particular, these sections show strong vertical gradients where deep resistivity values suddenly rises from depth. The anomalous gradient seems to be due to faults systems where hydrothermal fluids with temperatures above 200 degrees Celsius are rising. Particular attention was paid to the parts where the sections cross or intersect volcanic structures, hidden faults, fault scarps, superficial fumaroles, alteration zones or steamy soils, and especially the inferred rims of the calderas. In this latter case, it is evident the rising of the apparent resistivity values where sections cross the caldera rims.

Thus, the new photo-geological interpretation allowed identify the northern volcanic arc, whose location seems to be confirmed by the higher gradient lines in the Bouguer and residual anomaly maps. This arc defines the new superficial trace of the LHC rim, which also includes the truncated craters, the El Pájaro, El Jaral and Catorce volcanoes, the southern volcanic arc, the lateral explosion of the Maztaloya crater and the southeast escarpment of the rim indicated by topographic features as re-interpreted on the aerial photos (Fig. 5).

This work also allowed recognizing that the San Antonio volcano is more recent than El Gato volcano, after their respective lava flows. Both volcanoes are part of another volcanic arc composed also of the Sotoltepec and Don Fidel volcanoes. This volcanic arc is part of the new trace of the LPC, which is defined also by the volcanic edifices of Los Coyotes, Arenas and Maztaloya, and by the topographic features identified in the photo-geologic work (Figure 5).

The analysis of several sections of apparent iso-resistivity indicates strong gradients and apparent resistivity minima related to faults that are coincident with the new proposed traces of both calderas. The eastern portion of the maximum gravimetric linked to a structural high is considered as representative of the LHC rim.

The new layout of the LPC is an attractive target for future production wells.

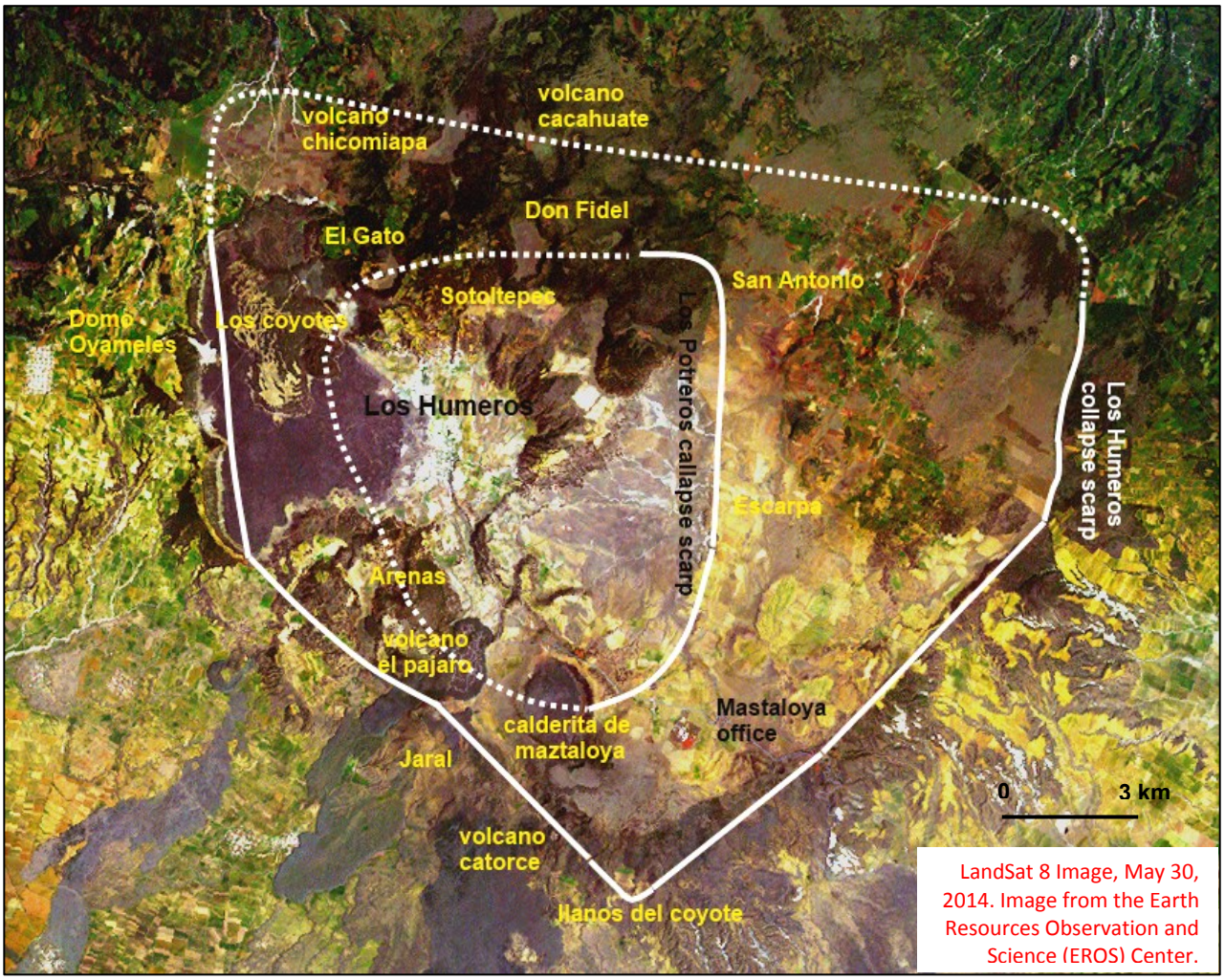

Figure 5. The new proposed rims of the Los Humeros and Los Potreros calderas.

5. CONCLUSION

The new proposed traces of the Los Humeros and Los Potreros calderas are presented in Figure 5. The modified trace of the LHC is based on the following features. Starting by the north, the CLH rim is defined by a volcanic arc composed of the volcanoes El Cacahuate, El Zorro and Chicomiapa. The rim trace continues to the truncated craters (see also Fig. 2) and goes to the El Jaral volcano, the crater of Catorce volcano, the Llanos de Oro crater and the Llanos del Coyote crater. Then the rim trace continues to the Cerro de la Antena, Cerro del Vigía (see also Fig. 5) and another unnamed small craters (that form the southern volcanic arc), the lateral explosion of the Maztaloya crater and go again to the El Cacahuate volcano and close the structure.

The new trace of the LPC is mainly limited by the conspicuous trace of the caldera escarpment itself, being supported in its northern section by the volcanic arc formed by the volcanoes San Antonio, Don Fidel, Sotoltepec and El Gato, and by the Los Coyotes and Arenas volcanoes and the Maztaloya crater (Figure 5). This new trace is considered to be an important target for future development geothermal wells in the Los Humeros field.

ACKNOWLEDGEMENTS

Author would like to thank Luis C.A. Gutiérrez-Negrín by the careful and detailed review and suggestions for improving the paper; Raúl Maya-González, general manager of the CFE's geothermal-electric division, by providing access to aerial photos; Jesús Arredondo-Fragoso, Camilo Yáñez-García, Gerardo García-Estrada, Venancio de la Cruz, Gerardo Carrasco-Núñez and José Luis Álvarez-Palacios for allowing use their maps, satellite imagery and figures; and Maximiliano Martínez by his support in the figures.

REFERENCES

Arredondo-Fragoso, J.F., and Campos-Enríquez, E.: Modelo tridimensional del contacto calizas-vulcano sedimentario del área del Campo Geotérmico de Los Humeros, Pue. CFE, Internal report 2/89 (1989). Unpublished.

Cedillo-Rodríguez, F.: Modificaciones de los bordes de los colapsos de las calderas de Los Humeros y Los Potreros, en el Estado de Puebla. CFE, Internal report (2006). Unpublished.

Dávila-Harris, P., and Carrasco-Núñez, G.: An unusual syn-eruptive bimodal eruption:The Holocene Cuicuilic Member at Los Humeros Caldera, México. *Journal of Volcanology and Geothermal Research*, 27 (2014), 24-42.

De la Cruz-Martínez, V.: Estudio geológico a detalle de la zona geotérmica Los Humeros, Pue. CFE, Internal report 10/83 (1983), 51pp, unpublished.

Ferriz, H., and Yáñez, C.: Mapa Geológico del Centro Volcánico de Los Humeros, Estados de Puebla y Veracruz. México. Preliminary edition. Comisión Federal de Electricidad. *Revista de la Unión Geofísica Mexicana*, Vol. 24, Num. 1 (1981).

Ferriz, H., and Mahood, G.A.: Eruption rates and compositional trends at the Humeros volcanic center, Puebla, Mexico. *Journal of Geophysical Research*, 89, (1984) 8511-8524.

García Estrada, G.: Análisis del procesamiento digital de campos potenciales en la exploración geotérmica, aplicación en Los Humeros, Puebla. MSc Thesis, UNAM, Engineering Faculty (1992), 69 pp. Unpublished.

Gutiérrez-Negrín, L.C.A., Izquierdo-Montalvo, G., and Aragón-Aguilar, A.: Review and Update of the Main Features of the Los Humeros Geothermal Field, Mexico. *Geothermal Resources Council Transactions*, Vol. 34 (2010), 771-778.

Palacios-Hartweg , L., and García-Velázquez, C.: Informe Geofísico del Proyecto Geotérmico Los Humeros-Derrumbadas, Estados de Puebla y Veracruz. CFE, Internal report (1981). Unpublished.

Pérez-Reynoso, J.: Geología y Petrología de Los Humeros, Pue. *Geomimet*, 91 (1978), 97-106.

Yáñez- García , C., and Casique-Vázquez, J.: Informe geológico del Proyecto Geotérmico Los Humeros-Derrumbadas . CFE, Internal report (1980). Unpublished.