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Volcán Casita, Nicaragua: A GIS Based Geothermal Assessment

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ABSTRACT

Ram Power's Volcán Casita 100 km^2 geothermal concession, located in northwestern Nicaragua, incorporates part of inactive Volcán Casita and La Pelona caldera. Tectonics are controlled by the subducting Cocos plate and local structural control is related to northeastwardly striking sinistral R' shears, which include the La Pelona fault system. Work done by Sinclair Knight Mertz (SKM) indicates a resource of >=250^o C with a potential production capacity of >137 MWe @ 90% probability for 20 years, making this an attractive exploration target. It is not uncommon to begin a geothermal exploration project with disparate data ranging from analog maps to state-of-the-art digital data sets. This was the scenario recently at Ram Power as the curtain was drawn on the Volcán Casita geothermal development project, where a geographic information system (GIS) was used to integrate, visualize, and interpret all data for thr project. Initially analog maps and graphics were scanned into raster formats. These were then georeferenced to a common coordinate system and datum. Some digital raster data were ready for immediate incorporation into the GIS system. Other data, such as lithologic units and faults from a paper geologic map, were digitized into vector files. The GIS also facilitated the direct use of multispectral satellite imagery, airborne synthetic aperture radar data, and a digital elevation model which supported further geologic evaluation. The GIS allowed the integration, processing, visualization, and analysis of the data for the Casita Volcano project creating a platform from which drilling decisions could be made with a reasonable level of confidence.

Introduction

The Ram Power Volcán Casita geothermal prospect, covering an area of 100 km^2, is located on the border between the Nicaraguan departamentos of Chinadega and Leon (Figure 1). The concession encompasses part of the La Paloma caldera and the Ollade crater on Volcán Casita. Previous exploration work in the area has produced a significant amount of geological, geophysical, and geochemical data indicating that a commercial geothermal system is likely present within the concession. Sinclair Knight Mertz (SKM) estimate a resource of >=250^o C with a potential production capacity of >137 MWe @ 90% probability for 20 years.

Data associated with this project was found in written reports, analog maps, ancillary graphics, and in tabular form -- both analog

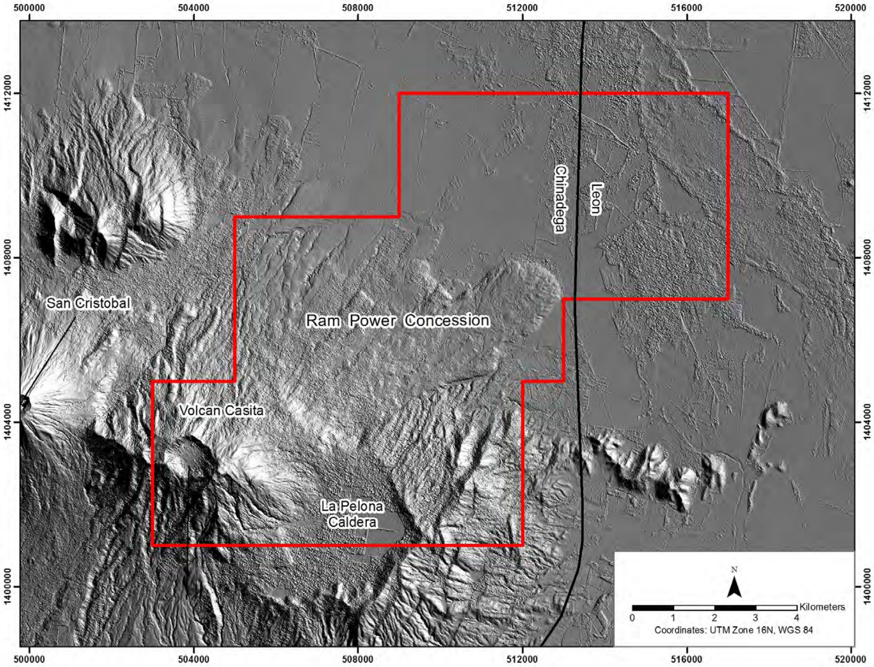

Figure 1. Ram Power's Casita concession in red overlying a shaded relief map created from a 5 m posting digital surface model (similar to a digital elevation model).

and in digital spreadsheets. New digital datasets included ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) multispectral imagery, a synthetic aperture radar (SAR) image at 2.5 m spatial resolution, and a 5 m posting digital surface model (InterMap – essentially a digital elevation model) derived from IfSAR (Interferometric Synthetic Aperture Radar). To facilitate the proper visualization and analyses of these data they need to be spatially co-registered in a digital format. GIS was used to fulfill this necessity and to create a geospatial database for data visualization, analysis, and interpretation.

Geology

Volcán Casita and La Pelona caldera are two of five volcanoes that make up the San Cristobal complex. San Cristobal is the youngest volcano in the complex and is active. The geologic structure in the area is controlled by the Cocos Plate, which is obliquely subducting with a northwest slip-rate of 14±2 mm yr^{-1} (DeMets, 2001). Van Wyk de Vries (1993) describes the main geologic structures in western Nicaragua as inactive northwest striking dextral faults and folds, younger active northeast striking sinistral strike-slip faults, and north trending tensional structures. In the general Casita concession area he (van Wyk de Vries, 1993) reports northeast striking faults as well as northerly trending faults and a major northeast striking fault zone immediately southeast of La Pelona caldera.

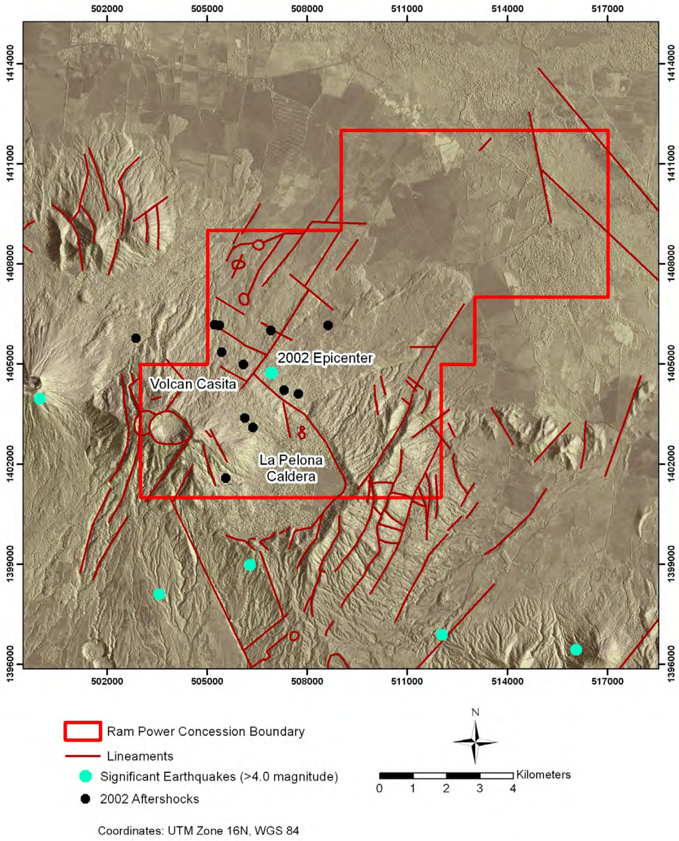

Figure 2. Preliminary lineament and recent earthquake map of the concession area. Most of the lineaments are on trend with the northeast striking regional sinistral fault system with a smaller set oriented close to what would be expected in relation to the regional northwest striking dextral fault system. Several earthquake epicenters are spatially associated with northwest striking faults/lineaments as well as northeast striking faults/lineaments.

In relation to the regional structure, other workers suggest that the northwesterly trending dextral arc-parallel structures are active locally (Guzmán-Speziale and Gómez, 2002), although La Femina et al. (2002) believe that the ~14mm/yr shear along the volcanic arc in Nicaragua (calculated by Demets (2001)) is accommodated by bookshelf faulting involving clockwise rotation of blocks separated by the northeast striking sinistral faults. Major earthquakes in Managua (3/31/1931 and 12/23/1972) are known to have occurred along the northeast striking Tiscapa fault, with documented left-lateral surface motion (Brown et al., 1973; Dewey and Algermissen, 1974; Ward et al., 1974). It is possible that permeability in Volcán Casita area will be controlled primarily by faults along this trend, which appear to be relatively dense in the area (Figure 2).

Seismic events have occurred recently in and near the concession that may have significance relative to permeability and that may also provide some evidence of activity along northwest striking faults. A 4.8 magnitude earthquake occurred on the northeastern margin of Volcán Casita/La Pelona caldera in 2002 which was followed by several smaller magnitude aftershocks (Figure 2). This cluster of seismic activity may be related to a northwest striking fault that forms the northeastern boundary of the La Pelona caldera. Other significant historical earthquakes have also occurred that may be related to different northwest striking faults

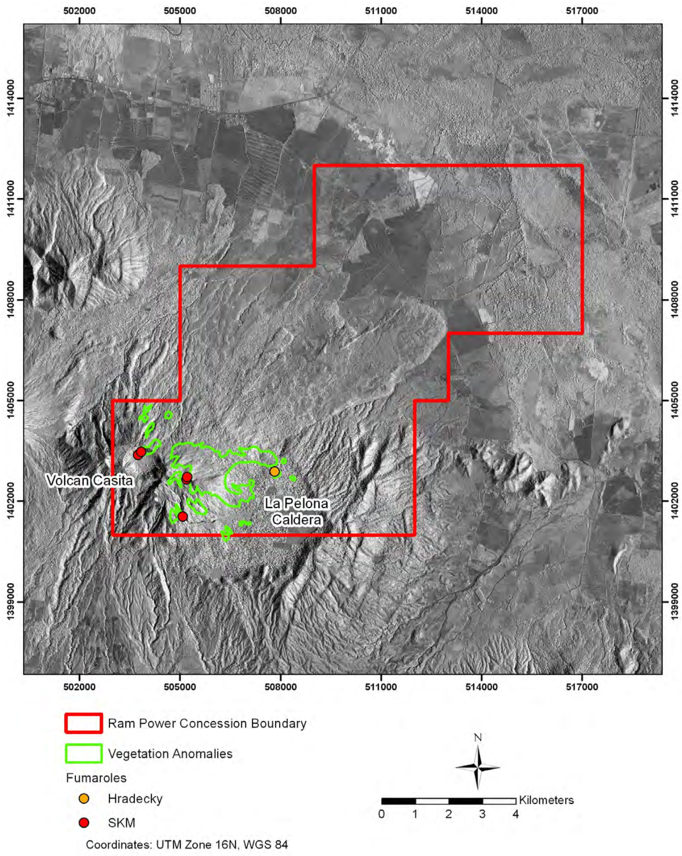

Figure 3. Mapped fumaroles and vegetation anomalies (vegetation anomalies mapped from ASTER multispectral data).

(Figure 2). This opens the possibility that both northwesterly and northeasterly striking faults may provide targets with permeability.

Hazards

Sector collapse is common in stratovolcanoes due to factors such as incompetent rock, hydrothermal alteration, flank spreading, and anomalous rain-fall. Several sector collapses are located along the edges of Ollade crater (Casita). Wyk de Vries (2001) suggests that these occur preferentially on the southwestern side due to the predominance of pyroclastic rocks in that area. Slope failures in this area include the devastating 1998 sector collapse and lahar for which anomalous rain-fall, associated with Hurricane Mitch, was the catalyst. The Ram Power concession is located on the relatively more stable northeastern side of Casita.

Geothermal Manifestations

No hot springs exist within the Ram Power concession. The closest are the distal El Bonete and Monte Largo springs. However, fumaroles and steaming ground are present within the Ram Power concession indicating the possibility of a commercial geothermal system. SKM (2005) reports fumaroles in a small area at northern rim of Ollade Crater, which are associated with hydrothermal alteration and a vegetation anomaly (lack of vegetation, Figure 4). Steaming ground is reported by SKM (2005) on the east flank of Casita, which also manifests as a vegetation anomaly (Figure 3). The latter, however, is believed to be caused by subsurface hot air convection rather than by fumarolic activity. Low CO_2 concentrations provide evidence for this. An additional fumarole has been mapped in the northeastern part of La Peloma Caldera by Hradecky (1999, Figure 3). GeothermEx (pers. comm., 2010) reports that this may be an ephemeral hot spring that is occasionally active during rainy periods.

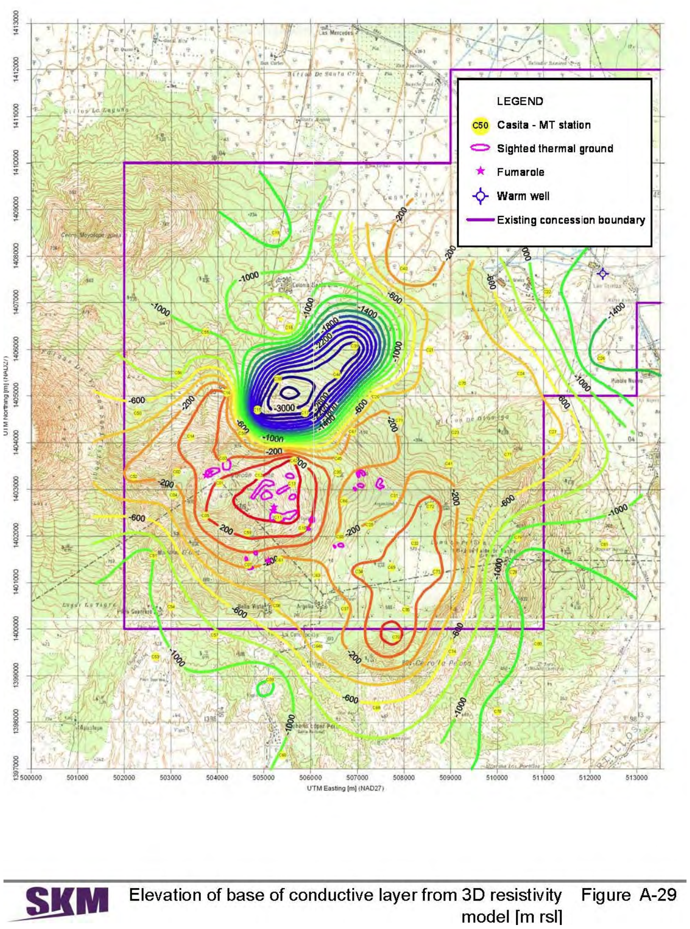

Figure 4. Magnetotelluric base of conductor contours from a proprietary SKM report in a PDF format.

GIS/Geospatial Database

ESRI ArcGIS™ software was used for this project. This software facilitated the critical processing steps necessary for preparation, spatial correlation, and visualization of the data as well as the development of geospatial databases. When using disparate data sets, such as those used in this project, the first objective is to digitize and georeference analog and non-georeferenced digital data. In this project numerous PDF (portable document format) files and some paper maps were available that needed to be georeferenced. In the first step, the PDF files were converted and the paper maps scanned to .tif (tagged image file format) files. A caveat here is that the maps or data must either have a minimum of three coordinates assigned to points, a grid, or tics on the digital images or have landmarks to which coordinates can be assigned. This is because the next step in processing is georeferencing (aka rectification), where an algorithm is applied to the image to adjust each pixel to a coordinate pair within a specific map projection and datum.

An example can be seen in Figure 4, a magnetotelluric (MT) base-of-conductor image taken from a proprietary SKM report (2005) in PDF format. This image has a UTM grid from which ground control points can be derived using ArcGIS™ (or other GIS and image analysis software packages) for use in the rectification process. Once rectified, the data in this example was used directly in overlays for visualization and the contour values were digitized as lines. The digital lines were then converted to points (the end of each line vertex), from which a georeferenced raster image was created for use in both 2D and 3D visualization (Figure 5a, 5b).

Unfortunately, not all data come with a nice coordinate grid from which to pick ground control points. The example in Figure 6 is from a new 3D inversion of the Casita MT data used in Figure 5. In this case "world files", which also allow the software to georeference the data, were created for horizontal MT conductivity slices. To create a world file there must be enough spatial information to allow the determination of the extreme upper-left pixel coordinates and the XY dimensions of the pixels. This information was available from the visualization software used with this data, which unfortunately did not have the capability to export georeferenced data. World files are a simple way to get around this. They can be created quickly with any text editor and the format is as follows:

5.0 (pixel width)
0.0 (rotation value – rarely used)
0.0 (rotation value – rarely used)
-5.0 (pixel height – value is always negative)
532893.0 (X coordinate)
4298745.0 (Y coordinate)

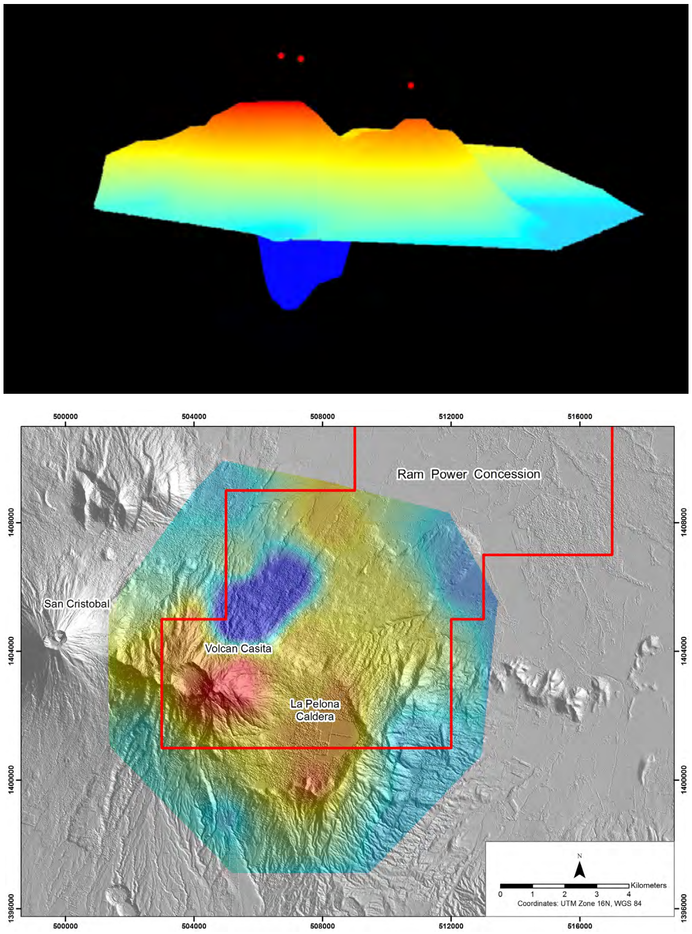

Figure 5a, 5b. Top: 3D magnetotelluric base of conductor contours after conversion to a rectified raster image. The three red dots floating above the base of conductor represent the locations of well pads chosen based upon the conductor doming in the dataset and structural considerations. Bottom: MT base of conductor in relation to topography.

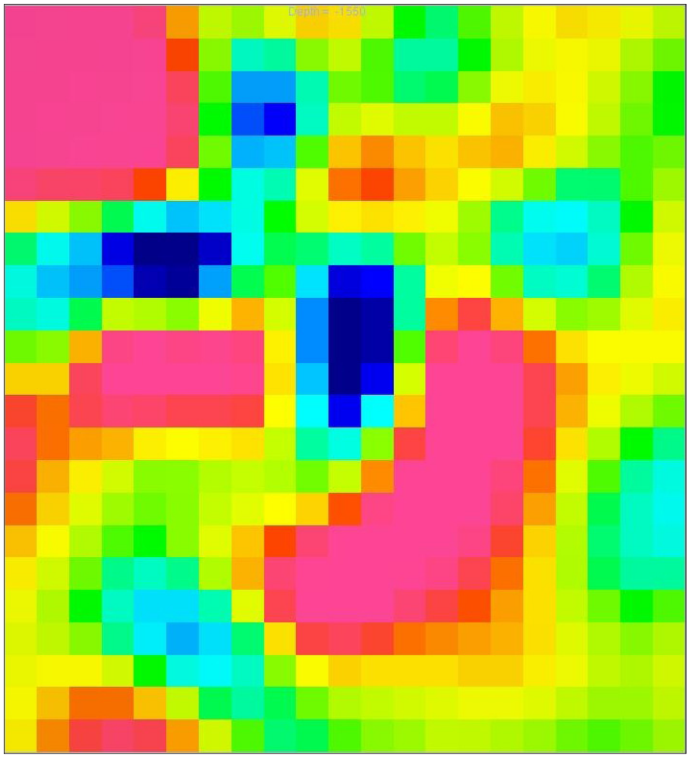

Figure 6. MT conductor slice at 1550 m depth that was not georeferenced.

The bracketed comments are not included in the file. To work properly, however, the world file must be named correctly and be stored in the same folder as the image it applies to. The name extension must always consist of the first and last letters of the raster file's extension followed by a "w." For example, if you have a raster image named gravity.jpg, the world file would be named gravity.jgw – for a file called gravity.tif, the world file would be named gravity.tfw. Figure 7 shows the georeferenced horizontal MT slice in relation to topography.

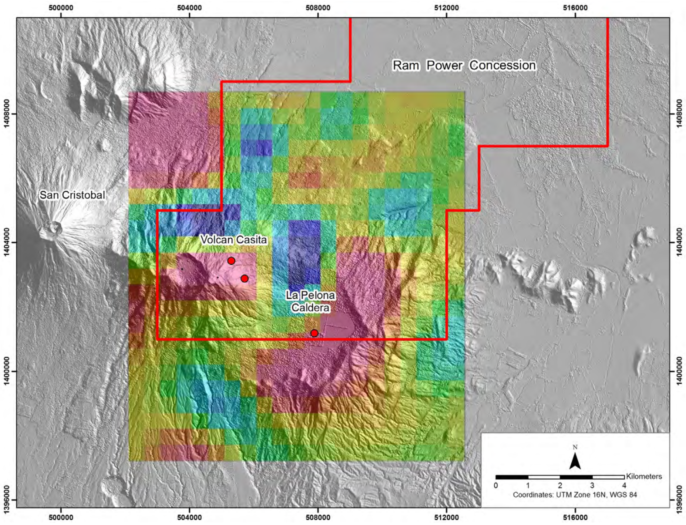

Figure 7. The same MT conductor slice seen in Fig. 6 after the application of a world file allowing it to be co-registered with other data in the GIS.

The GIS software also facilitated processing of the digital elevation data to create a shaded relief map, which is used throughout this paper as a backdrop for figures. Additionally, there is a very simple enhancement trick which in essence allows this data to be visually fused with other data, such as the synthetic aperture radar data used in this project, which have better spatial resolution to create enhancements such as an emphasis of texture. The fusion is achieved by adjusting the display transparency or either or both the shaded relief and/or the synthetic aperture radar data sets and displaying them both either in grayscale or in color or a mix of the two. Color can often enhance subtle fault scarps and structurally controlled geomorphic features making them easier to map. Figure 8 shows an example of this with the synthetic aperture radar image set to 40% and the shaded relief set to 10% transparency.

Conclusions

The geology, geochemistry, and geophysics acquired at the Casita concession in Nicaragua indicate the likely presence of a commercial geothermal system. A well-developed fault system, coupled with recent earthquakes, improves the probability of finding the subsurface permeability necessary for successful production wells.

GIS facilitated the incorporation of multiple spatially co-registered disparate data sets for visualization and analyses. This made the selection of potential drilling targets much easier than it would have been trying to interpret the data in their original formats. This also resulted in the development of a comprehensive exploration database consisting of two ArcGIS file geodabases, one which holds all of the vector data and one which holds all of the raster data relating to the Casita project. This will allow any authorized personnel to have access to and visualize Casita data within seconds.

The GIS platform also facilitated fault mapping using the synthetic aperture radar data and a shaded relief map created from the digital surface model. Hydrothermal alteration and vegetation anomaly mapping was also accommodated using band ratios created from the ASTER multispectral data. Upon completion of the geospatial database, logical production well siting was a simplified procedure and as more data is added in the future, the chances of successful drilling will be increased.

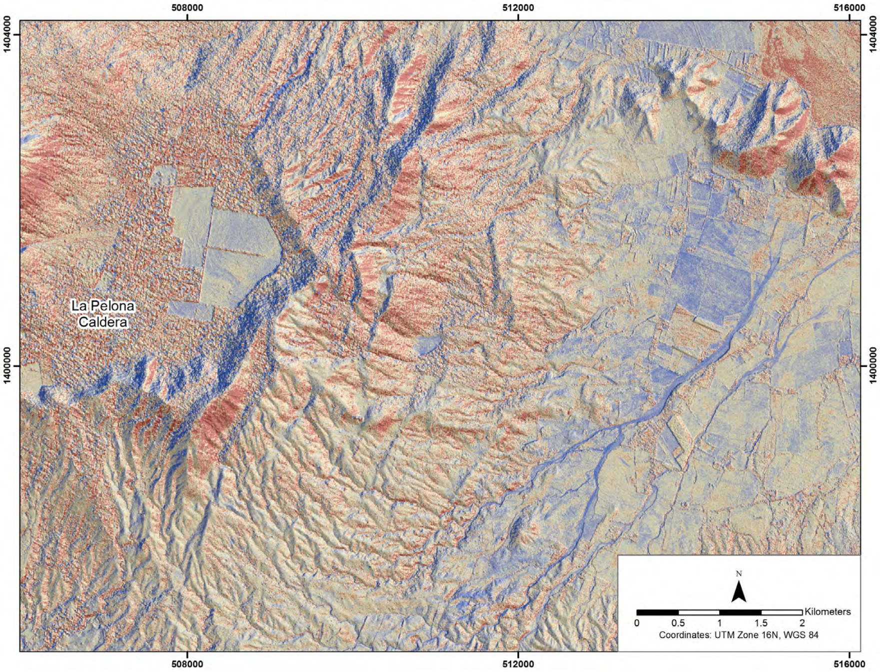

Figure 8. This image is a visual fusion of synthetic aperture radar and shaded relief images. It was created by setting the display transparency to 40% for the synthetic aperture radar data and 10% for the shaded relief image. This image enhances subtle fault scarps and structurally controlled geomorphic features. It was used primarily for fault/lineament mapping.

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