Reconnaissance Analysis of a Geothermal System Within the Central Cordillera of Colombia: Nevado Del Ruiz

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ABSTRACT

The present work interprets regional gravity and magnetic transects, GIS input, field work and magneto-telluric tactics, to understand structural variations in the northern section of the central cordillera of Colombia. This work is especially focused on refining our comprehension of structural complexities in the vicinity of the Nereidas geothermal system on the western flank of the Nevado Del Ruiz complex. This work will complement current/ongoing field efforts at the intersection of the San Jeronimo (N/S), Palestina (NE/SW), Santa Rosa (NE/SW), and Nereidas fault systems (NW/SE). The location of these fault systems, their fundamental geometric and structural relationships, and the relevance of understanding kinematic relationships between crustal structures and depth processes have bearing on seismic and volcanic hazards as well as implications for major untapped/undiscovered geothermal fields and actual geothermal exploration.

Regional to Local Frame

At the regional level, the study area is located in the northwest corner of South America. Colombia is located in the most northern area of the Andes cordillera. Complex tectonic settling resulting from the interaction between three lithospheric plates - the Caribbean, Nazca, and South American plates - characterizes the geology of the region.

The Nazca oceanic plate is converging eastward relative to the northwestern region of South America at 6 cm/yr, and the Caribbean plate is moving 1-2 cm/yr to the E-SE relative to the South American plate (Freymueller et. al. 1993; Kellogg and Vega 1995). The convergence of these plates produces the Colombia trench to the west and the southern Caribbean accretionary wedge to the north (Figure 1).

The interaction and active deformation between these three tectonic plates generates a wide area of continental crust deformation partitioning. In northwest South America, this process is highly dependent on the plate boundary configuration relative to oblique convergence, which leads to the development of significant...
trench-parallel strike-slip faults where strain is distributed over hundreds of active tectonic structures (Veloza 2002) (Figure 2). The most important such structures are oriented N-S and NE-SW, corresponding to the Romeral fault system and the Palestina fault system. All of these structures are capable of generating destructive earthquakes given their close proximity to dense population centers, including the regional capitals Manizales, Pereira, and Armenia, as well as hundreds of towns concentrated mostly in the central cordillera.

Geology of the Area

A wide variety of exposed rocks exist within the survey area boundaries. The majority is Paleozoic metamorphic rock, Cretaceous sedimentary rock, and intrusive igneous rock. There are also some Triassic and Tertiary sequences of extrusive volcanic rock, and a quaternary sedimentary layer covering collapsed lahar deposits and earlier sedimentary deposits.

Paleozoic rocks in the area show low and medium metamorphic grade green schist facies metamorphism to amphibolite; this forms the core of the central cordillera and has been grouped as Cajamarca Complex (Gonzales 1989).

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The Santa Rosa fault is located north of Pereira, passing through the town of Santa Rosa de Cabal and crossing north of the Nevado Del Ruiz Volcano in the direction N60°E to N70°E before joining the Palestine Fault. According to morphological features, this structure is continuous to where it meets the main segment of Palestina fault.

The Nereidas fault system runs along the joint of the three previous fault systems, preferentially in the NW/SE direction. The relations between these structures and the others are still a source of debate and discussion, and they play an important role in understanding the potential for geothermal reservoirs.

**Reconnaissance Analysis**

Speculative observations for the area were first held at the regional level by Dewhurst Group, LLC, using Space Spectral Analysis (SPAN) of available gravimetric/magnetic anomalies in the sample area (Internal Report 2011). This information was provided to Clients in Colombia and led to a complete ground survey and reevaluation of an existing site in Nereidas Valley. SPAN is a proprietary tool developed in conjunction with the Russian Academy of Sciences, St. Petersburg Branch of the Institute for Terrestrial Magnetism, Ionosphere, and Radio Wave Propagation (SPb-IFIZMIRAN).

A total of 12 SPAN profiles were used for this evaluation (Figure 3). Geomagnetic sections were made using open source near surface anomaly maps. Magnetic data were mostly taken from world maps of 2007-2011, and density sections were made using gravitational field anomalies mostly taken from GRACE satellites (Gravity NGDC NOAA GOV2010).

Gravity and density images are used mainly for density contrast (basement vs. basin), while magnetic/resistivity imaging of major structures such as geological faults and structural blocks are used mainly for conductivity contrast (fluid vs. solid), heat transfer, magma and geothermal fluid movement (cap vs. reservoir rock, and alteration rock vs. nonalteration rock).

Geomagnetic sections along the profiles show possible tracks of thermal zones that appear as feeble magnetic zones, rising from the depth to the surface. Density sections show the fault zones as subvertical untightened zones. The maps shown here demonstrate that various geophysical features generate gravity anomalies with considerable spatial variation over the surface of the earth.

The tracing of heat-fluidized tracks has been completed by compiling plotted geomagnetic sections of the earth’s crust in the vicinity of Volcano del Ruiz with features of well-known geothermal sources: Cascadia subduction zone (Vanyan et al. 2002; Petrishchev et al., 2011), Eastern Basin Range (CU) (Kopytenko et al. 2010a), Yellowstone National Park [Smith et al. 2009; Kopytenko et al. 2010a], Saudi Arabia (Reuter et al. 2007; Kopytenko et al., 2010b), and NPR-3 (Milliken M. 2007). These tracks are presented as narrow feebly magnetic zones ascending to the surface from depth.

With the current knowledge of the tectonic relations in the central cordillera of Colombia, we are unable to predict the behavior of the subsurface fluids or the relationship between the structures. This analysis will give us a new tool to map and interpret subsurface behavior and control over the lithology and the potential geothermal resource.

The observed values correspond to differential gravity and a magnetic field ranging from 1-10 km depth; units are specific to the environment, and are not correlated with an absolute value on the scale. This preliminary profound observation is useful for identifying locations with low magnetization points and vertical/subvertical trends, any of which may be the primary source for a geothermal system.

**Profile Interpretation**

Profile #5, taken to a depth of 10km, crosses the Nevado Del Ruiz Volcano southeast of the city of Manizales. In this image, the green layers correspond to the lowest density values (Figure 4). The shallow part may correspond to extrusive volcanic or sedimentary layers with a thickness that can vary between 2–3 km. Peaks observed may be related to variations in the thickness of the crust as well as the influence of fault blocks giving a first indication of the structural relationships on the western flank. A corresponding region of low density clearly shows a possible basin or graven of particular interest.

At a depth of 7 km, the observed elongated relatively low density area may correspond to an injection of low density material. In this case it is also correlated and more consistent with the structures of joint failure associated with the Romeral fault system, or the features of a subduction zone. In the center of the image, high-density values correspond to the core of the central mountain structure of the central cordillera. (Figure 4).

Low magnetization values (Figure 5) can be interpreted as indicative of a potential geothermal system, although plumbing systems from the upper mantle and high porosity and open spaces in the crust are also important to correlate with surface evidence such as hot springs, hot water, gases, and hydrothermal alteration.

![Interpreted gravity profile along central cordillera](image-url)

Figure 4. Interpreted gravity profile along central cordillera, Vertical scale is 10 km.
In order to avoid misinterpretations from possible magnetic effects in rocks without structure, by this point it is easy to identify the fault zone related to fault systems like Palestina fault. It is even more important to cross-reference the previous values of low gravity sectional density at the same point where a large amount of material is observed with very low magnetism at a depth 2-3 km related to another possible geothermal system in the area. 2 are visible in this section, to the west and east flank of the image.

All 2-D profile inversions were interpreted using contacts between conductors in order to infer regional and local structure and possible conductor target areas of interest. When a conductor shows connection or positional relationship to a fault zone (Figure 6), which could serve as a plumbing system, it becomes increasingly important. The major fault structure also is highly remarkable for the indication of two structural styles: compressional thrust blocks with involved basement structures, and folds and thrusting that do not fundamentally affect the basement. These superimposed structural styles are characteristic of high-pressure zones formed on orogeny belts. It is also important to locate low density-magnetic areas near the boundary of the ductile-brittle range that can be associated to a 2-phase geothermal system.

Ductile deformation can also be deduced from the changes in geophysical properties in areas of intense faulting, and high geothermal gradient conditions may favor the development of high-flux conductors also associated with high-permeability fault zones.

Analysis and processing of these data leads to the conclusion that there exists within this area 7 places with excellent prospects for the assessment of geothermal potential like the one presented above. One of those places which we focus is on the western slopes of the Nevado Del Ruiz Volcano which has been considered for this purpose for more than 50 years.

Summary

The structural relationship between active tectonics and the main structure of the central cordillera is limited by faults, and those appear to have significant control over the areas of weakness in the crust and the fluid motion and heat transfer. The integration of different fault systems in this area is of great significance due to the presence of major untapped/undiscovered geothermal fields.

This method gives us a subsurface perspective of the tectonic relations in the northern part of the Colombian central cordillera, refined tectonic model research in geothermal exploration, and shows us structural relationships between active tectonics and the volcanic system.

Profile #5 shows interesting sites, with low resistivity values, and potential paths for heat transfer, increasing the potential areas for geothermal resources. Due to the presence of the volcanic axis Ruiz-Tolima, and a new need for sources of clean and sustainable energy, the tectonic frame becomes more interesting. This region has been considered for over 50 years as a potential site for geothermal exploration. In recent years, the search for potential geothermal fields has increased. That is also beneficial for increasing knowledge in smaller scales of rock and tectonic mechanics in order to assess potential areas and generate a more accurate simulation of circulation in subsurface fluid flow of potential and specific reservoirs attainable with current technology for geothermal power generation.

Properly classifying structural geology in geothermal systems is essential because the environments for this type of resource have important stratigraphic and structural controls. Adequate research allows for better development of all phases of exploration and exploitation of the resource modeling.
Increased awareness of joints allows for a stronger interpretation of the geology and structural conditions in pursuit of increased secondary permeability. The modeling of geothermal reservoirs often highlights the need to take into account the natural fractures that influence the flow of fluids and heat.

Understanding the state and quantity in situ stress level for all important fault systems, and especially those in the vicinity of the intersection of these systems, has great importance because each system applies a level of deformation and different kinematics, increasing states deformation, which is the source of earthquakes as well as a generator of spaces for fluids to circulate in an active volcanic system.

Looking forward, more complex structural studies can be carried out, improving the understanding of this complex fault zone. The architectural scale, damage, affected area, and permeability direction are variables, not only influenced by kinematics but also by the direct relationship of magmatism and volcanism in the fluids canalization for geothermal systems, not only in present times but also in old flows traceable over time as hydrothermal activity.

References


