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Cartographic Standard for Geothermal Information of the Colombian Geological Survey

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ABSTRACT

The production of information during surface geothermal exploration through geological, geophysical and geochemical surface investigations allows the Colombian Geological Survey (SGC) to model and infer with greater certainty the existence of areas with geothermal resource potential in the country. The volume of geoscience information compiled and generated by the SGC does not have a standard for storage, representation and processing of geothermal data. Thus, the specialist does not necessarily have available the data necessary that meet quality and usage criteria that are required. The SGC, as a state entity and rector of geology in Colombia, has the function of "integrating and analyzing the geoscientific information of the subsoil," which requires guidelines to achieve the design, development, implementation and application of a cartographic standard for geothermal information. This standard will allow the constitution of a policy of simplification of processes for the storage and representation of information for each exploration area with geothermal resources in the country, positioning the SGC as the entity in charge of managing the geothermal information raised by future operators that exploit the resource. The components of the standard correspond to a geographic database to store the raster and vector information, which includes data from geological units, samples, structural, geophysical stations (gravimetric, magnetometric, magnetotelluric, shallow temperature surveys, vertical electric surveys), geophysical anomaly grids, geochemical data (springs thermal, fumaroles), among others. It also includes a catalog of symbols that stores the representation of each object (data to be represented), a catalog of texts to represent the annotations, a catalog of objects (geometries and grids) that describes each object and a data model to identify the type of data to be represented.

1. INTRODUCTION

The Colombian Geological Service (SGC) is the official governing body responsible for knowing and managing the resources of the Colombian subsoil, and is protected in its technical-scientific functions by Decree 4131 of 2011. Through the Directorate of Basic Geosciences and through the Group Exploration of Geothermal Resources, SGC conducts research focused on expanding, inventorying, characterizing, analyzing and modeling the geothermal resources of the Colombian territory (SGC, 2013). It must also guarantee that the information derived from geothermal exploration and research is framed within the primary data in the custody of the SGC, offered to the scientific community in general for the generation of new knowledge, products and services. In turn, this information is the pillar for the decision making of the nascent geothermal industry in the Colombian territory, for the generation of policies that manage the resource in the mining-energy sector.

The production of information during surface geothermal exploration, through geological, geophysical and geochemical surface investigations, allows the SGC to model and infer with greater certainty the existence of the resource in areas with geothermal potential in the country. The volume of geoscience information compiled and generated by the SGC does not have a standard for storage, representation and processing of geothermal data. Thus, the specialist does not necessarily have available the data necessary that meet quality and usage criteria that are required. The SGC, as the official entity and rector in Colombia, has the function of "integrating and analyzing the geoscientific information of the subsoil", which requires guidelines to achieve the design, development, implementation and application of a cartographic standard for geothermal information. This standard will allow the constitution of a policy of simplification of processes for the storage and representation of information for each exploration area with geothermal resources in the country, thus positioning the SGC as the entity in charge of managing the geothermal information raised by future operators that exploit the resource.

The components of the standard correspond to a geographic database to store the raster and vector information, which include data from geological units, samples, structural, geophysical stations (gravimetric, magnetometric, magnetotelluric, shallow temperature surveys, vertical electric soundings), geophysical anomaly grids, geochemical data (springs thermal, fumaroles), among others. It also includes a catalog of symbols that stores the representation of each object (data to be represented), a catalog of texts to represent the annotations, a catalog of objects (geometries and grids) that describes each object and a data model to identify the type of data to be represented. To achieve the standardization of geothermal information, it is essential to design, develop, implement and apply a cartographic standard for geothermal information. The standard will allow the SGC and all internal and external actors in the mining and energy sector to have the necessary documentation to simplify processes for the storage, representation and processing of information for each exploration area in the country (Struckmeier and Margat, 1995). The Cartographic Standard for Geothermal Information presented below shows the guidelines for unifying the storage and representation of the geothermal data acquired by the SGC and the guidelines for receiving the information captured by the operators interested in the exploration and exploitation of the areas geothermal of the country.

2. BACKGROUND

The incursion of Geographic Information Systems (GIS) has been imminent for the consultation of geo-referenced technical information generated from geological, geophysical and geochemical studies of geothermal systems (British Geological Survey, 2002). Knowledge that various countries have developed in the study of the phenomena causing geothermal resources worldwide are contained within such databases.

The systems developed by pioneering countries in GIS based on geothermal information, are a reference of consultation and accessibility that generates the interoperability of information among different users (Bureau of Mineral Resources, Geology and Geophysics, 1989). Different examples of the Geothermal Atlas are invaluable sources that provide first-hand data to the different communities interested in geothermal energy with the representation of updated maps of various geothermal systems present in the territories that exploit the geothermal resource (UNESCO, 1983). In Latin America, countries with availability of geothermal resources can be observed, whose governments have exploited to make feasible the potential use of geothermal energy as alternative energy while positively affecting the industry and the communities that benefit from its development (Hussien, 2007). Countries rich in geothermal systems that for several decades have consolidated a broad background in the matter granted the exploitation of the geothermal resource to private companies, which created a gap in the identification of geothermal systems (US Department of Energy, 2014), by conditioning information as a private and restrictive property that is not shared with official national authorities (China Geological Survey, 2012). The compilation and documentation of knowledge in geothermal energy, started from the base of the governing bodies of each country in this area, which implicitly are the national geological services. These national services do not have properly developed systems to spatially represent the information, but do have the research expertise and data collection that are necessary to dynamically feed the research on the analysis, design, modeling, development and implementation of a Geothermal Information System (Haugerud and Soller, 2018). The development of these systems allows for a reference macro of efforts to understand, learn, manipulate and exploit geothermal energy (AGRCC, 2010).

In the year 2000, the Geothermal Resources Exploration project developed the first version of the Geothermal Map of Colombia, thus becoming the first investigative achievement in the country to generate a very detailed technical outline of the geothermal potential of the Colombian territory and at the same time convert the SGC into a national and regional authority on the subject. This first version of the Geothermal Map of Colombia includes the Geothermal Gradient Map, Heat Flow Map and the Thermal Springs Map (Alfaro et al., 2010). In 2009, the second version of the Geothermal Gradient Map (Alfaro et al., 2009) was generated and the first detailed study for a sedimentary basin was completed with the Geothermal Gradient Map and the Heat Flow Map for Eastern Plains Basin (Alfaro et al., 2015).

The Geothermal Resources Research and Exploration Workgroup of the SGC has generated activities regarding the collection of geothermal, geochemical, geological and geophysical data, such as the application and organization of the index books used to collect geological, geophysics and geochemical information. In 2013, under the SIGER (Georeferenced Information System), the Analysis and Design of the Logical and Conceptual Model of the Geothermal Information Subsystem was generated (Matiz-León, 2013), which compiles a global, regional review and locality of existing geothermal information systems, and generates a data model based on the existing standard for the SGC. One of the components developed in the GIS field corresponds to the National Inventory of Hydrothermal Manifestations (www.hidrotermales.sgc.gov.co), which compiles all the geochemical information of the hydrothermal manifestations present in Colombian territory. This application contains general information on location, access routes, characteristics such as water temperature, tourist infrastructure, multimedia information, geological and hydrogeochemical information of thermal springs and other superficial manifestations of hydrothermal systems of the country (SGC, 2015). The information of the Inventory is presented through a geoportal offered to the academic community and the citizenship. It contains general and specialized information about thermal springs and fumaroles, with a view to promoting research in magmatic and hydrothermal fluids (SGC, 2015).

3. STRUCTURING OF GEOTHERMAL INFORMATION

The structuring of geothermal information is focused on the data collection from the central themes studied in geothermal energy systems: geology, geochemistry, and geophysics. The schematization of these data is based on the spatialization of all the elements observed in the exploration areas (International Organization for Standardization, 2015). Although the data meet the technical quality criteria to be presented to expert peers, they are not framed under standards for storage and representation in GIS or digital cartography (US Geological Survey, 2006). Standardization is needed in order to share among diverse users interested in the information that contain a public character (International Organization for Standardization, 2012). Figure 1 shows the types of studies by topic that are achieved to acquire all the necessary information in order to conceptualize each of the geothermal areas.

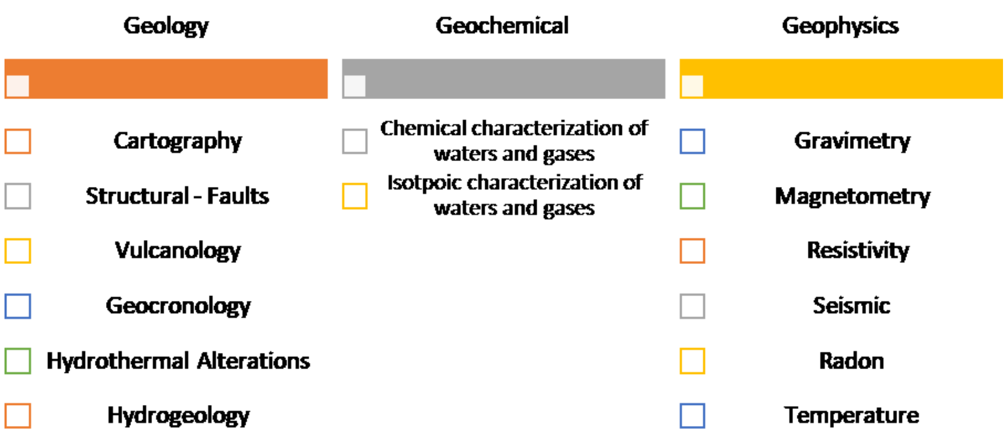


Figure 1: Studies developed in the field.

For the storage of the information, a Geographical Database (GDB) scheme was designed in the native ArcGIS format. Based on the existing standard for geological maps in the SGC (Gómez & Montaña, 2016), the GDB integrates datasets for geophysical and geochemical data. This scheme allows the implementation of a GDB with centralized storage structure, organized and nested in layers for features class and features datasets (Falcone et al., 2013). Figure 2 shows a representation of a GDB in its native structure in ArcGIS. It contains composite tables, raster data, the directory features defined by layers with line, point and polygon geometries, annotations, geometric networks, topologies and relations classes (Grasby et al., 2009). The GDB is structured in the geographic coordinate system National Geocentric Reference Framework (MAGNA) for Colombia based in Geocentric Reference System for Americas (SIRGAS).

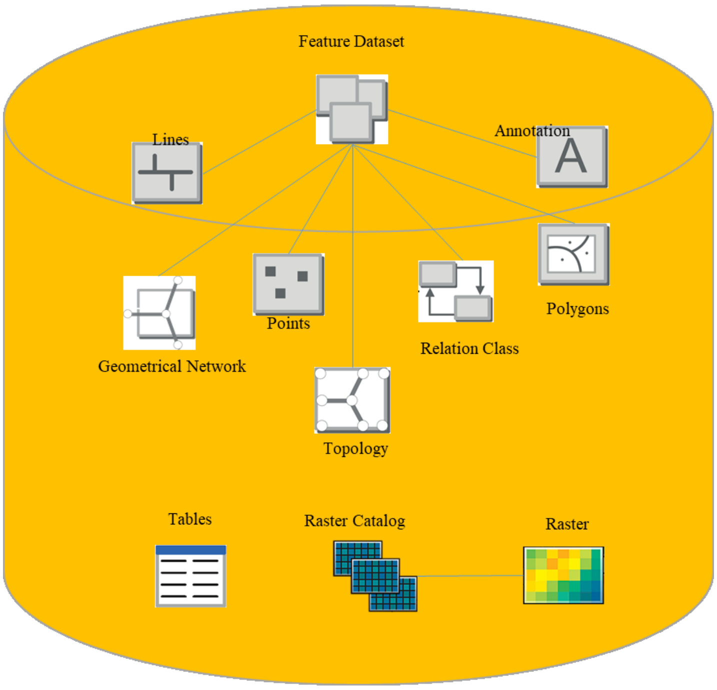


Figure 2: Diagram of a GDB.

3.1 Information Collection

The information used during the structuring is organized in the field formats prepared specifically for each subject (Pratt, 2003). The field data are structured in the index books, which correspond to the data organized by the collection and thematic campaign. This data is migrated to each feature class or tables as appropriate with the type of each attribute (short integer, long integer, floating, double, text, dates, binary data). Once the information is loaded, the presentation is made through graphical outputs based on the scale of representation of the geometries and the spatial extent of the data. The generation of maps and graphics of the information of the geothermal areas under exploration in Colombia by the SGC includes the collection of the information generated by each of the exploration topics (Figure 1). In Figure 3, the application process of the methodology for the data within the geothermal information standard is represented.

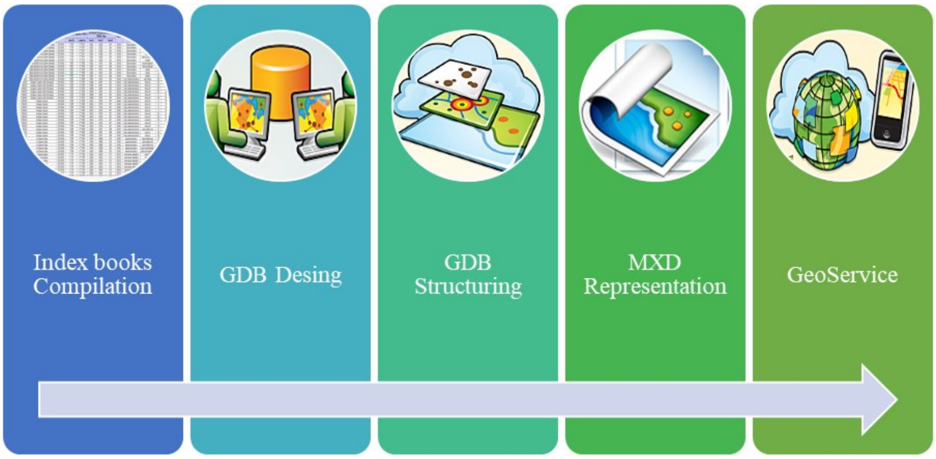


Figure 3: Compilation and structuring methodology.

The initial part of this phase within the methodology consisted of holding work meetings with each one of the persons in charge of the exploration topics that are listed in Figure 4. The disaggregation is carried out by general themes and the sub-themes in charge of each specialist. At each meeting, the main input that contains the data for the generation of the respective georeferenced layers was defined. The status of the data, its level of processing, the delivery dates, accessibility for internal and external users and those responsible for each subject were defined for each exploration area that could be loaded to the GDB.

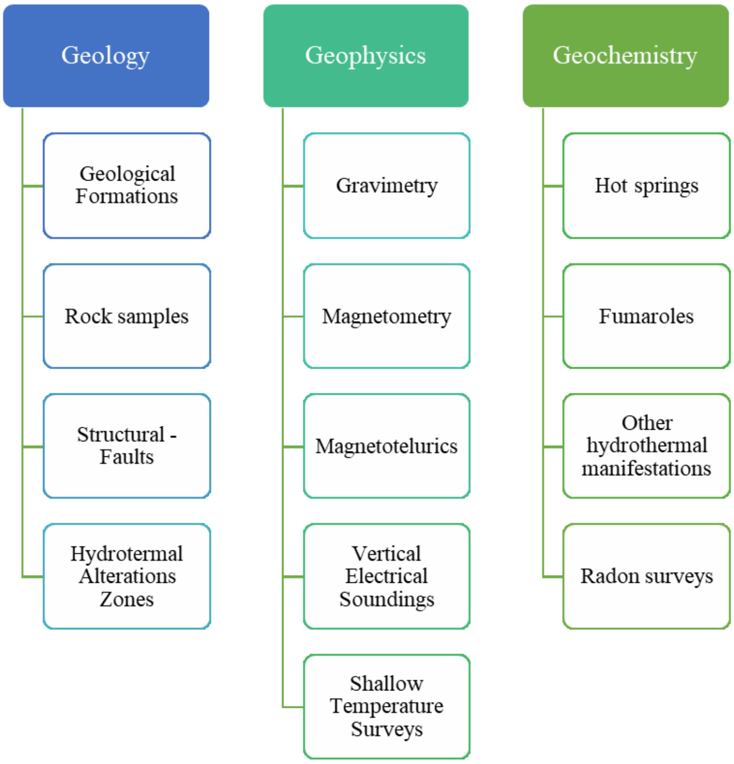


Figure 4: Types of data to be standardized in the different areas of geothermal exploration.

3.2 Books Index

From the work meetings with each specialist, it was determined that the main input prepared in the stage of information gathering in the field corresponds to the Book Index (LI). Although the LI was created in the Directorate of Geosciences (DGB) to compile the data taken in the field in each observed geological station, the collected samples and the laboratory analyzes applied to each sample are in the index books for each type of field data in the Resource Research and Exploration Group Geothermal. The design of the index books for each of the information capture processes in the field of the themes was developed from the data needed to fill in the forms, which generally includes the name of the station, coordinates, location (path and municipality), data equipment or measuring instrument (serial, calibration parameters), measured value and observations.

3.3 Design of the Geodatabase

The design initially starts with the verification of the existing storage and structuring standards for geology, geochemistry and geophysics applied in geothermal in the SGC. When finding the existence of the Cartographic Standard for Geological Maps at scales 1M, 500K, 100K, 50K, 25K and 10K (Gómez & Montaña, 2019), it is based on the storage and representation guidelines of the geological data since the great majority of the geothermal information corresponds to the geology scale 25K (geological formations, stations, faults, folds, diaclases, orientation data, among others). For geophysical and geochemical information, the SGC does not have georeferenced data storage and representation standards, for which the feature dataset and feature class is adopted for these topics, based on the type of data collected.

4. STORAGE AND REPRESENTATION

The storage of the information is subject to the way of uploading the information to the GDB. Because no data stored coherence structuring under the standard database, relevant data undergo a series of processes that enable the data to be represented spatially (Gebrehiwot, 2005). The representation of the geothermal data is focused on maps with formats that depend on the representation scale. However, the potential of geothermal information should be in web GIS, like Geoservices or Geoportals, to make for better dissemination to all of the geothermal community.

4.1 Migration and Transformation Processes and Reference Systems

The migration of the registries by each subject focused on the migration of the information from the index books (Excel files) to the feature class. The process takes as a basis the coordinates assigned in each register, converting the data that be represented as a point in X and Y values for its representation in the space with real coordinates. The data with line and polygon geometries generally have already had some type of cartographic process for its representation. To load this data to the GDB, a relationship between the initial attributes and the target attributes is set by a join with georeferenced geometries. The assignment of the reference system in MAGNA geographic coordinates is established due to the scale of data capture. The verification of the reference systems of each registry is relevant to avoid erroneous locations of the data that do not correspond to each geothermal exploration area.

4.2 GDB Structure

Based on the collection of information, diagnosing its structures and with the geological standard already defined, the feature dataset and feature class was created in the GDB of geothermal data. The selection of feature dataset names was made based on the names of the dominant themes within geothermal: geology, geophysics (Society of Exploration Geophysicists, 1991) and geochemistry (Kipng'ok, and Kanda, 2012). In turn, for data that were not part of these themes. we created additional feature datasets, such as sample and geothermal. In Figure 5 the GDB structure for geothermal data shown with the respective feature dataset, raster catalog, and tables that compose it.

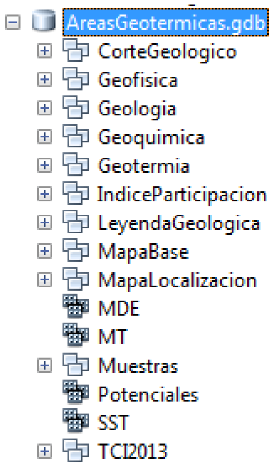


Figure 5: GDB structure for geothermal data.

<u>4.2.1 Feature Dataset: Geophysics</u>

This feature dataset contains the information of the materialized stations for the gravimetric, magnetometric, magnetotelluric studies, for the vertical electric soundings (SEV) and for the shallow temperature surveys (SST). Most feature datasets contain geometries such as points for geophysical stations. In Figure 6, the outline of the feature dataset with the feature class for the stations is observed.

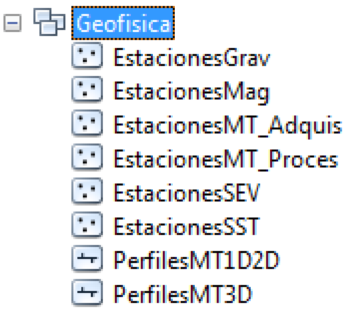


Figure 6: Structure for geophysics feature dataset.

<u>4.2.2 Feature Dataset: Geochemistry</u>

In the ambit of the geothermal information, geochemistry provides the analysis of the chemicals of hydrothermal fluids. For this standard, we included the carbonic gas and radon stations, hot springs, fumaroles, and other hydrothermal manifestations. Most feature datasets contain geometries such as points for hydrothermal manifestations. The sketch of the feature class is denoted in Figure 7.

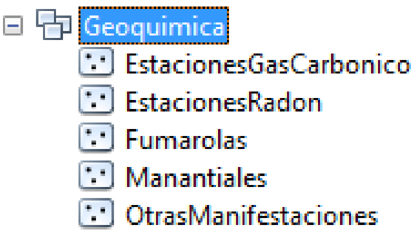


Figure 7: Structure for geochemistry feature dataset.

<u>4.2.3 Feature Dataset: Geology</u>

For the geology feature dataset, the features class, relationships and topologies were partially based on the Cartographic Standard for Geological Maps (Gómez & Montaña, 2019). The layers included correspond to the data of geological formations, faults, lineaments, folds, contacts, shears, geological stations, stratifications, diaclases, mud diapirs, salt domes, locations of the geological profiles, among others. In Figure 8, the total scheme for the included elements is provided.

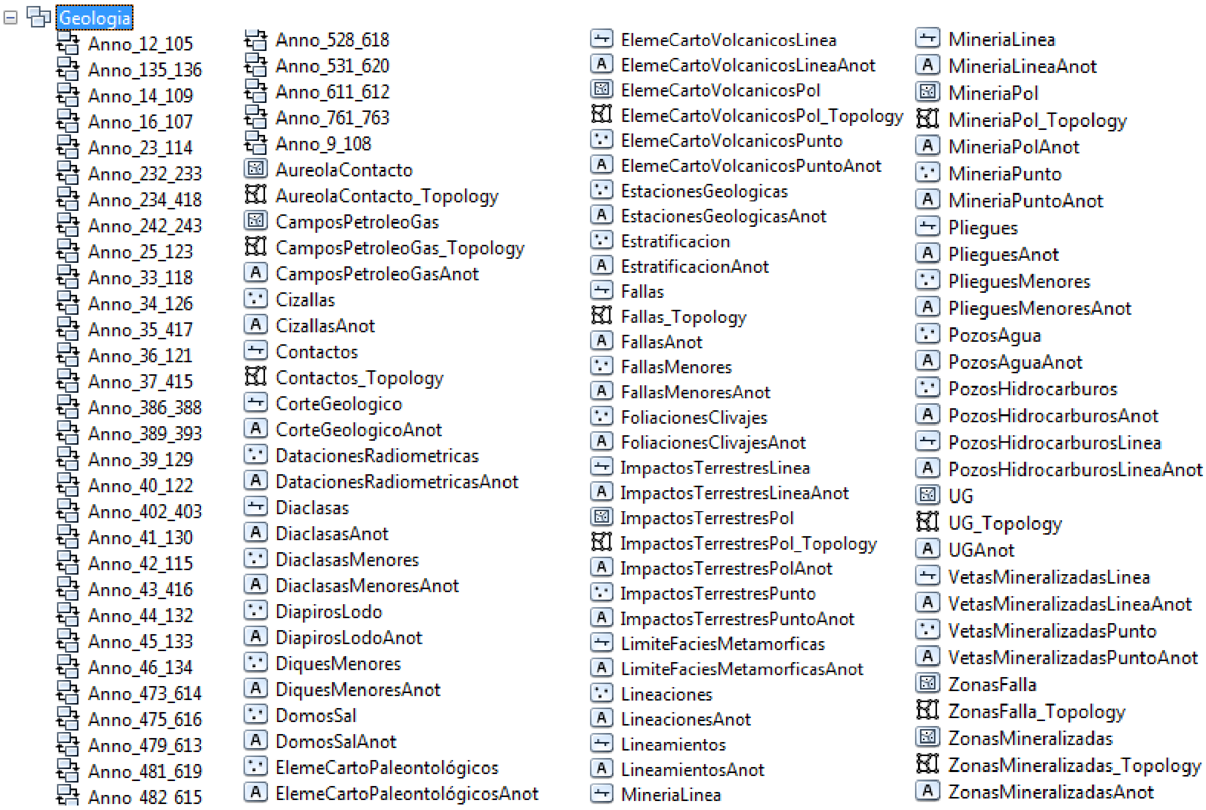


Figure 8: Structure for geology feature dataset.

4.2.4 Feature Dataset: Geothermal

Some of the specific layers of the geothermal exploration have no place within the themes of geology, geophysics, and geochemistry. These layers are about hydrothermal alteration zones and its stations, and the polygons for the extensions of geothermal areas. The geometries to represent in this feature dataset correspond to polygons and points. Figure 9 shows the features included in this group.

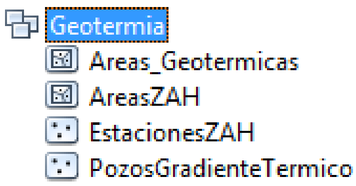


Figure 9: Structure for geothermal feature dataset.

4.2.5 Feature Dataset: Samples

The samples feature dataset collects the layers that contain the analyses made to the samples taken in the field, which correspond to rock dating, x-ray diffraction, granulometry, fluid inclusions, lithogeochemistry, binocular magnifier, microprobe, and thin sections. The geometries to represent for the feature class correspond to points. In Figure 10, the structure for the layers included in the feature is provided.

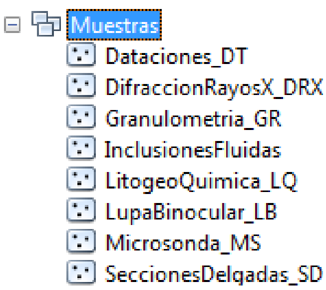


Figure 10: Structure for samples feature dataset.

4.2.6 Feature Dataset: Base Map

The base map feature dataset specifies that the structure is conserved from the GDB standard of the Instituto Geografico Agustín Codazzi (IGAC) governmental entity charged to elaborate the official maps for the country. The layers included correspond to the data of administrative points, built areas, canals, power plants, swamps, constructions, contour lines, double and simple drainages, wetlands, islands, lagoons, orographic names, roads, its corresponding topologies, and others. Figure 11 shows the overall scheme for the elements included.

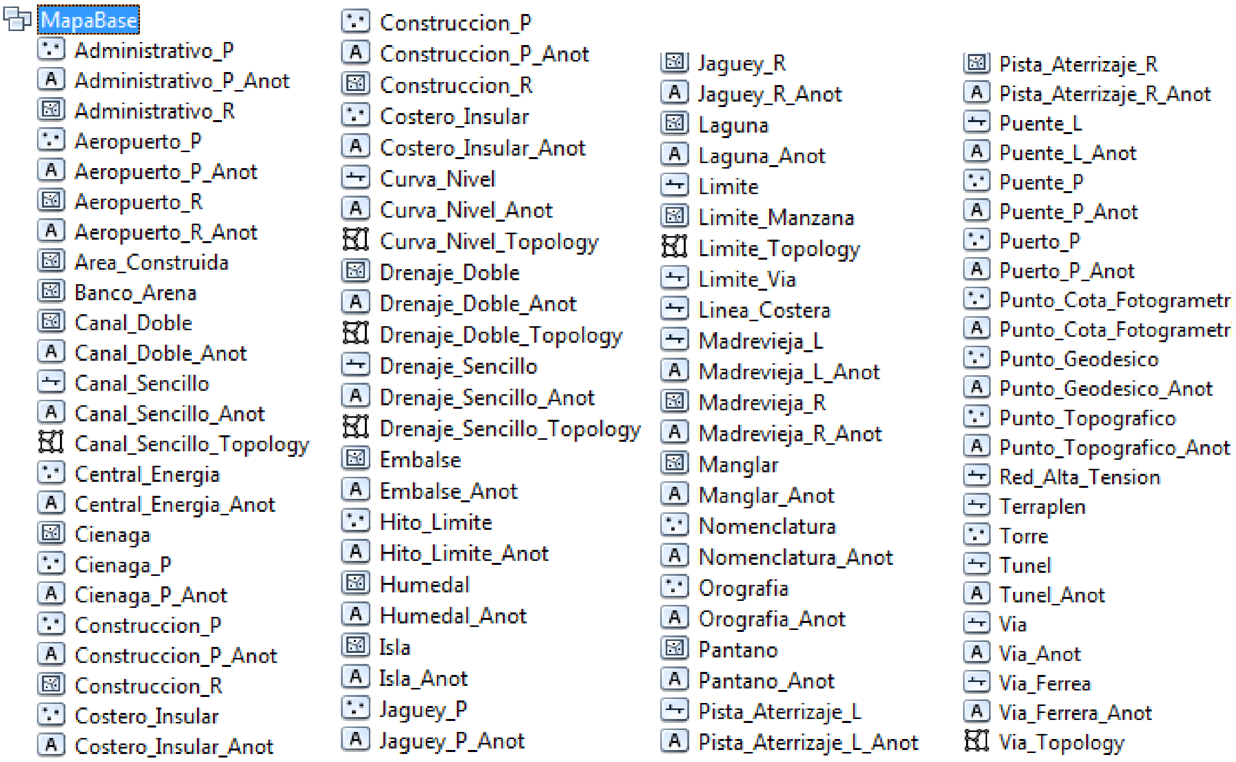


Figure 11: Structure for base map feature dataset.

4.2.7 Raster Catalog: Potentials

This raster catalog contains the data in raster format for the gravimetric and magnetometric studies of the geothermal areas. The images included correspond to the Total Bouguer Anomaly (ABT), the Total Bouguer Regional Anomaly (Reg_ABT), the Total Bouguer Residual Anomaly (Res_ABT) for the gravimetric part, and the Magnetic Anomaly (AM), the Residual Magnetic Anomaly reduced to the Pole (Res_AM_RP), the Regional Magnetic Anomaly reduced to the Pole (Reg_AM_RP) for the magnetometric information. In Figure 12, the raster data included in the image catalog is provided.

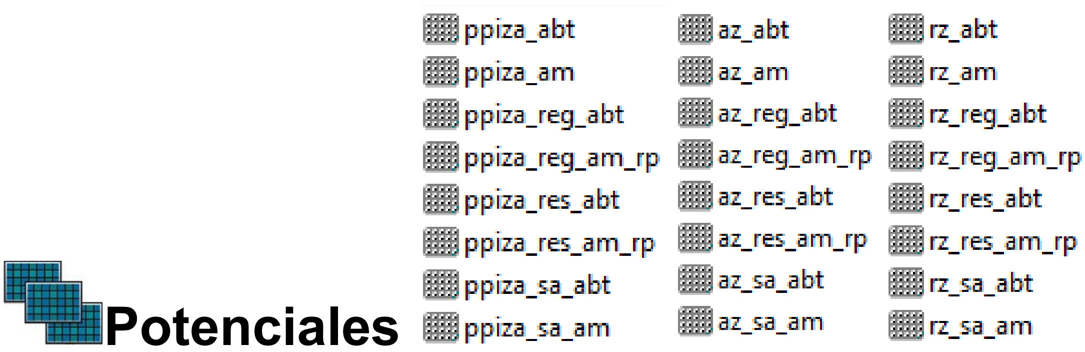


Figure 12: Structure for potentials raster catalog.

4.2.8 Raster Catalog: MT

The magnetotelluric raster catalog includes the images with magnetotelluric models generated in geothermal exploration areas. The included images correspond to the depths generated in modeling 1D and 3D. These types of elements that correspond to images with raster information are represented by matrix data grids. The resolution depends on the geostatistical interpolation previously used. This type of elements that correspond to images with raster information, are represented by matrix data grids. In Figure 13, the scheme of the included grids is shown.

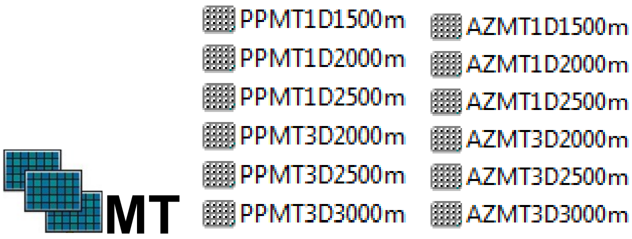


Figure 13: Structure for MT raster catalog.

4.2.9 Raster Catalog: SST

The SST raster catalog collects the resulting interpolations to represent anomalies of surface temperatures in the work zones. Grids include the pp_150cm raster that contains temperature anomalies at 150 cm of depth from Paipa geothermal area, and the az_150cm raster that contains anomalies at 150 cm for Azufral Volcano geothermal area. Figure 14 denotes the structure for the grids included in the raster catalog.

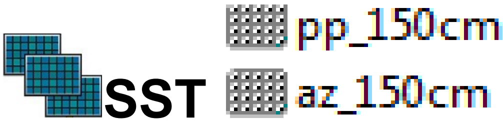


Figure 14: Structure for SST raster catalog.

4.2.10 Raster Catalog: DEM

For the base map with raster data, the DEM raster catalog gathers the Digital Elevation Models at different resolutions for each of the geothermal areas under exploration. The DEMs contained correspond to ppiza_12_5m and ppiza_30m for the MDE at 12.5 m and 30 m resolution respectively from the geothermal area of Paipa-Iza. The grids az_3m, az_12_5m, and az_30m are the MDE of 3 m, 12.5 m and 30 m resolution respectively for the geothermal area of Azufral. The raster of ruiz_12_5_m, ruiz_30m, sd_12_5m, and sd_30m correspond to the MDE of 12.5 m and 30 m resolution for Nevado del Ruiz geothermal area, and the MDE of 12.5 m and 30 m resolution for San Diego Maar Volcano geothermal area, respectively. In Figure 15, the structure for the grids included in the raster catalog is observed.

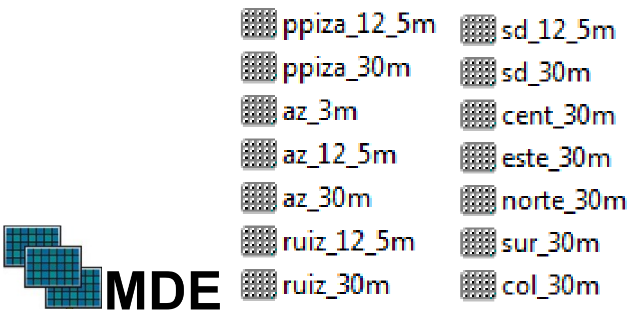


Figure 15: Structure for DEM raster catalog.

4.2.11 Attributes: Bibliographic Reference

Part of the dynamics of the geothermal data used in each exploration area corresponds to identifying the origin of each record. In the process of data collection and subsequent processing and analysis, each raw data becomes a processed data, resulting in the georeferenced data that is taken as the final data for the theme that is being represented. Generally, these data are associated to a cartographic product (geological map, geophysical map, and geochemical map) or in its use in to a report or technical report, which records all the information corresponding to the corrections, processing, and analysis that has taken place. To identify the provenance in a faster way in your query, two attributes were included for all GDB feature classes: Source and Observations Source (Obs_Source). Source corresponds to the bibliography citation of each cartographic product or technical report associated with each record, using the APA standard (American Psychological Association) 6th edition. The Obs_Source field refers to the title of the cartographic product or technical report associated with the data. Figure 16 shows the structure of the two attributes within the Feature Class schema.

Fuente	Observación Fuente
Pinilla et al., 2006	Mapa Geológico del Altiplano Nariñense. Escala100k
Velandia, 2003	Cartografía geológica y estructural sector sur del municipio de Paipa
Pardo, 2004	Mapa geológico de vulcanitas de Paipa
Rueda, 2017	Cartografía de los cuerpos dómicos del área geotérmica de Paipa
Grupo Geología de Volcanes - SGC, 2014	Geología del Complejo Volcánico Nevado del Ruiz. Escala 100k. Anexo B-01
Rueda & Rodríguez, 2016	Mapa Geológico Área Geotérmico de San Diego. Escala 50k. Anexo A
Rojas et al., 2009	Geología del Domo Volcánico de Iza y sus alrededores, sector Pesca e Iza

Figure 16: Reference and reference observation attributes for each record.

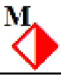
4.3 Representation

The catalog of symbols associated with the thematic of geology is based on the Geological Standard of the SGC (Gómez & Montaña, 2019). For the symbols linked to geophysics, geochemistry, and geothermal, the first version that collects the data raised in the field was prepared. As part of the purpose of the representation standard, the different geothermal data are displayed and loaded to the Geovisor that shows the information of the different exploration areas.

4.3.1 Symbols

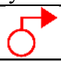
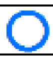
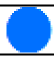
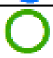
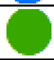
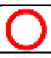
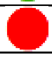
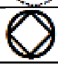
Below are the symbols proposed for geophysics, geochemistry, geothermal, and for the samples feature dataset belonging to geology. In Table 1, the symbols for the stations included in the geophysics subjects are denoted, specifically within the study of the potential fields (gravimetric and magnetometric surveys), the representation domain proposed for the stations of acquisition and processing of MT, SST and SEV data.

Table 1: Symbols for the geophysics subject.

Geometry	Symbol	Description	Theme
Point		Gravimetric Stations	Geophysics
		Magnetometric stations	
		Magnetotelúricas Acquisition Stations where MT and AMT were acquired	
		Magnetotelúricas Acquisition Stations where MT was acquired	
		Magnetotelúricas Acquisition Stations where AMT was acquired	
		Magnetotelluric Processing Stations	
		Shallow Temperature Surveys - SST	
		Vertical Electrical Soundings - SEV	

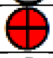
The following group of symbols focuses on the representation of elements included in the geochemistry subject. In this type of representation, shapes and colors were combined to give the user more information contained within the symbol. In Table 2, the representations for hot springs without classification and classified according to its temperature and chemical classification, fumaroles, other hydrothermal manifestations, radon and carbon gas stations are shown.

Table 2: Symbols for geochemistry subject.

Geometry	Symbol			Description	Theme
Point				Hot spring without classification	Geochemistry
	<40 ° C	40 ° C - 60 ° C	> 60 ° C	Chemical Classification / Temperature	
				Bicarbonate	
				Sulphated	
				Chlorinated	
				Fumaroles	
				Other Hydrothermal Manifestations	
				Radon stations	
				Carbonic Gas stations	

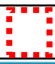
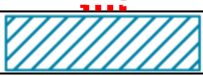
The following elements, although they are contained within the geology theme, make up a feature dataset due to the configuration of the data. These correspond to the rock samples obtained in the geological survey of an exploration area. The types of analyses applied to the samples included in the feature dataset (Table 3) correspond to radiometric dating, X-ray diffraction, fluorescence, mass spectrometry, granulometry, fluid inclusions, binocular magnifier, lithogeochemistry, microprobe, and thin sections.

Table 3: Symbols for samples feature dataset.

Geometry	Symbol	Description	Theme
Point		Radiometric Dating	Samples
		X-Ray diffraction	
		Fluorescence	
		Mass Spectrometry	
		Granulometry	
		Fluid inclusions	
		Lhitogeochemistry	
		Binocular magnifier	
		Microprobe	
		Thin sections	

The last group of symbols represented was included in the geothermal feature dataset which collects all the specific information that is not directly linked to the topics of geology, geophysics, and geochemistry. For this standard version, the thermal gradient wells, boundary of the geothermal areas and a classification of hydrothermal alterations were included (Table 4).

Table 4: Symbols for geothermal feature dataset.

Geometry	Symbol	Description	Theme
Point		Thermal Gradient Wells	Geothermal
Polygon		Geothermal Areas	
		Argillic	
		Advanced Argillic	
		Phyllic	
		Propylitic	
		Potassic	
		Deposits	
		Fillings	

4.3.2 Geoservice

The last stage of the standard is focused on the representation of geothermal information in platforms that allow the visualization of the data raised by the SGC and made available to the academic community, scientific community, and the general public. The initial effort was oriented towards the data already collected from the geothermal areas that are currently being explored in the Colombian territory by the SGC: Paipa-Iza, Azufral Volcano, Nevado del Ruiz Volcano, San Diego Maar Volcano. The information was loaded into the ESRI geographic data web platform: ArcGIS Online. In Figure 17, the four geothermal areas containing information are located, and Figure 18 shows the faults visualized with the gravimetric stations for the Paipa-Iza geothermal area, and the faults, gravimetric stations. In Figures 20 and 21, the geological units at 25k scale are denoted for the San Diego Maar Volcano geothermal area, and the faults, magnetometric stations and the ABT for Nevado del Ruiz geothermal area.

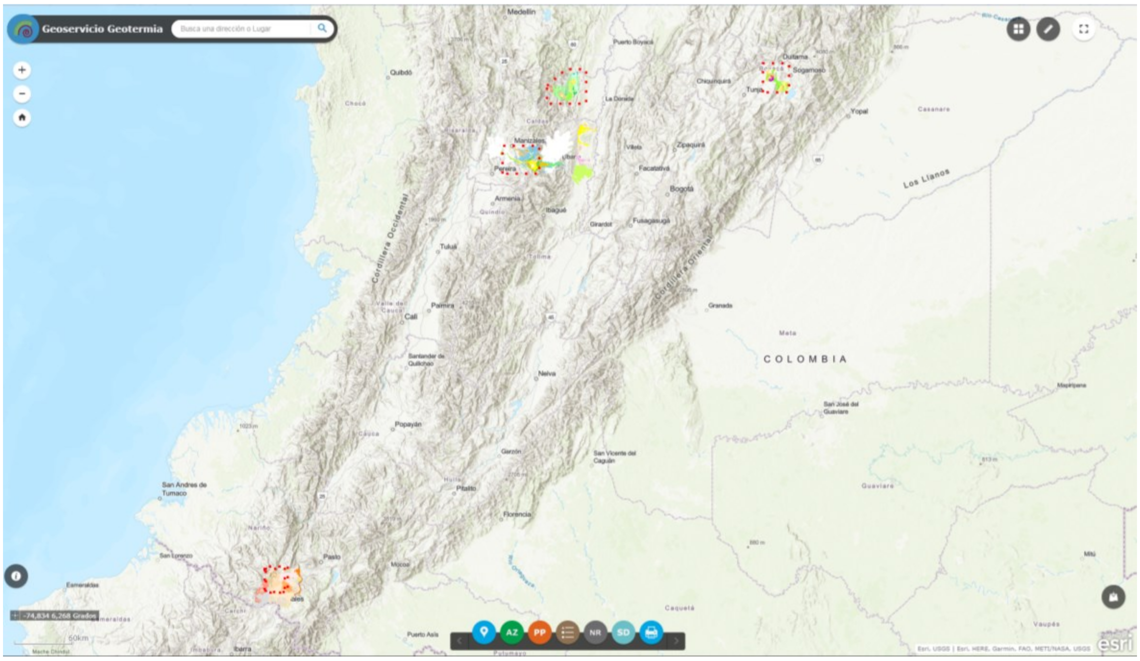


Figure 17: Visualization of the geothermal exploration areas in the Geoservice.

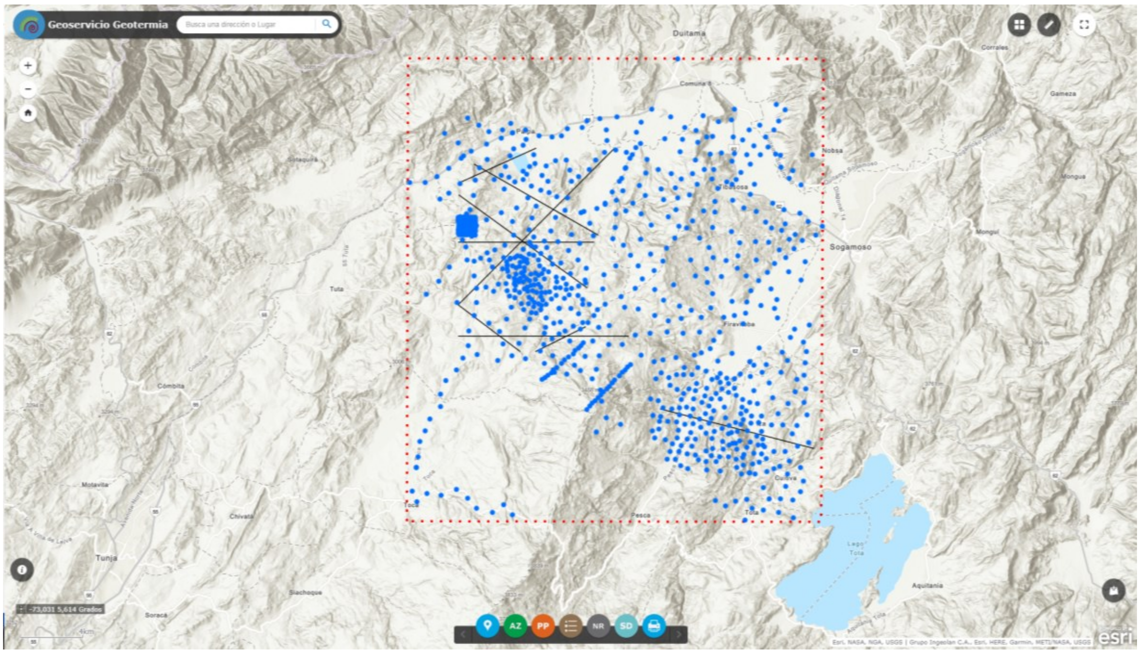


Figure 18: Cross sections and gravimetric stations in Paipa-Iza geothermal area.

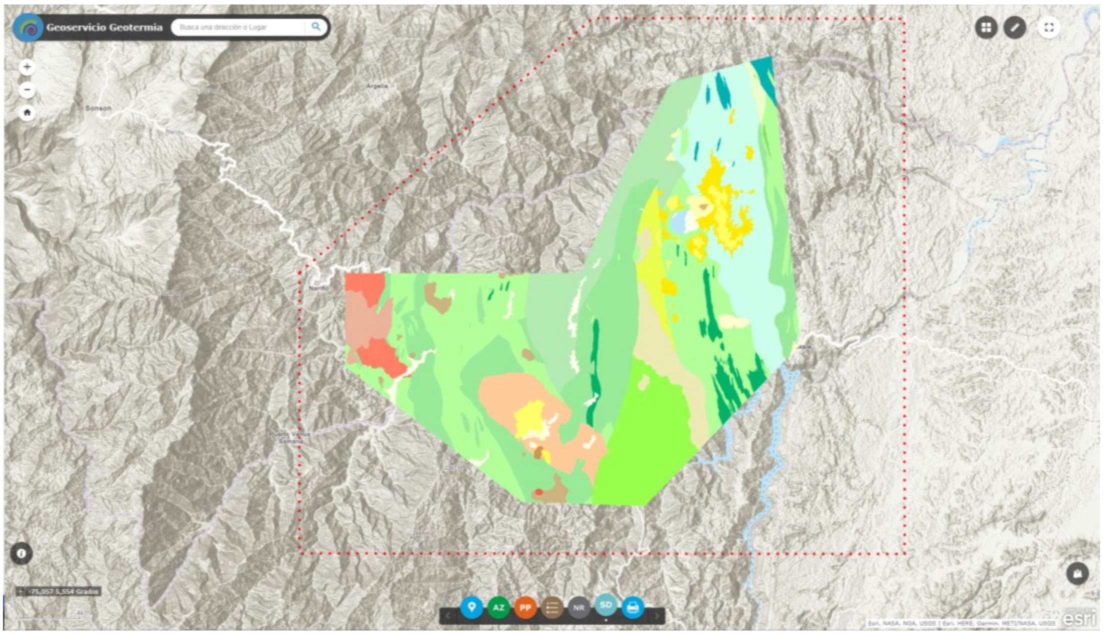


Figure 19: Geological formations for San Diego Maar Volcano geothermal area.

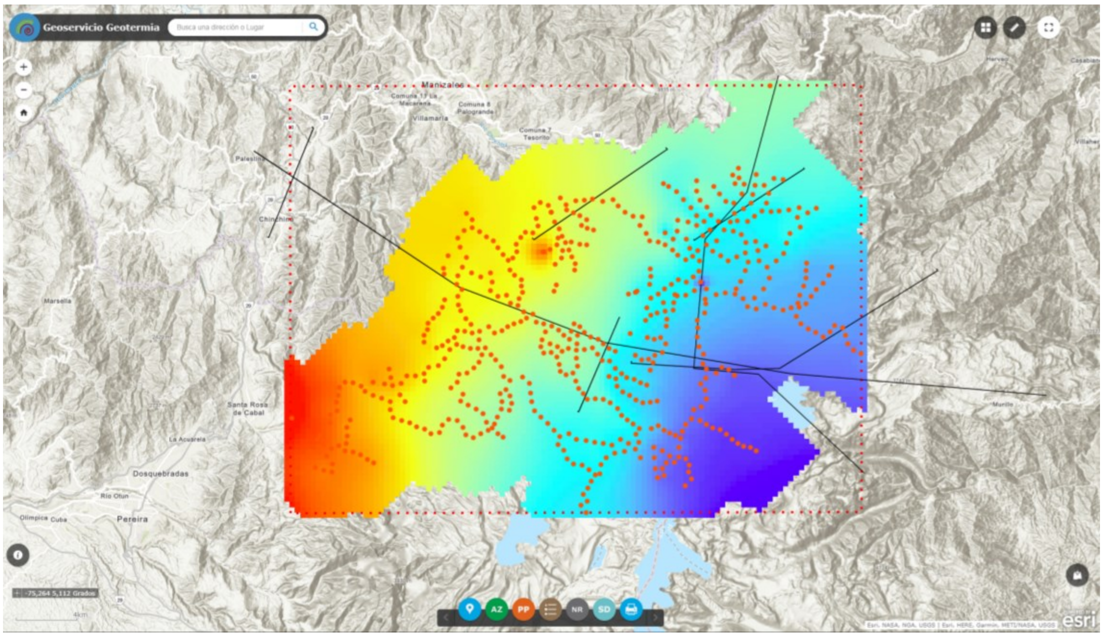


Figure 20: Cross sections, magnetometric stations and ABT for Nevado del Ruiz geothermal area.

CONCLUSIONS

The SGC as the governmental entity in the generation of knowledge of the resources of the Colombian subsoil proposes a series of guidelines and procedures within the Geothermal Information Cartographic Standard. This standard allows for good practices to store and represent the geothermal data of the areas under exploration in an adequate and organized way. Under this direction, all products generated in the country based on exploration and geothermal exploitation should tend to keep these guidelines to build a community of scientific information focused on the generation of knowledge and the development of the nascent geothermal industry in Colombian soil. As part of the function is to capture geophysical and geochemical information, a first approach is presented for the storage and representation of elements, such as stations, acquisition data techniques, samples, classifications, among others, which for this purpose are not standardized in the SGC. At the same time, a first outline is offered in the representation of raster information, which contains all the results of the potential fields, interpolations of some components of the geochemistry, and the modeling of the magnetotelluric data, taking into account the visualization criteria for the anomalies of each process and the range of colors for its representation. The definition of a geothermal data standard allows organizing the capture of data in the field based on the acquisition formats and its structuring in the various index books, as indicated by the topic. With some guidelines to follow in the storage of the data in a GDB, the procedure of loading information is made schematized and automated to be more understandable and user-friendly. The inclusion of the fields of bibliographic reference and reference observations to refer to the author or authors and the name of the cartographic product and/or technical product that gives origin to the geothermal data allows one to carry out a traceability on the technical origin of each registration. This allows the user to decide on their inclusion or not in the characterization that is being carried out on the model that is being built for each geothermal area.

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