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

Geothermal Information System – GISTº as support for exploration of geothermal resources in Colombia

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Keywords: geographic information system, GIS, geothermal data model, geothermal information system, geothermal database.

ABSTRACT

The Colombian Geological Survey – SGC (for its initials in Spanish) is the governmental institution in charge of the scientific research on Earth sciences, which includes the exploration of geothermal resources, among others. In Addition the SGC is responsible for managing the information of the subsoil, including the information produced by the oil industry and several documentary resources.

The large amount of geological, geophysical, geochemical and other geo-referenced data, obtained in activities of geothermal exploration and exploitation, demands the implementation of systems to store, organize, search, visualize and integrate data and information, in order to make it available for modeling and for a sustainable management of the resources. This work presents a proposal of a geothermal information system structured and developed to meet the needs of institutional and external users, taking into account the developments of other countries, as a reference.

The Geothermal Information System (GIST°) was built following the Unified Modeling Language - UML methodology. For conceptualizing and modeling this system, the phases of compilation and review of information, listing requirements and generating the logical model, were carried out. The information review was based on an extensive literature compilation of documented related experiences in countries at global and regional scale. For listing requirements phase, the survey methodology was applied to a target group which consisted of geologists, geochemists and geophysicist, involved in geothermal exploration and other institutional projects. Once the information was characterized, discussion workshops were held, with the participation of geoscientists who produce and use the information to be loaded in the information system. The structure of the logical model of the Geothermal Information System was finally proposed by means of entity-relationship diagrams to represent the entities and their related attributes.

1. INTRODUCTION

The geothermal systems have an absolute geospatial position to geo-referencing each of its components. These components (heat source, reservoir, fluid circulation structures, cap rock, recharge and discharge zones), are characterized by information provided mainly by geological, geophysical and geochemical studies. To abstract absolute position and convert together with the attributes in a source of information, Geographic Information Systems - GIS are used. The GIS have the capability to store, search and display information in order to represent the geothermal systems.

On a global scale some of the most prominent prototypes of geothermal information systems were developed by Spain (Catalan Atlas of Geothermal), Germany (the Geothermal Information System – GeotIS) and United States (the National Geothermal Data System - NGDS by United States). In Latin America few efforts have been reported to integrate geothermal GIS data, even in countries with resources and advanced geothermal exploration and exploitation. Some of them are the Argentine Catalog of Thermal Manifestations and the Medium and Low Temperatures GIS of Mexican Geothermal Resources. However these developments do not have all the functionalities and interoperability of an information system.

The main background to raise the proposal of the GIST°, were prototypes as those above mentioned. The design of the system was based on the identification, characterization and analysis of the great diversity of geo-scientific information produced in the geothermal exploration process. To identify and establish the information system requirements, surveys and periodic workshops, targeting specialists involved with geothermal information were carried out. These specialist reported their roles as producers or users of different kind of information, the current availability, accessibility, interoperability of the information in the existing infrastructure and their expectations for the geothermal system in development. In the survey and identification information, databases and GIS institutional from SGC was examined and mainly complemented with own information of the Geothermal Resources Exploration Working Group.

The data structure model was abstracted with their attributes in a descriptive and spatial level. The methodology used by the Unified Modeling Language – UML framed inside the software engineering. UML allows viewing of information through entities, attributes and relations represented in diagrams generating the GISTº logical model (Matiz León, 2013).

The Colombian Geological Survey has an institutional information system which contains thematic data sets with a particular data structure followed by the new developments, as in this case.

2. REVIEW

The forerunners in the development of the first geothermal information systems at global scale are Germany and United States, where GeotIS and NGDS. These systems and other described by the literature developed by Spain, Australia, China, Iceland, Italy, Kenya and New Zealand are briefly described in Table No 1.

<table>
<tr><th>Country</th><th>Development (Application)</th><th>Scope</th><th>Structure</th><th>URL</th></tr>
<tr>
<td>Germany</td>
<td>Geothermal Information System – GeotIS</td>
<td>Contribute to improving the quality of planning and projection of geothermal plants and provide preliminary statistics of the basic parameters for determining exploration risks (risk minimization): temperature and productivity of aquifers and based on these data , limited to the GeotIS resources hydrogeothermal (Pester et al., 2010)</td>
<td>Data
<table>
<tr><td>Drilling and geological sections</td><td>Temperature</td></tr>
<tr><td>Porosity and Permeability</td><td>Depth of stratigraphic units containing aquifers</td></tr>
</table>
System Tools
<table>
<tr><td>Source data</td><td>Technical data</td><td>Standardization nomenclature geological</td><td>Geographical Searches</td></tr>
<tr><td>Conversion geological record</td><td>Viewing underground</td><td>Statistical evaluations</td><td>Web application developed</td></tr>
</table>
</td>
<td>https://www.geotis.de/</td>
</tr>
<tr>
<td>United States of America</td>
<td>National Geothermal Data System – NGDS</td>
<td>The main objective is to support the exploration and generation of geothermal energy sources, where NGDS provides critical data relating to geothermal, to which may be easily and freely accessible (Department of Energy U.S., 2012)</td>
<td>Map
<table>
<tr><td>Temperature - depth</td><td>Thermal Conductivity</td><td>Heat Flow</td><td>Downhole temperature</td></tr>
<tr><td>Lithological information</td><td>Digitize temperatures taken by the oil companies</td><td>Water chemistry</td><td>Radiometric ages of young volcanic rocks</td></tr>
<tr><td>Porosity and permeability</td><td>Temperature record - depth</td><td>Isotope data of thermal waters</td><td>Geothermal mineral dating system</td></tr>
</table>
Applications
<table>
<tr><td>Be a tool in decision making</td><td>Increase public awareness of geothermal energy</td></tr>
<tr><td>Progress in the study of earth sciences</td><td>Provide a reliable source of energy as the basis of knowledge</td></tr>
<tr><td colspan="2">Support the creation of a large repository of knowledge and data files geothermal</td></tr>
</table>
</td>
<td>http://geothermaldata.org/</td>
</tr>
<tr>
<td>Spain</td>
<td>Geographic Viewer and Geothermal Atlas of Catalonia</td>
<td>The main goal is to collect and self-disclosure of the current state of geothermal knowledge in Catalonia, closer to the various communities specialized, academic and society in general to geothermal. In turn, aims to achieve a sufficient level of information to efficiently count the geothermal potential of Catalonia, so that it can be taken as a relevant fact in the decision-making of future national energy plans (Geological Institute Catalan, 2012)</td>
<td>Data
<table>
<tr><td>Geological Map of Catalonia</td><td>Fracture Zones Map of Catalonia</td><td>Depth Map Paleozoic basement ceiling</td></tr>
<tr><td>Regional Map Bouguer Anomaly</td><td>Residual Map Bouguer anomaly</td><td>Areas Map of deep geothermal potential</td></tr>
<tr><td>Geothermal Map Gradients</td><td>Temperature Map in the base of the crust</td><td>Temperatures Map at 15 km depth</td></tr>
<tr><td>Heat Flow Map</td><td>Temperature Map to 3 km depth</td><td>Map Thermal Conductivities</td></tr>
<tr><td>Geothermal Evidence Map (thermal springs)</td><td>Temperature Drop Map to 100m deep summer and winter</td><td>Synthetic Map of water flows</td></tr>
</table>
</td>
<td>http://taure.icc.cat/geoLocal/crearAplicacionAtles.jsp?tipus=atl&codi=igc&schema=atles_geotermic_cast</td>
</tr>
</table>

<table>
<tr>
<td>Australia</td>
<td>Western Australian Petroleum and Geothermal Information Management System - WAPIMS</td>
<td>Is an oil exploration database. The query is done through a tree structure in the layers of information but does not allow for geographic queries (Government of Western Australia, 2009)</td>
<td>Data
<table>
<tr><td>Wells</td><td>Geophysical Surveys</td><td>Mineral Boreholes</td></tr>
<tr><td>Excel spreadsheets with information for WAPIMS.</td><td>Reports of well</td><td>Seismic Service 2D</td></tr>
<tr><td colspan="3">Records of well data (files in LIS, DLIS, LAS or ASCII formats)</td></tr>
</table></td>
<td>https://wapims.dmp.wa.gov.au/dp/controller/</td>
</tr>
<tr>
<td>China</td>
<td>First Database of Geothermal Resources</td>
<td>This database was established since October 1990. Their function is to provide original data for the evaluation of the quality and quantity of the hot springs in China, the analysis since its inception and methods for routine processing of geothermal data and a higher valuation of the potential of using these resources in industry, agriculture and medicine (Liang-Ping et al., 1991)</td>
<td>Data
<table>
<tr><td>Basic data drilling</td><td>Data of the nature and age rock</td><td>Mineral alteration data</td></tr>
<tr><td>Data on well geotemperature</td><td>Data pumping well and observation wells</td><td>Data cations in thermal waters</td></tr>
<tr><td>Data from the anions in thermal water</td><td>Basic data of the well test</td><td>Data flow testing</td></tr>
<tr><td>Data isotopes in hot springs</td><td>Hot Springs</td><td>Basic data geothermal area</td></tr>
<tr><td colspan="3">Data of the thermo-physical properties of the rock and radioelements</td></tr>
</table>
System
<table>
<tr><td>Data Entry</td><td>Data Correction</td><td>Data Collection</td></tr>
<tr><td>Calculate heat productivity</td><td>Drawing isolines geotemperature</td><td>Plotting geothermal and groundwater regime</td></tr>
<tr><td>Mapping lithological units</td><td>Calculation of the total amount of steam and water</td><td>Analysis Correction ions thermal waters</td></tr>
<tr><td>Calculate reservoir temperature by geothermometers</td><td>Identification of chemical type of thermal waters</td><td>Potential power generation</td></tr>
<tr><td colspan="3">Evaluation of geothermal resources by finite element method</td></tr>
</table></td>
<td>http://www.sinica.edu.tw/main_e.shtml</td>
</tr>
<tr>
<td>Iceland</td>
<td>Gagnavefsja</td>
<td>The application works over a transmission system Oracle database, generating a geoportal in ArcSDE and ArcIMS. The geoportal is aimed at certain user communities: the scientific community OseISOR, general public, private energy companies and academia, especially the community of the Geothermal Program of the United Nations University (Hauksdóttir et al., 2005)</td>
<td>Data
<table>
<tr><td>Geothermal field</td><td>Hot Springs</td><td>Wells</td></tr>
<tr><td>District heating system</td><td>Pools</td><td>Power Plants</td></tr>
</table></td>
<td>http://www.nea.is/geothermal/</td>
</tr>
<tr>
<td>Italy</td>
<td>Geothopica, (Geothermal National Database)</td>
<td>The geothermal data base was created with the purpose of collecting information relating to the location and attributes of geothermal resources that</td>
<td>Data
<table>
<tr><td>Hot springs</td><td>Fumaroles</td><td>hydrocarbon exploration wells</td></tr>
<tr><td>Unproductive wells</td><td>Geological data</td><td>Drilling data</td></tr>
<tr><td>Hydrogeological data</td><td>Geophysical data</td><td>Termal data</td></tr>
</table></td>
<td>http://geothopica.igg.cnr.it/</td>
</tr>
</table>

<table>
<tr><td></td><td></td><td>occupy the Italian territory (Barbier et al., 2000)</td><td></td><td></td></tr>
<tr><td>Kenya</td><td>-</td><td>GIS was developed in order to identify areas of geothermal production containing high permeability, surface manifestations and anomalous values from geophysical measurements (MT, TEM, gravity), geological (structures, centers of eruption), geochemical (sampling subsurface gases) and with some specificity of the reservoirs (heat loss measurements) (Shako and Mutua, 2011)</td><td>Data<table><tr><td>Faults and fractures</td><td>Eruptive centers and fumaroles</td><td>Geochemical data</td></tr><tr><td>Geophysical data</td><td>Surface temperature measurements</td><td>Cartographic base layers</td></tr></table></td><td>-</td></tr>
<tr><td>New Zealand</td><td>GDManager</td><td>GDManager is currently software developed for storing all kinds of geothermal data. The goals of the software are: storage and retrieval of large amounts of data, easy graphical representation of integrated approaches between and within the same disciplines, networking to promote interdisciplinary work and integrating data analysis and interpretation methods (Anderson et al, 2000)</td><td>Data<table><tr><td>Well</td><td>Subsurface resources</td><td>Geological data</td></tr><tr><td>Geophysical data</td><td>Geochemical data</td><td>Depth</td></tr></table></td><td>-</td></tr>
<tr><td>El Salvador</td><td>LaGeo</td><td>Design and Implementation of Energy Information System of El Salvador, where geothermal and geo-referenced information will be standardized for the entities, companies, academia and general users (National Council of Energy, 2012)</td><td>-</td><td>-</td></tr>
<tr><td>Argentina</td><td>Argentine Catalog Thermal Manifestations</td><td>Build a database systemic and completely of geothermal resources, generate a friendly source queries for different users for the dissemination of knowledge about the resources that have Argentina and provide a collection of literature published research and unpublished generated by various actors (Miranda and Pesce, 2000)</td><td>Data<table><tr><td>Location</td><td>Schematic map</td><td>General features</td></tr><tr><td>Chemical analysis</td><td>Geothermometry</td><td>Bibliography</td></tr><tr><td colspan="3">Isotopes and gas chemistry</td></tr></table></td><td>http://www.energia.gov.ar/contenidos/verpagina.php?idpagina=2990</td></tr>
<tr><td>Mexico</td><td>GIS Medium and Low Temperatures of Mexican Geothermal Resources</td><td>Facilitate the visualization and analysis of data sets needed to interpret geothermal data, help infer the existence, size and location of individual geothermal systems and media low temperature, assist in the evaluation of geothermal reservoirs, correlate the characteristics of the geothermal resources for socio-economic parameters of populations collocated, recommend particular applications of the corresponding geothermal reserves and to promote their use in direct applications (Martinez et al, 2005)</td><td>Data<table><tr><td>Geothermal location</td><td>Geothermal system</td><td>States</td></tr><tr><td>Municipalities</td><td>Urban area</td><td>Islands</td></tr><tr><td>Capital city</td><td>Cities</td><td>Towns</td></tr><tr><td>Geothermal fields</td><td>Roads</td><td>Railway lines</td></tr><tr><td>Rivers</td><td>Lakes</td><td>Digital Elevation Model</td></tr></table></td><td>-</td></tr>
<tr><td colspan="5">Table 1. Description of some geothermal information system developed around the world</td></tr>
</table>

Other developments with a scope similar to the one intent in Colombia can be underlined. They belong to Philippines, Indonesia, Japan, and Switzerland. They structured the GIS systems by organizing the information in thematic data structures (thematic data like geology, geophysics, geochemistry, hot springs, depth and temperature data). This data structures are based on databases repositories, supported by GIS software and external viewers like Google Earth for information that contains coordinates (Matiz León, 2013).

Regional developments in geographical information systems for geothermal, belong to countries such as El Salvador, Argentina and Mexico, which have a political geographic, economic, and social proximity with Colombia. Their most relevant characteristics summarized by Matiz León, 2013, are also presented in Table No.1.

3. METHODOLOGY

As methodology for data abstraction and information relevant to the GISTº, the survey and workshop tools as direct observational uptake were used to identify the information requirements. The focus of the surveys is the characterization of the information regarding the criteria of availability, accessibility and distribution of technical information utilized as inputs in the production of thematic products. As intrinsic guideline of any GIS, the survey took into account the characterization on the management of data, identification of users and producers of information. All the surveying requirements are lined up to the policies and standards of geospatial information (Colombian Space Commission, 2001).

As next stage, the design of the Logical Model of the Geothermal Information System, was developed, on the basis of the information requirements collection stage. This is an Entity-Relationship (ER) model. As it is known, this type of models perceives the real world in a set of objects named entities with their attributes or characteristics and, their relationships. Their graphical representation is done through the Entity-Relationship Diagrams (Galán, 2005 and Gómez, 2005).

3.1 Information requirements

As mentioned before, the information requirements were establish through surveys and workshops.

3.1.1 Surveys

The surveys were versioned in two editions. Version 1 was addressed to professionals in Earth sciences working in geology, geophysics and geochemistry for different institutional projects and for Geothermal Exploration. Version 2 is aimed at specialists who handle the data that shape the GISTº entities, most of them, members of the Working Group of Geothermal Resources Exploration of SGC. These data were identified considering all the activities involved in the development of geothermal studies from the field data collection to documents, reports, maps and other products.

The contents of the surveys included questions about different topics as follows (Matiz León, 2013):

Version 1: Document information; general information; availability, accessibility and distribution of information related to geothermal; producers of geographic information and related information with geothermal; users of geographic information and related information geothermal; interoperability and infrastructure processing technology and geographic information systems.

Version 2: Document information; general information; entities-attributes and load information; queries; base cartography.

3.1.2 Workshops

The information requirements workshops were developed with the objective of present and discuss the survey results. This method allows to collect concepts, suggestions and comments of the group of specialist (about 12 people).

3.2 Model design

Following the software development process (Jaramillo Villegas, 2013), the analysis and design phases were performed. A brief description is shown in Table 3.

Table 3. Analysis and Design Phases of Software Development Process

Phase	Description
Analysis	Stage in which get and verify the requirements and necessities of the system, also the state of the information that will be its main component and its solution for future implementation.
Design	During this phase, which allow to obtain models guide designs for implementing the system are generated.

3.2.1 UML Methodology

The Unified Modeling Language - UML is a language that became an international standard used for modeling engineering systems. As a standard established, is used for representing methods and software through many object-oriented schemes that combines graphic techniques like diagrams Entity - Relationship, workflows, object modeling and component. The processes that handle UML correspond to the software development methods, modeling and diagrams with different structures. ER diagrams are the most characteristic language through boxes representing classes. Some of the advantages of UML correspond to enhance the total development time, establishing concepts and executable artifacts, better support planning and project control, cost optimization, better understanding the machine language, among others (Medina Pasaje, 2005).

4. RESULTS

The logical model presented in the Figure 1, contains the identified entities for the GISTº with their attributes and the relationships between them. In the representation of the underlying relations between entities, the corresponding types of multiplicity of each relation (one to one, one to many, many to many) were determined.

As the model suggests, the information requirements include: Geology, Geophysics, Hydrogeology, Fluid Geochemistry of Hydrothermal Manifestations, Well and Geothermal Model. Different attributes of each type of information, characterize each one of the entity.

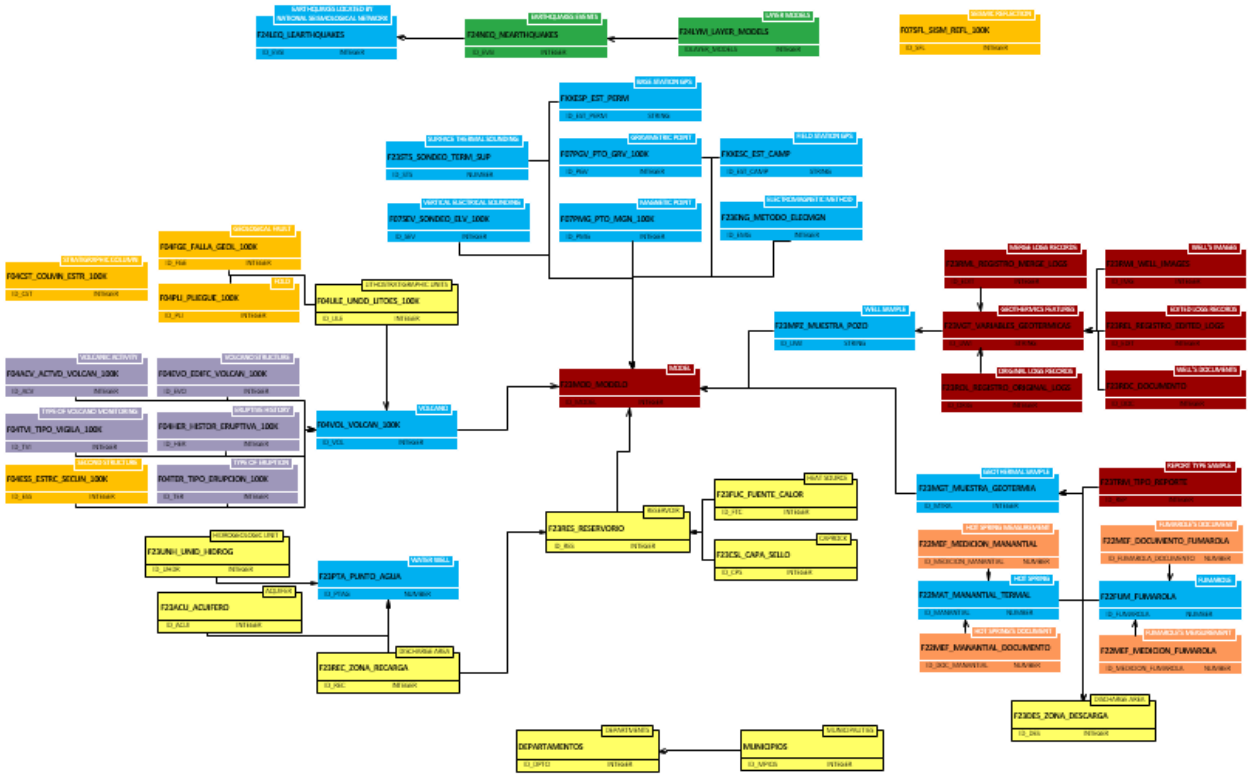
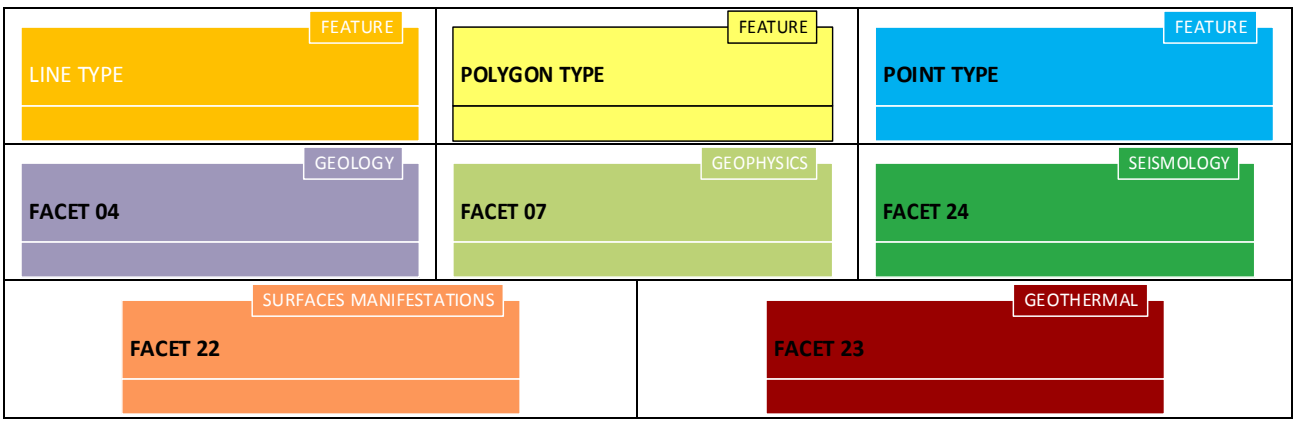


Figure1: Logical Model of GISTº

Entities are exemplified by colors depending on the type of geometry and facet (the facet is a guideline from Geoscientific Information System, institutional GIS of SGC). For the Line, Polygon and Point geometry, the colors are Ochre, Yellow and Blue respectively. For the facets the colors are: Geothermal: Dark Red, Geology: Purple, Geophysics: Light Green, Hydrothermal Manifestations: Light Orange and Seismology: Dark Green (Matiz León, 2013).

Table 4: Color for the geometry and the facets that intervene in the GISTº



Then the classification of entities is shown according to the information requirements:

4.1.1 Geology

The entities integrated to GISTº for the Geology thematic are: Geological Fault, Fold, and Stratigraphic Column with line geometry and Lithostratigraphic Units is represented with polygon geometry.

Volcanoes is an entity included facet of geology and is described separately because of its relevance within the institutional GIS of the SGC, because of its importance for geothermal research and because of the amount of existing data. As shown in Table 6, the entities integrated to GISTº for the Volcanoes are: Volcano represented by point geometry. Second Structure represented by line

geometry. Type of Eruption, Volcano Structure, Eruptive History, Type of Volcano Monitoring and Volcano Activity represented like descriptive tables without geometry related to the entities with spatial geometry.

Table 5: Entities for Geology thematic

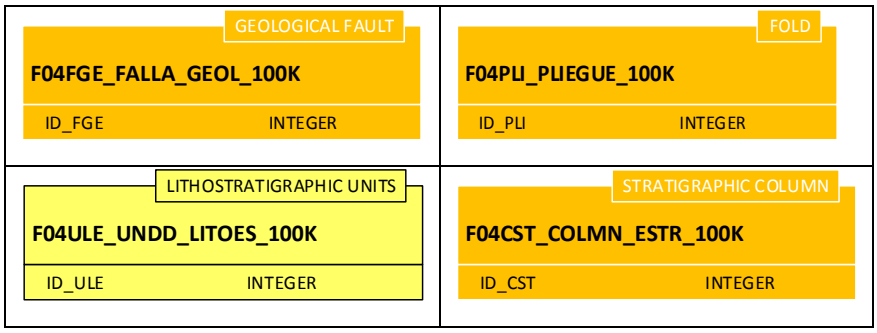
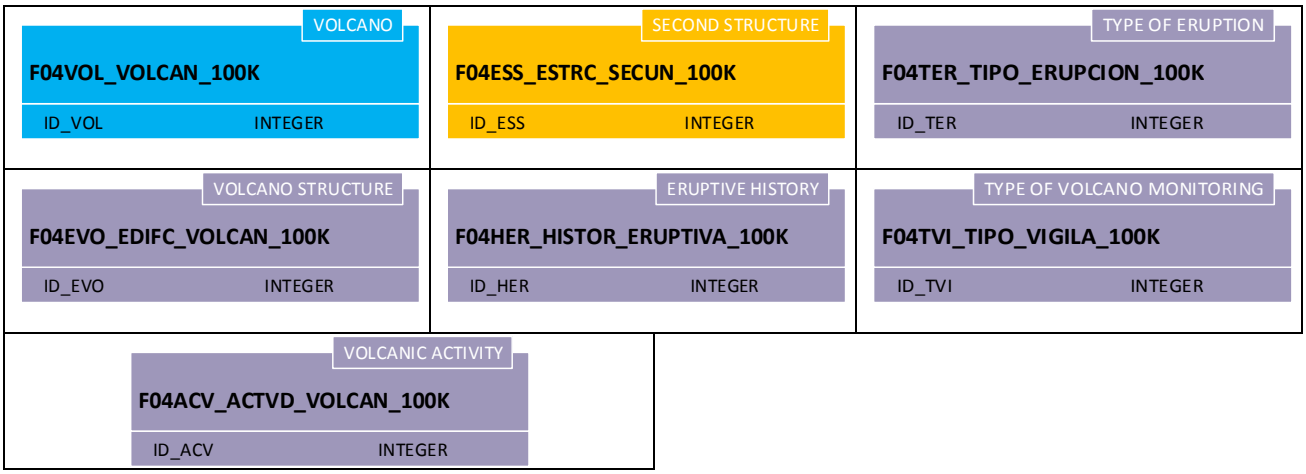


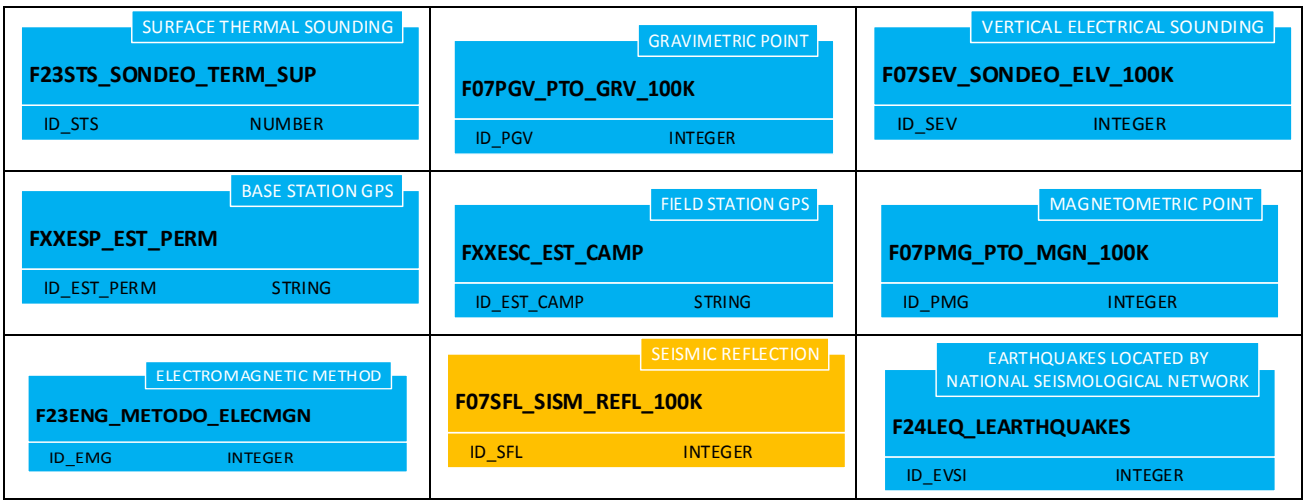
Table 6: Entities for sub-thematic Volcanoes within Geology

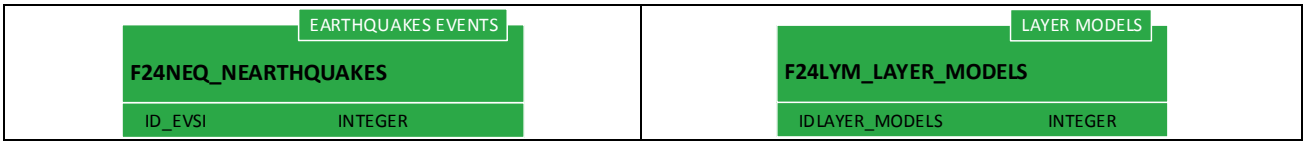


4.1.2 Geophysics

The entities collected from institutional GIS were Gravimetric Point, Vertical Electrical Sounding and Magnetometric Point, all with point geometry. Field Stations and Base Stations, entities were conducted with the intervention of the specialists in Geodesy. The Surface Thermal Sounding and Electromagnetic Method entities, with point geometry although geophysical methods related to the collection of information depend directly of the Working Group of Geothermal Resources Exploration of the SGC. Seismology was taken within a Geophysics thematic of and was based on information provided by the National Seismological Network of Colombia - RSNC (for its acronym in Spanish), supported in concept by specialists in this working group. The entities Earthquake Localized by RSNC, point geometry, Layers Models and Seismic Events, descriptive tables without geometry are taken from the database that have instituted the RSNC. The Seismic Reflection entity is a layer of existing information on institutional GIS of the SGC. See Table 7.

Table 7: Entities for Geophysics thematic

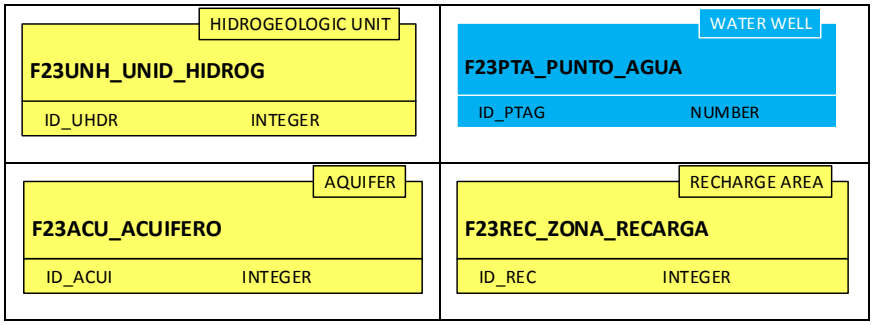




4.1.3 Hydrogeology

The entities are generated for this thematic are Water Point, with point geometry and, Hydrogeological Units, Aquifer and Recharge Zone with polygon geometry were taken as characteristic of GIST°.

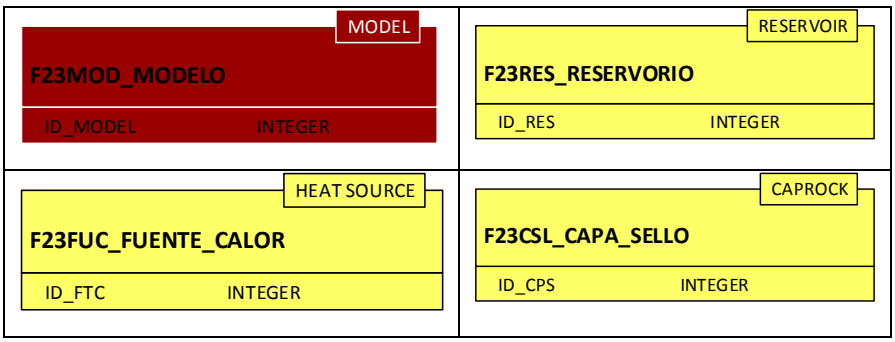
Table 8: Entities for Hydrogeology thematic



4.1.4 Geothermal Model

For Geothermal Model (Table 9), the entities that make a geothermal system such as Reservoir, Heat Source and Cap rock with attributes describing their identifiers, coordinates, area, temperature, depth, thickness, reservoir types were identified, heat source, volume, and others, with polygon geometry type. The Model entity, descriptive table without geometry, is contained within this theme and grouping the various models used in the representation of the physical characteristics that geothermal, geological, geophysical and geochemical data.

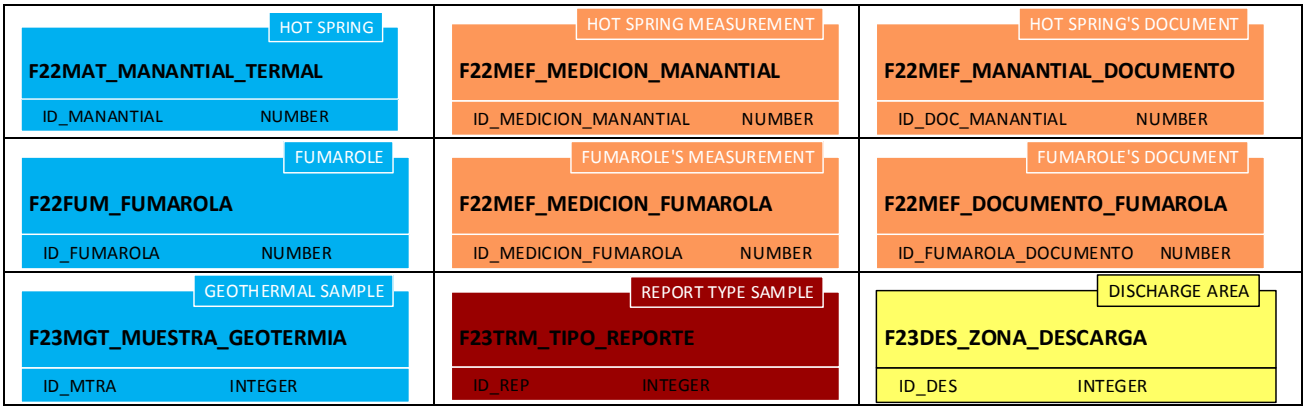
Table 9: Entities for Geothermal Model



4.1.4.1 Fluid Geochemistry of Hydrothermal Manifestations

The fluid geochemistry is described for the entities: Hot Springs, Fumaroles (illustrated in Table 10), steaming ground, mud pools, geyser and Geothermal Sample which have geometry of point. Hot Spring's Measurement, Hot Spring's Document, and Fumarole's Measurement, Fumarole's Document are descriptive tables without geometry. The Discharge Area entity, with polygon geometry, is included in this theme because this zone is defined by the occurrence of the hydrothermal manifestations.

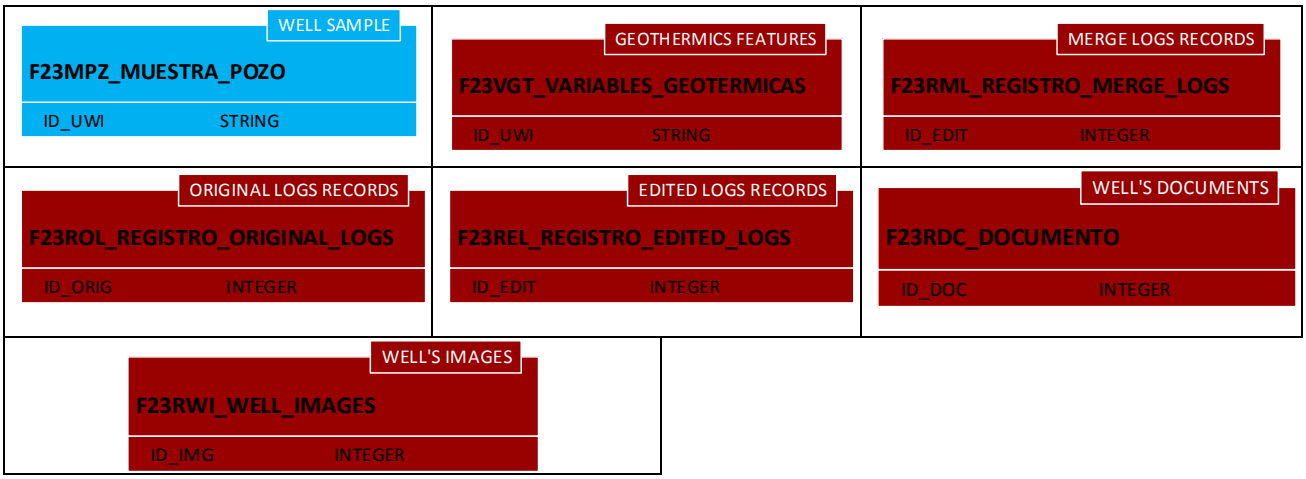
Table 10: Entities for Fluid Geochemistry of Hydrothermal Manifestations



4.1.5 Wells

The entities generated are Wells (Table 11) with point geometry, Original Logs Records, EditedLogs Records, MergeLogs Records, and Images. Documents of the Well as descriptive tables without geometry.

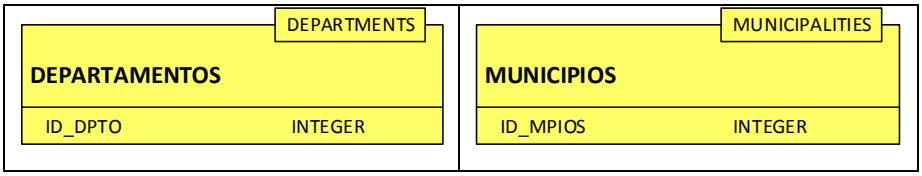
Table 11: Entities for Well thematic



4.1.6 Basic Cartography

GIST° uses basic cartography as support for the representation of thematic layers as Municipalities, Departments (illustrated in Table 12), drainage, population centers, roads, digital elevation models and others, were included in the GIST°. They are produced officially in Colombia by the IGAC (Instituto Geográfico Agustín Codazzi).

Table 12: Entities for Base Cartography (political and administrative division)



5. CONCLUSIONS

A logical model based on the data analysis was built as the foundation of the GIST°, the geothermal information system of the Colombian Geological Survey. This system is being designed to be fed with information generated by the SGC as well as external companies working currently in geothermal exploration. This is why this system will be an important decision-making tool that would support the evaluation of resources and possibilities of utilization of the geothermal resources. The GIST° is conceived as a result of the growing interest in geothermal research and exploration in Colombia.

The GIST°, includes an information repository which is already in operation, through which the diffusion and use of the geo-referenced and other information type generated and compiled by the Geothermal Exploration Group, has been optimized.

The UML methodology was successfully applied to the conceptualization of the geothermal information system of the Colombian Geological Survey, which will be implemented and integrated to the institutional information systems, in the next future.

6. ACKNOWLEDGEMENTS

The most sincere thanks to the members of the Working Group of Geothermal Resources Exploration and of the SGC and officials directly involved with surveying requirements with consolidated inputs relevant information for GIST°. To Lucila Gómez, specialized civil servant of the group Geoscientific Information System of the SGC for her technical contributions to the conceptualization of GIS for the GIST°'s Logic Model.

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