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Database of Mexican Medium- to Low-Temperature Geothermal Resources

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ABSTRACT

Mexico is blessed with abundant geothermal resources. The high-temperature resources have been extensively explored and a significant number have been under commercial exploitation for more than 30 years. However, a few years ago there was still little knowledge about the potential of the country's medium- to low-temperature geothermal resources, despite ample evidence that they are widespread in Mexico. Motivated by this, we started a project to estimate Mexico's medium- to low-temperature (<200°C) geothermal reserves. In the context of this project we collected and interpreted relevant data and developed an appropriate relational database, in preparation to estimating the reserves. In this work we describe our data collection and processing results, and the database we developed.

This tool proved very useful for our reserve assessment project. So far, it has allowed us to achieve a partial assessment of the medium- to low-temperature Mexican geothermal reserves, as well as preliminary assessments of the geothermal reserves of several individual Mexican States. It was also used as a main component of a Geographical Information System developed by our group for the Mexican geothermal resources.

1. INTRODUCTION

Due to its particular geologic conditions, Mexico is blessed with abundant geothermal resources (Iglesias and Torres, 2003; Iglesias et al., 2002; Torres-Rodríguez, 2000; Torres-Rodríguez et al., 1993; Herrera and Rocha, 1988). High-temperature resources, appropriate for power generation, have been well-characterized. A significant fraction of them have been assessed and are currently under exploitation (e.g., Quijano-León and Gutiérrez Negrín, 2000). Five geothermal fields have been extensively drilled, and four (Cerro Prieto, Los Azufres, Los Humeros and Tres Vírgenes) are currently producing power commercially. Exploitation of three of these fields began many years ago: Cerro Prieto started generating electricity in 1973, Los Azufres in 1982, and Los Humeros in 1990. Tres Vírgenes went on-line recently, in 2001.

In contrast, a few years ago there was still little knowledge about the potential of the country's medium- to low-temperature (<200°C) geothermal resources, despite ample evidence of the existence of widespread thermal activity (e.g. Torres-Rodríguez et al., 1993), and these resources were generally underutilized (Iglesias et al., 2002). The existing applications were mostly in balneology and spas (Quijano-León and Gutiérrez-Negrín, 2000).

One important cause for this unfortunate situation was lack of knowledge about the characteristics and potential uses of these indigenous resources. To promote knowledge and exploitation of these valuable indigenous resources, for the past few years our group has been involved in a project to assess the Mexican medium- to low-temperature resources and their possible applications (Iglesias et al., 2002). As part of this project we searched existing literature to obtain an updated Mexican inventory of hot springs, water wells and other geothermal localities with surface temperatures ≥ 28°C. This survey included a comprehensive set of published and unpublished documents, with data collected by *Comision Federal de Electricidad* and *Instituto de Investigaciones Electricas*, but, for jurisdictional reasons, did not include the already-identified high-temperature resources. As a result we obtained information on 2,332 individual geothermal localities, lying in 27 of the 32 Mexican States. We sought information on the location, type of source, heat source, geologic age of production zone, water chemistry and stable isotopic composition, temperature, etc. of these geothermal localities.

We developed an appropriate relational database to deal with this massive body of data and facilitate its use for reserve assessment. In this paper, we describe our data collection and processing results, and the database that we developed.

2. THE DATA

As mentioned above, we reviewed data generated and collected by the Mexican *Comision Federal de Electricidad* (CFE) and the *Instituto de Investigaciones Electricas* (IIE). During the last three decades CFE conducted an extensive exploration program in order to catalog the thermal sources in Mexico. The purpose of this exploration was to provide information to assess their potential for power generation.

On the basis of these studies, CFE prepared the *Thermal Manifestations Chart of the Mexican Republic* (Herrera and Rocha, 1988), which includes 1,380 thermal localities with temperatures ≥ 30°C. A compilation of CFE's unpublished geochemical data together with published geochemical data was carried out by Unocal (CFE, 1991). Torres-Rodríguez et al. (1993) at IIE compiled an updated geothermal database including 1,380 thermal sites, in which the first *Geothermal Chart of Mexico* was published. A new condensed version of this chart at 1:2,000,000 scale was released by Torres-Rodríguez in 2000.

For this work we carried out a new document review to collect an updated inventory of Mexican hot springs, water wells and other geothermal localities with surface temperatures ≥ 28°C. This review included the studies cited above, numerous unpublished technical reports issued by CFE, and a few journal articles by authors from IIE (Barragán et al, 2001; Portugal, 2000). It did not include the known high-temperature (T>200°C) geothermal resources, appropriate for power generation, for jurisdictional reasons.

As a result we obtained information on 2,332 geothermal localities, in 27 of the 32 Mexican States. We sought information on the location (geographical coordinates, state, county), type (spring, well, geyser, steaming ground, etc.), heat source (intrusive, caldera, recent volcanism, etc.), geologic age of production zone (Quaternary, late Tertiary, etc.) water chemistry (anions, cations, stable isotopes, etc.), temperature (sample and reservoir temperature), etc. of these geothermal localities.

Predictably, the original documents did not always provide the complete set of data we sought for each geothermal manifestation. In Table 1 we highlight this through some basic statistics of the data collection. (Note that some of these datasets overlap, so that the sum of their percentages does not equal 100%.)

Table 1. Basic statistics of the data

Individual geothermal localities	**Number**	**%**
With any kind of data	2,332	100.0
With coordinates	2,023	86.8
With chemical data	1,680	72.0
With coordinates and chemical data	1,493	64.0
With coordinates, without chemical data	530	22.7
With chemical data, without coordinates	187	8.0
With data other than chemical or coordinates	122	5.2

2.1 Geographical coordinates and projection systems

In our main project, briefly described in the Introduction, among other things we are interested in mapping the geographical distribution of Mexico's geothermal resources on a wide range of scales. For example, we want to produce geothermal maps of the whole country, of each state having geothermal resources, of groups of geothermal localities, and even of extended individual geothermal systems. For this reason we had to carefully consider geographical coordinates and projected coordinate systems in our database.

Projected coordinate systems are coordinate systems that represent spherical or spheroidal geographical coordinates on flat surfaces (e.g., maps, computer screens). Due to this transformation, each projection system (there are many) causes a particular type of distortion. To minimize distortion, one chooses appropriate projections for particular applications. For the mapping applications in Mexico mentioned in the preceding paragraph, the most convenient projection coordinate systems are the Universal Transversal Mercator projection (UTM) and the Lambert Conical Conformal (LCC) projection.

The UTM projection divides the globe into sixty north and south zones, each spanning six degrees of longitude. The division between north and south zones is the equator. Each zone has its own central meridian. Zones 1-N and 1-S start at –180°W. Mexico spans UTM zones 11 through 16. Within each zone the scale error does not exceeds 0.1 percent. Error and distortion increase for regions that span more than one UTM zone. For this reason we use the UTM projection for relatively small areas, e.g. covering perhaps one to several geothermal systems and small states.

The LCC projection is one of the best for middle latitudes that have an East-West orientation. It is referred to two standard parallels, which for Mexico are 17°30' N and 29°30'N for larger regions, e.g., large states and the entire country.

As mentioned, 2,023 of the compiled geothermal manifestations included geographical coordinates. Originally these were expressed mostly in latitude and longitude, but a significant fraction was in UTM. In order to achieve our mapping goals, we converted all the available coordinates to latitude and longitude, UTM and LCC coordinates. These conversions were processed by means of commercial software. The results were integrated in the database.

3. THE DATABASE

In the context of our main project, briefly described in the Introduction, and consistently with its main goals, we conceived this database mainly as a practical tool to:

- facilitate visualization and analysis of the complex datasets necessary to interpret our geothermal data and their relationships with Mexican geographic, geological, political and economic information;
- assist the planning for sampling campaigns of geothermal localities;
- help infer the existence, size and location of individual medium- to low-temperature geothermal systems;
- assist the assessment of geothermal reserves;
- facilitate the development of a Geographical Information System (GIS) for the Mexican geothermal resources.

3.1 Main system specifications

The main system specifications considered for our database were:

(1) the software package implementing the database must be a Relational Database Management System (RDBMS);

(2) the software package must run on Windows, the dominant computing platform in our institution;

(3) the package should be able to set a dynamical link between the RDBMS and the planned GIS software.

3.2 The database management system

To implement our database we chose the MS Access RDBMS. This is a well-developed relational platform that runs on Windows, and our group has considerable experience with it. In addition, it can be easily programmed in MS Visual Basic, with which our group has also considerable experience.

3.3 Architecture of the database

Our system is based on a relational database model. A relational database is a collection of *tables* (or *relations*). Each table consists of a set of *records* (or *tuples*) of *fields* or *columns* (or *attributes*), each of which has a defined *type* (or *domain*). Relational databases also have a set of operators that allow convenient manipulation of the data. The Structured Query Language (SQL), a programming language, is a concrete interpretation of the relational model, and implements the necessary tools for data manipulation. SQL is supported by most relational database management systems, including Access, and there is an international ISO SQL standard.

As mentioned, we chose the MS Access RDBMS to implement our system. Currently the database includes eight conveniently related tables (Figure 1). Five of them (*Localities*, *Coordinates*, *Chemistry*, *Geothermometers* and *Additional_Information*) store data corresponding to the individual geothermal localities. The rest (*Geothermal_Systems*, *Reserves_Data* and *Reserve_Estimates*), store data corresponding to entire geothermal systems.

Localities includes the following fields: ***Locality_Number***, *Locality_Name*, *System_Number*, *State*, *Municipality*, *Heat_Flow*, *Code*, *Current_Use* and *Observations.*

The fields of table *Coordinates* are ***Locality_Number***, *Longitude*, *Latitude*, *LCC_X*, *LCC_Y*, *UTM_Zone*, *UTM_X* and *UTM_Y*.

Table *Chemistry* contains fields ***Locality_Number***, *Sample_Number*, *Date*, *Sample_Temperature*, *pH_Field*, *pH_Lab*, *SiO2*, *Na*, *K*, *Ca*, *Mg*, *Li*, *Al*, *Fe_+2*, *Fe_+3*, *Cl*, *F*, *HCO3*, *CO3*, *SO4*, *B*, *As*, *δ18O*, *δD* and *Comments.*

Geothermometers includes ***Locality_Number***, *Sample_Number*, *KMg*, *NaK_Truesdell*, *NaK_Fournier*, *NaKCa*, *NaKCa_(Mg)*, *CCG*, *CCG_Index* *SiO2*, *SiO2_Giggenbach.*

Additional_Information includes the following fields: ***Locality_Number***, *Locality_Type*, *Reference*, *Rock_Where_It_Surfaces*, *Flowrate*, *Access*, *Comments.*

From data in these tables we infer which localities belong to a particular geothermal system, as well as likely statistical distributions for its area, thickness and temperature. We also estimate the geothermal systems' heat reserves and their uncertainties via Monte Carlo simulations. To facilitate its use by non-specialists, the system includes a user-friendly interface (e.g., Figure 2) that we developed with the programming tools provided by the software package. Users may access pre-defined tools from this screen. These are: forms for manually loading data (*Pantallas de Captura*), reports (*Informes*), queries (*Consultas*), the relationships of the database shown in Fig. 1 (*Relaciones de la Base de Datos*) and the tools provided to maintain the database (*Mantenimiento de la Base de Datos*).

The database includes also standard forms to manually load data in each of the tables, nine standard reports and a user-friendly interface that was developed with the programming tools provided by MS Access.

4. APPLICATIONS

We have successfully applied increasingly more complete versions of our database to assess the medium- to low-temperature reserves of Mexico and various Mexican States (Iglesias et al., 2002; Iglesias and Torres, 2003, Iglesias et al., these Proceedings). Currently we are working on a state-by-state reserve assessment.

We have also used our database as a principal component of a Geographical Information System, also described in these Proceedings (Martínez-Estrella et al, 2005).

5. CONCLUSIONS

Our relational database incorporates most of the existing information on the Mexican medium- to low-temperature geothermal resources. As such, it is an extremely valuable asset to increase our knowledge about these important national resources. In particular, it provides the basic information necessary to assess the Mexican medium- to low-temperature geothermal resources.

This tool proved very useful for our reserve assessment project. So far it allowed us to achieve a partial assessment of the medium- to low-temperature Mexican geothermal reserves, as well as preliminary assessments of the geothermal reserves of several individual Mexican States.

Our database is also a major component of the Geographical Information System developed by our group for the Mexican geothermal resources.

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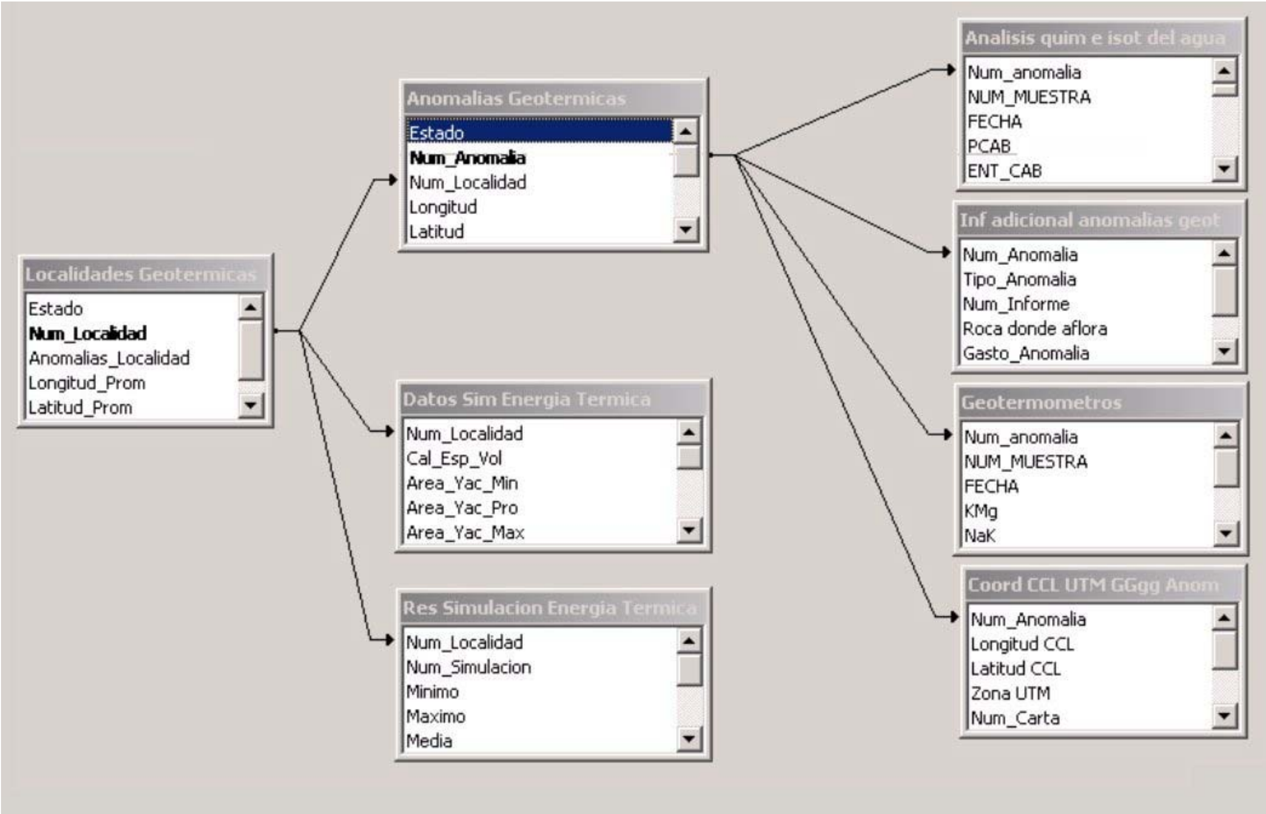

Figure 1. Tables and relationships in the database

Figure 2: Main panel of the user interface