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Towards the Digital Data Model for Geothermal Databases: Technology Trends, Fundamental Concepts, Case Study of Java Island, and Preliminary Data Model

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ABSTRACT

The conceptual model and physical implementation of a digital data model for geothermal databases are investigated. The system requirements are that the system should be capable to manage various types of geothermal datasets with their complex behaviors in respect to the 3D nature of our earth. It utilizes the state-of-the-art geoinformation technology trends and conforms to database projects among other geoscience fields. This quest comes out with a core system that integrates an open platform geographic information system (GIS) and a relational database management system (RDBMS). The integration of a GIS and RDBMS allows complex and spatially enabling databases, in which interwoven contents of a database can be interrogated visually. Yet this system is open and highly interoperable with other systems; these are keys for easiness of information sharing among geoscience fields and towards the realization of an integrated geologic analysis system (i.e., integration of data caption, management, analysis-modeling process and visualization into single workflow).

We use the ArcGIS package and its *geodatabase* data model from the Environmental Systems Research Institute, Inc. (ESRI) for the physical implementation of data model. Geothermal events are modeled as *Concept, Occurrence,* and *Description.* The ESRI Geology Data Model and North American Data Model for digital geologic maps are adapted as the starting point. The case study is conducted in the Java island, Indonesia. Different project circumstances with different data types are dealt with, including survey datasets from a geothermal prospect, a borehole dataset from a producing geothermal field, and an island-scale geothermal compilation project. The model is proven workable and many intelligent GIS tools are applicable for geothermal applications. Topology rules are used for setting constraints on data contents, relationship classes for creating networks among tables, and the linear referencing system for modeling borehole data. Database contents are successfully interrogated using a map interface, from which we conduct further analysis and produce visualization. A preliminary digital data model for geothermal is finally proposed and some future developments are suggested.

1. INTRODUCTION

A data model for digital geothermal databases is still lacking. We investigate such model that hopefully can be accepted by involving parties for managing geothermal-related datasets. The aim is to establish common standards and a generic data model among geothermal society. The purpose is to enforce standards that enable an easiness of information sharing within and across geothermal institutions, and with non-geothermal geoscience institutions.

The spirit underlying a data model is to be open and interoperable, so that geothermal databases can communicate with each other. In a larger view geothermal databases should conform to other geoscience data models for enabling information sharing across fields. And, the data model should be an integral part of geologic analytical system, in which its platform and design directly support the analytical system purposes.

In this search for a geothermal data model, first an investigation over several on-going geoscience data model projects were done. Based on visions and technology trends used among these projects, the proper conceptual model and technology platform for geothermal were selected. A physical implementation using real geothermal datasets was then done to show that the selected model is workable on real datasets. Finally we built a preliminary data model for digital geothermal databases and suggest some further developments.

2. GEOSCIENCE DATA MODEL PROJECTS

Within the geoscience community, several data model projects are currently being implemented such as North American Data Model for digital geologic map (NADM), the Public Petroleum Data Model (PPDM), and the Environmental Systems Research Institute, Inc. (ESRI) Geology Data Model. Each project works on different focus. The NADM (http://geology.usgs.gov/dm/) focuses on defining the grammar, vocabulary, and contents to be used to represent information in a geologic map database system (Johnson et al., 1999; North American Geologic-map Data Model Steering Committee, 2003). Meanwhile, the PPDM focuses on developing standards to integrate petroleum business databases with spatial engines such as ESRI geodatabase (Batty et al., 2002). The ESRI started the Geology Data Model project in 2002 with a focus to implement the NADM model using the ArcGIS software (Grise and Brodaric, 2003).

There are significant similarities among these projects in terms of standards and platforms of geoinformation technology used. First is the use of a relational database management system (RDBMS) to manage the database. Second is the integration of the RDBMS with a spatial engine, i.e. a geographic information system (GIS). Third is the development of standards that support open and highly interoperable systems.

3. GEOINFORMATION TECHNOLOGY TRENDS

The visions and standards applied within the on-going data model projects reflect the current technology trends in the geoinformation science. The fundamental trend is now to be open and interoperable. Many application systems are now built based on non-proprietary subsystems such as the component-object model (COM). Using this platform, a complex, integrated application system can be built from several subsystems. Each subsystem can be developed by different developers. This means that the application developers can concentrate on the development of their core business, while they also take benefits from the developments of other subsystems by their own developers. And example of this trend is the GIS technology that recently migrated into an open and non-proprietary architecture. Until few years ago, the most popular geographic data models such as the *shapefile* and *coverage* were developed by ESRI using their proprietary language systems, i.e. *avenue* and *Arc Macro Language* (AML). Now ESRI move completely to ArcGIS system that is built using the COM technology from Microsoft, and their new geographic data model (i.e. *geodatabase*) utilizes the industry-standard RDBMS. A GIS that utilizes this kind architecture is therefore more open and interoperable with other GIS and non-GIS systems.

These geoinformation technology trends are attractive to the geoscience fields. Geoscientists have been demanding such an integrated analytical system for a long time (e.g., Raper, 1989; Turner, 2000). The geologic analytical system is very complex system because it demands many specialized subsystems and geoscientists desire the full 3D analysis for modeling earth phenomena. So far it is very difficult to expect a developer to build a brand new integrated system specialized for geologic applications because its market is relatively small. Meanwhile, there are already many advanced subsystems that serve well at their own markets such as GIS, RDBMS, 3D modeling, geophysical processing, and image processing. The easiest way to realize an integrated geologic analysis system is to combine available subsystems. It is now made easier with the open technology trend.

On the database side, now the RDBMS is an integral part of some GIS. This integration firstly means that we acknowledge the spatial nature of most contents of geologic databases. The integration also supports topologically integrated features, complex networks, relationships among features and other custom object-oriented behaviors on features (Zeiler, 1999; MacDonald, 2001). Complex behaviors of geologic phenomena are possible to model. And, the contents of a complex, relational database can be navigated visually through a map interface of GIS, i.e. spatially enabling.

4. DATA MODEL CONCEPTS

We adapted the conceptual models underlying the ESRI Geology Data Model and NADM to initiate a data model for geothermal. The ESRI data model is used as the core for the physical implementation of geothermal databases, while the NADM is mainly used for building the standard geologic vocabulary.

According to the adapted data model, all geologic events are modeled using three fundamental terms, i.e. the *Concept, Occurrence,* and *Description* (Grise and Brodaric, 2003). The *Concept* represents all geologic vocabulary and is used to control vocabulary standards within the database. The *Concept* consists of both local names such as a Formation name and standard geologic names such as lithology types. The NADM project works intensively with building the geologic vocabulary standards because the geologic vocabulary is the key for the data model. So far the NADM has released a hierarchical classification of geologic map units (Geologic Map Unit Classification, ver. 6.1, http://geology.usgs.gov/dm/).

The *Occurrence* represents geologic events within a concept (e.g. a lithological map unit consists of occurrences of several lithology outcrops with similar, but not always the same, characteristics). Each occurrence is linked optionally to at most one spatial feature (point, line or polygon) and necessarily to one *Concept*. The spatial description is used by a GIS to create a map interface in order to investigate database contents.

The *Description* is an abstract class that compiles many types of attributes. The basic design approach is to have a set of *Concepts* with *Descriptions*, and *Occurrences* with *Descriptions* (Figure 1). A complex database can be built by compiling interwoven network of many classes of concepts, occurrences and descriptions. Meanwhile, custom behaviors of geologic phenomena can be modeled using many topology rules, domain, and subtypes available from an object-oriented geographic data model.

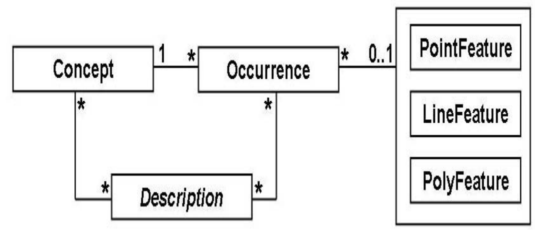

Figure 1: The basic design of Geology Data Model (Grise and Brodaric, 2003).

5 PHYSICAL IMPLEMENTATION

We use the ESRI ArcGIS 8.3 package for the physical implementation of the geothermal database. This package uses a geographic data model named the *geodatabase data model*, a new geographic data model that utilizes a RDBMS and supports an object-oriented data model. The native format of geodatabase data model is a MS Access. The geodatabase that uses the MS Access is called a *personal geodatabase*. Another type is an *enterprise geodatabase* that facilitates other industry-standard RDBMS such as Oracle, Informix, DB2, and SQLServer. The main difference between two is that the size of a personal geodatabase is smaller than the enterprise geodatabase.

The geodatabase data model enables smart features within a database by endowing natural behavior and allowing sorts of relationship among features. Features behaviors are defined using topology, domains, validation rules, subtypes, and relationships to set how an object behaves and interacts with other objects.

The geodatabase contents can be *spatial* and *non-spatial* objects. The spatial objects contain spatial information and are implemented as *feature classes*. A feature class is a collection of features that have the same geometry type (point, line or polygon), attribute fields, spatial reference, and behavior. A feature class can stand-alone or be a part of a *feature dataset*, i.e. a collection of feature classes that have the same spatial reference and a topological relationship. The non-spatial data are implemented as *object classes* or stand-alone tables. Tables contain descriptive information about geographic features and are linked to feature classes using *relationship classes* (Figure 2).

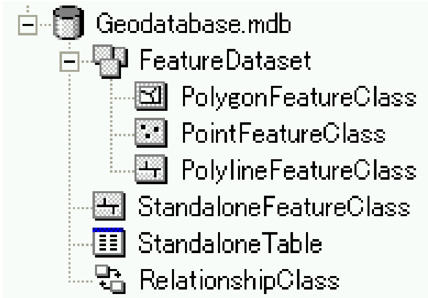

Figure 2: The basic components and structure of the geodatabase data model.

There are two different ways of building a geodatabase. First is by the ArcCatalog interface from the ArcGIS, whose function is similar to the Explorer in the MS Windows. Second is using the *computer aided software engineering* (CASE) tools such as MS Visio to build the geodatabase schema using various *unified modeling language* (UML) diagrams. The UML diagrams are in turn exported into the ArcCatalog to generate the physical geodatabase. For further discussions on the geodatabase data model, the interested readers are suggested to read the official documentations by Zeiler (1999) and MacDonald (2001).

6. RESULTS FROM A CASE STUDY OF JAVA ISLAND

The case study for the physical implementation of geodatabase data model is done on the Java island, Indonesia. The island is an island-arc setting and contains many active volcanoes associated with significant numbers of geothermal activities. In order to work with different projects and data types, our work is divided into three parts, i.e. data from a geothermal prospect, a producing geothermal field, and a regional compilation of the island scale. The results are summarized as follows.

6.1 Data from a Geothermal Prospect: Parangtritis Case Study

The Parangtritis geothermal prospect is located within a famous beach resort bearing the same name, about 30 km south of Yogyakarta city, central Java. The geothermal manifestation is found as two hotsprings near the beach. It is a peculiar phenomenon because the nearest active volcano is the Merapi volcano located about 50 km to the north. In year 2003 the Geothermal Division of the Directorate of Mineral Resources Inventory Indonesia (DMRI) conducted geologic, geochemistry, and geophysical survey to reveal its system and potential for further development (Team Geothermal Investigation Java, 2003).

Datasets collected include the geologic map, access map, stream, topography, water geochemistry (i.e. two hot springs and several surrounding cold springs), soil geochemistry (i.e. gas and solid), magnetic survey, gravity survey, and resistivity mapping, sounding, and head-on surveys. The DMRI originally managed the data using the MapInfo package for feature data and MS Excel for the geochemical and geophysical survey datasets.

Using the geodatabase data model, all data are transformed into single relational database using the MS Access format (Figure 3). Feature contents are here grouped into to feature datasets, i.e. the *Maps* and the *PTSamples*. The first compiles the map-based datasets such as geologic maps and access maps. The second compiles all spatial representations of survey datasets such as water, soil, and geophysical sampling points.

All attribute tables are managed as stand-alone tables. The attribute tables are linked to their associated feature classes using relationship classes through a third table called *OccurrenceDescription* (i.e. a stack relationship). The *OccurrenceDescription* table compiles all occurrences IDs within the geodatabase. Each occurrence has a spatial description ID attached. All feature classes are then linked to the *OccurrenceDescription* table using the occurrence ID, while all attribute tables are linked to the *OccurrenceDescription* table using the spatial description ID. Here all relationship classes are compiled inside the *RelationshipClass* feature datasets. As some feature classes have more than one associated attribute tables, the result is an interwoven network of spatial features and their attribute information tables.

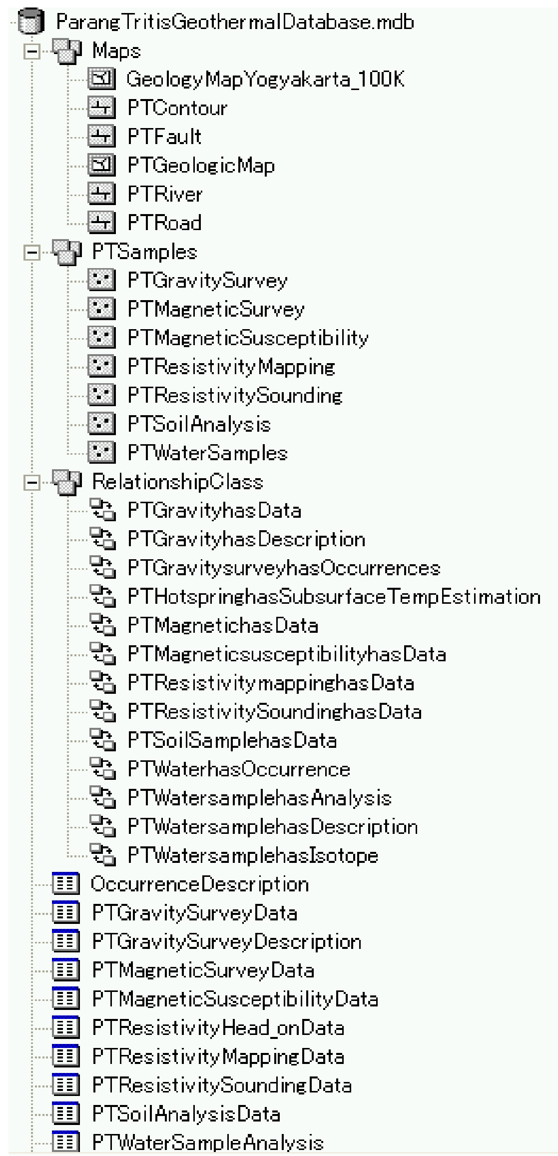

Figure 3: The relational database of the Parangtritis geothermal prospect.

All works are done using the ArcCatalog interface that encapsulates all internal programming process on the

RDBMS. The database structure shown in Figure 3 is the structure as shown using the ArcCatalog interface. If we see it using its original RDBMS package of MS Access, the database is seen as collection of tables with internal codes whose structure and relationships among database contents are difficult to recognize.

Figure 4 (see Enclosure) shows the visualization of the spatial features within the Parangtritis relational database as a map. The spatial features are especially important as the gateway to explore data contents visually. As the database is fully georeferenced, its spatial features can be visualized and combined with other features from other sources as long as their spatial reference is known. This shows the benefit of an integration of a GIS and RDBMS, in which the database acknowledge the spatial nature of most geoscience datasets and is highly visual.

The database contents can then be interrogated using a map interface. An example is shown in Figure 5, in which the relational attribute information associated with a water sample (*AAPW1*) is interrogated using a query function on the map shown in Figure 4. In this case, the water sample feature class has relationships with attribute tables of *Water sample description, Water Sample Analysis, Water Sample Isotope, Subsurface Temp Estm* and *Gravity Survey.* Among these, information attributes for the *AAPW1* sample are available from the *Water Sample Description, Water Sample Analysis, Water Sample Isotope* and *Subsurface Temp Estm*. Figure 5 shows that the *Water Sample Analysis* attribute table is selected and its detailed information is displayed on the right column of the figure.

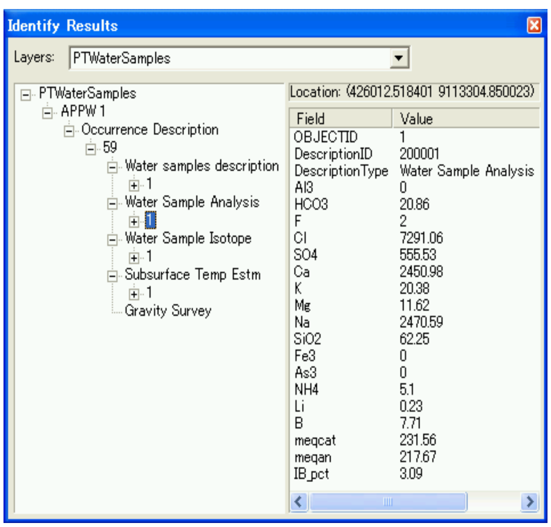

Figure 5: Relational attribute information related with a water sample point as exposed using a map query.

6.2 Borehole Data from a Productive Geothermal Field: Kamojang Case Study

The Kamojang geothermal field, located 32 km south of Bandung in West Java, is the oldest operating field in Indonesia. The field is operated by Pertamina with a current installed capacity of about 140 MWe (Sudarman et al., 2000; Utami, 2000).

The data model study of Kamojang focuses on the borehole dataset that consists of more than 60 wells. The main reasons are the facts that boreholes play a crucial role in a lifetime of the industry and many datasets are associated with boreholes. Datasets are compiled from previous published papers (Purba et al., 1996; Sudarman et al., 2000; Utami, 2000) and unpublished reports archived by the Geothermal Research Center Gadjah Mada University (e.g., Team Pokja Kamojang, 1995). The volume of data contents used in this study does not reflect the actual volume of existing data, but it does reflect the types of geoscience data associated with geothermal boreholes in the study area.

The borehole is modeled using the *linear referencing system* (ESRI, 2001, 2003). A borehole line is modeled as a line feature having x, y, z, and m (measure length) dimensions. Each line path is referred to as the *linear reference* or *route* and has an interval measure dimension (i.e. zero point at the well collar to a certain length value at the end of an interval, until a maximum measure length at the hole bottom). All events along the paths or *route events* can be determined dynamically as long as the path ID and the measure distance along the path (m) are provided.

The result of a relational borehole database of Kamojang is shown in Figure 6. Borehole events data consist of hole summary, lithology, alteration, density, magnetic susceptibility, density, porosity, fluid inclusion, temperature and well scale geochemistry. All are managed as stand-alone tables and are linked to borehole routes using relationship classes via the *KMJOccurrenceDescription* table. The relationship classes are not shown individually in that figure but compiled inside the *RelationshipClass* feature dataset. In addition, several other features such as the reservoir boundary map are included.

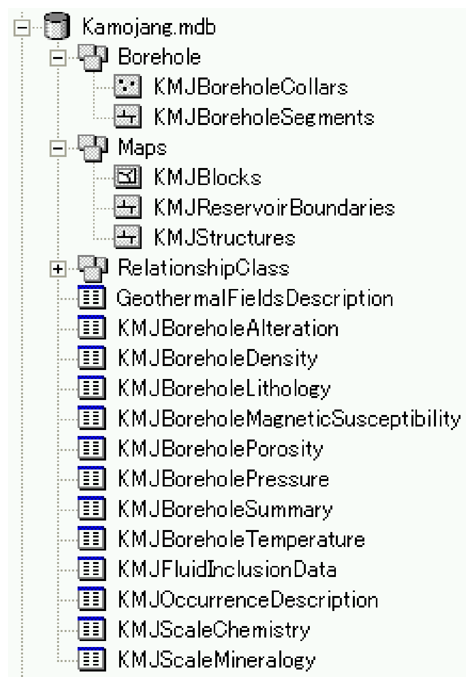

Figure 6: The relational borehole database of the Kamojang geothermal field.

On a GIS map, the borehole events can be plotted on the borehole routes using the linear referencing geoprocessing tool. The referencing is done through the hole ID and measure length(s) data. Events can either be point or line features. As the hole routes are actually 3D features (each contains x, y, z values), the hole routes and associated events can be displayed in a 3D visualization using an appropriate 3D visualization system. Figure 7 (see Enclosure) shows the 3D visualization of the borehole routes and events using the ArcScene 3D Analyst extension of the ArcGIS.

From the map, the hole events attributes can be interrogated using query tools available from the GIS. An example is given in Figure 8 that shows all associated events available for the borehole KMJ-63. Potentially each borehole has attribute information related with lithology, alteration, temperature, pressure, fluid inclusion, scale mineralogy, scale chemistry, rock density, porosity, magnetic susceptibility, borehole summary, and collar information. In the case of KMJ-63, the events attributes are only available from the lithology, alteration, and borehole summary (details are shown in the right column).

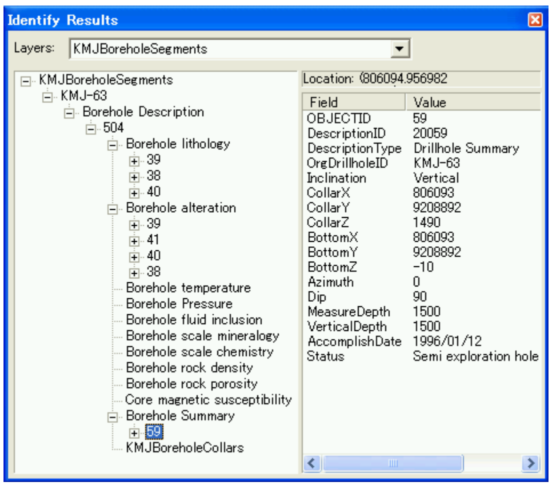

Figure 8: Attribute events associated with the borehole KMJ-63 are exposed after a query using a GIS map interface.

6.3 Geothermal Database of Java

A relational geothermal database of Java is built from individual geothermal databases (i.e. Kamojang and Parangtritis databases) and other regional geologic datasets (Figure 9). The regional datasets are compiled from many sources. The main source of regional datasets is the South Pacific GIS data from the USGS Global GIS Project (http://webgis.wr.usgs.gov/globalgis/) such as digital elevation model (DEM), geologic province map, 1 M scale geologic map, earth quake, and volcano databases. Other sources include the SE Asia Research Group, Department of Geology, Royal Holloway, University of London for the heatflow dataset that is available from their homepage (http://www.gl.rhbnc.ac.uk/seasia/Research/Heatflow). All regional datasets are compiled inside the *SEAsiaData* feature dataset.

Meanwhile, the *JavaDataset* feature dataset compiles datasets from Java island. These include the topography maps, the 250,000 scale geologic map of Java, several 100,000 scale geologic maps from selected areas, the regional gravity anomaly map, and the Quaternary volcanic rocks geochemistry as compiled from Wheller et al. (1987), Whitford (1975), and Whitford et al. (1981).

The compilation effort is done quite easily, in which each database from specific area can be combined with databases from other areas, creating a bigger database. Unfortunately the geodatabase data model structure supports only one-tier feature dataset level that keeps the database structure simple. Therefore the Kamojang and Parangtritis geodatabases now become a feature dataset each within the new Java geodatabase. In this case, all feature classes from each area are compiled into one feature dataset. Also, there is no way to group the attribute tables but to put them all directly underneath the geodatabase level.

This database structure may seem as inconvenience for people who usually work with multi-tier folders using the Windows Explorer environment. But the conceptual model of a feature dataset in geodatabase is different from a folder in the Windows Explorer. In Explorer we are free to decide how to organize data into folders and subfolders. Meanwhile the function of a feature dataset is not merely a container of a group of data, but more importantly it offers the control of the spatial reference and topological relationship among its members (Zeiler, 1999; MacDonald, 2001). A feature dataset is used by database designers to set rules and behaviors on some data contents within a geodatabase. In the case of Kamojang and Parangtritis, the original databases (Figure 3 and 6) may contain different coordinate system for each feature dataset. In the compiled geothermal database of Java (Figure 9) we have to use single coordinate system for all feature classes from Kamojang and Parangtritis. If we want to keep original coordinate system from each feature class, we have to organize them as several feature datasets or as stand-alone feature classes.

Figure 9: The relational geothermal database of Java, resulted by combining the databases of Kamojang, Parangtritis and regional geoscience database.

Also, the use of systematic occurrence IDs and geologic concept names should be taken care of. In order to create a scalable database, the occurrence IDs for all datasets must be unique and of similar type. In this case we use a long integer data type for occurrence IDs and create several series number codes for each data type. For the geologic concept names, we create three different concept tables, i.e. the *LocalConcepts* (contains very local geologic names), *JavaConcepts* (contains island-scale geologic names), and the *GeologicVocabulary* (contains standard geologic vocabulary such as the map unit classification names from the NADM). Each geologic event occurrence is linked to all three concept' tables that provide local, regional, and standard geologic terms for each occurrence.

7 CONCLUSIONS

Following current geoinformation technology trends adapted by other geoscience fields, we propose the use of an open GIS that utilizes a RDBMS as the core system for building the digital geothermal databases. We have demonstrated in previous case studies that such system is capable of managing geothermal datasets. The system is open, non-proprietary, yet is capable of modeling simple to complex behaviors; it can therefore satisfy multi user needs. The implementation of real coordinate systems on feature datasets means the ease of data integration from different sources. The spatial feature is the key to a spatially enabling database when the database becomes highly visual and its data contents can be investigated using a map interface. Databases are scaleable, in which one database can be integrated seamlessly with other databases into a bigger database. The use of linear referencing system for managing borehole dataset shows how we have taken benefits from the open system chosen. The linear referencing system, originally developed for other GIS applications such as highway and hydrography, is proven applicable for geoscience applications.

The chosen system is also the gateway to the realization of an integrated geologic analysis system that extends the traditional GIS capabilities to address unique data characteristics and interrogations desired by geoscientists. The properly configured GIS can potentially support the data management, analytical process, and visualization systems into single workflow. While a GIS is still a generic software package, its open architecture supports such integration with most common geologic applications. Some geologic analysis developers have been responding to this trend by creating extensions to a GIS.

After working with several geothermal projects in Java, we come out with a preliminary data model for digital geothermal database (Figure 10, see Enclosure). The data model is presented as an UML diagram. This is an extension version from the core ESRI Geology Data Model 812 from Grise and Brodaric (2003). Many geothermal business datasets have been included. All attribute tables are descriptions to feature classes and they inherit the *Description* abstract class. Many attribute fields are still empty as we need to work with more data to be able to include standard fields for some data types. To understand the proper meaning of the diagram, non-familiar readers should refer to the UML modeling text books.

A significant conceptual difference between this model and the Grise and Brodaric (2003) model is that here we suggest a differentiation between local concepts (here named the *Concept* table) and universal concepts (here the *GeologicVocabulary*). The local concepts are applicable for a specific region database, while universal concepts are potentially valid for worldwide scale databases.

8 FUTURE WORKS

The further development of this data model initiative is very much depending on how the geothermal community responds on the proposed model. It is expected that many parties will be interested to start similar projects in their own environment and further discussions will be developed for the maturity of the data model. Some topics are not yet dealt with such as modeling more complex geologic relationships, raster datasets, and production datasets from geothermal fields. These will be the focus of further development. The NADM project is expected to continue their effort of building standard geologic vocabulary for other concept names. As we progress, we hope to be able to set up a formal digital data model for geothermal business datasets.

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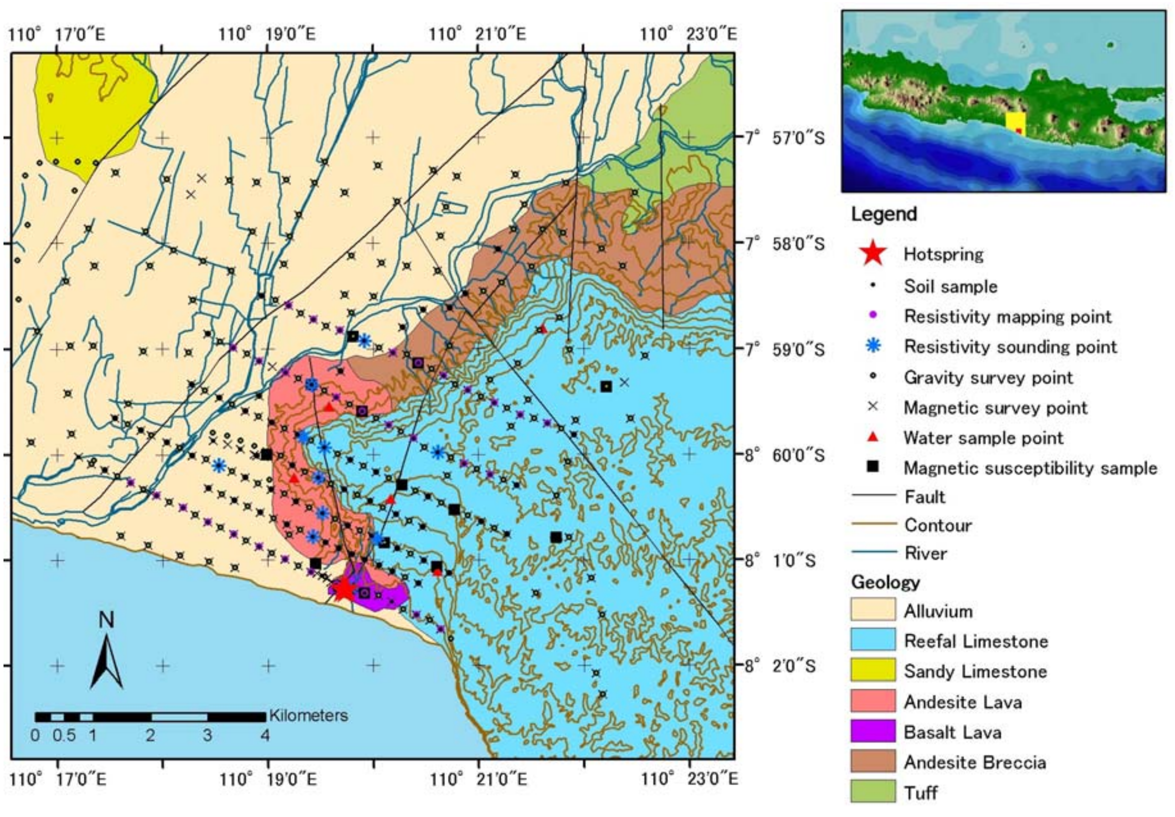

Figure 4: The visualization of the spatial features within the Parangtritis geothermal relational database. The spatial features are the keys for exploring the relational attribute tables associated with each data type.

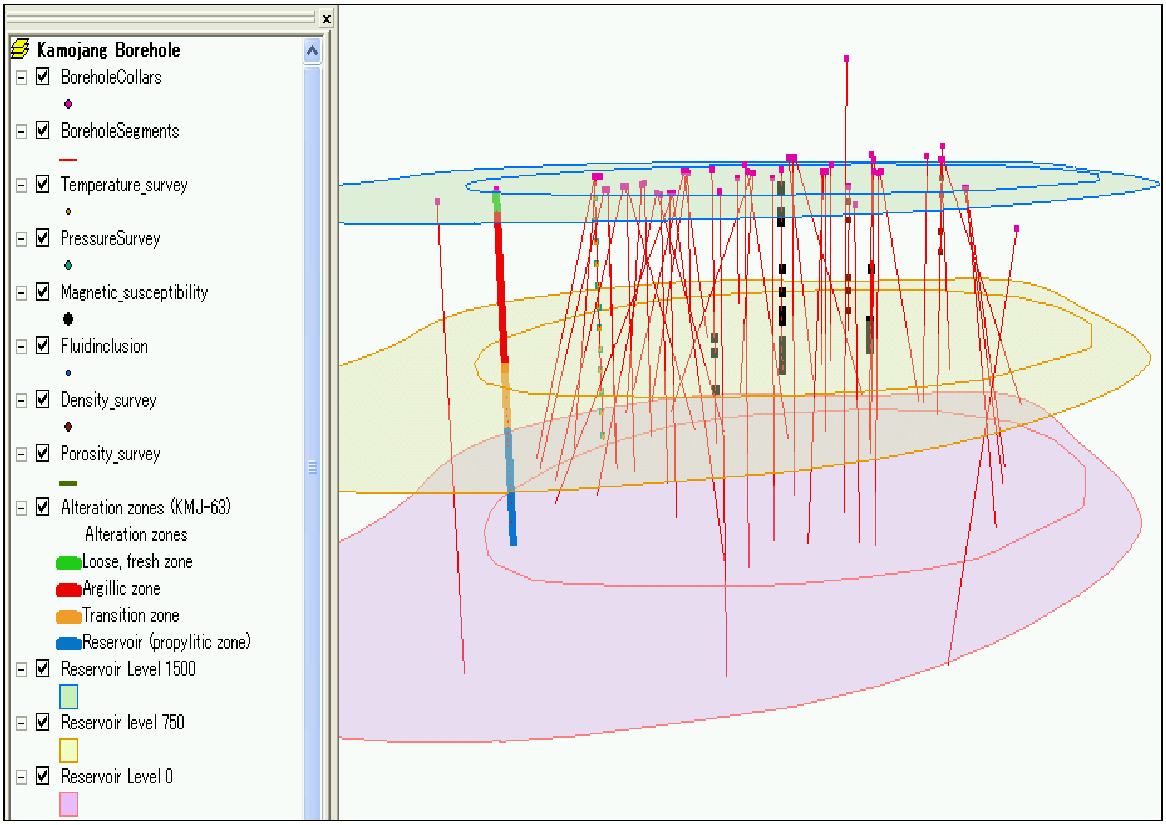

Figure 7: A 3D visualization of borehole routes and events of the Kamojang geothermal field. Hole events are plotted using the linear referencing system. Three levels of reservoir boundary (1500m, 750m and 0 m asl) are displayed to help enhancing the 3D perception.

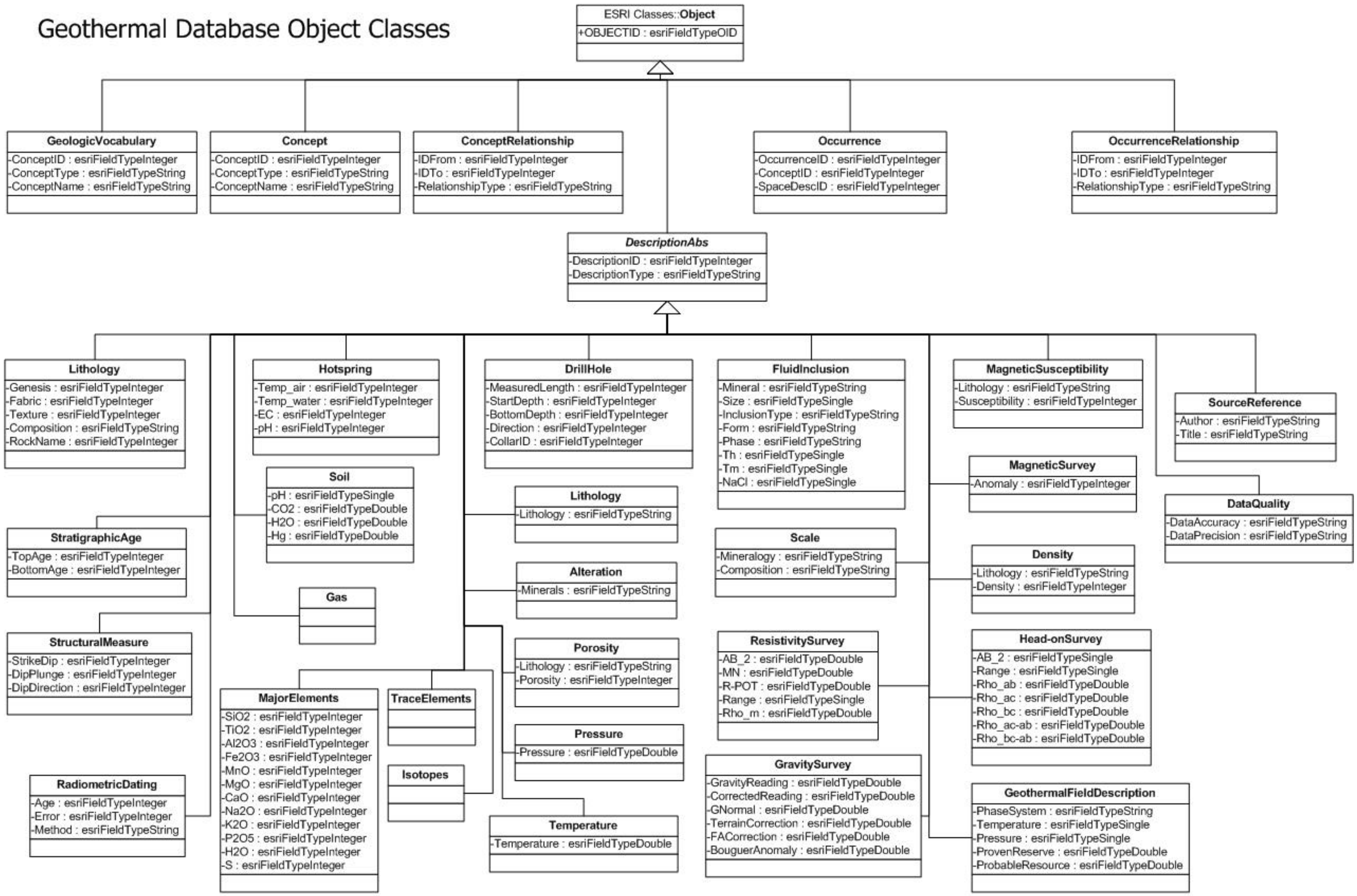

Figure 10. The unified modeling language (UML) diagram of the preliminary data model for digital geothermal databases.