Integrated Geo-information Database for Geological Disposal of High-Level Radioactive Waste in China

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Introduction

Deep geological disposal is widely considered the most suitable option to deal with high-level radioactive waste (HLW). In China, geological disposal of HLW has entered a critical stage (Wang 2010). Moreover, the development of a geo-information database is an important component in the HLW disposal research and development (R&D) process. In developed countries, research fields related to HLW disposal typically develop and apply information technologies such as data management and data mining. For example, the Nirex Digital Geological Database holds extensive information relating to the Sellafield disposal site in England (Hawkins 2007), and Japan has developed an effective information system for radioactive waste disposal (IAEA CN-1353–7 2005). The Swedish Nuclear Fuel and Waste Management Company began developing the Geo-Tab database for site selection in the 1990s (Eriksson et al. 1992). A site characterization database, i.e. SICADA, which covers multisource research data, has also been developed (Kärnbränslehantering 2000). These two databases have provided a powerful data entity basis for data development and utilization throughout the disposal process. The French National Radioactive Waste Management Agency has developed three major information management systems for the Meuse/Hante Marne underground research laboratory (URL). These systems include a geo database for scientific research data, an SAGD management system for dynamic monitoring of URL data

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and a powerful distributed document management system (Mangeot et al. 2012). This method of organizing related management systems according to different user demands should receive due consideration. Information technology-based research into HLW disposal started late in China, which mainly focused on the practical applications of geographic information systems (GIS) and data management technology in specific fields related to HLW disposal (Li et al. 1998, 2007; Gao et al. 2010; Zhong et al. 2010; Wang et al. 2013, 2014a, b, c). This study will introduce the latest research in geo-information models, integrated geo-information databases and management system development.

Construction of Geo-information Model

An effective data management system for HLW disposal requires development of a geo-information model and construction of a geo-information database. Different types of geo-information data obtained in the previous site selection processes must be considered. To explicitly express data features and connections between different types of data, a geo-information model must be able to handle datasets of various data types such as geographical, geological and geochemical datasets. Therefore, a geo-information model is required prior to developing a geo-information database and management system. When developing a geo-information model, it is extremely important to consider the logical and physical relationships of various data.

Logic Design of Geo-information Model

The main task of logical design is to describe the logical structure of the geo-information database. This task primarily focuses on designing the data structure. At the current stage of HLW disposal, three levels of data features can be obtained and described, i.e. data features associated with a pre-selected area (biosphere), a site (lithosphere) and the rock surrounding the repository. According to ten criteria listed in the *Site selection criteria for an URL for geological disposal of high level radioactive waste in China* (HAD401/06 2013), datasets can be classified into various types such as geological, geographical, hydrogeological and geochemical datasets. Therefore, based on the domains from which existing data are derived and subsequent data expansion, a logical model was established to describe a data entity (i.e. specific to each type of data object) (Fig. 1).

As shown in Fig. 1, considering the characteristics of non-spatial and spatial data, non-spatial data are stored as attribute data and spatial data are organized and stored as map layer objects related to a point, polyline or polygon, which are controlled by metadata. The storage format for spatial data is either well-known binary or well-known text (PostgreSQL 9.2.6 Documentation 2014).

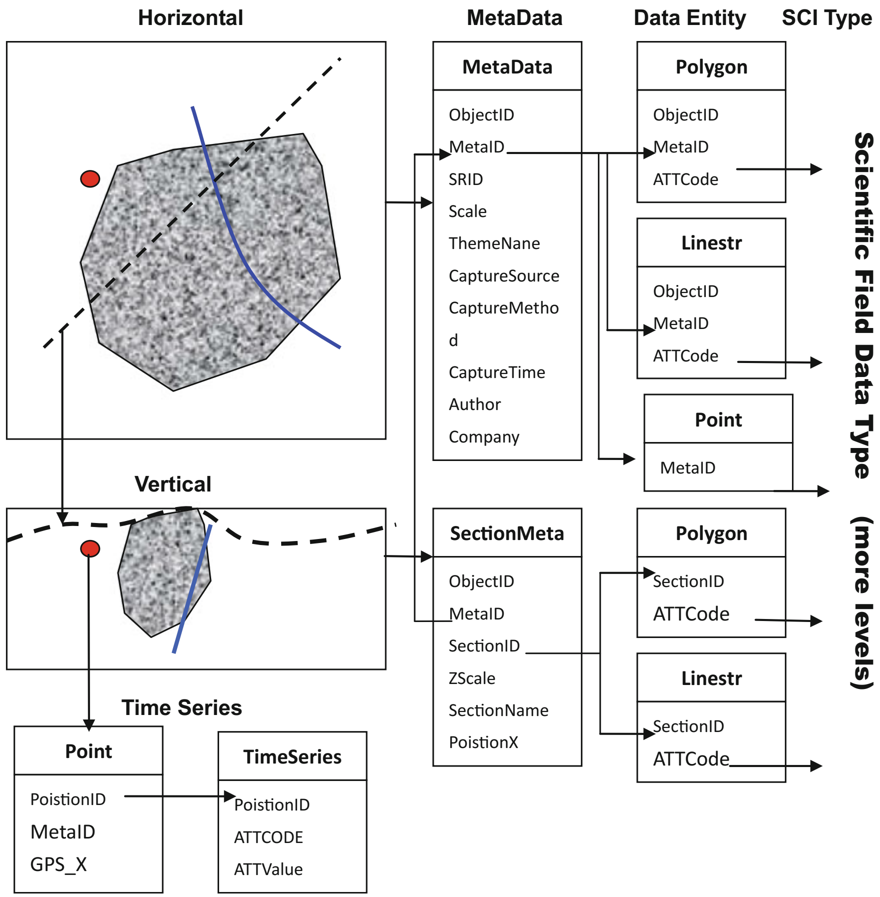

Fig. 1 Logical data model for data associated with geological disposal of HLW

Physical Design of Geo-information Model

Multisource and multidisciplinary thematic data are the main components of a geo-information database for areas pre-selected for HLW disposal. The main content of thematic data and their mutual relations are shown in Table 1. Thematic databases are the primary components of the physical design of a geo-information model. The first design step is to define mutual relations between different datasets and/or data types. Then, different storage methods for different types of data are considered. Finally, the consistency and integrity of the data storage and data expression are achieved.

Table 1 Brief description of data content and mutual relations of geo-information database for pre-selected HLW disposal area

ID	Sub-database	Classification of data entity	Data type	Relationship illustration
1	Metadata database	Metadata information: identification, data quality, spatial reference, content and distribution and the responsible department's contact information	Spatial data, attribute data	Basic descriptive information for thematic data, construction of data dictionary, index reference for all other data
2	Basic geography database	Topography, transportation, pipelines, hydrographic net, geomorphology, vegetation, administrative area and protection zone	Vector data (point, polyline and polygon), attribute data	Basic data such as administrative district, relevant to other data through geometry field
3	Geology database	Rock mass data, characteristics of rock mass, tectonic, fault, stratum, geological boundary, fracture, minerals and alteration, geological section and label	Vector data (point, polyline and polygon), attribute data	Basic geology data, such as fault, lithology, geological boundary, relevant to other data through geometry field
4	Borehole database	Basic borehole information: Engineering geology, geology logging, hydrogeological logging, geophysical logging, hydrologic monitoring, daily drilling records, documentation	Vector data (point, polyline and polygon), attribute data	A series of data obtained around boreholes, relevant to other data through borehole ID and depth fields
5	Remote sensing database	Remote sensing data, target spectral data, image data descriptions, geographical environment, atmospheric environment, measuring method, instrument and equipment, typical spectrum	Raster data (image, photo), attribute data	Relevant to other databases through geometry field

(continued)

Table 1 (continued)

ID	Sub-database	Classification of data entity	Data type	Relationship illustration
6	Hydrology database	Surface water, underground water, geology body, geologic body, hydrological experiment and analytical test	Vector data (point, polyline and polygon), attribute data (test results)	Relevant data of hydrology scientific research field, relevant with other data through geometry field
7	Geophysical database	Airborne geophysical prospecting, geophysical logging, ground physical exploration, interpreted results for physical exploration	Vector data, attribute data and raster data	Borehole geophysical survey can be connected to the Borehole database through the borehole ID, Surface geophysical survey can be connected to the geology database through section ID
8	Geochemistry database	Field test data, indoor sample analysis results, geochemical exploration maps and results	Spatial data (vector and raster data), attribute data	Relevant to sample database through sample ID and geometry field
9	Rock mechanic database	Field test data, laboratory test data, regional survey, digital simulation for test results	Spatial data (vector and raster data), attribute data	Relevant to sample database through sample ID and spatial geometry field
10	Hazardous database	Thematic data such as earthquake, volcano and climate and historical data storage	Spatial data (vector and raster data), attribute data	Thematic data, such as natural hazards, relevant to other databases through spatial geometry field
11	Ecological environment database	Environmental impact assessment data	Spatial data (vector and raster data), attribute data	Relevant to other databases through spatial geometry field
12	Documents database	Achievements reports, scientific reports, domestic and foreign literature	Attribute data, documentation	Relevant to other databases through spatial geometry field
13	Photo database	Scientific results image, thematic images and photos	Vector data, attribute data and raster data	Relevant to other databases through spatial geometry field
14	Sample database	Sample information descriptions, sample locations	Spatial data (vector and raster data), attribute data	Connected to other databases through sample ID and geometry field

Construction of an Integrated Geo-information Database

An integrated geo-information database can be constructed based on the design of the aforementioned geo-information model. First, a powerful database management system (DBMS) should be selected. Considering the unstructured and multisource characteristics of the data, the DBMS should support object-oriented functions such as geometric object abstraction and establishment. To fulfil data storage and retrieval requirements associated with huge amounts of data, the DBMS should also support partition table and partition index technology, parallel data processing technology and distributed database construction technology (Coronel et al. 2011). In this study, the geo-information model and integrated database are both based on PostgreSQL, which is a powerful open-source object-relational database (PostgreSQL 9.2.6 Documentation 2014).

The geo-information database for a pre-selected area (PAGD) has been designed to facilitate the management of a large amount of multidisciplinary research data. The PAGD is classified into sub-databases according to specific professional disciplines. Therefore, there are clear dependency relationships that can be used to establish the hierarchical structure. Constraint conditions, such as major key, unique key, foreign key and default values, are used to correlate information and facilitate data transfer between tables or between spatial and non-spatial data tables. Despite there being some differences between the spatial data and attribute data in the database, the PostgreSQL DBMS can handle the differences easily (PostgreSQL 9.2.6 Documentation 1996–2014). The spatial data can be represented as a geometry column that can be stored and managed in the same way as other data. This will facilitate the realization of the data structure and the organization of data tables.

As shown in Fig. 2, all the data or information related to boreholes can be obtained and organized through the Borehole ID. The borehole spatial position data can be taken as a single geometry column in the BH_General_Info table. Thus, it is easy to correlate and retrieve such data.

Development of Management System for Integrated Geo-information Database

Accomplishment of Metadata Management

In general, metadata describes other data; in particular, metadata can describe a resource object and helps the management, positioning, acquisition and utilization of a data object. Therefore, the integrated geo-information database includes a metadata database that is used for data management, data queries and distribution of

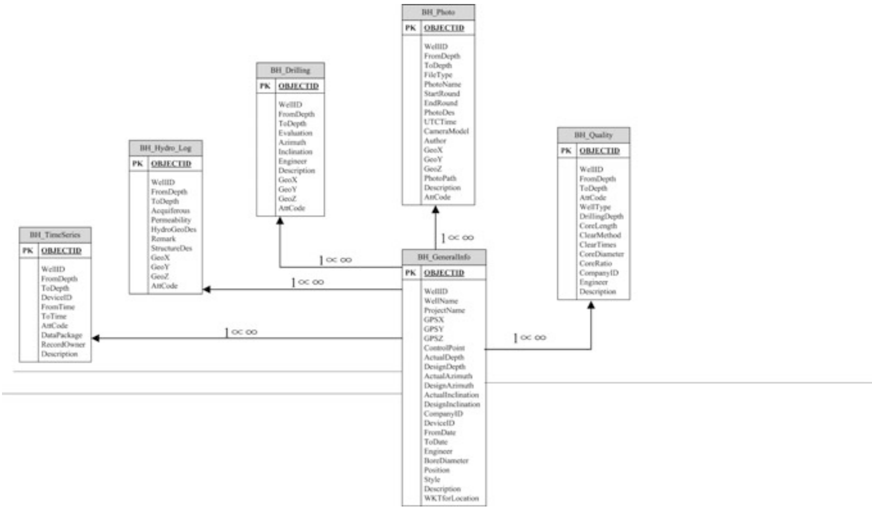

Fig. 2 Examples of data table organization in the Borehole sub-database

Fig. 3 Metadata management interface: ① Function menu area, ② Data directory list area and ③ Metadata display area

all datasets and data features. A robust metadata manager that unifies metadata management was developed to facilitate consistent descriptions and associations. As shown in Fig. 3, data management functions include data preview, additive, maintenance and query functions.

Development of Management System

Development of an appropriate data model and an inclusive, well-structured database are fundamental prerequisites for an efficient data management system. However, the ultimate objective is to retrieve and apply the data. Therefore, given the characteristics of geo-information data and the application requirements, a hybrid C/S and B/S architecture was adopted to accomplish data management. In addition, Open Geospatial Consortium standards and the TCP/IP protocol are used for database management and connectivity. Finally, based on a function module of commercial GIS software, a technological development framework was designed and achieved (Fig. 4). The accomplishment of the framework indicates that the geo-information data model can be developed and realized during the process of secondary development. Thus, a powerful management system can be developed and realized. The main interface of the data management system is shown in Fig. 5.

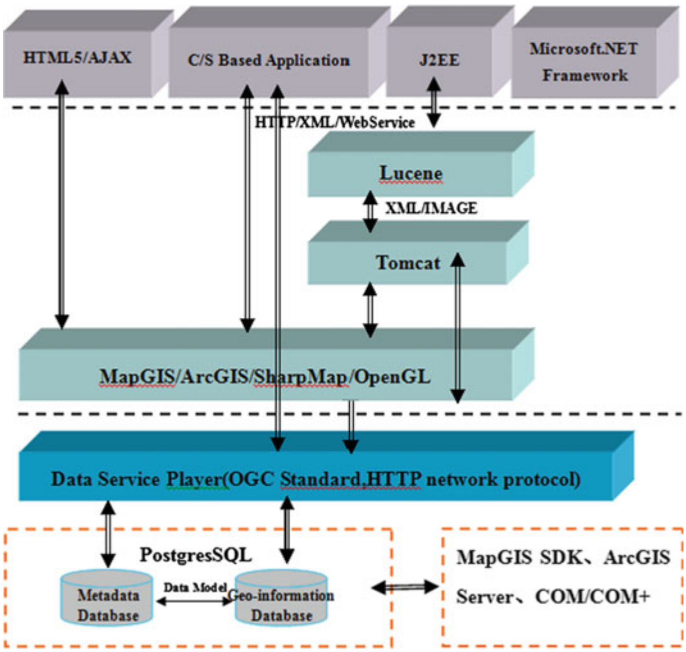

Fig. 4 Technology framework

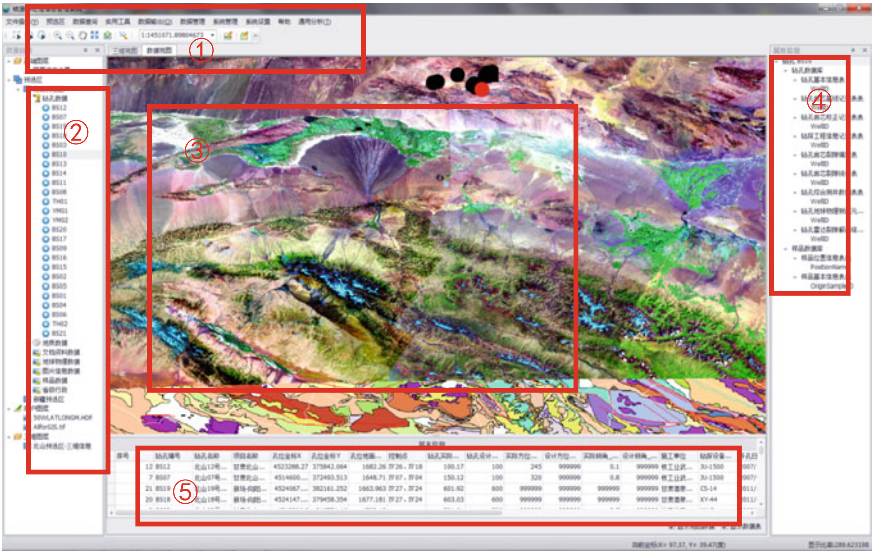

Fig. 5 Main interface of HLW-GIS management system: ① Function menu area; ② List area for data source; ③ Visual expression area; ④ Data directory and detailed description; and ⑤ Attribute data area* (*The database and management system are both designed for HLW disposal R&D teams in China. Therefore, the system content and user interface are in Chinese.)

Conclusions

Construction of a geo-information data model and development of a data management system are vital steps toward the parts for digitalization construction of an integrated geo-information database system for a pre-selected area. The model and system can also provide technical support for the development of HLW disposal. Some important conclusions are summarized as follows.

(1) Many different types of data are generated during the site selection process for HLW disposal, which are useful for determining the complexity of the geo-information model and database construction. Classification of thematic data is the key to constructing the geo-information model, which should select the most stable and essential attributes as a basis for classification. The integrity and generality of classification results should also be ensured.

(2) An integrated geo-information database was built using the geo-information model. This integrated database will be a powerful foundation for HLW disposal R&D.

(3) A technical framework that facilitates the development and realization of a data management system was developed based on the integrated geo-information database. It directly confirmed the reliability of the geo-information model and the feasibility of secondary development. In addition, the data management

system and the framework are expected to provide solid technical support for future data mining work.

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