

Terrestrial Heat Flow Database Management System and Geographical Information System, P. R. China

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ABSTRACT

Terrestrial heat flow data are significantly important to characterize the thermal regime and to reveal the geodynamic processes of the continental lithosphere. Heat flow data for the continental area of China have been collected using both published data (up to 2000) as well as unpublished data. The data set is composed of 970 observations (1080 records) from different sites. Within the continental area of China, heat flow values range from 15 to 364 mW/m^2 , with a mean of $64.2 \pm 75.6 \text{ mW/m}^2$ ($n=1013$).

The terrestrial heat flow database was constructed based on Microsoft Access 97. And it was developed with Microsoft Visual Basic 6.0 and composed of 27 forms, 2 modules and 10 reports. Furthermore, the terrestrial heat flow database system has also provided a powerful querying system containing a graphic query system and a text query system. The user can query the data what he wants rapidly and effectively, and then the user also can customize his own query condition. The GIS technology was imported in this study. The heat flow GIS of China has been developed based on the ArcInfo 8 and MapObjects made by ESRI. And we plugged the MapObjects control into the Microsoft Visual Basic 6.0 development environment and the following functions have been implemented: adding a layer or the whole layers, finding the features from the layers, zooming in or out the map and panning etc.

Finally, the geothermal data interpretation toolbox has been developed in this study, which includes temperature data interpretation on a single borehole, one-dimensional temperature field data interpretation and two-dimensional temperature field data interpretation. In addition, it's very convenient for the users to solve the various geothermal problems by using the geothermal data interpretation toolbox.

1. INTRODUCTION

Generally, the terrestrial heat flow is the vertical heat flux flowing through the earth's surface per unit area and unit time. The heat flow data are very useful in determining the thermal structures, thermal evolution and deep dynamic processes and can be used to interpret the structure of the crust and upper mantle (Cermak.V., 1982; Cermak, 1989; Cermak et al, 1989).

It is generally acknowledged that heat flow is foundation of geothermics. Systematic heat flow measurements in China were first initiated in the 1970s. The Geothermal Group, Institute of Geology, Chinese Academy of Sciences published the first group of terrestrial heat flow data in 1979 (Group Investigating Geothermic, Academic Sinica, 1979).

Since then, heat flow measurements throughout China have been accumulating rapidly. Especially, with the GGT (Global Geoscience Transect) project putting into practice in 1980s, lots of departments such as former Ministry of Geology and Mineral, P.R. China, Chinese Seismic Bureau, Chinese Academy of Sciences invested vast amount of capital in implementing the continental terrestrial heat flow and marine heat flow measurement. The survey points are widely distributed in whole Chinese mainland and adjacent sea area and there are about 900 heat flow data which have been published in China now (Andong Dang et al. 1987).

Wang and Huang first compiled heat flow data from Continental China in 1988, and subsequently updated this in 1990. The number of observations of heat flow data in the second compilation reached 366(Wang and Huang, 1990); this dataset was later incorporated into the International Heat Flow Committee (IHFC)'S Global Heat Flow Database (currently available from the US National Geophysical Data Center, NGDC). Wang and Huang updated the compilation once again to produce a grid average heat flow map in 1992 and 1994. The most recent compilation is by Hu et al. in 2000 (Shengbiao Hu et al. 2000).

In 1998-2002, we collected and compiled newly whole of the published and unpublished heat flow data from the continental area and the marine area of China, and then constructed Terrestrial heat flow database of China, totaled 970 continental heat flow data and 172 marine heat flow data. Within the continental area of China, heat flow values range from 15 (Qinhai province) to 364 mW/m^2 (Tibet province), with a mean value of $64.2 \pm 31.7 \text{ mW/m}^2$. If non-conductive values related to local hydrothermal systems are excluded, the representative average heat flow is $61.6 \pm 17.6 \text{ mW/m}^2$ ($n=1013$), with an associated range of $30\text{-}140 \text{ mW/m}^2$.

Generally speaking, the geothermal information about lithosphere was obtained in borehole; most of these data were stored with spatial data, figures, images or tabular data such as geotherm, temperature logs. Therefore we need a kind of the software tool which can manage not only the spatial data, but also the attribute data, such as the input, compilation and print out in various formats of the spatial data and the attribute data. The Geographical Information System (GIS) meets appropriately the requirements mentioned as above. Since GIS technology integrates not only the common database operations such as query and statistical analysis but also the unique visualization and geographic analysis functions offered by maps.

The Terrestrial heat flow database is built on Microsoft Access 97 and Geographical Information System (GIS). And the database program is built with Visual Basic 6.0, in which several technologies such as MO(MapObjects), DAO(Data Access Object), API(Application Programming Interface) etc. are utilized. And the following functions have been

implemented in spatial query section: adding a layer or the whole layers, finding the features from the layers, zooming in or out the map and panning the map etc. What is more, double language versions (Chinese language and English language) and general data interpretation toolbox are developed in this database.

2. THE STRUCTURE OF THE HEAT FLOW DATABASE

The terrestrial heat flow database is a branch database management system of the deep geophysical measurement database system in the Ministry of Land and Resources, P.R. China(Xu Jin, 2001). The structure of the heat flow database has been established based on the analyses of the whole parameters about the heat flow measurement, and then Relation Data Model has been selected as the logical model of the database system. And the detailed structure of the heat flow database can be shown from Fig. 2. Generally speaking, the database can be divided into two parts, one is information about terrestrial heat flow section, and another is the heat flow itself. The terrestrial heat flow database system is comprised of 27 forms, 2 modules and 10 reports.



Fig 3.1 the forms of log on

3. THE BASIC FUNCTION OF THE HEAT FLOW DATABASE

There are many data such as temperature data, heat flow data, heat generation, radioactive element data and the data of the physical qualities of the rock on the corresponding measurement location and so on stored in the database as raw data. We can browse, edit, delete or add the raw data, and at the same time we can get the subsequently data and plots by utilizing the data interpretation tools. The database has also provided a powerful querying system containing a graphic query system and a text query system. The user can query the data what he wants rapidly and effectively, and then the user also can customize his own query condition, and the GIS technology which is more convenient to the users was imported the study. Simultaneously, the database can print out various reports such as the table of heat flow, the table of temperature and the table of radioactive element etc. and graphs such as temperature-depth curves in a single borehole or isotherm vertically along one GGT (Global Geoscience Transect) to meet the requirement of the different users.

There are double rights (administrator or general user) to operate the database. When we double click the terrestrial heat flow database shortcut icon, the database system firstly opens the "Logging In" forms (Fig. 3.1), on which there is a combo box including "User" and "Administrator" from which one should be asked to choose his right. Provided that one chooses the "User", he only can use these functions as follows: browsing data, querying data and printing data, but he cannot use the following functions, such as adding, deleting and modifying data. If the user who choose the "Administrator", after he entered the correct password, he has the right of whole operation.

After the user logs on, the main interface of the terrestrial heat flow database would be shown (Fig. 3.2), which is composed of many graphic buttons and menus that the user can operate it easily and conveniently. And the double languages versions have the same functions.

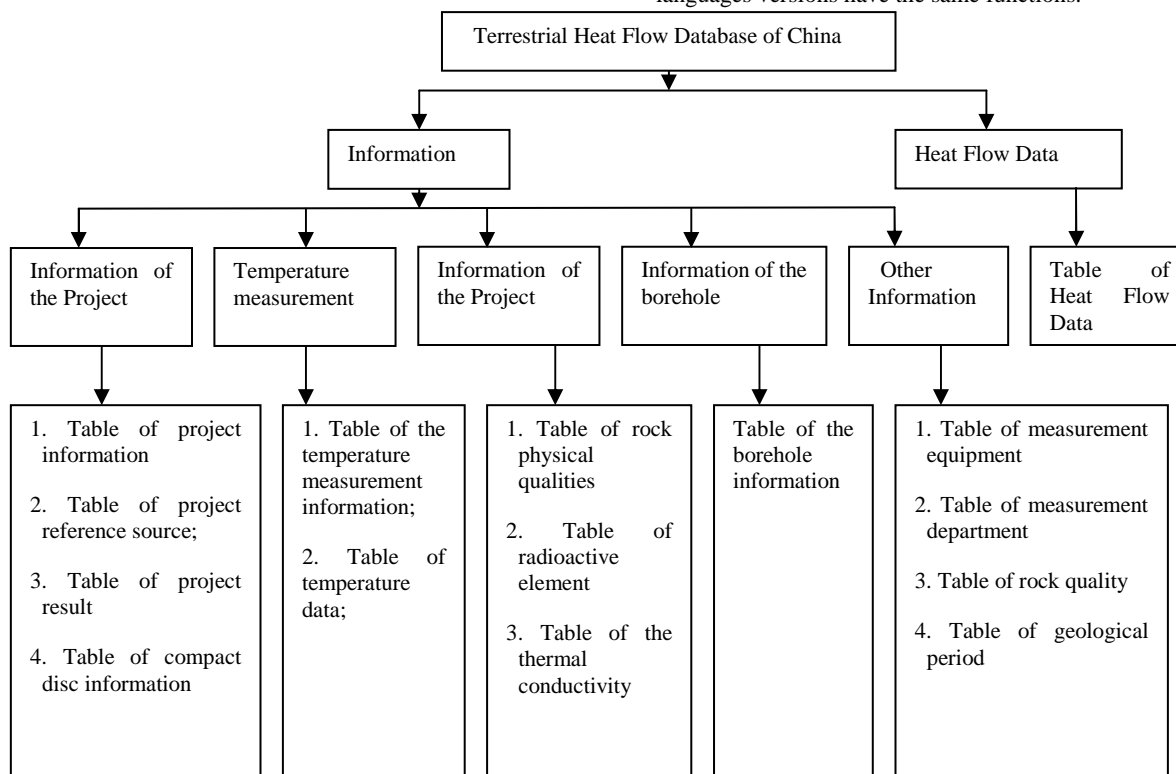


Fig 2. The structure of the terrestrial heat flow database

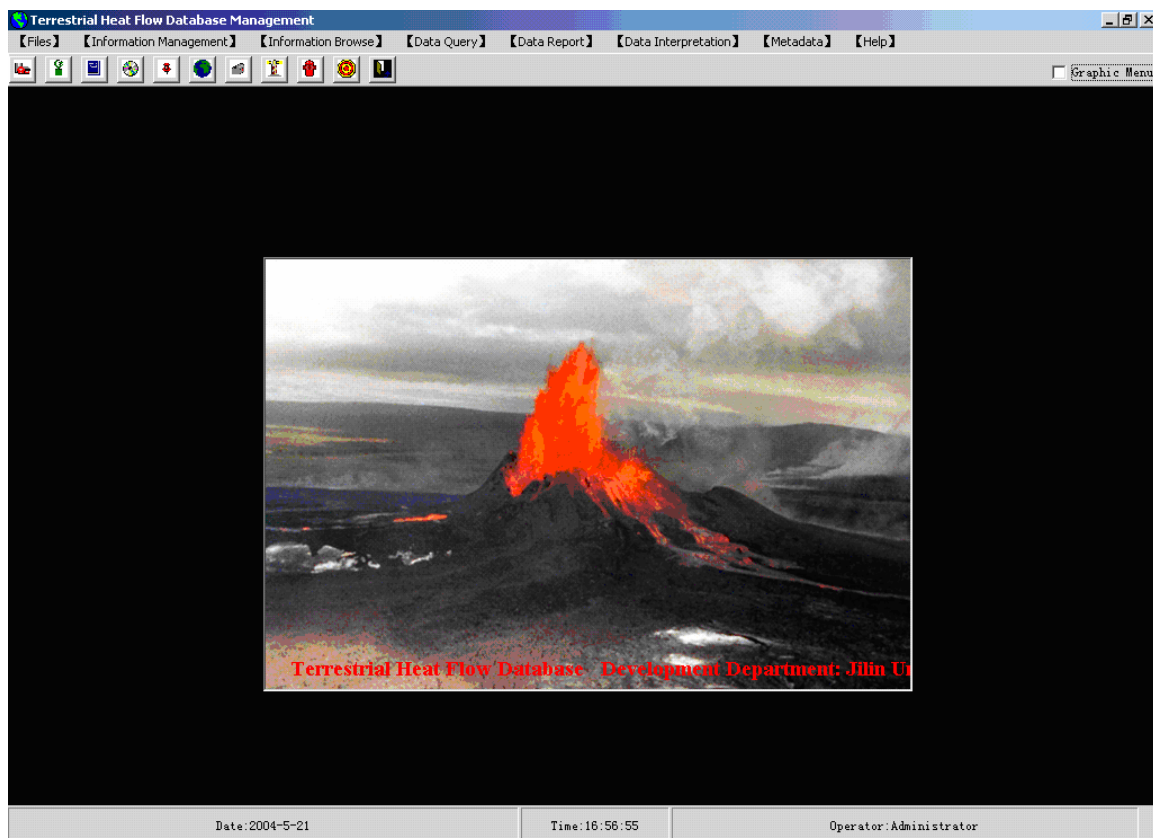


Fig 3.2. The main interface of heat flow database

Terrestrial Heat Flow Data							
BoreholeID	ProjectID	Borehole Name	Depth Range(m)	Thermal Gradients	Thermal Conductivity	Counts of Rocks	Heat
HF00001	GC7001			37.8	1.65		6
HF00002	GC7001			40.6	1.66		6
HF00003	GC7001			40.6	1.72		6
HF00004	GC7001			41.1	1.69		6
HF00005	GC7001			45.4	1.57		7
HF00006	GC7001			37.8	1.65		6
HF00007	GC7001			39.1	1.62		6
HF00008	GC7001			34.2	1.68		5
HF00009	GC7001			39.7	1.71		6
HF00010	GC7007			31.4	1.84		5
HF00011	GC7007			33.7	1.6		
HF00012	GC7001			33.2	1.73		5
HF00013	GC7001			34.2	1.63		5
HF00014	GC7001			33.9	1.65		5
HF00015	GC7001			31.3	1.85		
HF00016	GC7001			30	1.95		5
HF00017	GC7001			33.6	1.62		5
HF00018	GC7001			36.6	1.65		6
HF00019	GC7001			40.1	1.58		6
HF00020	GC7001	ZK856	20-370	14	2.91	5	4
HF00021	GC7001	ZK842	20-630	13	3.09	8	4
HF00022	GC7001	ZK709	20-235	11	3.62	5	3
HF00023	GC7001		1200-1540	44.5	1.66	7	6
HF00024	GC7001		1480-1700	56.8	1.67	5	!
HF00025	GC7001		2480-3900	32.4	2.5	5	8
HF00026	GC7001		1400-3025	36.4	2.31	4	8
HF00027	GC7001		1050-3175	33.7	2.23	6	7
HF00028	GC7001		760-880	41.3	1.36	3	5
HF00029	GC7001		500-800	33.3	1.33	3	4
HF00030	GC7001		640-740	40	1.13	3	4
HF00031	GC7001		400-800	47.8	1.62	2	8

Fig. 3.3 Browsing Terrestrial Heat Flow Data

Adding heat flow data

BoreholeID:

ProjectID:

Borehole Name:

Depth Range:

Thermal Gradients:

Thermal:

Counts of Rock:

Heat Flow:

Corrected Heat Flow:

Quality Rank:

Remarks:

Tips: Borehole ID, i. e. HF00001, HF00002, ..., Primary key, is unique value.

OK Cancel

Fig.3.4 The forms of Adding Heat Flow data

Query Condition

Query Style

☒ Province

☐ GGT

Query Condition

☒ Query by Borehole

☐ Query by Location

☐ Query by Project

☐ Query by Date

OK Cancel

Fig. 3.5 The forms of Query Condition

3.1 Information Management System

Information management system includes the following functions: data browse, data input, data modify, data save etc.

We can open “Terrestrial Heat Flow” forms as an example here (Fig. 3.3), and then you can browse terrestrial heat flow data by clicking the buttons on the top of the forms. When clicking the button , a forms would be shown for you to add heat flow data. (Fig. 3.4). If you want to modify the data on the table, you can click the button , then a forms like Fig. 3.4 would be shown too. Now, the terrestrial heat flow data have been change. A message “The data have been changed, do you want to save these

changes?” would be given by the system when closing the forms, and if your answer is “yes”, the database management system will store these changes. On the other hand, you can click the button to save these changes too. There are the same cases in the “Thermal Conductivity Data” forms and other forms.

3.2 Data Copy Wizard

To avoid losing data, we should store the data at intervals, because the system maybe be destroyed or damaged by virus or other unimaginable factors. Consequently, we developed a data copy wizard, which can export the whole or single table data to the hard disc or other removable media by specified file formats such as *.dbf, *.txt, *.html, *.xls et al..

3.3 Data Query System

In order to meet the need of the different users, we developed several various querying and index style which is more convenient for the user to query data quickly. In the main interface, there are 7 sub-menus in the menus “Data Query”, such as “Temperature Data”, “Heat Flow Data”, “Physical Qualities”, “Borehole Information”, “Condition Query”, “Graphic Query”, “Spacial Query (GIS)” et al.. Each of them will be introduced in the following discussions.

3.3.1 General Query

The forms “Query Condition” will be shown after the user clicks the menus sub-menus “Temperature Data”, “Heat Flow Data”, “Physical Qualities”, “Borehole Information”, which contains a Chinese regionalism map, two frames, 6 option-buttons and 2 command buttons (Fig. 3.5). We can select the query style which including querying by province or by GGT and the query condition which including querying by borehole, by location, by project or by date on the forms. And then another forms will be shown the query result.

On the forms “Condition Query”(Fig. 3.6), we must select at first the different table, different fields and the correlative conditions such as some fields equal to something etc., and the following steps are clicking the button “Show SQL”, then we can get the SQL sentence, and then get the result satisfied the conditions hereinbefore.

On the forms “Graphic Query”, it is very easy and simple to query the data what you wanted. It is just to click the province name or click the location in a province on the map. Then you can get all the data in the province you selected.

3.3.2 Spacial Query (GIS)

Geographic Information System (GIS) have become indispensable instruments for the geoscience and environmental sciences in the last years. They are of fundamental significance for all levels of urban, regional and landscape planning (Streit et al., 1994) and are the basic for spatial decision support systems. The broad potential of GIS for practical applications has led to high growth rates of the GIS market and to a relatively quick development of additional GIS functions (P. et al, 2000).

ARC/INFO is a GIS software package made by Environmental Systems Research Institute (ESRI). And it is used worldwide by thousands of different organizations for handling, managing and analyzing geographic information. ArcInfo 8 is composed of two parts: Workstation Arc/Info and Desktop Arc/Info. Based on the three application programs ArcMap, AcrCatalog and ArcToolbox, the Desktop Arc/Info provided the elementary methods and interfaces used for the communion between the user and the maps, data and tools of GIS.

The screenshot shows a 'Data Query' window with the following components:

- Select Table:** A list box containing 'Project Information', 'Project Result', 'Project Reference Sour', 'CD Information', 'Temperature Data', 'Borehole Information' (highlighted), 'Radioactive Elements', 'Thermal Conductivity', and 'Heat Flow Data'.
- Select Field:** A list box containing 'structure', 'longdu', 'longfen', 'longmiao', 'latdu', 'latfen', 'latmiao', 'corx', 'cory', 'holelevel', 'holedepth', 'waterlevel', 'waterdepth', 'longitude', 'latitude', 'ProvinceId', and '333'. To its right is another list box containing 'bhid', 'bhname', 'projectid', 'begindate', and 'enddate'.
- Query Condition:** A section with two dropdown menus and a text field. The first dropdown shows 'begindate', the second shows '=', and the text field contains '1998'.
- Buttons:** At the bottom are three buttons: 'Show SQL', 'Show Result', and 'Cancel'.

Fig. 3.6 The forms of Condition Query

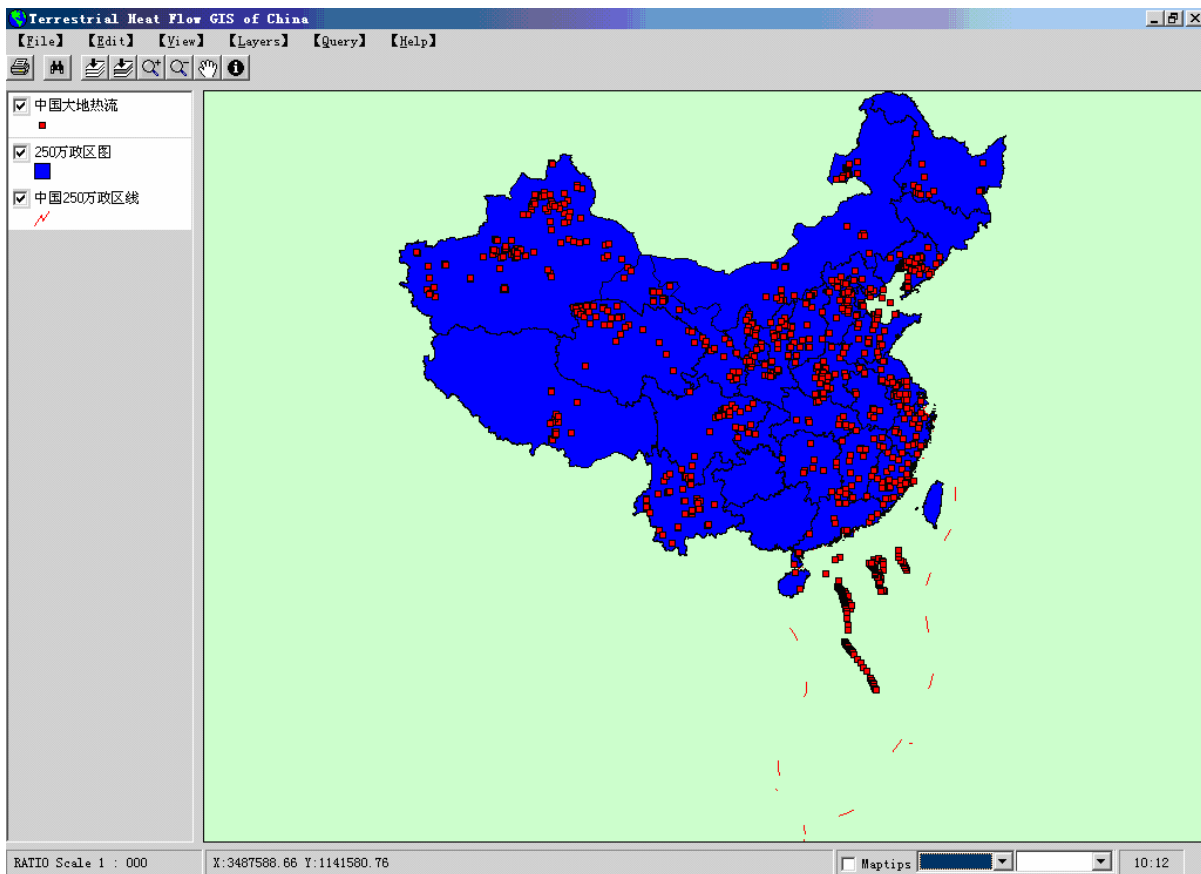


Fig. 3.7 The main interface of terrestrial heat flow GIS of China

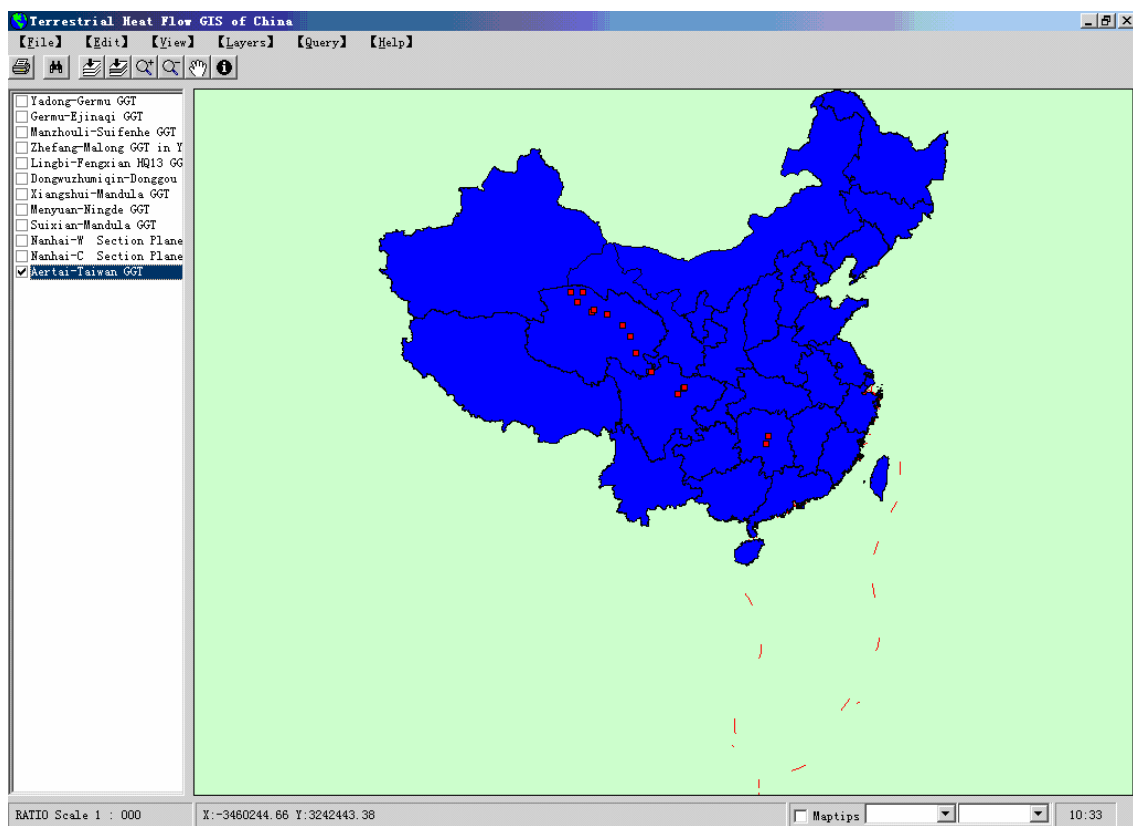


Fig. 3.8 The forms of query by GGT

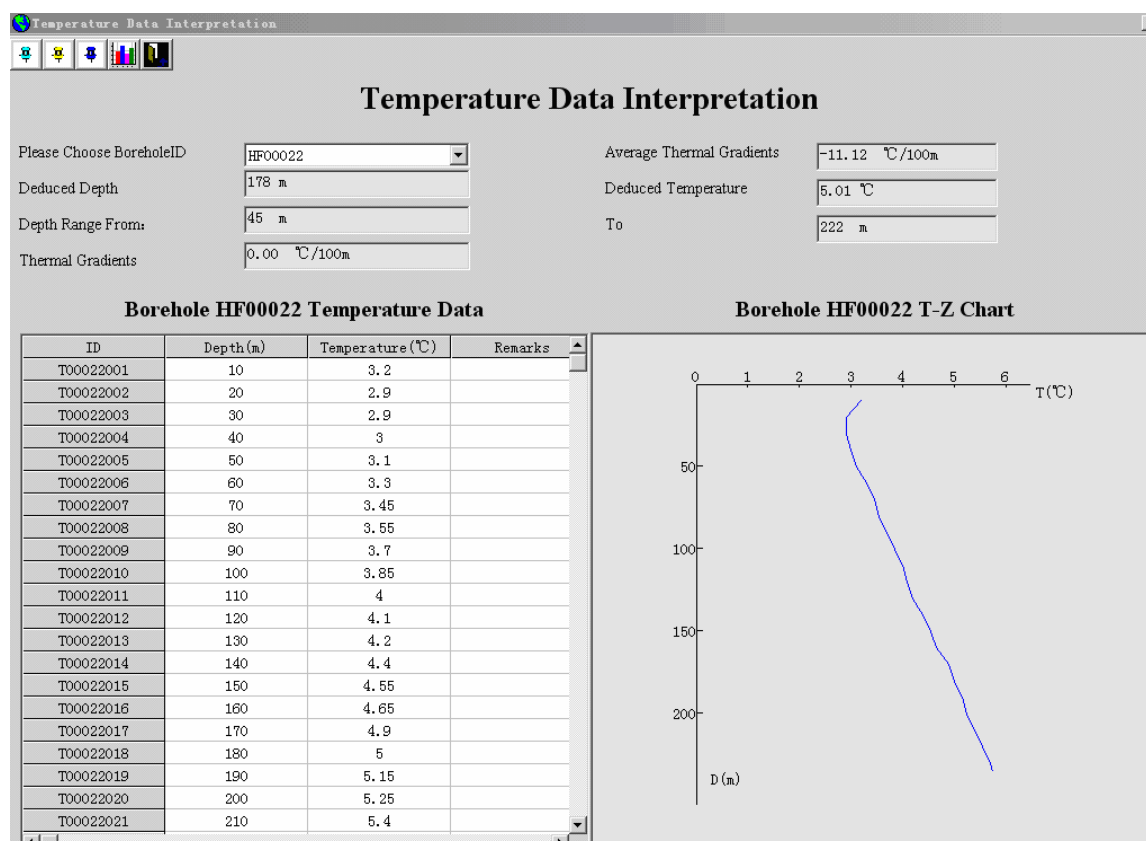


Fig. 3.9 The forms of the temperature data interpretation

In this study, the projection of the electronic map is Lambert Conformal Conic projection, i.e. the area, and the shape are distorted away from standard parallels and the directions are true in limited areas, its reference latitude is 25° and 47° , central longitude is 105° and the density of the latitude and longitude grid is $1^{\circ} \times 1^{\circ}$. We can accomplish the projection by two methods. One is the projection wizards in the ArcToolbox, and we can draw these points by its tips step by step. Another is the tool “AddXY Data” in the ArcMap. (Anrong Dang et al, 2001)



The metadata standard of terrestrial heat flow of GIS of China is constructed based on *metadata content and format standard in geology surveying* (Chinese Geology Surveying Bureau, 2001), And the metadata which is upbuilt in this study, can be browsed by clicking the menu “Metadata” on the main interface of the database in the following four formats: ZGYSQ3D format, XML format, ESRI format and FGDC format.

Certainly, we can manage all of the spatial data in the terrestrial heat flow database by ArcMap, however, although ArcMap has very powerful functionalities, it takes too much memory space (WeiChang Wang, 2000) when it runs. So we choose MapObjects which is also developed by ESRI to develop the terrestrial heat flow GIS of China. At first, we plug it into the Microsoft Visual Basic 6.0 development environment, and then we can develop the terrestrial heat flow GIS of China now.

The main interface of the heat flow GIS of China is shown in Fig. 3.7, which is made up of a menu, a toolbar, a map control and a Legend control containing lots of map layers.

The function of the first button on the toolbar is printing the map, and the second is finding the correlative attribute of the appointed map layers. The others are panning the map,

zooming out or zooming in the map, full map extent, active layer extent, identify the map etc.

We have developed different query styles such as querying by GGT, by province, by location or by borehole etc. The forms of “query by GGT” is shown on Fig. 3.8. The other querying styles are like the forms very much, and we can see the detail data by clicking the button  and the button . We have also developed a legend edition toolbox.

3.4 Geothermal Data Interpretation Toolbox

The database stored some temperature data, heat flow data and other interrelated data such as radioactive element data and the data of the physical properties of the rock on the corresponding measurement location etc. in a single borehole as raw data, and at the same time, we developed several tools such as borehole temperature field data interpretation toolbox, one-dimensional temperature field data interpretation toolbox and two-dimensional temperature field data interpretation toolbox etc. to calculate the temperature gradient, deduce the temperature and heat flow at the appointed depth etc. based on these raw data.

Borehole temperature field data interpretation toolbox includes calculating the temperature gradient at an appointed depth, the average temperature gradient at a single borehole, the temperature at an appointed depth and drawing a temperature-depth chart at a single borehole automatically. (Fig.3.9)

In order to calculate the temperature and heat flow (including surface heat flow and mantle heat flow) in different stratum in one single borehole, we developed a wizard of one-dimensional temperature field data interpretation toolbox based on the following formulas:

$$T = T_0 + (q_0 Z) / K - (A_0 Z^2) / (2K)$$

$$q_{(z)} = q_0 - A_0 Z$$

where, T =temperature, Z =depth, K =thermal conductivity, $q_{(z)}$ =heat flow at depth Z . A_0 , q_0 and T_0 are heat generation, surface heat flow and surface temperature respectively. Therefore, if we know the surface heat flow, surface temperature, heat generation (Rybach.L. et al, 1984) and thermal conductivity, we can get the temperature, heat flow at appointed depth in a single borehole, draw automatically a depth-temperature chart at the same time. In this toolbox, what we must input are surface temperature, thermal conductivity, heat generation and a appointed depth, and then we can get the heat flow and temperature at the appointed depth, at the same time, the system can draw the temperature-depth curve automatically just in one borehole.

In the two-dimensional temperature field data interpretation toolbox, we developed the finite element method program on the Microsoft Visual C++ 6.0 development environment and made it a *.exe file. And the EXE file was transferred into the Microsoft Visual Basic 6.0 development. (Lijun Lin, 200; E.Winemiller, 1999; Microsoft Co., 1998;)

The essence of the finite element method in modeling the temperature field is to convert the continuous temperature field to the limited nodal temperature in the study region, to calculate the temperature at these nodes and to approximate the whole temperature field.

Generally speaking, the heat transfer equation can be expressed by the following equation:

$$\frac{\partial}{\partial x} \left(k \frac{\partial T}{\partial x} \right) + \frac{\partial}{\partial y} \left(k \frac{\partial T}{\partial y} \right) + \frac{\partial}{\partial z} \left(k \frac{\partial T}{\partial z} \right) + A = \rho c \frac{\partial T}{\partial t} \quad (3.4.1)$$

where, k =thermal conductivity, T = temperature, A = heat generation, ρ =density, C = specific heat capacity, t =time and $\frac{\partial T}{\partial t}$ =temperature change during unit time.

In the two-dimensional temperature field data interpretation toolbox, we provided that the whole study thermal physical parameters in each element are constant, and the study field temperature is the equilibrium condition. So the two-dimensional heat transfer equation can be expressed by the following equation according to formula (3.4.1):

$$k \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial z^2} \right) = -A \quad (3.4.2)$$

And we can get the following functional analysis factor $J[T(x, z)]$ from the formula (3.4.2):

$$J[T(x, z)] = \frac{1}{2} \int_S K \left[\left(\frac{\partial^2 T}{\partial x^2} \right)^2 + \left(\frac{\partial^2 T}{\partial z^2} \right)^2 \right] ds - \int_S A T ds - \int_{\Gamma} q_n dl \quad (3.4.3)$$

where, S =the domain to simulate, Γ = the boundary of the studying domain \square K =thermal conductivity \square A =heat generation, q_n = the heat flow on the boundary of the studying domain.

In accordance with the formula above, we can get the solution of the equation (3.4.2) by calculating the minimal value of $J[T(x, z)]$, and then the system can draw the

isotherm if we input the following parameters: K , A and the boundary conditions.

After the user clicks the menus “Two-dimensional temperature field data interpretation” on the main interface of the database, the system will open the “Two-dimensional temperature field data interpretation tool” forms and ask the user to initialize the conditions. And then the wizard will lead you completing the interpretation and a isotherm will be given by the system.

3.5 Data Reports

When clicking the menus “Data Report” which including several reports such as heat flow data report, CD information report, temperature data report, borehole report, rock physical qualities report, thermal conductivity report and project information report etc., and selecting one of them, then you will get a beautiful corresponding report.

4. DISCUSSION

In order to satisfy the international learning communication and studying each other, we developed the double language versions (the Chinese Version and the English Version). And at same time, the database can be used in some other geographical location just by modifying several places, such as the raw data which stored in Microsoft Access 97, and the map layers which developed based on MapObjects and ArcGIS, the metadata standard which was constructed based on *metadata content and format standard in geology surveying* (Chinese Geology Surveying Bureau, 2001) and the metadata itself etc.

In regard to the data interpretation, we only have developed borehole temperature field data interpretation, one-dimensional temperature field data interpretation and two-dimensional temperature field data interpretation. We will develop the three-dimensional temperature field data interpretation toolbox in the near future based on the three-dimensional heat transfer equation and the finite-element method (FEM).

5. CONCLUSION

In conclusion, terrestrial heat flow database has provided a powerful querying system containing a graphic query system and a text query system. The user can query the data what he wants rapidly and effectively, especially when having introduced the GIS technology into the database, and the user also can customize his own query condition. In addition, we also developed the general data interpretation toolbox, which including temperature data interpretation on a single borehole, one-dimensional temperature field data interpretation and two- dimensional temperature field data interpretation. It is very convenient for the users to solve the various geothermal problems by using the geothermal data interpretation toolbox. And at the same time, we can output several beautiful reports.

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