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Application of Remote Sensing Technology in Geothermal Exploration: a Case Study of Taizhou City in Jiangsu Province

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ABSTRACT

Remote sensing (RS) technology has played an increasingly important role in the fields of geology and ore deposit research and been widely used in various aspects. It is not only convenient, but also accurate and economical. This approach began to be used abroad in the 1970s. After about 20 years, it began to be used in China. The prospecting for subsurface geothermal resources is still a worldwide problem, and RS technology provides an effective means to solve this problem. This technology was used with less input to quickly obtain high accuracy results to explore concealed geothermal resources in Taizhou city in the Jiangsu province.

1. THE PRINCIPLE OF SATELLITE REMOTE SENSING SURVEY TECHNIQUE

The use of RS techniques to survey the underground resources has been developed for almost 30 years. Commonly used data from satellite remote sensing are Landsat / (ETM) data, the TERRA / EOS data from a new generation of earth observation satellite launched by the United States in recent years, and data from resource satellites launched by China. The main features and applications of these remote sensing data are shown in Tables 1–4. Table 1 reflects the bands and the main scope of the application of Landsat / TM (ETM +). Table 2 shows the NOAA / AVHRR meteorological satellite's bands and applications fields. Table 3 illustrates the bands and resolutions of TERRA / ASTER data. Table 4 lists TERRA / MODIS instrumental characteristics (thermal infrared channel) and the main applications.

Table 1: Bands and main scopes of application of Landsat / TM (ETM +)

Band	Spectral range (μm)	Resolution (m)	Main scopes of application
1	0.45-0.52	30	Discriminate water system, shallow-sea mapping, monitoring of chlorophyll content in sea water
2	0.52-0.60	30	Identify the types of plants, evaluate the productivity of plants, water pollution research
3	0.63-0.69	30	Distinguish the types of plants, coverage, identify the plant growth state, health state
4	0.76-0.90	30	Biomass survey, determinate crop growth, soil moisture, looking for groundwater
5	1.55-1.75	30	Reflect the plants and soil moisture, distinguish cloud from and snow
6	10.4-12.5	120 60 (ETM)	Detect the anomaly of the thermal radiation under common temperature
7	2.08-2.35	30	Geologic prospecting

(According to Zheng Lanfen et al, 1992)

Table 2: Bands and main application fields of NOAA / AVHRR meteorological satellite

Band	Spectral range (μm)	Resolution (m)	Main application fields
1	0.58-0.68	1100	Ocean color, chlorophyll, sediment, sea water, marine pollution, land surface, vegetation
2	0.725-1.1	1100	Vegetation, land and sea boundaries, sea water, beaches, atmosphere status
3	1.58-1.68 (NOAA-K added)	1100	Soil temperature, water content of vegetation, identify cloud and snow, high-temperature hot spots, imaging at night
4	10.5-11.3	1100	Earth background temperature field, thermal pollution, sea temperature, currents and the vortex
5	11.5-12.5	1100	

(According to Zheng Lanfen et al, 1992)

Table 3: Bands and resolutions of TERRA / ASTER data

Features	VNIR	SWIR	TIR
Spectral range (μm)	Band1:0.52-0.60	Band4:1.600-1.700	Band10:8.125-8.475
	Band2:0.63-0.69	Band5:2.145-2.185	Band11:8.475-8.825
	Band3:0.76-0.86	Band6:2.185-2.225	Band12:8.925-9.275
		Band7:2.235-2.285	Band13:10.25-10.95
		Band8:2.295-2.365	Band14:10.95-11.65
Ground resolution (m)	15	30	90

(According to Zheng Lanfen et al, 1992)

Table 4: TERRA / MODIS instrumental characteristics (thermal infrared channel) and main applications

Channel	Spectral range (μm)	SNR	Resolution (m)	Main applications
20	3.660-3.840	0.05	1000	The temperature of earth surface and cloud top
21	3.929-3.989	2.00	1000	
22	3.929-3.989	0.07	1000	
23	4.020-4.080	0.07	1000	
30	10.780-11.280	0.05	1000	
31	11.770-12.270	0.05	1000	

(According to Zheng Lanfen et al, 1992)

The use of infrared detection technology to explore geothermal resources is a high-tech method that has been developed since 1970s. The basic principle of this technology is identification due to the sensitivity of the reaction of mid-infrared (3-5μm) and far-infrared (8-14μm) spectrums to temperature change. Solar radiation and continual upward transportation of underground thermal energy through day and night lead to different surface temperatures. The average value of several surface temperatures in one area is called the geothermal background value of this area. If there were heat energy hosted under the ground, this energy would be transported to the surface via different types of conduction and convection. This effect makes the surface temperature higher than the normal surface temperature. This shapes "heat islands", or heat anomalies, which have higher temperatures than that of the surface and can often be detected and recorded by satellite remote sensing and formed as images by computer processing (Geothermal Group, 1972). Of course, such heat anomalies maybe also result from many other factors, such as heat discharged by thermal plants, power plants, large chemical plants, metal smelters, and so on. This kind of heat can also form local heat islands, which are confused with heat island and make it difficult to distinguish true anomalies from false ones. Particularly, populated areas can also generate "heat island" phenomena, where the temperature is higher than the geothermal background value. Therefore, it is necessary to recognize true and false heat islands (Li yongyi, Li binshan etc, 1990). Initially, all types of identification required artificial investigation and were verified one by one. Now, special software can eliminate urban heat islands, factory heat islands, and water pollution heat and retain the true geothermal heat islands, greatly reducing the labors and the costs.

The basic principle of satellite remote sensing surveys can be depicted as follows:

Physical experiments show that all objects with temperatures higher than 0 K emit radiation. Mainland surface temperatures are about 300 K. Its radiation is almost long-wave radiation, of which the wavelength is more than $3\mu m$. The largest wavelength of electromagnetic radiation is from $8\mu m$ to $11.3\mu m$, or in the thermal infrared band. This band can be inducted and recorded by the thermal sensors fixed on the satellite during day and night. As the induction energy of thermal sensors fixed on the satellite is proportional to the temperature of launching objects, the temperature distribution of the surface can be determined and used to generate pictures. These pictures use depth changes in gray-scale to present the high and low temperatures of objects. If there is a zone whose temperature is higher than the Y0 background value, the thermal sensors can capture it and reflect it. Once these heat islands have been located, scientists can verify the existence of heat reservoirs beneath the surface. Thus, heat islands on the remote sensing pictures are from underground heat reservoirs.

2. TECHNOLOGY INTEGRATION OF SATELLITE REMOTE SENSING SURVEY

Auxiliary exploration tools are needed in geothermal resources exploration, including the satellite remote sensing technology, in order to save time and money. In the processing of geothermal exploration in Taizhou in the Jiangsu province, the novel '3S imaging technology,' which is integrated by RS, GIS and GPS, was adopted. This technology was first applied in the fields of military reconnaissance and resource surveying by developed countries. It is extremely accurate in speculating the unknown from the known. However, the application of this technology in known geothermal or natural outcrop areas has high accuracy, but its application in the unknown areas is in experimental and exploratory phases (Huo mingyuan, 1992). There are no natural outcrops of geothermal resources on the surface in the city of Taizhou. The known underground resources have all been detected by oil drilling. There are thick caprocks over these resources, concealing them. This led to increased difficulties and risks in the exploration of these geothermal resources. Using the 3S technology to successfully find the geothermal resources in this area is not only the key of implementation, but also the innovation of this project. 3S multiple imaging technology is not simply the stacking of these three technologies, because each technology has its shortcomings. In other words, stacking these technologies can add both the inherent advantages and disadvantages of each technology. In order to keep the advantages and minimize the disadvantages, this multiple technology was used.

Using the satellite remote sensing technology, and the 3S multiple imaging technology in particular, to explore geothermal resources is a difficult and high level practical activity which combines science to productions. The success of this activity depends on two basic points: firstly, there are indeed underground geothermal resources in Taizhou; secondly, satellite remote sensing technology can reflect the position, size, and temperature of the geothermal abnormal area, and the distribution levels of the thermal reservoir.

Though the basic principle is clear, while trying to turn it into a practical technology, the most critical step is the realization of technological innovation. Usually, technological innovation can not be completed by a single technology, but requires more than two kinds of technology. In this article, 3S technology integration is adopted and includes RS, GIS and GPS. This greatly enhances the accuracy and speed of geothermal resource exploration. It not only saves valuable time and money, but also improves efficiency.

In this type of satellite remote sensing, the long-wave band from MODIS (Moderate-Resolution Imaging Specerora-Diameter) was used. MODIS is a hyperspectral sensor fixed on the American satellite TERRA. It has 36 bands with a resolution of 1000 m. It has 31 bands data and a central wavelength of $11\mu m$. This long-wave band can reflect the surface temperature accurately. Winter data were selected to cover up other heat sources. The base map is composed of 6 pieces of pictures from winter data with a resolution of 30 m.

After correcting, registering and synthesizing MODIS data with TM data, MODIS data was set as the red band, and band3 and band4 of TM were set as the green and blue bands, generating a colorful picture. After that, a density slicing operation was performed on MODIS data according to the radiance test value of the known geothermal area. Finally, a distribution map of the geothermal anomaly was obtained, which shows the heat islands of geothermal resources in Taizhou city and neighboring zones. From the above processes, it was found that once basic principles are changed to technologies, complicated things become easy.

In order to reflect the remote sensing anomalies of geothermal resources in Taizhou city, the anomalies were divided into 3 types: high-temperature, moderate-temperature and low-temperature corresponding to strong, medium and weak radiance. To avoid confusion of these 3 categories, they were presented in maps. Table 5 lists the corresponding relationships between radiances and the abnormal temperatures of geothermal resources.

Table 5: Corresponding relationships between radiances and abnormal geothermal temperatures

Radiance	Strong	Medium	Weak
Abnormal temperature of geothermal	High-temperature	Moderate-temperature	Low-temperature
	>60°C	60-40°C	<40°C

It is worth noting that this corresponding relationship is caused by the actual geothermal situation in Taizhou city. In accordance with national standards of geothermal exploration, GB11615-89, geothermal resources are divided into 3 levels: high-temperature, moderate-temperature and low- temperature. This standard is described in Table 6.

Table 6: Temperature classification of geothermal resources (GB11615-89)

Temperature classification		Temperature boundary (°C)
high-temperature		$T \geq 150$
Moderate-temperature		$90 \leq T \leq 150$
Low-temperature	Hot water	$60 \leq T \leq 90$
	Moderate-hot water	$40 \leq T \leq 60$
	Warm water	$25 \leq T \leq 40$

3. THE RESULT OF ACTUAL APPLICATION

1. A satellite remote sensing distribution map of geothermal anomalies (1:100000) was drawn to locate 76 geothermal abnormal areas with a large distribution.

2. In geothermal abnormal areas, their vertical distribution statuses were surveyed using V_5 system, and well drilling locations were affirmed.

3. The drilling of a well was planned to a 1000 m depth, and the actual depth of drilling was 1006 m. Hot water is classified into 3 layers. Wellhead water temperature is 42°C and its flowrate is 30 m^3/h.

So far, the accuracy of the satellite remote sensing distribution map of geothermal anomalies can be confirmed.

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