EXPLORING OIL AND GAS DEPOSITS BY TEMPERATURE ANOMALY SHOWN IN SATELLITE THERMAL INFRARED IMAGES BEFORE EARTHQUAKES IN THE NORTHERN SOUTH CHINA SEA

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ABSTRACT: The northern South China Sea (NSCS) is the potential area for the occurrence of hydrocarbon reservoirs and gas hydrates. The paper applied temperature increase anomaly before earthquakes in satellite thermal infrared (STIR) image to prospecting for hydrocarbon reservoirs and gas hydrates in NSCS for the first time, which was proved to be effective. The mechanism of temperature anomaly shown in STIR images before earthquakes was analysed. The relationship between the temperature anomaly and the occurrence of conventional oil/gas reserves and gas hydrates was discussed. It was founded that temperature increasing probability came to 64% before earthquake in those areas where the oil and gas reserves had been prospected. The areas of high temperature shown in the images were mainly distributed in the abyssal zone of Pearl River Mounth basin (PRMB), Southwest Taiwan basin (TSWB), Xisha trough, Dongsha Island slopes, Bijianan basin (BJNB) of NSCS, showing potentials for oil and gas reserves and gas hydrates to grow. In these areas, there existed some other known indicators, such as BSR, geological structure and geochemical and radioactive anomalies, which was helpful for hydrocarbon resources to enrich. Therefore, in the NSCS, the high temperature anomaly shown in the STIR images before earthquakes could give an indirect evidence for the existence of marine oil/gas reserves and gas hydrates in deep water.

KEY WORDS: northern South China Sea (NSCS); oil and gas deposits; satellite thermal infrared (STIR); temperature anomaly

ABBREVIATIONS: northern South China Sea (NSCS); satellite thermal infrared (STIR); Pearl River Mouth Basin (PRMB); Southwest Taiwan Basin (TSWB); Qiongdongnan Basin(QDNB); Beibuwan Basin(BBWB); Yinggehai Basin (YGHB); West Taiwan Basin(TWB); Zhongjiannan Basin(ZJNB); Bijianan Basin(BJNB); West LuZon Basin(LZWB); Sea Surface Temperature(SST)

1 INTRODUCTION

Since the early 1970s, the oil and gas industry has benefited from remote sensing technologies-opening up new opportunities for discovering oil well location. The imagery displayed in selected spectral bands provides the detail to identify specific surface lithologies, geologic structures, and fracture systems associated with mineralized areas. Remote sensing was used to interpret both regional geology and local anomalies related to oil prospects. Information-rich multispectral data can reveal subtle vegetation characteristics anomalies and estimate soil relative mineral content in oil and gas fields, thus identify indirectly oil and gas storage (Arthur et al., 1985; Gilman et al., 1982; Hoeks, 1972).

Submarine hydrocarbon reservoirs are widespread and give rise to unusual seafloor features, but the special sea environment and complicated oil/gas storage condition determine that hydrocarbon exploration in ocean needs expensive investment, high technology and needs to afford high risk. In view of these facts, developed countries have applied remote sensing to oil/gas reservoirs exploration in ocean since 1980s and have obtained obvious effects. Hydrocarbon seeps are common phenomenon in oil/gas-producing basins around world, which is one of the theoretic foundations of using remote sensing for oil/gas exploration. Remote sensing is used because it responds to hydrocarbon seeps, gives high-resolution images and can cover a large area rapidly at modest expense.

In early 1990s, Qiang Zuji (1990) reported that satellitic thermo-infrared temperature increased before earthquake in continent of China. This phenomena occurred 7~9 days before earthquake with the temperature increase of 2~10℃. He explained before the occurrence of an earthquake, the rock stratums around a large area were under pressure, fissure occurred, thus releasing large amount of gases, such as CH_4, CO_2, CO, H_2, H+, He and H_2O from deep within the globe. They applied thermal IR satellite data to oil-gas field exploration in continent of China (Qiang Zuji, 1994). The method application for oil-gas field exploration in ocean was studied by Huang Fulin et al (1998). In their research, oil-gas areas had methane concentration anomaly in the low-layer atmosphere around the earthquakes, had a temperature increase by 1-6℃ at the occurrence of moderate and strong earthquakes and indicated that concentration anomaly of methane in the low-layer air and temperature anomaly could be used as important indexes for petroleum geochemical exploration.

The South China Sea (SCS) contains hundreds of hydrocarbon seeps today because of its geologic past. Deposition and burial of organic continental margin sediments provid the source material and reservoirs for the maturation of hydrocarbons, whereas faulting provides the release mechanism and conduits to the seafloor. Numerous Cenozoic sedimentary basins developed in shelves and slopes of SCS (Fig.1) and have been explored for hydrocarbon to various extends. Deepwater basins in the NSCS and their hydrocarbon potential have been hot topics of study in recent years (Sun et al., 2008). The most important thing which should be taken into account is that it is necessary to have an inexpensive, easy and rapid method to observe the hydrocarbon resources distribution. Remote sensing is playing an increasingly important role in this survey. In this study, the general procedure was to identify temperature anomaly features of surface water based on MODIS SST images before earthquake in NSCS and to analyse and interpret mechanism of temperature increase. It was pointed out that the high temperature was caused by the seepage of gases such as CH_4 and CO_2 from conventional oil gas fields in shallow water and gas hydrates in deep water. It was also founded that temperature anomaly in images were mainly distributed in oil and gas field which indicated that the area where temperature increase before earthquake could be used as a clue about the distribution of oil and gas resources.

2 MATERIALS AND METHODS

2.1 Study area

The northern South China Sea (NSCS) is connected to the East China Sea via the shallow Taiwan Strait and to the Philippine Sea through the Luzon Strait, with water depth varying from 30 m in the northern continental shelf to more than 4500 m in the south sea basin. It is bounded by vast shelves accounting for 52% of the area of the SCS. In the northern margin, there are several oil and gas bearing sedimentary basins, e.g. the Pearl River Mouth Basin (PRMB), the Southwest Taiwan Basin (TSWB), Qiongdongnan Basin(QDNB), Beibuwan Basin(BBWB) and the Yinggehai Basin (YGHB)(Lin and Zhang, 1997; Fig 1). It is generally agreed that the SCS has a passive margin in the north, so the NSCS is an excellent natural laboratory for geosciences, and the rich hydrocarbon resources have enhanced the charm of the NSCS.

2.2 Satellite data

The MODIS radiance data provide improved information about the physical structure of the Earth’s atmosphere and surface. MODIS sea surface temperature (SST) products provide per-pixel temperature values. Temperatures are extracted in degrees Kelvin with a view-angle dependent algorithm applied to direct observations. This method yields 1 K accuracy for materials with known emissivities (Justice et al., 1998).

In order to observe Sea Surface Temperature (SST) of NSCS before moderate and strong earthquake, MODIS SST products during earthquake periods occurred near SCS in recent years were processed. In recent years, the strong earthquake occurred around NSCS in South China Sea and around south of Taiwan on 2006-12-26(21.9N 120.6E, Time: 20:26:19, M=7.2). Two periods of observations were involved in processing: (1) average SST data from December eleventh to eighteenth in 2006; (2) average SST data from December nineteenth to twenty sixth in 2006. The reason for selecting average of 8 days SST products is that the qualities of average of 1 day or 3 days SST data were poor and a mass of clouds covered the surface information of sea.

Image processing includes standard procedures for MODIS SST images: data reading, sub-regions cutting, image coloring, image output. MODIS SST product includes 2 files: SST data file and data quality file. The data processing used IDL language of software ENVI. As a result of first step, temperature images of the sea surface were obtained by using function of IDL. On the next step, the northern South China Sea was selected (15°~24°N, 106°~122°E). Then all values on the image were separately colored using the swatches of IDL or the custom swatches. Hence we output the image and annotated the text and swatches.

3 RESULTS

3.1 Anomaly features of SST before earthquakes in NSCS

In our research, systematic and long observations of MODIS SST images in NSCS were processed and distinct surface temperature anomaly before earthquake was found. The results of SST processed image were shown in Fig.2,3. Fig.2 showed average SST values from December eleventh to eighteenth in 2006; Fig.3 showed average SST data from December nineteenth to twenty sixth in 2006.

During December 11th to 26th in 2006, notable temperature changes had taken place in SST image of NSCS. Dynamic evolution of the surface temperature appeared from local temperature increase to extensive temperature increase. During December 11th to 18th, besides the abnomal temperature increased in local regions of YGHB, ZJNB and LZWB, the temperature in other regions kept in unaltered condition (Fig. 2). During December 19th to 26th, widespread temperature increase anomaly appeared in NSCS, especially in three segments. The first segment of this zone extended from YGHB belt, through QDNB to Xisha Trough and Dongsha Islands, and then to TWSB belt. While the second segment was identified along the north LuZon Trough belt and the third segment extended from BJNB to north of Deep Sea basin belt (Fig. 2).

According to long observations, the SST anomaly of NSCS before or during earthquake had more complex condition. The analysis of digital images for NSCS showed the following:

(1) A part temperature increase anomaly regions were in conformity with the distribution of oil and gas bearing basin, such as in PRMB, QDNB, YGHB and TSWB. While the other anomaly regions extended towards Central Basin slops, such as Dongsha Islands, Xisha Trough, LuZon Trough, BJNB and ZJNB.

(2) The temperature anomaly regions were divided to 4 belts: YGHB-QDNB-Xisha Trough-PRMB-Dongsha Islands-TSWB belt, ZJNB belt, LuZon Trough belt, Zhongsha Islands-BJNB belt. The 4 segments were in position of shelves and slopes fault zone of NSCS, western margin fault zone, Manila trench fault zone and Zhongsha Islands-BJNB trench structural belt, respectively.

(3) There were few temperature anomaly or few conspicuously abnormality in centers of deepwater basins.

3.2 Analysis of SST increase

We mainly paid attention to increase of SST before earthquakes. Take the temperature variation during earthquake in 2006 for example, the increase of SST was shown in Fig.4. The value in Fig.4 indicating the increase value of SST during earthquake was the difference between value in Fig.3 and in Fig.2. The amplitude of SST increase anomaly was up to 6℃. The large-scale anomaly was located on PRMB, Dongsha Islands, TSWB and northern of BJNB. The SST of small regions in QDNB, YGHB, Xisha Trough and ZJNB also increased. The maximum increase of SST lied in the interface of PRMB and TSWB, and in the border between TSWB and BJNB.

On the temperature increase image (Fig.4), the oil wells, gas wells and oil-gas shows in PRMB and QDNB which had been exploiting were annotated with rhodo spots. The probability of temperature increase before earthquake in oil and gas reservoirs was calculated and shown on table 1. The statistics showed that the 67 percentage of oil wells occurred SST increase in PRMB and QDNB before earthquakes. Meanwhile, 60% of gas wells and 63% oil-gas shows appeared SST increase. The total probability of SST increase in different types oil/gas occurrences was up to 64% and the maximum increase of SST was up to 3.64℃. The statistics indicated that the SST where distributed oil/gas resources in seafloor had great chance to increase before earthquakes. The temperature increase phenomenon could indicate the existence of oil/gas resources effectively.

4 DISCUSSION

4.1 Physical mechanism of temperature anomalies before strong earthquakes

The most commonly accepted explanation (Tronin, 2000) mainly ascribed the observed pre-seismic thermal infrared (TIR) anomalies to the increase of green-house gas emission rates with possible concurrent contributions from deep water and convective heat flux rise at surface. Qiang Zuji et al.(1990) claimed that the satellite thermal infrared (STIR) anomaly related to seismic activity. It is well known that Earth degassing activity (and particularly for optically active gases like CO_2 and CH_4) is common phenomenon before earthquake and is generally more intense alongside seismogenic faults (Irwin & Barnes, 1980). Abrupt variations of such gases in near-surface atmospheric layers could result in a local greenhouse effect that increases near-surface temperature and, consequently TIR emission.

It was reported by Du (1993) that there were 5 gas spheres from surface to core of the earth. In the second and third gas spheres, there existed not only different rich gas reservoirs, like oil reservoirs and natural gas reservoirs, but also masses of gas aggregates from deep of earth. The second gas layer included extremely large amount of gas hydrate in seafloor. Especially in earth spheres where gases are enrichment such as oil and gas bearing and gas hydrate deposits in seafloor, the extensive process of micro-crack formation, a consequence of the continuously increasing stress field, supports the increase of such degassing activity that, together with deep-water rise and convective heat flow toward surface, could contribute to strongly increase thermal infrared emission by increasing not only near surface temperature but also ground and water emissivity. When the stress field becomes locally so high as to close the cracks and earthquake occurrence is approaching, all the above processes are expected to reduce up to the time of earthquake occurrence (Tramutoli et al., 2005).

Air temperature, surface temperature, retrieved from satellite data, indicates correlation with seismic activity. Water temperature is considered as one of the main parameters and is observed as a response to seismic events. The response of water in wells and reservoirs and surface temperature in thermal anomaly on earthquake look similar (Tronin et al., 2004). Water flow and air temperature have this maximum values about 10-15 days before shocks, while water temperature and thermal anomaly temperature start to increase about 7 days before the event. It was proved by Qiang et al.(1994) that increase anomaly of STIR temperature before earthquakes showed great correspondence with oil and gas accumulation zones of continent. The same condition in ocean was confirmed by Huang (1998). Therefore, lower air temperature and water temperature increase anomaly before earthquakes based on STIR images may be an indirect indicator for exploring oil and gas deposits and gas hydrates in marine.

4.2 Prospecting potential for oil and gas resources in NSCS

There are numerous oil/gas-bearing sedimentary basins which developed in shelves and slopes of the NSCS and have been explored for hydrocarbon to various extends. So far, great attention has been paid to YGHB, QDNB and PRMB because of a number of oil/gas fields and oil/gas-bearing structures have been discovered in these areas. In our research, most of oil/gas reserves in YGHB, QDNB and PRMB appeared sea surface temperature increase which was proved by Fig.4 and Table 1.

For last two decades, hydrocarbon exploration and development of NSCS in China is just in continental shelf and shallow areas of YGHB, QDNB and PRMB. What is certain is that the deepwater slope of the NSCS has oil-gas resource potentials and bright prospecting future. But the degree of prospecting in deepwater basins is lower because prospecting work is restricted by technical and economical conditions and high risk.

In our study, we founded that deepwater basin of PRMB appeared temperature anomaly before earthquakes. The regions where the gas hydrates potentially existing also appeared temperature increase anomaly. According to the results, the distribution of potential hydrocarbon resources is in conformity with the distribution of temperature increase anomaly before earthquake. It suggests that the temperature increase anomaly before earthquakes in NSCS were caused by oil-gas microleakage and gas hydrates decomposition. The temperature increase anomaly before earthquake is expected as possible one of the indicators for exploring oil/gas resources or gas hydrate. This indicator will help to better delimit oil-gas distribution boundaries and reduce the time, cost and risk of future exploration efforts. Therefore, Dongsha Islands, Xisha Trough, TSWB, BJNB and deepwater area of PRMB where appeared SST increase before earthquake are probably prospects of hydrocarbon exploration in NSCS.

5 CONCLUSIONS

Due to its abundant oil and gas resources potential, the northern South China Sea is known as the most important region with good prospect. Hundreds of exploration wells have been drilled in continental shelves and shallow basins such as BBWB, YGHB, QDNB and shelf of PRMB. However, surveys on deepwater basins for oil and gas reservoirs prospecting are very few.

In this paper a new approach to analyse sea surface temperature anomaly before earthquake based on satellite thermal infrared images have been proposed as suitable tools for investigating the potential of hydrocarbon resources in the NSCS. From the results presented in part 3 we founded that the SST increased anomaly in some regions of the NSCS before earthquakes. Anomaly regions in NSCS were divided to 4 belts and a part of anomaly regions were in conformity with the distribution of oil and gas bearing basin. The total probability of SST increase in oil/gas occurrences which had been drilled was up to 64%. It was concluded that the SST increase anomaly before earthquake could indicate the existence of oil and gas resources effectively. According to the interpretation of the SST images we proposed that Dongsha Islands, Xisha Trough, TSWB, BJNB and deepwater area of PRMB where appeared distinct SST increase before earthquake were probably prospects of hydrocarbon exploration in NSCS. This forecast will show clear direction for further detailed investigation of hydrocarbon exploration. It is urgent to accelerate exploration and development in Dongsha Islands, Xisha Trough, TSWB, BJNB and deepwater area of PRMB and make full use of the rich oil and gas resources there.

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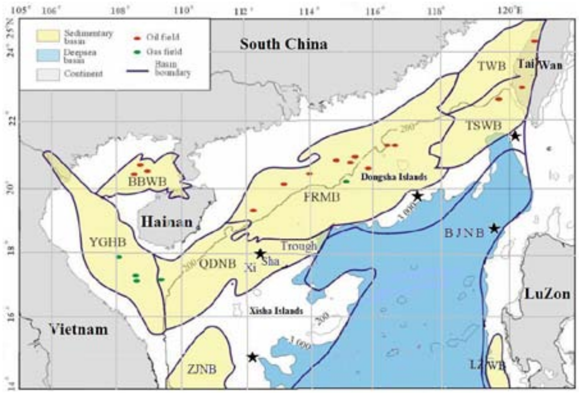

Figure 1 Simplified geological map showing major Genozoic basins in NSCS

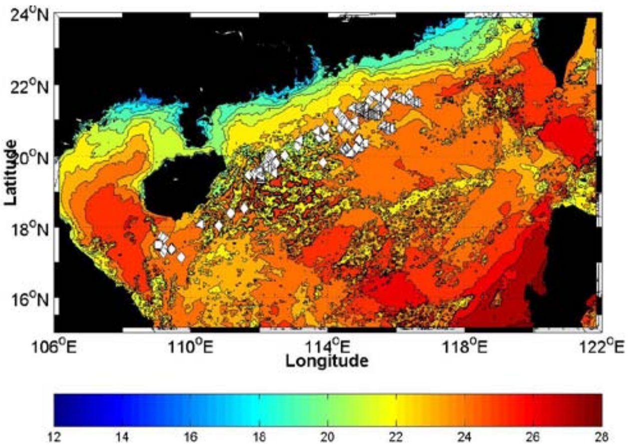

Figure 3 The average SST values from December 19th to 26th in 2006 of NSCS

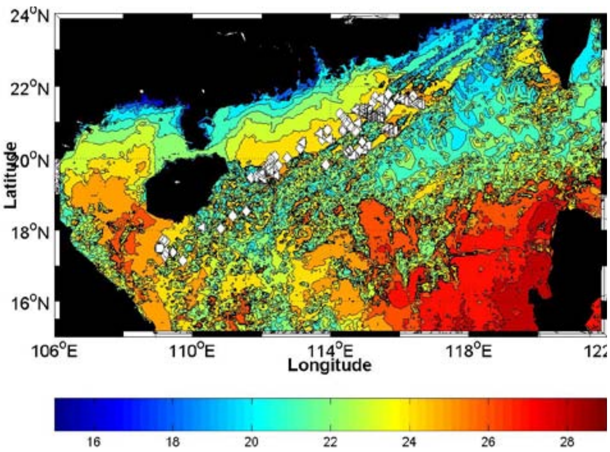

Figure 2 The average SST values from December 11th to 18th in 2006 of NSCS

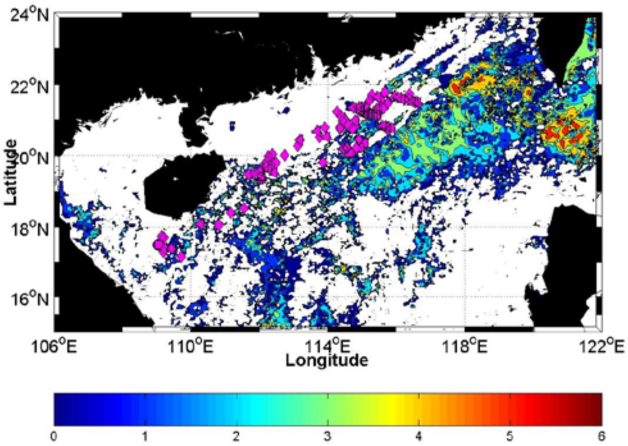

Figure 4 The increase value of SST during earthquake in 2006 of NSCS

Table1 The relationship of oil and gas occurrence and temperature increasing before earthquake in 2006 (in QDNB and PRMB)

	Oil wells	Gas wells	Oil-gas shows
The number of different types oil/gas occurrence exploited	36	5	55
The number of oil/gas occurrence which SST increased	24	3	35
The maximum value of SST increase(℃)	3.47	2.78	3.64
The probability of SST increase in different types oil/gas reservoirs (%)	67	60	63
The total probability of SST increase (%)		64	