

## Geochemical exploration for oil and gas in northern South China Sea

CHEN HAN-ZONG, ZHOU DI AND WANG PING

South China Sea Institute of Oceanology, Academia Sinica  
Guangzhou China

**Abstract:** Geochemical methods have been used to assist the petroleum exploration in sedimentary basins of the northern South China Sea. A total of 1,560 stations have been sampled on 12 cruises for sea-surface air, near-bottom water, and seabed or near-surface sediments. Irregular grids or cross sections were deployed above target traps to identify geochemical anomalies. Known oil/gas fields and barren structures were sampled to provide anomaly models for comparison. About 50 chemical indices have been determined, including gaseous hydrocarbons ( $C_1$  to  $C_6$ ), dissolved hydrocarbons, alternation carbonates ( $\Delta C$ ), mercury, trace elements, ultraviolet and fluorescence intensities, as well as carbon isotopes in methane. These data were analyzed by robust statistical methods to ensure the reliability of anomaly delineation. Identified anomalies were interpreted based on geochemical theories and the comparison with known models. It is found that composite geochemical anomalies with various assemblages of indices and of halo or circular/half circular shapes appear above all of the oil/gas fields studied, in a clear contrast with the geochemical features of their adjacent barren traps. Geochemical methods provide important multivariate geochemical information for the assessment and prediction of hydrocarbon potential of traps identified by geophysical means.

### INTRODUCTION

Near-surface geochemical methods have been proven effective in the exploration of hydrocarbon both inland and offshore (Faber and Stahl, 1984; Shiener *et al.*, 1985; Horvitz, 1986; Duchscherer, 1986; Brooks *et al.*, 1986; Yang, 1987; Saunders *et al.*, 1993). In order to assist the booming petroleum exploration in the South China Sea (SCS), geochemical exploration was carried out on 12 cruises since 1989 by the South China Sea Institute of Oceanology together with eight other Chinese institutions. Different geochemical methods and survey schemes were adopted respectively for the northern shelf of the SCS and the Nansha Islands area south of the deep-sea basin of the SCS.

On the highly studied northern shelf of the SCS, our major goal has been the assessment and prediction of petroleum potential of structural or lithological traps identified by geophysical methods. 1,560 stations have been sampled for sea-surface air, near-bottom water, and seabed or near-surface sediments. Irregular grids or cross sections were deployed above target traps to identify geochemical anomalies. Known oil/gas fields and barren structures were sampled to provide anomaly models for comparison. About 50 chemical indices have been determined, including gaseous hydrocarbons ( $C_1$  to  $C_6$ ), dissolved hydrocarbons, alternation carbonates ( $\Delta C$ ), mercury, trace elements, ultraviolet and fluorescence intensities, as well as

carbon isotopes in methane. These data were analyzed by robust statistical methods to ensure the reliability of anomaly delineation. Anomalies identified were interpreted based on geochemical theories and the comparison with known models.

In the area of Nansha Islands, where the geology is poorly known and the seafloor topography is rather rugged, our effort has been placed to the development of a geochemical method which may be used on-board in non-stopping geophysical survey for reconnaissance purpose. Mercury contents in sea-surface air and seawater were measured for the first time in the world by the highly sensitive JM-3 Gold-film Mercury Detector, which was a Chinese patent product with a detection limit of 0.02 ng (Yang, 1987). So far a total of 1,790 points along 11,700 km survey lines have been measured. Among 19 anomalies identified so far, 10 are related to known oil/gas fields or possibly related to undiscovered fields. These anomalies are characterized by high mercury contents in both air and seawater and occurring in relatively continuous and regular shape. Anomalies with rugged shape occur above continental-oceanic crust boundary or deep fracture zones.

This paper briefs the methods and results of our geochemical surveys on the northern shelf of the South China Sea including the southern Taiwan Strait. For the mercury studies in the Nansha area, readers are referred to Chen *et al.* (1990, 1994).

## GEOLOGY AND HYDROCARBON POTENTIAL OF THE NORTHERN SOUTH CHINA SEA

The northern shelf of the SCS, including the southern Taiwan Strait, is geologically composed of two NE-extending depression belts sandwiching an uplifted belt. Large petroliferous sedimentary basins were found in the depressions, such as the Yinggehai Basin (YGHB), the Qongdongnan Basin (QDNB), the Zhujiangkou Basin (ZJKB), the SW Taiwan Basin (TXNB), and the West Taiwan Basin (TXB) (Fig. 1). These basins developed in Mesozoic-Cenozoic continental margin since Late Cretaceous. They have a double-layered structure of rifts overlain by post-rifting downwarps, and filled with firstly continental then marine sedimentary sequences. Source rocks includes not only Paleogene lacustrine, but also Miocene marine strata. Episodic rifting in the area resulted in various source-reservoir-cap assemblages, which were separated by faults, forming multiple sedimentary centers (Ru *et al.*, 1993).

To the present, the ZJKB, QDNB, and YGHB are the areas of most active petroleum exploration. By the end of 1991, 180,000 km seismic lines were completed; 180 wells were drilled with a total depth of 500,000 m; and more than 30 oil fields or oil-bearing structures were discovered (Chen and Li, 1992; Zhang, 1992). In the western TXB the exploration is starting. A medium-scaled geophysical survey in the area and large-scaled geophysical survey in selected depressions were finished.

### METHODS IN OFFSHORE GEOCHEMICAL EXPLORATION

The offshore geochemical exploration has the advantage of a fast acquisition of large amount of multivariate geochemical information on the presence/absence of hydrocarbon. Data of multiple geochemical indices may supplement and check each other; thus the quality of anomaly delineation and interpretation may be improved. Compared with that of inland, the offshore geochemical exploration is more advantageous because the seafloor is less open and less contaminated than the land and thus the offshore geochemical anomalies are relatively well preserved, more stable, and more reliable.

According to the scale and aerial distribution of target traps, offshore sampling has been designed in irregular grids or cross sections. Above each target trap there were at least two lines crossing. When possible, one known oil/gas-bearing trap and one known barren trap near the target traps were

sampled as training set in order to establish geochemical models for comparison.

Seven to eight geochemical methods were used with nearly 50 indices, and sample media include sea-surface air, seawater, and near-surface sediments (Table 1).

Laboratory determinations were subject to quality-control rules. Data bases were built including determined and computed indices, such as the heavy gaseous hydrocarbon ( $C_{2+}$ ), wetness ( $C_{2+}/\Sigma C$ ),  $iC_4/nC_4$ ,  $C_{2:1}/C_2$ , F405/U216, etc. Robust statistic methods (Zhou, 1985) were used in the delineation of geochemical anomalies to ensure its reliability.

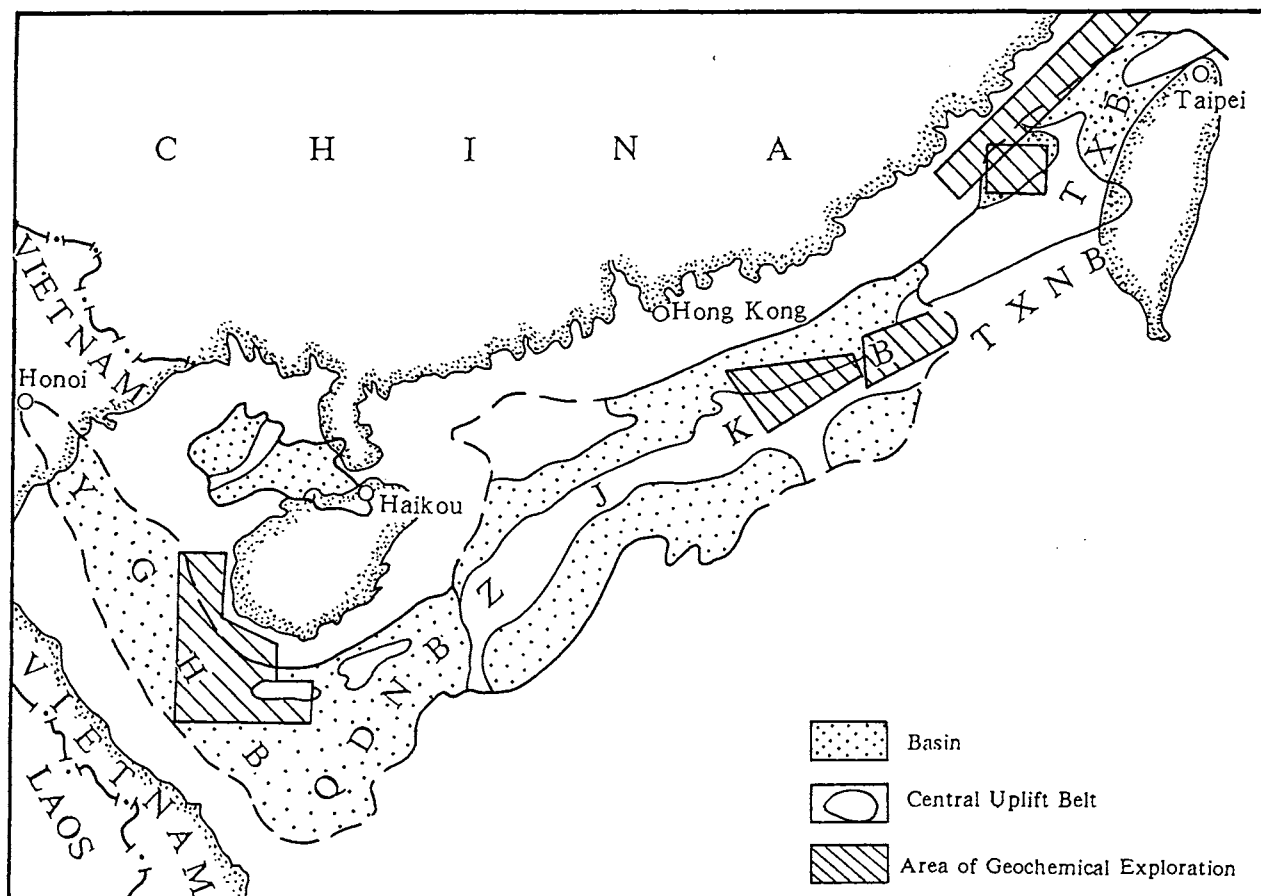
### GEOCHEMICAL ANOMALIES ABOVE OIL/GAS FIELDS AND BARREN STRUCTURES

To establish models for comparison, known oil/gas fields and barren traps near the target traps were studied with the same methods as those applied to target traps. Geochemical anomalies above oil/gas fields appear quite different with those above barren structures.

A geochemical section of 134 km in length was deployed across the Huizhou depression of the ZJKB (Fig. 2). A geochemical anomaly including 11 indices was found above two oil fields HZ21 and HZ27, which contain commercial oil and gas at about 2,100 m depth. Phenol and methane in bottom seawater have the highest anomaly contrast,  $C_{2+}$ ,  $C_{2+}/C_1$ , fluorescence intensity of sediments, and Hg in air and bottom seawater also show clear anomalies.

Cross sections show that geochemical anomalies above an oil field LF22 differ remarkably from those above a dry structure HJ32 in the ZJKB (Fig. 3). Median contents of gaseous hydrocarbons are 4 to 7 times higher above LF22 than those above HJ32. Gaseous hydrocarbons, phenol, and mercury in seawater and fluorescence in both sediments and seawater also show high anomalies on LF22.

Irregular sampling above YA13-1 big gas field in the YGHB found low content of gaseous hydrocarbon above the center of the field, but half-circular anomalies of hydrocarbons appear above the faults along the NW and SW margins of the field (Fig. 4a). The ratio of  $C_{2+}/C_1$  shows an anomaly above the field (Fig. 4b), indicating a thermal origin of the gas. Characteristic peaks of light aromatic hydrocarbons were found in the spectrum of total scanning fluorescence (TSF) and in the derivative curve of ultraviolet intensity. These features differ from those for barren area, where hydrocarbons are very high but  $C_{2+}/C_1$  ratio is low. The low hydrocarbon above YA13-1 is interpreted by the



**Figure 1.** Sedimentary basins and areas of geochemical exploration on the northern shelf of the South China Sea. YGHB — Yinggehai Basin, QDNB — Qiongdongnan Basin, ZJKB — Zhujinagkou (Pearl River Mouth) Basin, TXNB — Taixinan (SW Taiwan) Basin, TXB — Taixi (West Taiwan) Basin.

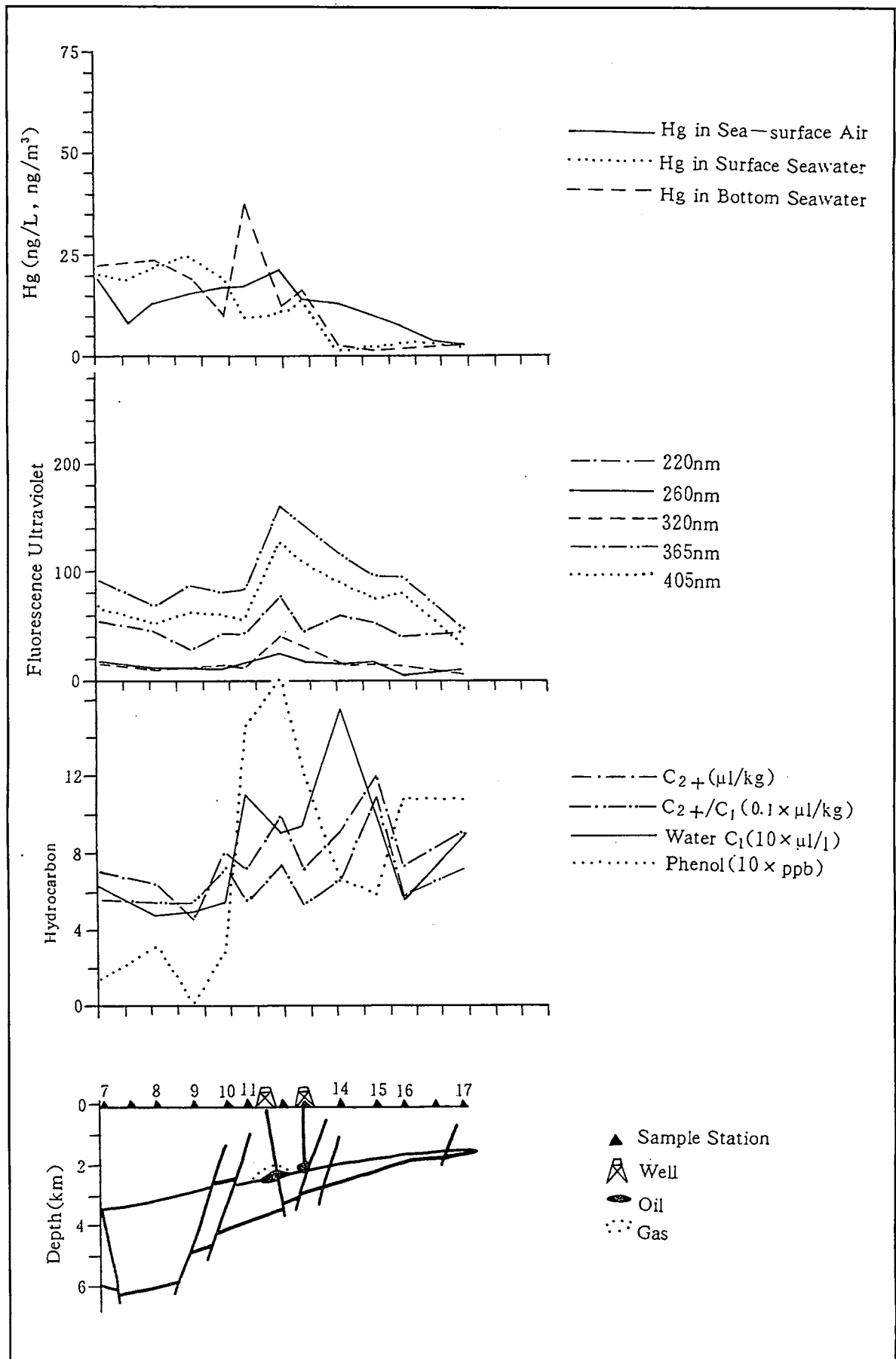
**Table 1.** Methods and major indices used in geochemical exploration for oil/gas in the northern South China Sea.

METHOD	SAMPLE MEDIUM AND MAJOR GEOCHEMICAL INDICES			
	Air	Seawater	Sediments	Pore Water
Mercury Detection	Hg	Hg	Hg (Heat-released)	
Hydrocarbon Detection		Gaseous hydrocarbon, Phenol, Benzene, etc.	Gaseous hydrocarbon	
Ultraviolet spectrum		216–296 nm	216–296 nm	
Fluorescence spectrum		320–450 nm	320–450 nm	
TSF <sup>1)</sup>			200–500 nm	
ICP <sup>2)</sup>				Na, Ca, Mg, B, Sr, Ba, Zn, Al, Ti, Cu, Cr, Fe, Mn, Ni
Alternated Carbonate			$\Delta C$	
Isotope			$\delta^{13}C_1$	
GC/MS <sup>3)</sup>			$C_1-C_{30}$	

1) Total Scanning Fluorescence.

2) Inductively coupled plasma emission spectrometry.

3) Gas chromatography/mass spectrometry.



**Figure 2.** Geochemical anomalies above HZ21 and HZ27 oil fields in the Huizhou Depression of the Zhujinagkou Basin.

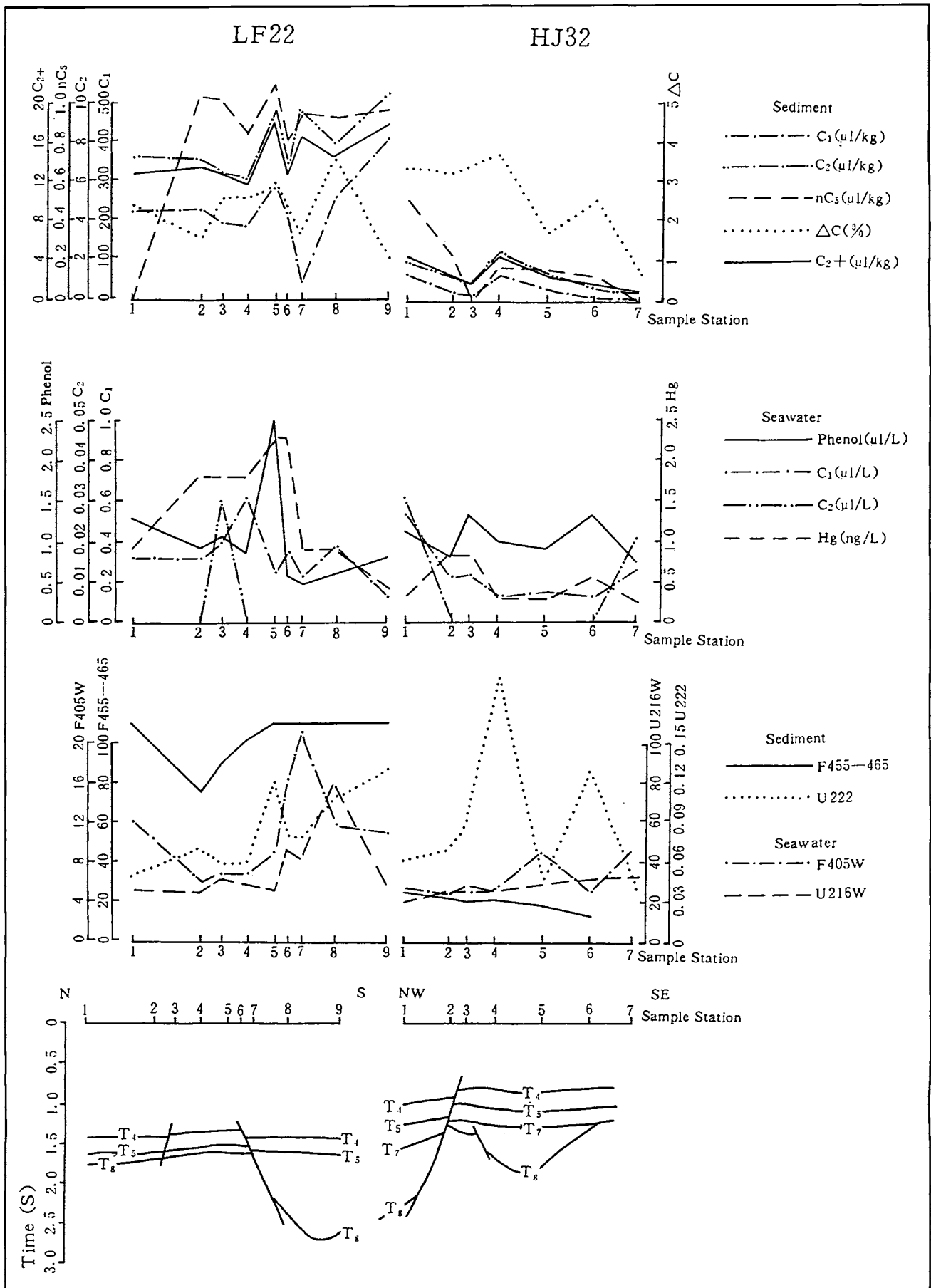
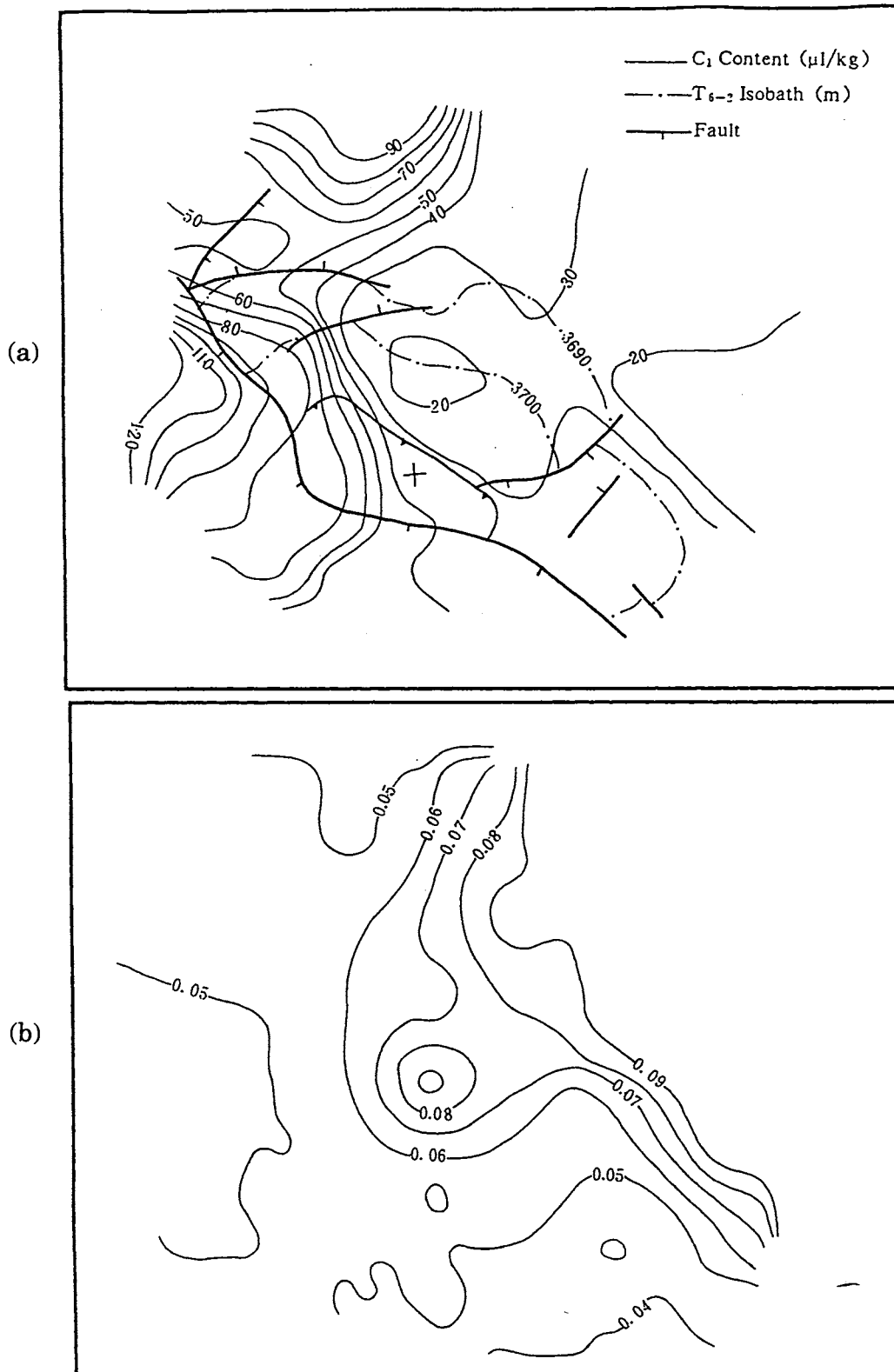
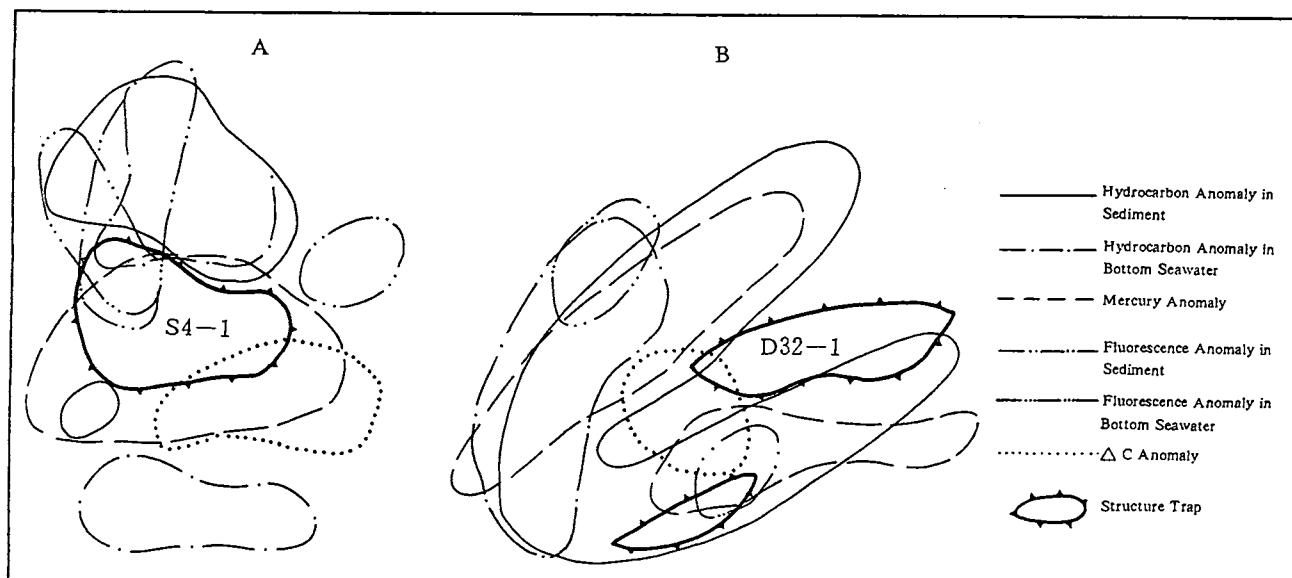


Figure 3. Geochemical anomalies above the oil field LF22 and the barren structure HJ32 in the Zhujiangkou Basin.



**Figure 4.** Contours of (a) methane and (b)  $C_{2+}/C_1$  ratio above YA13-1 gas field in the Yinggehai Basin.



**Figure 5.** Examples of composite geochemical anomalies in target area. (A) The anomaly A above S4-1 structure in the Zhujiangkou Basin. (B) Half-circular anomaly B above the D32-1 structure in the West Taiwan Basin.

excellent sealing of cap strata and the barren erosional window on the yield horizon in the center of the field. Natural gas is rather abundant in the YGHB, as indicated by the high hydrocarbon content in sediments in barren areas. The most important factor for forming gas-field in the basin is the cap condition. Thus "negative" hydrocarbon anomaly together with positive  $C_{2+}/C_1$  anomaly may be a favorite anomaly combination in this particular basin.

### EVALUATION AND RANKING OF TARGET TRAPS

Selected structures, stratigraphic traps, or AVO anomalies in several regions were evaluated and ranked according to the characteristics of associated geochemical anomalies. The knowledge on organic geochemistry and on characteristics of geochemical anomaly above known oil/gas fields was used to guide the evaluation. Test results so far available agree quite well with our geochemical evaluation.

Figure 5 provides two highly ranked composite geochemical anomalies. The composite anomaly A is 125 sq km in area and composed of 27 indices, among which 8 indices have high to medium anomalies. A zonation is seen with high mercury anomaly in the center and others in the surrounding. This composite anomaly appears above a buried hill ST4-1 in the eastern ZJKB. It has Paleogene lithologic trap capped by Neogene mudstone layers. The composite anomaly B is 115 sq km in area. It appears as half-circular in shape with its eastern extension not controlled. The anomaly has 12 anomalous indices, among which hydrocarbons in

sediments are of the highest and largest anomalies,  $C_{2+}/C_1$  in sediments, hydrocarbon in seawater, mercury in sediments and seawater, and fluorescence intensity of sediments are also of high anomalies. This composite anomaly circumscribe the structure JM32 on the northern flank of a depression in the TXB. Hydrocarbon ratios and carbon isotope of methane in sediments of the anomaly indicate a thermal origin of hydrocarbons.

### DISCUSSIONS

In our experiences composite geochemical anomalies often appear above oil/gas fields and promising traps in the sea-surface air, seawater, and near-seafloor sediments. However, features of composite geochemical anomalies may vary with geological background and the geochemistry of the fields. In many cases high or medium anomalies of gaseous alkane,  $C_{2+}/C_1$ , phenol, high-wavelength fluorescence intensity, mercury, and certain TSF peaks are rather informative. They form various associations and appear on top or along the edges of the field or trap, forming halo-shaped, circular or half-circular composite anomalies. Vague areal zonation is seen for times, with mercury and/or phenol anomalies in the center and other anomalies along edges (e.g., Fig. 5B). Anomalies in seawater and sea-surface air have some drift with respect to the location of the trap. Vertically the content of gaseous compounds often decrease upwards, showing the upward dispersion of the compounds.

The differentiation of biogenic and thermogenic hydrocarbon in the anomalies has been a major difficulty in anomaly interpretation. In the areas

we have worked, values of methane  $\delta^{13}\text{C}$  in sediments from the surveyed areas range in  $-33\%$  to  $-38\%$ , indicating a dominance of thermal origin for the hydrocarbon in the area. Anomalies of alkane, ultraviolet intensity, and iso-alkane as well as a  $\Delta\text{C}$  anomaly without associated alkane anomaly are often indicative of higher portion of biogenic hydrocarbon.

## REFERENCES

- BROOKS, J.M., KENNICUTT II, M.C. AND CAREY JR., B.D., 1986. Offshore surface geochemical exploration. *Oil & Gas Journal* 85(42).
- CHEN, H.Z., DI ZHOU, PING WANG AND WANG, W.X., 1990. Mercury anomalies in the Liyue (Reed) Bank, South China Sea and their geological significance. *China Offshore Oil and Gas (Geology)*, 4(3), 7-12, in Chinese.
- CHEN, H.Z., DI ZHOU AND PING WANG, 1994. Mercury geochemical investigation in the sea area of Nansha Islands.
- CHEN, S.Z. AND LI, D.S., 1992. Retrospect and prospect of the petroleum exploration and development in the eastern Zhujiang River Mouth Basin. *China Offshore Oil and Gas (Geology)*, 6(2), 21-22, in Chinese.
- DUCHSCHERER JR., W., 1986. Delta carbonate geochemical hydrocarbon prospecting. *Unconventional Methods in Exploration for Petroleum and Natural Gas IV*, 173-182.
- FABER, E. AND STAHL, W., 1984. Geochemical Exploration for hydrocarbons in North Sea. *AAPG Bull.*, 68(3), 363-386.
- HORVITZ, LEO, 1986. Hydrocarbon geochemical prospecting after thirty years. *Unconventional Methods in Exploration for Petroleum and Natural Gas IV*, 147-161.
- RU, KE, DI ZHOU AND HAN-ZONG CHEN, 1993. Basin evolution and hydrocarbon potential of the northern South China Sea. In: Zhou, Di et al. (Ed.), *Oceanology of China Seas*, 2. Kluwer Academic Publishers, Dordrecht, 361-372.
- SAUNDERS, D.F., BURSON, K.R., BROWN, J.J. AND THOMPSON, C.K., 1993. Combined geological and surface geochemical methods discovered Agaritta and Brady Greek fields, Concho Country, Texas. *AAPG Bull.*, 77(7), 1219-1240.
- SCHIENER, E.J., STOBER, G. AND FABER, E., 1985. Surface geochemical exploration for hydrocarbons in offshore areas — principals, methods and results. *Petroleum Geochemistry in Exploration of the Norwegian Shelf*, 223-228.
- YANG, YU-BIN, 1987. Retrospect and prospect of geochemical exploration for oil & gas in China. *Oil & Gas Geochemical Exploration*, 1987(5), 1-7, in Chinese.
- ZHANG, Q.M., 1992. The western portion of the northern shelf of the South China Sea — the most reliable area for exploiting natural gas. *China Offshore Oil and Gas (Geology)*, 6(2), 11-12, in Chinese.
- ZHOU, DI, 1985. Adjust geochemical background by robust multivariate statistics. *J. Geochem. Explor.*, 24, 207-222.

---

Manuscript received 2 December 1994