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The Hydrocarbon Potential and Tectonics of Indochina

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Abstract: Indochina covers a wide area between the South China Sea and the Bay of Bengal. The eastern half of the region is selected for tectonic analysis study and hydrocarbon potential investigation.The Kontum Massif, composed of a metamorphosed basement complex, seems to be the core of the Indochina region, and crops out from eastern Vietnam to Laos and Kampuchea. The concept of concentric growth of orogenic belts along the periphery of this massif seems to have been accepted as being within the scope of the classic theory of orogeny. The application of a modern plate tectonic hypothesis with the aid of LANDSAT image analysis, has however enabled a new interpretation of the tectonic development of the area to be made.

The hydrocarbon potential of Indochina is here investigated, based on this interpretation of the region's tectonic development,taking into account the morphological and textural characteristics detected from the LANDSAT imagery and integration with fundamental geological factors. Three areas, (1) the Mekong Delta, (2) the Khorat Plateau, and (3) the Hanoi Basin, are selected for detailed discussion on their hydrocarbon potential.

INTRODUCTION

A geographical definition of Indochina is *"the southeastern part of Asia between the Bay of Bengal and the South China Sea including Vietnam, Laos, Kampuchea, Thailand, Malaya and Burma"*. The objective area for this study is roughly the eastern half of this region.

Basic geological information has been accumulated through activities in which Idemitsu Oil Development Co. has recently participated. Important ones are extensive seismic survey work and the drilling of exploratory wells in the Gulf of Thailand; technical and financial cooperation with the Burmese state oil company (called MOC) for exploration in the Gulf of Martaban; exploration in the Beibu Gulf of the People's Republic of China, with subsequent participation in the development and production operation of the first oil field there; extensive exploration activities in the Block SK-1, offshore Sarawak, Malaysia and drilling of several exploratory wells in the Bay of Bengal. Based on information accumulated through these activities, the author attempts here to analyze the tectonics of Indochina, and to evaluate the hydrocarbon potential of the area. The scarcity

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of relevant geological data has, however, made this somewhat difficult against the author's will.

LANDSAT imagery is widely accepted to be of use in preliminary evaluation for hydrocarbon exploration and structural analysis, particularly for areas for which base maps are not available or geological information is limited. Moreover, the low data acquisition costs make imagery an especially attractive research tool (Sabins, 1978) and its uses in the exploration for subsurface resources have been widely discussed.

In this context, Halbouty (1976) noted in an important paper that "LANDSAT imagery can be used effectively to outline sedimentary terrains". The same author subsequently investigated the LANDSAT imageries for 15 giant oil and gas fields, and showed that the method is indeed valuable in initial exploration programmes *(Halbouty,* 1980).

A case study of North China Basin and Burma made by the present author (Hayashi, 1983), confirmed the validity of the method. LANDSAT imagery was therefore chosen for this study on Indochina and the results were integrated with published geological information including geological maps (Academy Geol. Sci. China, 1975; UNESCO, 1976; General Dept. of Geology, Vietnam, 1973, 1986) a tectonic map (Comm. Geol. Map of the World, 1982) and various published papers in order to explain the relevance of the various anomalies delineated and also to assess the hydrocarbon potential of the region.

LANDSAT MOSAIC

A photo mosaic of LANDSAT imageries of the eastern part of Indochina was prepared at a scale of 1:1,000,000. MSS (Multi-Spectral Scanner) Band-7 imageries were used in this study. This wavelength proved to be more suitable than MSS Bands 4,5 and 6, because the imageries of Band-7 are, in general, relatively little.affected by the vegetation cover, therefore, geological surface anomalies seem to be clearly delineated. Consequently, Band 7 imageries recorded during the dry season (to minimize the effect of vegetation and cloud cover) from 1973 to 1979 were used to create the mosaic. Individual imagery covered an area of 34,385 sq kms (185 X 185 kms) with some duplication between neighbouring imageries.

INTERPRETATION OF LANDSAT IMAGERY

Fig. 1 is an interpretation of the LANDSAT photo mosaic. Surface anomalies, which reflect both changes in textural and structural characteristics, have been detected; these anomalies, including lineaments, circular anomalies and strike ridges, were selected as the objectives of more detailed interpretation.

Two groups of elements were found to be particularly distinctive: (1) a group of lineaments generally trending SE-NW located in northern Vietnam and

southern China (the "Red River lineament"); (2) a group of lineaments and traces of strike ridges trending SSW-NNE from northern Thailand through northern Laos to northern Vietnam, and disappearing by collision with the Red River Lineament. The former coincides with the Song Chay (Red River) Fault Zone, and the latter with the Dien Bien Phu Fault Zone (Fig. 2). These two groups of lineaments divide the Indochina region into three subareas.

The geological structure of northern Vietnam has recently been investigated by a number of Vietnamese and Soviet geologists (Izokh & Nguyen 1965, Morgunov 1970, Nguyen 1972, Staritskiy *et al.* 1973). A number of deep-seated normal faults with vertical or steep dips, trending NW-SE, have been recognized. Some of these faults, such as the Cao Bang-Lang Son, Song Da, Song. Ma, Song Lam and Rao Nai Fault Zones, are traceable in the interpreted LANDSAT imagery as shown in Fig. 2.

The Song Chay Fault may extend to the southeast, possibly being connected with a large fault cutting magnetic basement rocks to the west of Hainan Island (Li, 1984). The occurrence of two ophiolite belts in northern Vietnam (Hutchison, 1975) seems to be closely related to the Song Da and Song Ma Fault Zones. The Dien Bien Phu Fault Zone has a completely different trend, however, and may extend to the south and seems to be connected with the Uttaradit ophiolite (Thanasuthipitak, 1978) in northern Thailand (Fig. 2). The theory that Indochina is divisible into three subareas is thus supported tectonically by the presence of ophiolites which are often observed in sutures of plates, although it should be noted that ophiolites have not yet been recognized in the Dien Bien Phu Fault Zone (General Dept. of Geology, 1973. General Dept. of Geology, 1986). Indochina may therefore in fact have resulted from the collision of three plates. The sutures indicated by these ophiolite belts are named the Song Da and Uttaradit-Dien Bien Phu Sutures (Fig. 3). These three plates separated by these sutures are here tentatively named as the Kontum, Shan-Thai, and South China Plates.

The Song Da Suture seems to be connected with a tectonic line in the Gulf of Tonkin (Valencia, 1985). The tectonic line controls the basin configuration with large vertical displacement rather than horizontal movement. It indicates that the origins of thetectonic line and the Song Da Suture are of a rifting nature.

FUSION OF THREE PLATES AND FORMATION OF INDOCHINA

Based on the distribution and age of igneous rocks in northern Thailand, and the occurrence of ophiolites in the Uttaradit area, the hypothesis of a westward dipping subduction of the Kontum Plate under the Shan-Thai Plate in the Paleozoic has been proposed (Thanasuthipitak, 1978; Chantaramee, 1978; MacDonald & Barr, 1978; Bunopas & Vella, 1978; Hamilton, 1979; Ridd, 1980). A westerly direction of subduction is suggested on account of the distribution of volcanic rocks in northern Thailand, which show a consistent age zonation, with

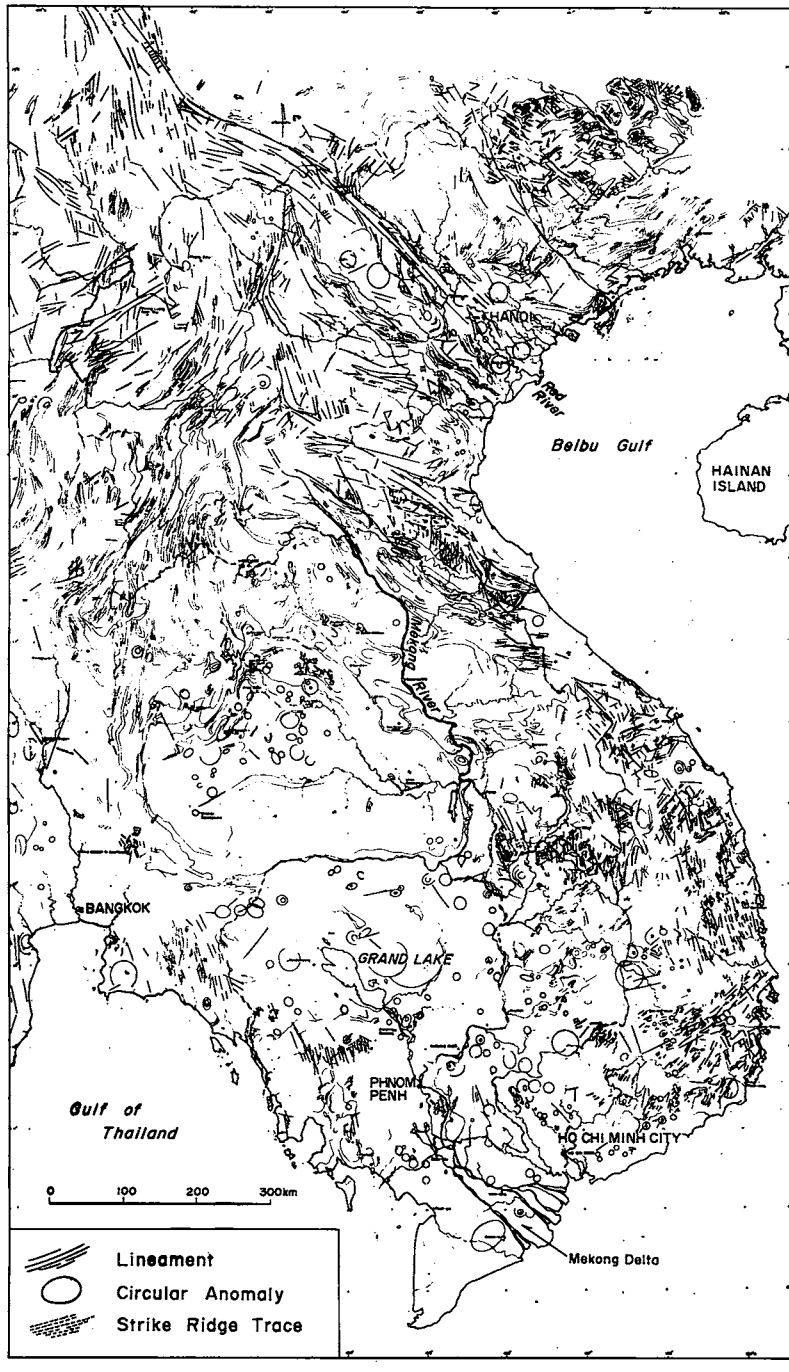

Figure 1 : Interpretation of LANDSAT Imagery

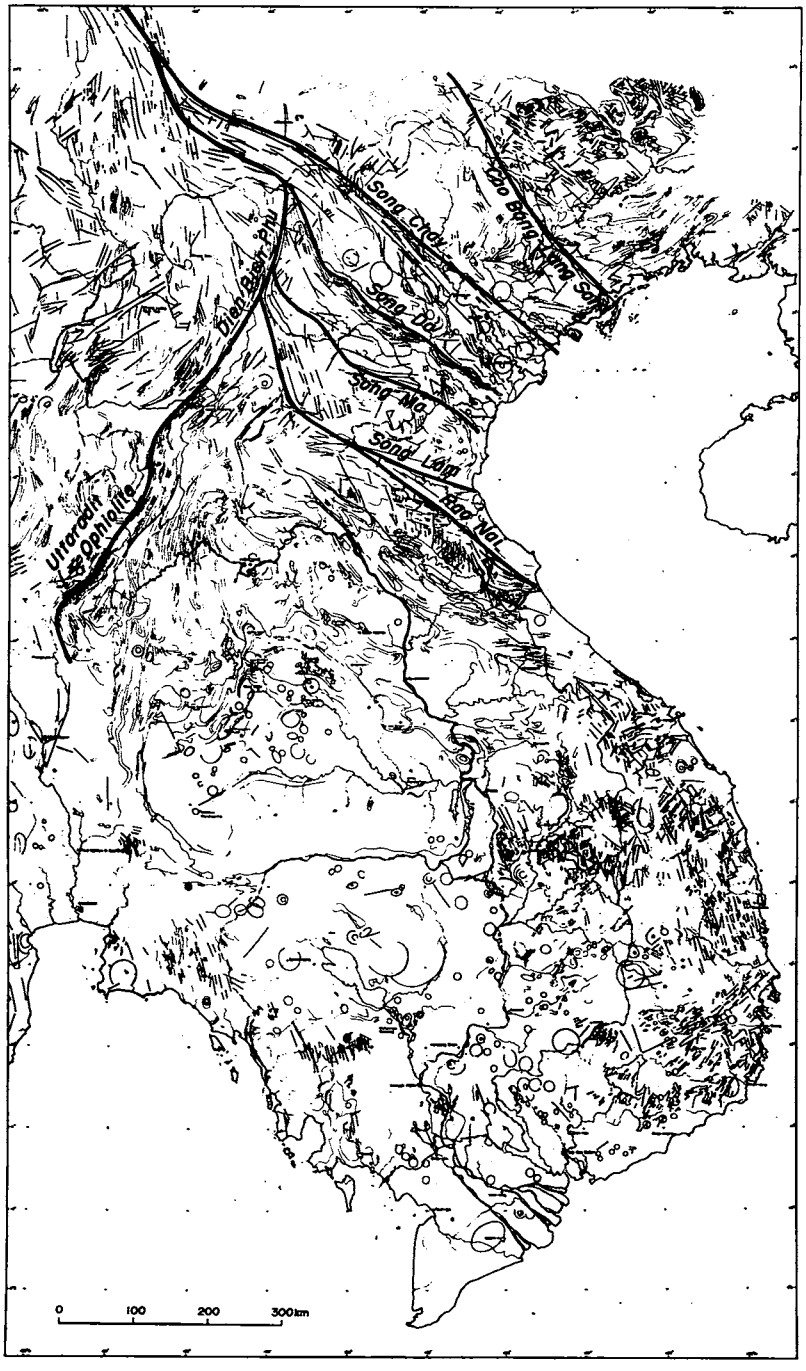

Figure 2 : Fault zones in Nothern Vietnam

Figure 3: Sutures and Plates in Indochina

rocks becoming older to the west and younger to the east, ophiolites being located on the eastern side. A schematic subduction model for the Shan-Thai and Kontum Plates is shown in Fig. 4; it is believed that fusion of these two plates formed the Indochina Plate.

The subduction relationship between the Indochina and South China Plates is not certain, since there are differing views on the structural vergence of the region. For example, in the Hanoi Basin, the basement descends by step faults to northeast (Morgunov 1970). On the other hand, the Song Da Fault (also known as the Black River Fault) may be an overthrust some 70 kms wide, according to Fromaget (1937). Nguyen (1972) reached a somewhat different conclusion, namely that the Song Da is a large normal fault with a vertical downthrow on its northeastern side.

The present author considers that the South China Plate was subducted beneath the Indochina Plate, because a linear distribution of the Triassic plutonic rocks has been recognized in the area further.southwest of the Song Da and Song Ma opiliolite belts, so a schematic subduction model is summarized in Figs. 5 and 6.

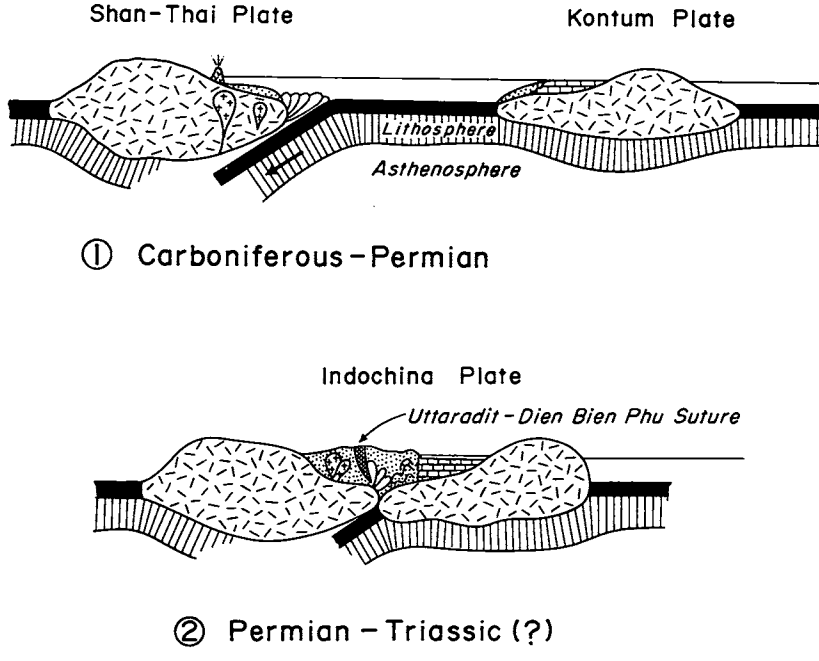

Figure 4 : Schematic subduction model between the Shan-Thai Plate and the Kontum Plate

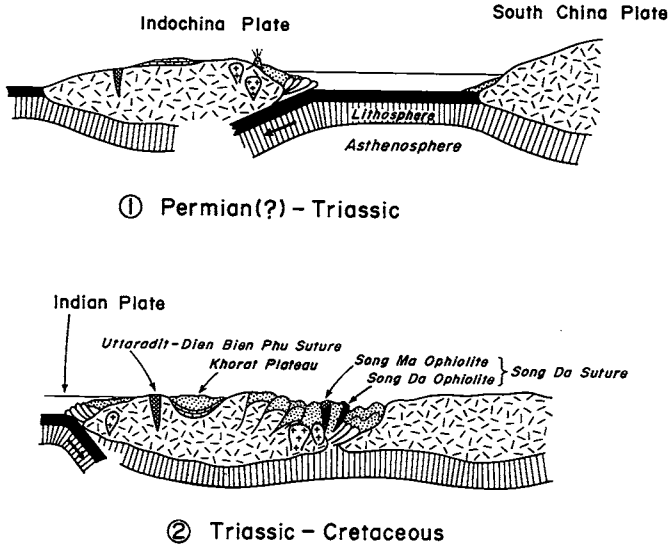

Figure 5 : Schematic subduction model between the Indochina Plate and the South China Plate

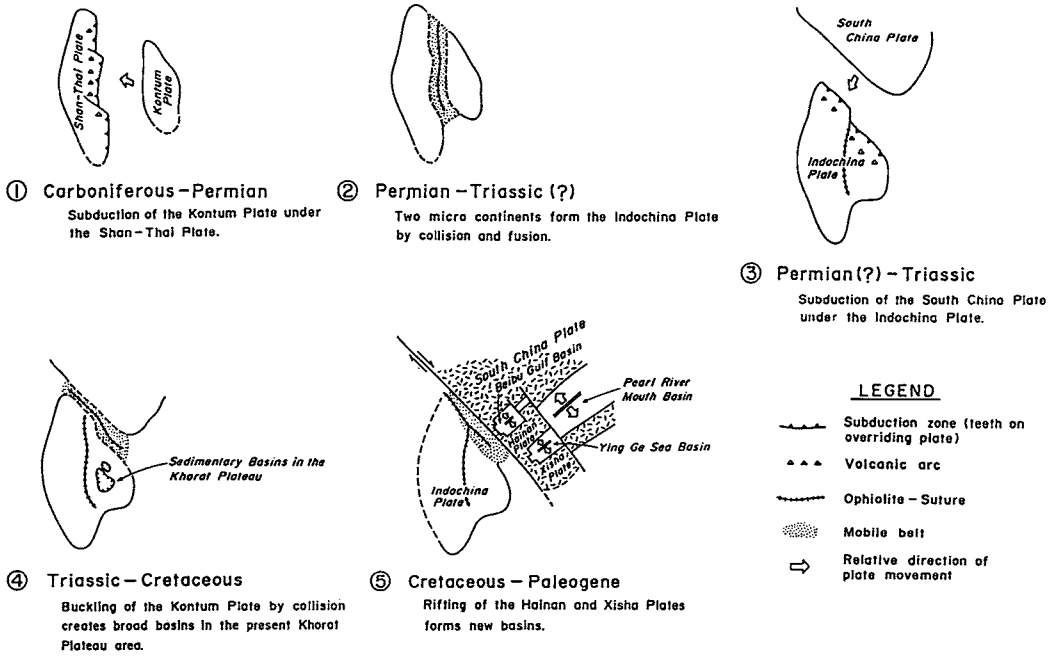

Figure 6 : Tectonic development of Indochina

THE HYDROCARBON POTENTIAL OF INDOCHINA

Many sedimentary basins have developed in Indochina and the adjacent regions. Of these, the Gulf of Thailand Basin (the Pattani Trough and the Chumphon Basin), the Phitsanulok Basin (central Thailand), the Beibu Gulf Basin of the People's Republic of China, and the Vung Tau Basin (off southern Vietnam) are hydrocarbon producing areas.

In the region under study, three areas are suggested as future objectives for hydrocarbon exploration, based on both the interpretation of LANDSAT imagery and the results of current exploration activities. These are (1) depressions in the Khorat . Plateau and adjacent areas; (2) the Mekong Delta; and (3) the Hanoi Basin and its offshore extension, the Gulf of Tonkin (Fig. 7).

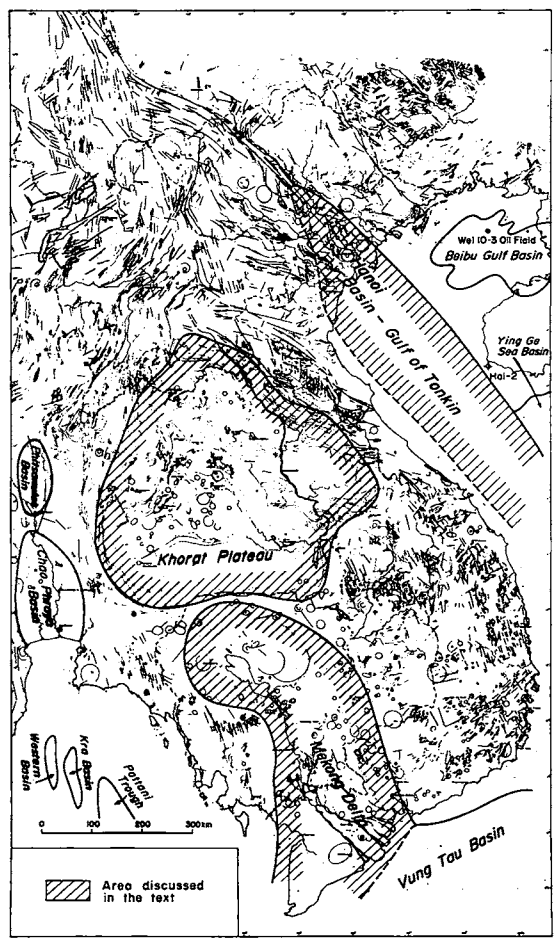

Figure 7 : Petroleum provinces in Indochina

The Khorat Plateau

Several basins have been formed in the Khorat Plateau area but until recently it was considered that they are floored by basement rocks, with the intervening Paleozoic strata thin or absent (Workman, 1975). However, exploratory wells drilled in the area have revealed the presence of thick Permian limestones (Sasaki, 1985). Extensive exploration activities since 1979 have resulted in the discovery of several gas pools in these Permian carbonates. About ten wells have been drilled in this area, all located on large anticlinal closures identifiable on the LANDSAT imagery.

Detailed interpretation of LANDSAT imagery has also revealed the presence of many other undrilled anticlinal closures (Fig. 1). It is expected that geological conditions similar to those in Thailand extend to Laos (Workman, 1981); hence, new discoveries might therefore be made in this area in the future. However, the results of previous exploration suggest that the area is gas prone, and the probability of locating liquid hydrocarbons is small.

The Mekong Delta

The discovery of oil in adjacent offshore areas has been reported (Du Bois, 1985). It is suggested that the Vung Tau Basin may become of world scale importance in terms of hydrocarbon exploration.

The onshore part of the basin has a Quaternary cover, and basement outcrops are observed in several localities. The existence of a sedimentary basin beneath the Quaternary beds is not certain. Fontaine and Workman (1978) predicted the existence of a buried NW-trending fault between Ho Chi Minh City (formerly Saigon), Pnomh Penh and the Great Lake, and hence the development of a graben of aulacogenic origin may be a possibility here. Such structures are known to host prolific hydrocarbon accumulations elsewhere in the world such as the Gulf of Suez, the Sirte Bäsin, The Cambay Basin etc.

Furthermore, LANDSAT imagery of the area is characterized by the presence of many circular anomalies, representing tonal anomalies. Tonal anomalies are thought to show a high correlation with hydrocarbon occurrences in petroliferous basins (Halbouty, 1976, 1980). Therefore, exploration activity should be concentrated in this region.

The Hanoi Basin-Gulf of Tonkin

Discoveries of hydrocarbon in the Hanoi Basin have been documented in a number of publications (*International Petroleum Encyclopedia* 1985; *Oil and Gas Journal* 31/7/1978, 23/10/1978, 2/8/1982). One of the fields is called "Tienhung C" and has produced gas and condensate since its discovery in 1975 (United Nations, 1987). Information on the petroleum geology of the region, in general, is very scarce and it has been very difficult to assess the hydrocarbon

potential of the region. However, following the progress of exploration activities in the Beibu Gulf and in the Ying Ge Sea (offshore south Hainan Island) basins in China, the disclosure of geological information has increased, and the general area is now considered to be prospective for hydrocarbons.

The Hanoi Basin is separated from these basins in China by a tectonic line (Li, 1984; Lin, 1984); basin development here seems to have had a different origin. The possible generation of oil in the Gulf of Tonkin as an extension of the Hanoi Basin, is suggested by the discovery of low wax, low pour point crude oil in the Hai-2 Well (Fig. 7), which was drilled in the southwestern offshore of the Hainan Island in early 1960 (Guo & Chen, 1985). The properties of this crude oil are totally different from oils found in the Beibu Gulf and in the Ying Ge Sea. High wax content and high pour point of latter suggest an origin in nonmarine source rocks (Tissot & Welte, 1978). Although two deep wells, Ying-1 and Ying-2, were drilled in the Gulf of Tonkin down to the middle Miocene (Wu *et al.*, 1981), it is concluded that the source rock potential of the interval is low (Su, 1981). The oil located in the Hai-2 Well may therefore have migrated from the deeper parts of the Gulf of Tonkin through faults, where source rocks of marine origin were buried sufficiently deeply for oil generation to take place.

The plate tectonic model described above suggests that the Hanoi Basin and Gulf of Tonkin have been regions of marine sedimentation since the Paleozoic. The development of the Paleozoic formation in the Hanoi Basin has indeed been recognized (Morgunov, 1970). After the continental collision between the Indochina and South China Plates, a depression in the Song Da suture zone was preserved, and shallow to deep marine sedimentation took place within it during the Late Mesozoic. It is notable that in other parts of the world, many collision type plate boundaries have proved to be important oil producing areas (Hayashi, 1985).

In the Cenozoic, the Song Da suture gave rise to wrench faulting and rifting (as indicated by the presence of mylonite belts: Fontaine & Workman, 1978). The linear distribution of the Neogene sediments in the grabens, and the high temperatures recorded during the drilling operations in the Hanoi Basin (*Oil and Gas Journ.*, 23/10/1978), suggest subsequent rifting. However, the lack of volcanic activity in the Song Da suture zone indicates that this may not have been severe.

Magmatic activity caused by subduction and continental plate collision in the Hanoi Basin-Gulf of Tonkin area may have supplied the heat required for the maturation of hydrocarbons in the Paleozoic and Mesozoic source rocks there.

CONCLUSION

The tectonics and hydrocarbon potential of Indochina have been studied, based on the integration of interpretation of LANDSAT imagery with published

geological data. It is shown that ophiolite distribution is closely related to the lineaments and strike ridges delineated on LANDSAT imagery.

Two geosutures (the Uttaradit-Dien Bien Phu and Song Da sutures) have been identified in the Indochina region. Fusion of the Kontum and Shan-Thai Plates along the former line created the Indochina Plate; fusion of this plate with the South China Plate along the latter suture line formed Indochina as it is known today.

It is suggested that hydrocarbon exploration should be concentrated in three areas; (1) the Mekong Delta, which seems to have had an aulacogenic origin of the type often associated with prolific hydrocarbon accumulations; (2) the Khorat Plateau, where several gas fields have already been discovered, and where additional gas discoveries may be located in the many identified but undrilled anticlinal closures; (3) the Hanoi Basin-Gulf of Tonkin region, which may become one of the most important areas for hydrocarbon exploration in Indochina, as indicated by its sedimentary and paleoheat history since the Paleozoic.

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