中国、东南亚湖相盆地油气勘探国际学术研讨会
INTERNATIONAL SYMPOSIUM ON OIL & GAS EXPLORATION IN LACUSTRINE BASIN

HEDBERG RESEARCH CONFERENCES

OCT. 16~20. 1995

山东 中国 东营

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INTERNATIONAL SYMPOSIUM ON OIL & GAS EXPLORATION IN LACUSTRINE BASIN

中国山东省东营市
Dongying, People's Republic of China

摘　要
ABSTRACTS

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Please note that the original book of abstracts contained both Chinese and English translations of the abstracts. Only the English translations are included here.

前言

H·D·赫德伯格(Hedberg,Hollis Dow)是美国著名的石油学家、地质学家,1960年获美国石油地质家协会鲍尔奖,1980年获美国地质协会的彭罗斯金质奖章。并将石油地质研讨会命名为Hedberg Research Conferences (H. R. C. 会议)。近几年,先后在美、英、法、加拿大、墨西哥等国举办了五次H. R. C. 会议。

中国是提出陆相生油理论的最早国家,大庆、胜利等陆相大油田勘探、开发进一步丰富了陆相成油理论。受美国石油地质家协会的委托,首次在中国东营市举行“中国、东南亚湖相盆地油气勘探研讨会”,会议主题是“开拓湖相盆地油气勘探”。会议摘要汇集了中国、美国、印尼、泰国等国24个湖相盆地54篇优秀论文(其中展版论文9篇),涉及石油地质、地球物理、地球化学、地层学等多门学科。相信,通过本次专题研讨会的交流,将有助于促进湖盆油气勘探的发展。

感谢

对中国科学技术委员会的关注,和中国石油天然气总公司的指导,以及美国石油地质家协会的信任表示衷心的感谢,对来自世界各国160余名代表致以热情的欢迎。

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FORWARD

Hollis Dow Hedberg is a noted American petroleum expert and a geologist who won Sydney Power Memorial Award from the American Association of Petroleum Geologist in 1960 and in 1980 won Penrase Medal. The Association named the Petroleum Geology Symposium as Hedberg Research Conference(H. R. C.). In recent years five H. R. C. meetings have been held in America, Britain, France, Canada and Mexical.

China is the first one to advance the theory which hydrocarbon generating from lacustrine source rock which were proved and enriched by exploratory and exploitive practice of big oilfields of continental facies in Daqing and Shengli Oil Provinces. Entrusted by the Petroleum Geologist Association, the Conference of Petroleum Exploration of the lacustrine basins in China and Southeast Asian is to be held in Dongying, China. The theme on the conference is "to pioneer oil—gas exploration in lacustrine basins". The abstracts in this Simposium have collected 54 excellent papers from China, America, Yindonisia and Tailand etc., including 9 poster sessions, in which the contents involve multiple sciences such as petroleum geology, geophysics, geochemistry, and stratigraphy etc.. We have full confidence that technology exchanges on the conference will surely accelerate the exploration and exploitaion of the lacustrine basins.

ACKNOWLEDGEMENT

sincerely acknowlegement is given to the concern of China Science and Technology Committee and guidence of China National Petroleum Corperation and American Association of Petroleum Geologist and warmly welcome to 160 representatives from all parts of the wold.

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PETROLEUM SYSTEMS IN EAST CHINA MESO-CENOZOIC RIFT BASINS

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Under strong subduction of the Pacific Plate, the East China craton suffered strong regional tensional and tensile-shearing stress. These stresses formed a series of Meso-Cenozoic rift basin zones including the Songliao, Enenhot, Bohai Gulf, Subei, Nanyang-Biyang and Jianghan petroliferous basins.

There are three lacustrine petroleum systems developed in East China rift basins, (1) the Paleogene petroleum systems, (2) the Lower Cretaceous petroleum systems and (3) the Jurassic petroleum systems.

Each Meso-Cenozoic rift basin behaves as an independent petroleum system, having its own nonmarine source area, which controlled various composite megastructural oil and gas belts surrounding each source area center. A total 306 oilfields and 109 gasfields have been discovered with different types of traps and different source-reservoir-seal formations in the East China Meso-Cenozoic rift basins.

LACUSTRINE PETROLEUM SYSTEMS IN THE FAR EAST

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In areas where substantial oil production has been established, regional crude oil geochemical studies are excellent ways of identifying, evaluating and comparing the various petroleum systems that have contributed to reserves. The number and type of effective source units can be determined by establishing the number of compositionally distinct oil families. Inferences regarding source rock depositional environment are possible since the geochemical characteristics of crude oils reveal important information on paleoenvironmental conditions of source rock deposition and possible age.

In order to better understand the petroleum systems of the Far East, approximately 375 oils from basins in the Circum-Pacific region (Japan, China, Taiwan, Philippines, Vietnam, Thailand, Myanmar, Malaysia, Indonesia, Sarawak, Kalimantan, Irian Jaya, Papua New Guinea, Australia, and New Zealand) have been geochemically analyzed. The detailed analytical program included measurements of bulk parameters (API Gravity, %S, V and Ni content),, stable carbon isotope composition of C15+ hydrocarbon fractions, whole oil gas chromatography, and terpane and sterane biomarker distributions using GC/MS. The analytical data were compared using multivariate statistical techniques such as cluster and principal component analyses. With this approach a number of general petroleum systems were confidently identified, differing from each other in terms of age, maturity, and type of depositional environment of the source rocks. The geochemical parameters included in the statistical approach (Figure 1) were used to separate the Far East oils into the three broad groups shown in Figure 2: marine, lacustrine and terrigenous. Further detailed examination of each group of oils, sometimes using more specific geochemical criteria, typically resulted in the establishment of sub-groups of oils according to specific source environment, such as lacustrine fresh versus lacustrine saline.

More than half of the analyzed oils originated from Tertiary source rocks enriched in terrigenous organic matter deposited in either paralic, fluvial deltaic or swampy environments. These oils are easily characterized by high Pr/Ph, high abundances of low molecular weight tricyclic terpanes and C24 tetracyclic terpanes, low proportions of steranes to hopanes, enrichment of C29 αββ steranes, and variable abundances of oleanane and/or bicadinane, two markers generally associated with Tertiary-aged source rocks receiving significant higher land plant input (angiosperms). These oils are primarily from South Sumatra, Java, Mahakam Delta and Sarawak, but are also found in the Gulf of Thailand, Gippsland Basin, New Zealand, and Taiwan. Marine oils are not as widespread as the nonmarine oils, but are typically derived from Tertiary or Late Cretaceous source rocks. These oils are characterized by high sterane/hopane ratios, high proportions of C31 + terpanes, low Pr/Ph, the presence of C30 n-propyl steranes, and, in several cases, variable abundances of oleanane and/or bicadinane. Marine oils are primarily located in Papua New Guinea, Japan, Northwest Palawan, East Natuna Basin, Tonga, onshore Thailand, East Indonesia, Seram, and Northwest Australia.

Lacustrine oils are widespread in the area and are characterized by variable isotopic compositions, intermediate Pr/Ph ratios, low proportions of steranes to hopanes, an abundance of C26 relative to C25 tricyclic terpanes, high Ts/Tm, abundant extended tricyclic terpanes, low proportions of C31+ terpanes, and, particularly in China, abundant methyl steranes. In addition, bottryococcane was identified in oils from onshore Central Sumatra and the Sunda Basin. Lacustrine oils are from the Malay and West Natuna Basins, offshore Vietnam, Gulf of Thailand, Phitsanulok Basin, Central and South Sumatra, Fast Java Sea, the Philippines, Taiwan, and the Bohai, Beibu Gulf, and Qiongdongnan areas of China.

Both lacustrine and nonmarine oils were identified in several areas, including the Gulf of Thailand, Natuna Sea and South Sumatra. Certain oils from these areas displayed intermediate geochemical characteristics, possibly suggesting commingling of resin-derived and algal-derived oil and/or the existence of a mixed kerogen assemblage.

Certain geochemical characteristics of lacustrine oils can often be used to separate the oils according to source environment. For example, oils that contain relatively abundant gammacerane are thought to originate from lacustrine source rocks deposited in a more saline environment. However, source inferences based on other geochemical parameters can often be misleading and should be made with caution. For example, lacustrine oils are difficult to classify based on carbon isotopes alone because of multiple possible variations in the carbon budget and cycle in lacustrine settings. This is reflected in the large (7 to 8 permil) isotopic variation of the lacustrine oils in the Far East.

A geochemical comparison of Far East lacustrine oils with Cretaceous lacustrine oils from West Africa and Brazil suggests that several geochemical criteria can be used to identify lacustrine oils, regardless of geographic position or source age. For example, the increased abundance of C26 relative to C25 tricyclic terpanes is shared by lacustrine oils from the Far Fast, West Africa, Brazil, and Utah. Similarly, all of these lacustrine oils have relatively low proportions of steranes to hopanes, decreased abundances of extended hopanes, and high relative abundances of a C30 tetracyclic terpane (m/z 259) for which precursor information is presently unknown.

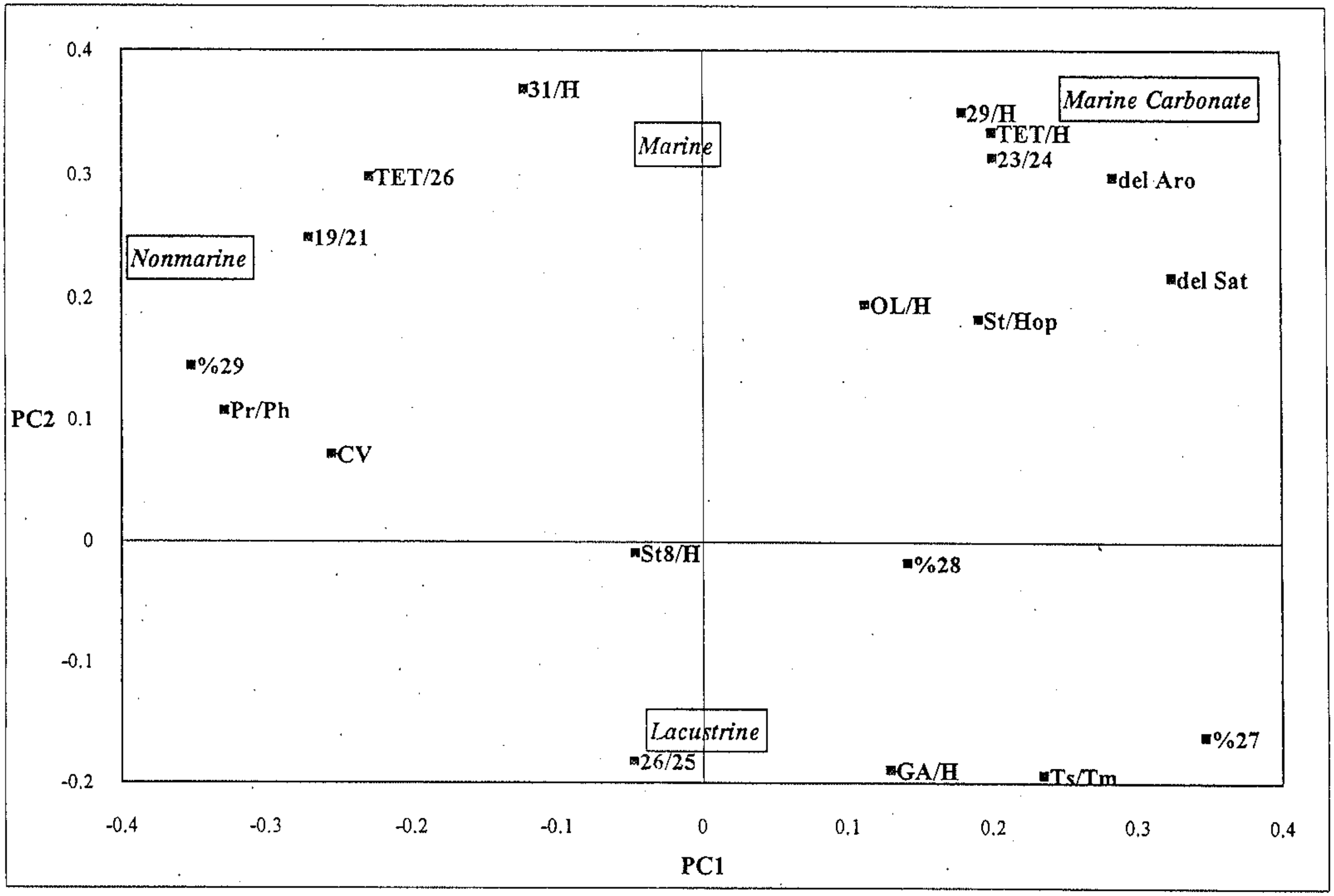

Figure 1. Principal Component Loads Plot: Far East Oils

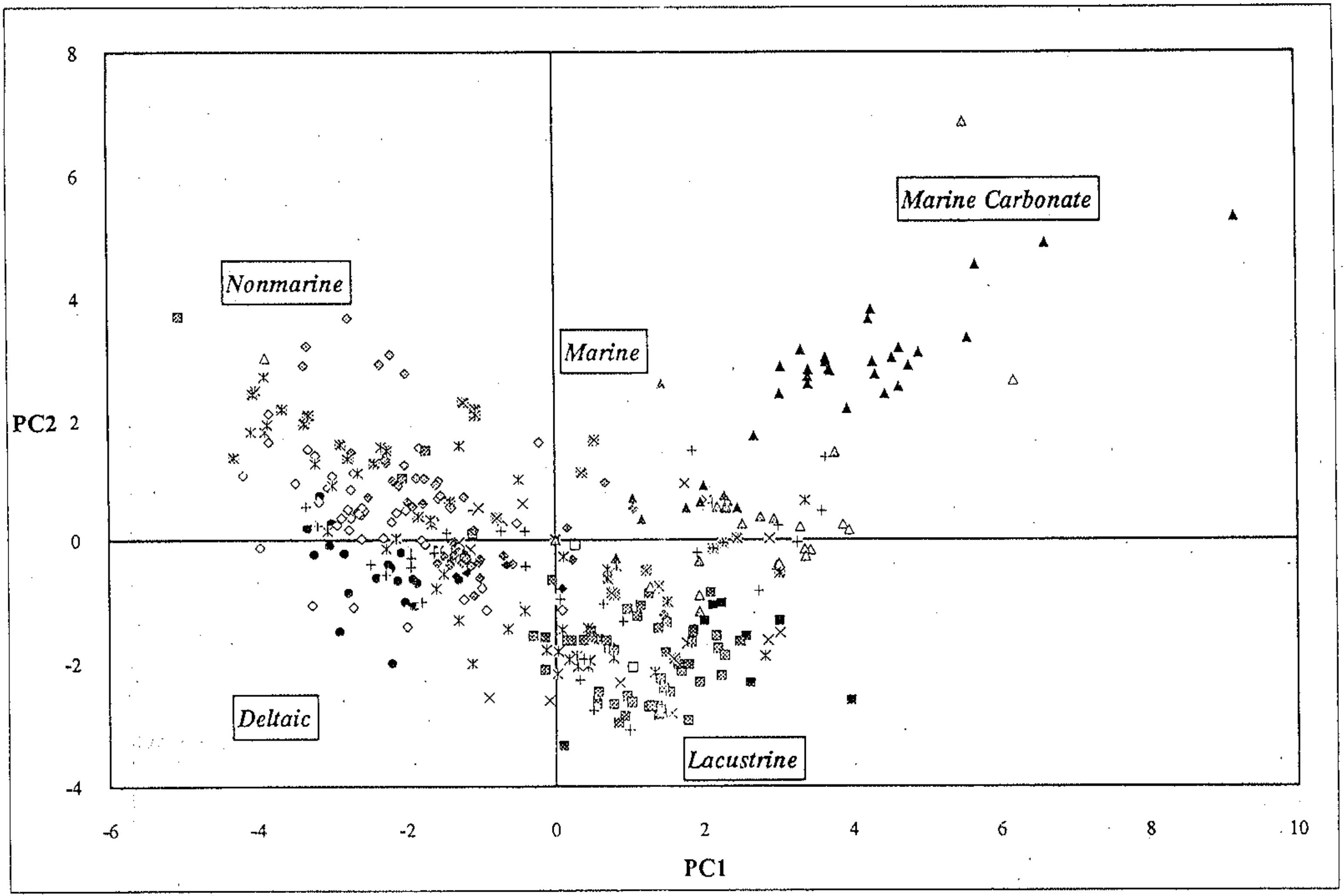

Figure 2. Principal Component Scores Plot: Far East Oils

COMMON FEATURES OF NONMARINE BASINS IN CHINA AND PETROLEUM SYSTEMS

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China discovered some 400 oilfields related to continental genesis in more than 30 nonmarine basins. The proved reserves and oil production from these nonmarine basins accounts for more than 95% of those of China.

The recent tectonic framework of China results from convergence and merging of three paleocontinental blocks: Simo-Korea, Tarim and Yangze. After the Hercynian orogeny, the main Meso-Cenozoic nonmarine basins were formed on either old (Precambrian) or young (pre-Mesozoic) cratons. Only a few of small nonmarine basins were formed in active areas such as collision belts or subduction zones.

The China nonmarine basins are commonly characterized by special regionally tectonic settings, paleoclimate zones, depositional systems, sediment rates, sequence stratigraphic models, and thermal environments that result in good source rock, reservoir, seal combinations.

The petroleum geology of Meso-Cenozoic nonmarine basins are characterized by widely developed source rocks and stacked reservoir sand bodies with favorable diagenetic evolution. This has resulted in multiple petroleum systems vertically controlled by predominant seals and regional unconformities. Petroleum supersystems are controlled by both regional factors in plane and by vertically fracture-developed belts.

Meso-Cenozoic nonmarine basins will be the main focus of China's oil exploration in the future. These basins have good exploratory potential. It is estimated that 90% of oil resources to be discovered in China will be in nonmarine basins.

PEMATANG (BROWN SHALE)- SIHAPAS PETROLEUM SYSTEM CENTRAL SUMATRA - PART 1: RESERVOIRS

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Petroleum systems analysis is a methodology which allows recognition and delineation (both spatial and temporal) of geologic elements and processes necessary for a hydrocarbon accumulation to exist. The essential stratigraphic elements of a petroleum system include: source rock, reservoir, seal, and overburden. Geologic processes essential to a petroleum system are: trap formation, porosity development/preservation, as well as generation, expulsion, migration, and accumulation of hydrocarbons. A petroleum system exists wherever these essential elements and processes occur in the proper spatial and temporal context. The name of a petroleum system includes the source rock and major reservoir unit, followed by the *level of certainty*. The level of certainty indicates the degree of confidence that a particular source rock has generated the hydrocarbons present in a reservoir. Three levels of certainty have been defined: known (!), hypothetical (.), and speculative (?). The Pematang (Brown Shale)-Sihapas petroleum system is an example of a known (!) petroleum system.

The Brown Shale Formation (lacustrine) of the Pematang Group has sourced an estimated 50 to 60 x 10^9 BO in extensional basins of central Sumatra. Reservoirs are developed within the uppermost Pematang Group (Paleogene) and superjacent Sihapas Group (Early Miocene). In terms of oil-in-place, Sihapas sandstones are the principal reservoirs of this petroleum system. Giant fields (e. g., Minas and Duri) having Sihapas (marine sandstone) reservoirs occur principally along eastern margins of central Sumatran rift basins. Considerably smaller fields having Pematang (nonmarine sandstone) reservoirs are confined to the rift basins. Hydrocarbon accumulations in both Sihapas and Pematang reservoirs are controlled mainly by structural entrapment.

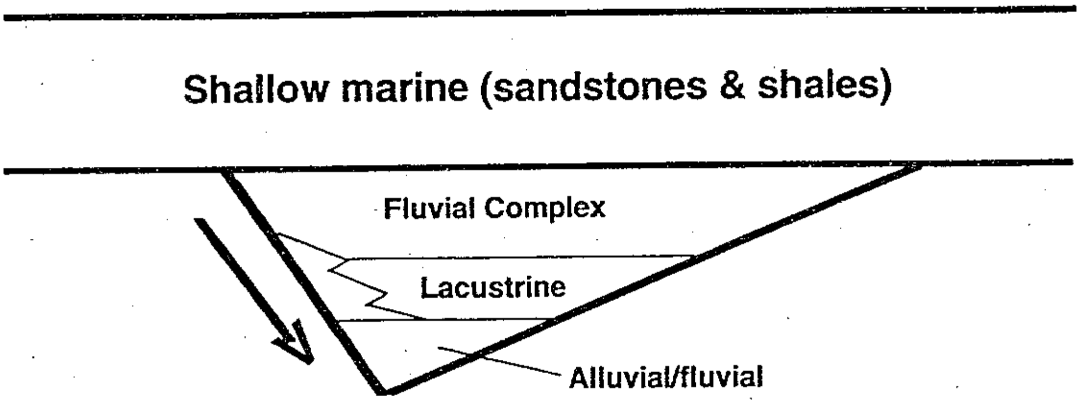
Pematang strata exhibit a tripartite arrangement: basal (Lower Red Bed) fluvial/alluvial unit; medial (Brown Shale) lacustrine unit; and upper (Upper Red Bed) fluvial/alluvial unit, that typifies most syn-rift stratigraphic packages. Established production in Pematang reservoirs is derived mainly from cyclically-stacked, amalgamated, braided-fluvial sandstone lithofacies within the Upper Red Bed unit. Additionally, some fields have oil saturated sandstones developed within the Brown Shale (lacustrine) unit. Upper Red Bed reservoirs are characterized by average porosities of < 15% and permeabilities of < 100 md. The amount of sandstone (gross) in the Upper Red Bed unit averages about 30%. These sandstones are moderately sorted and have subarkosic and sublithic modal compositions. Most porosity is secondary and has resulted from dissolution of detrital framework-grains (especially feldspars). Reservoir characteristics have been degraded by precipitation of quartz overgrowths and authigenic kaolinite (by-product of feldspar dissolution). Pematang reservoirs are sealed vertically by interstratifted floodplain lithofacies.

The overlying Menggala Formation (basal transgressive unit of Sihapas Group) has an average porosity of >20 % and an average permeability of 1500 md. The amount of sandstone (gross) in the Menggala Formation typically exceeds 50%. Menggala strata consist of well-sorted quartzose to subarkosic sandstones. Glauconite and marine fossils are conspicuous accessory components. The improved textural and mineralogic maturity exhibited by Menggala sandstones, relative to subjacent Pematang sandstones, reflects prolonged reworking by marine processes as well as derivation from a quartz-rich provenance. Furthermore, there is a paucity of authigenic clay minerals in Menggala sandstones. Because of these sedimentologic and diagenetic attributes, Menggala sandstones are the most prolific hydrocarbon reservoirs in central Sumatra.

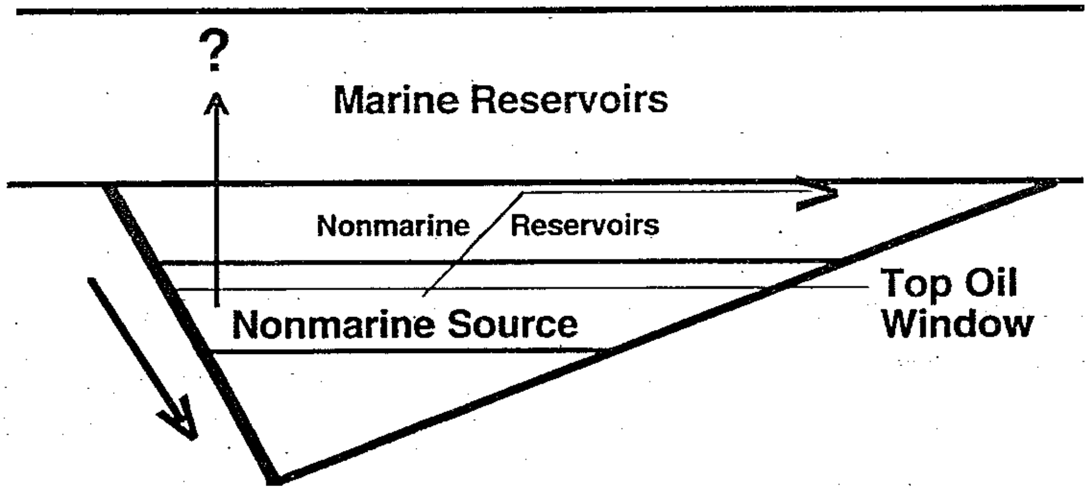
Many of the major oil fields in central Sumatra are associated with structures formed during a mid-Miocene compressional event. Hydrocarbons generated from lacustrine shales, deposited within Paleogene grabens, migrated laterally (dominantly in an eastward direction) into Miocene marine sandstones and probably vertically into Pematang nonmarine sandstones. Pematang reservoirs are sealed by interstratified floodplain lithofacies, and Menggala reservoirs are sealed by interstratified marine shales.

North Aman Trough (Central Sumatra)

Generalized Pematang/Sihapas Model



Rift Basin Petroleum System
Brown Shale-Sihapas (!)



Strong lateral component of migration essential to source large fields (e. g., Minas & Duri) along eastern margin of rift basins.

THE PEMATANG (BROWN SHALE) - SIHAPAS (!) PETROLEUM SYSTEM OF CENTRAL SUMATRA: PART 2 SOURCE

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The Pematang (Brown Shale) - Sihapas (!) petroleum system of Central Sumatra is one of the most important lacustrine oil systems in Southeast Asia. Recoverable reserves exceed 10 billion barrels of oil. A significant percentage (>50 %) of these reserves is contained within two giant fields, Duri and Minas. Although the viability of the Central Sumatran petroleum domain has been established for half a century, it has only been over the past 15 years that a general understanding of the true origin of the oil has been established. In part, the confusion associated with the oil's origin was a result of the lack of synrift penetrations and the distribution of the source itself (i.e., the Pematang Group is limited to the subsurface).

The Pematang Group was deposited in a series of small grabens or sub-basins within Central Sumatra. The Pematang Group, which may exceed 1800 meters in thickness, is composed of five "formations" which represent depositional facies rather than chronostratigraphic units. The five formations are: the Lower Red Beds, Lake Fill, Coal Zone, Fanglomerate, and Brown Shale. The Lower Red Beds Formation represents deposition within shallow lacustrine and fluvial settings. The Lake Fill principally represents fluvial-lacustrine deposition. The Coal Zone represents deposition within a marsh/bog setting. The Fanglomerate Formation is restricted to basin-bounding fault scarps and largely represents the coalescing of alluvial fans. The Brown Shale represents a well developed lacustrine sequence, including shallow water, deep water and marginal facies. It is the Brown Shale Formation that is the principal source rock for the region's petroleum. Not all of the formations or facies are present in each of the recognized sub-basins. Depositional facies appear to be largely controlled by the relationship between sedimentation and subsidence rates.

Age assignment for the Pematang has been problematic. The unit lacks age diagnostic-fossils. An Eo-Oligocene age assignment has been made principally on stratigraphic position.

Source rock attributes of the Brown Shale are highly variable. Organic carbon contents range from less than 1 to greater than 20 wt.%. The mean organic carbon content is ~3.7 wt.%, with approximately 75% of the analyzed samples containing at least 1.0 wt.% TOC. Total pyrolysis yields (S_1+S_2) of those samples containing a minimum of 1.0 wt.% TOC range from less than 1 to greater than 120 mg HC/g rock, with a mean of ~25.3 mg HC/g rock. Approximately 80% of the pyrolyzed samples have generation potentials consistent with good or excellent source rocks ($S_1+S_2 > 6$ mg HC/g rock). Pyrolysis, elemental, and visual kerogen data reveal that the primary character of the sedimentary organic matter ranges from type I to type III. Differences in kerogen composition appear to reflect variations in the degree of organic preservation rather than the nature of the organic input (i.e., vitrinitic material is largely absent even in the "type III" facies). In general, the more oil-prone facies are associated with the later phases of Brown Shale deposition and with deeper water facies. Pyrolysis-gas chromatography reveals that, independent of organic richness and apparent kerogen composition, the expected hydrocarbon product is a waxy crude. Further analysis, however, reveals significant variations at the molecular and isotopic level. For example, the carbon isotopic composition of the Brown Shale kerogen and bitumens varies by as much as 9‰.

Brown Shale-derived oils have API gravities which range from less than 20 to 47°. The oils contain less than 0.2 wt.% sulfur. Pour points range from 4 to 46°C. Unaltered oils are classified as paraffinic. Although all of the oils are derived from a single stratigraphic unit the chemical character of the oils varies across the basin. The oils can be divided into a series of distinct subfamilies based on their isotopic and biomarker compositions. Each subfamily is geographically restricted and appears associated with a discrete sub-basin. This implies that such factors as ionic concentration, character and water depth varied among the Brown Shale sub-basins during deposition.

The establishment of the current level of thermal maturity within the Brown Shale is complicated by the general absence of vitrinite. Thermal maturity can, however, be modeled. Much work has been performed on the kinetics of hydrocarbon generation from Brown Shale kerogen. This work has established a narrow distribution of activation energies. Consequently, the transformation of kerogen occurs over a relatively restricted depth range. Thermal maturity of the Brown Shale is variable within and across the unit. This variability is caused by the variations in sedimentary overburden, the thickness of the unit, and the geothermal gradient (36 to > 90°C/km). Higher geothermal gradients are currently associated with uplifted basement blocks. The Brown Shale ranges in thermal maturity from immature to over-mature. Assuming current geothermal gradients, the main phase of hydrocarbon generation and expulsion may be encountered at depths as shallow as about 1100 meters or as deep as 2400 meters. These models also indicate that petroleum generation may have begun as early as the Lower to Middle Miocene. However, it is not clear when the current geothermal gradients were established. Arguments can be made that, unlike many rift basins, the current geothermal gradients represent near maximums and are the result of the more recent phases of tectonic activity (i.e., basin inversion), which permitted the establishment of the current subsurface flow regime.

Hydrocarbon migration displays both a vertical and lateral component. The half-graben, asymmetric character of the sub-basins results in larger gathering areas preferentially feeding the hinge-zone margin. Lateral migration distances appear limited largely as a consequence of the structural character of the basin. Vertical migration appears limited by the presence of Sihapas Group (Bangko and Telisa) shales, which provide the major regional seals.

The documentation of the various components of the source permits defining the timing (Figure 1) and areal extent of the petroleum system and its various sub-systems. An analysis of the petroleum system's timing diagram reveals that, within some of the various sub-basins, generation may have begun prior to the development of the primary reservoirs, associated seals and basin inversion structures. These early hydrocarbons would either have been trapped internally within the Pematang Group or would alternatively have been lost from the system.

With the establishment of the Brown Shale as the source, the hybrid character of the Central Sumatra petroleum system was also established, where the source rock is lacustrine and the primary reservoir is marine (Sihapas Group sandstones). Such hybrid systems are not unique. Within Southeast Asia and China many other hybrid systems exist. For example, the Wenchang-Zhuai (.) petroleum system of the Pearl River Mouth basin (South China Sea) shares a lacustrine source rock and a marine sandstone reservoir. These hybrid systems tend to share the benefits of both types of environments, i.e., the excellent source potential of the lacustrine environment and the higher lateral and vertical continuity, and higher reservoir potential, of the marine setting.

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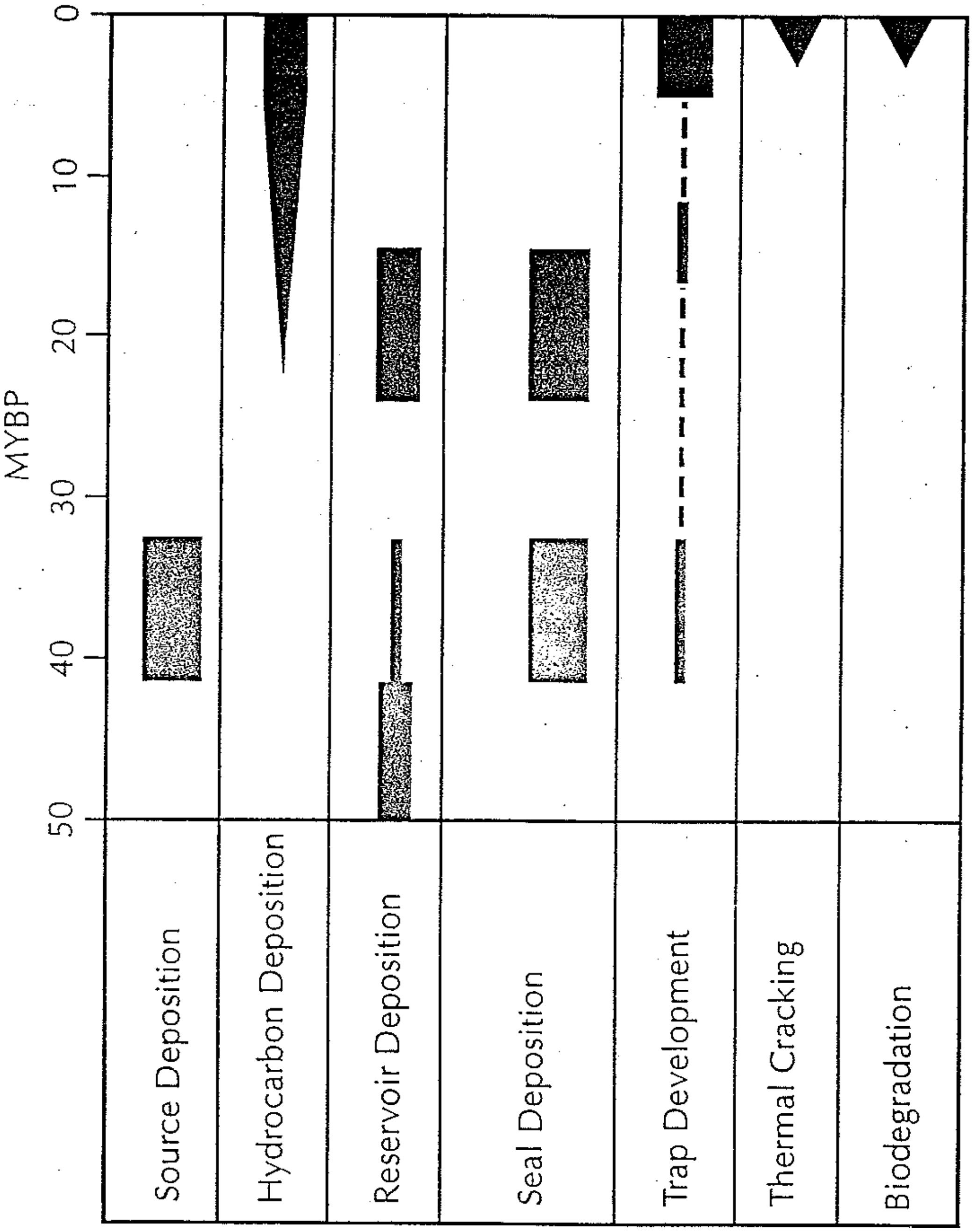
Pematang-Sihapas(!) Petroleum System

THE GENESIS AND DISTRIBUTION OF NATURAL GAS OF CENOZOIC AND MESOZOIC CONTINENTAL BASINS IN CHINA

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The continental basins in China can generally be divided into four types by their tectonic evolution: 1) the faulted-depressional basin systems in southern and eastern China Sea; 2) the rift basin systems in eastern China; 3) the depressional craton basin systems in Middle China; and 4) the composite basin systems of western China. Within each type of basins rich gas resources can be found.

The gas found in the Cenozoic and Mesozoic continental basins in China includes two types, abiogenic gas and organogenic gas. These two main groups can be further subdivided into six sub-types by the nature of the organic matter and their thermal evolution. These gas sub-types are abiogenic combustible gas (methane), abiogenic noncombustible gas (CO_2), organogenic biogas, sapropetic thermolysis gas and mixed thermolysis gas.

The gas pool types differ in the basin types. Structure and structure-stratigraphic gas pool are the dominant traps in all basins now. The stratigraphic gas pool reserves account for only a small percentage. The dominant reservoirs are continental sandstones. The big pools (fields) are usually present in the depressional basins, the medium-small gas fields are present mainly in the rift and extensional basins.

From a stratigraphic point of view, potential gas reservoirs are mainly distributed in the Tertiary and in descending order of importance Triassic, Cretaceous, Quaternary and Jurassic strata. But the gas is actually distributed principally in the Jurassic and Tertiary. Gas reserves can be viewed as a function of geographic districts: 1) the western oil district with rich gas (composite basins); 2) the middle gas district with oil; 3) the eastern oil district with gas; and 4) an offshore oil/gas district. Obviously, the strategies of China's natural gas exploration should be to strengthen the western, develop the middle, stabilize the eastern, value the offshore area.

TECTONICS OF MESO-CENOZOIC NONMARINE BASINS IN CHINA

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China is situated at the junction of three plates which strictly controlled the nature, distribution and evolution of basins. The difference in behavior and timing of their activities caused tectonic localization and zonation within basins.

The locations of basins, the styles of their tectonic activities and the degree of fault block tilting were influenced by basement characteristics and ancient faults.

Three major strike-slip faults, the Tanlu, Altun and Jinshajiang-Honghe faults, played an important role in basin formation and crustal deformation.

Nonmarine basins in China were controlled strictly by the regional stress field, that is, extensional, compressional and torsional stress fields. These stress fields created three major types of nonmarine basins in China, i.e. rifts, foreland basins and strike-slip basins. Each kind of basin is characterized by its own structural style and hydrocarbon pool type.

Multi-stage changes in the regional stress field created different basins which were juxtaposed vertically to form “China type” nonmarine basins with multiple series of hydrocarbon-bearing sequences.

THE PALAEOGENE RIFTS OF WESTERN INDONESIA - A REVIEW

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Palaeogene rifts underlie all the major basins of Western Indonesia, including those that are presently in a fore-arc position. Fourteen of these basins are of economic importance since together they contain proven in-place reserves of more than 70 billion barrels of oil equivalent. Historically, many similarities between these basins have been recognized, but due to the extensive use of lithostratigraphy as a correlation tool the early development of these rifts has been poorly understood. The interpretations of this paper result from a correlative framework established for Western Indonesia using sequence stratigraphy that is based on seismic data, well logs, biostratigraphy, radiometric dating, etc., and also integrates reservoir, seal and geochemical data. This correlative framework provides a better understanding of the hydrocarbon system in each basin and the similarities between basins.

The main aspects of the Palaeogene rifts of Western Indonesia are briefly discussed below:

Structural History

Most of Western Indonesia is located on the Sunda plate, which on the basis of the restricted areas of preserved Cretaceous sediments, would appear to have been largely emergent at the end of the Mesozoic. The Palaeogene rifts of the Sunda plate of Western Indonesia have undergone significant modification as a result of Neogene compressional events which have caused partial to complete inversion of the earlier rifts. However, it is possible to identify two, possibly three, rifting phases.

The earliest possible phase of rifting is of ?late Paleocene to early Eocene age and is poorly constrained. This phase is identified on seismic data and occasional well intersections in the

Northeast Java, North Lombok and Spermonde basins. The older sedimentary section indicated on seismic data in these basins is considered to be pre-rift. Seismic data indicate that this early rifting phase may be present in the deeper sections of the Central Sumatra (Bengkalis Depression and Aman Trough), South Sumatra (Jambi Depression), Northwest Java (Zaitun sub-basin), Central Java, Barito, Kutei, Melawi and Northeast Kalimantan basins.

A second phase of rifting of middle Eocene to middle Oligocene age is clearly recognized throughout Western Indonesia. Biostratigraphic control of the middle Eocene is limited to the East Java Sea area (Northeast Java, North Lombok and Spermonde basins) and to Kalimantan (Kutei, Melawi and Northeast Kalimantan basins) where significant thicknesses of marine sediments have been encountered in wells and occasionally in outcrop (western Kutei and Melawi basins). Elsewhere sediments of this age are continental and contain no age diagnostic fauna or flora. However, these continental sediments are overlain by marine sediments in the North Sumatra, Sumatra Fore-arc (Sibolga and Bengkulu segments), Java Fore-arc (Southwest Java segment), East Java, Northeast Java, North Lombok, Barito, Kutei (northern margin) and Northeast Kalimantan (Tarakan sub-basin) basins that are reliably dated as late Eocene. A late Eocene to early Oligocene phase of volcanism is also recognized in outcrop, in wells and on seismic data from all basins with the exception of the Natuna, Central Sumatra, Sunda and North Lombok basins. These widespread volcanics and volcanoclastics provide additional top, or minimum age, control to the older underlying and undated continental sediments.

This second phase of rifting was drawing to a close in the middle Oligocene. Significant marine incursions in to the rifts occurred during the early Oligocene in the North Sumatra, Sunda, Northwest Java, Central Java, Barito and Melawi basins. The rift systems and intervening stable platforms in the East Java Sea area and East Kalimantan were largely drowned during the latest Eocene. A major compressional tectonic event occurred during the middle Oligocene which can be recognized on seismic data and in wells throughout Western Indonesia.

Following this middle Oligocene compressional event, differing tectonic regimes were established in Western Indonesia. In Sumatra, rifting was re-established but the preferred orientation became parallel to the emerging Barisan arc indicating the onset of the present back-arc basins. The late Oligocene to early Miocene period was also essentially transgressive with marine conditions becoming more widespread throughout Sumatra and reaching their maximum extent at the close of the early Miocene.

In the Natuna area subsidence continued along the existing rift trends until terminated by the Neogene compressional events. A marine transgression is recognized during the latest Oligocene in the northern East Natuna basin and this becomes more extensive and spreads south-westwards across the West Natuna basin during the early Miocene. The late Miocene inversion is particularly pronounced in the-West Natuna basin.

A similar tectonic development occurred in the Java basins: in the Sunda and Northwest Java basins the inversion is mild, however major inversion occurred in the East Java, North Lombok and Spermonde basins. All basins in Java indicate continued transgression of the Sunda plate and by the close of the early Miocene most of the arches and ridges separating the basins had been submerged.

In Kalimantan extensive shallow marine carbonate platforms were established from the northern margins of the East Java Sea basins through to the Northeast Kalimantan basin indicating a period of quiescence and perhaps doming prior to the rifting away of western Sulawesi from Kalimantan in the Miocene.

The prevalent orientation of the various rift phases would appear to be dependent on the differing regional stress regimes through time and pre-existing zones of weakness. Whereas it can clearly be established that the prevalent orientation of the middle Eocene rifting phase in the Java area is Northeast - Southwest and a similar trend can be identified elsewhere in Western Indonesia, significant exceptions do occur.

Source Rocks

Source rocks and oils have previously been classified as lacustrine (non-marine algal), fluvio-deltaic (terrestrial) and marine (marine algal). There were no purely marine classified oils in Western Indonesia. Although the classification is widely used, its simplistic nature does not allow for an adequate differentiation of depositional environments, and is a confusing mix of organic facies and rock facies concepts. We have re-classified the oils and source rocks as deep lacustrine algal, shallow lacustrine algal, shallow lacustrine terrestrial and marine. This classification is based on a combination of geological and geochemical parameters but is still inadequate for understanding the genetic significance of many of the oils.

Because of the close association of coal measures with large oil and gas accumulations in Southeast Asia, coal has been postulated as a major source. Redistribution by transport of the detrital plant components from the coal environments to the different sub-environments results in little differentiation of the various environments at the molecular biomarker level.

The Mahakam Delta is the most prominent example of the fluvio-deltaic coal source model. It has been broadly speculated that type III terrestrial kerogens in shales, and coals in the fluvio-deltaic environments are the dominant sources of the oil and gas. The organic matter within the Miocene deltaic sequence is dominantly of terrestrial (type III) origin, regardless of its deltaic environment of deposition, lithology or stratigraphic position. Therefore, considerable caution is necessary when interpreting an oil's source environment based on biomarker data.

Studies of coals from Southeast Asia have been published which support the conclusion that most Indonesian coals are not effective source rocks for oil because of their relatively liptinite poor contents (<10%) and limited expulsion efficiencies. Coals with high resinite or other liptinite contents may have made a minor contribution to the oils. This may be more significant in oils migrating through, or reservoired in, thick coal sequences such as the Northeast Kalimantan, Kutei, South Sumatra and Northwest Java Basins.

Examples can be found in the literature of studies that cite coal source rocks in Western Indonesia. However, subsequent drilling of prospects dependent on these source rocks have been unsuccessful and in some examples where the full stratigraphic section has been subsequently tested by the drill, deeper syn-rift source rocks have been identified. We believe the terrestrial biomarker characteristics of many fluvio-deltaic oils may be due largely to an overprinting picked up during migration through these coaly sequences.

As a result of our work we conclude that the post-rift Late Oligocene and younger fluvio-deltaic source rocks, so often cited in the literature, have not contributed significantly to the hydrocarbon reserves of Western Indonesia. The effective source rocks of Western Indonesia being those defined as having sourced commercial hydrocarbon accumulations are mainly of middle Eocene age and are found in deep lacustrine, shallow lacustrine and marine sediments. In certain basins, for example South Sumatra, synrift sediments of late Eocene to early Oligocene age are possibly also effective source rocks.

Reservoirs

Syn-rift reservoirs contain some 18.7% of the estimated proven hydrocarbon reserves of Western Indonesia. These are mainly clastics in the basins of Sumatra and West Java and in the North Lombok basin. As the Oligocene to early Miocene transgression extended across Sundaland carbonate deposition became established in all basins apart from Central Sumatra and West Natuna. The Palaeogene sections of these sequences form significant reservoirs in the South Sumatra, Sunda, Northwest Java and Northeast Java basins. Recent drilling results indicate that carbonate reservoired fields in the East Java and North Lombok basins may prove to be commercial.

It should be noted that the reservoirs of the immediate post-rift sequences contain 38.83% of the estimated proven hydrocarbon reserves of Western Indonesia.

Seals

Intraformational seals occur throughout the syn-rift sequences. However, the marine shales of the Oligocene to early Miocene form extensive regional seals which effectively seal the rift sequences. It is in areas where these regional seals are thin, for example the North Sumatra and Kutei basins, where significant hydrocarbon reserves are found in the middle Miocene to Pliocene reservoirs.

In conclusion, the Palaeogene rifts of Western Indonesia contain the effective source rocks for all of the hydrocarbons in the area and also contain significant reservoir sequences. This latter point, in particular, is often overlooked and with it the fact that these sequences are under explored and probably contain most of Western Indonesia's remaining potential hydrocarbon reserves.

MAIN PALEOLAKE INFILL PATTERNS IN CENOZOIC RIFT BASINS IN CHINA OFFSHORE

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Cenozoic rift basins in East China formed by the lithospheric extension and their tectonic-stratigraphic frameworks were controlled by the kinematic characteristics of the decollement fault systems. Episodic rifting in these basins can be divided into four evolutionary stages. The main stage of paleolake development was associated with the highest rates of extension and sedimentation. The rate of subsidence is the principal controlling factor on depression infill.

Dominated by the rate of subsidence climate, clastic source and sedimentary base level, resulted in five types of paleolake infill patterns in rift basins in offshore China. The infill patterns are: (A) intrabasinal lake in an arid climate, (B) lake filled by short-distance rivers in a wet climate, (C) intrabasinal lake in a wet climate, (D) swamp lake in a wet climate, and (E) lake filled by long-distance river delta. Those paleolake infill patterns have various types and richness of organic matter and it is believed that the study of paleolake infill patterns can serve as the sedimentary method for evaluating source rocks.

THE FAR EAST HYDROCARBON HABITAT - THE CHARGE PERSPECTIVE

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From a hydrocarbon exploration point of view, the Far East is typically the realm of Tertiary basins with youthful prospects. Considering the archipelagic nature of the area and the extensive marine environments associated with shallow seas, it is perhaps surprising that nearly all of the oil and gas in these basins is of terrestrial origin (typical for the basins are low-sulfur, light waxy oils with strong land-plant imprint, and a superabundance of gas). The reason for this can be sought in the late Mesozoic - early Tertiary history, when the current cycle of tectonic development commenced. At that time, much of what is now east and southeast Asia consisted of a large land area, comprised of microcontinental blocks welded together by fold belts. In the Paleogene, this continental area became subject to back-arc extension and collapse as a consequence of complex plate readjustments.

Subsidence took place in fault-bounded (graben) depressions of many orientations throughout the area, and widespread lacustrine environments were established, especially in the Oligocene. The middle to late Tertiary history of these basins was dictated by their proximity to the open ocean and by the extent of crustal subsidence, but follows a transgressive-regressive cycle that gives rise to the following groups of plays: (1) early Tertiary transgressive clastics, basically oil-prone, (2) Miocene carbonates of the maximum, transgression, gas prone, and (3) coastal and marine, especially related to deltas, where terrestrial organic material is introduced, accumulates, and is bacterially degraded and preserved.

The distribution and types of hydrocarbons produced from these source rock and their relations to hydrocarbon habitat are examined in this review.

CRETACEOUS NONMARINE SEDIMENTATION AND OILFIELD DISTRIBUTION

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The Songliao basin is a craton-transfer-type basin rich in oil and gas. The Cretaceous system provides both the main source and reservoir. This sequence is wholly fluviolacustrine. Based on paleontologic and sedimentologic data, this lacustrine basin was near-sea level. The lake and the sea were in communication twice in the past. These episodes coincide with two significant global marine transgressions. Its lacustrine characteristics are very similar to present day Maracaibo lake.

From sequence-stratigraphic research, Qingshankou and Nenjiang Formations represent two supersequences. Condensed sections contain the better source rock and control the areal and vertical oilfield distributions. A giant-type fluviodeltaic sedimentary system developed along the long and short axial directions of the basin during the transgression and highstand periods of the supersequence. The Daqing oilfield is located in this giant fluviodeltaic sedimentary system. Daqing is a placantine formed under compression and late tensional and compressive structural stress. During lowstand periods, the river moved towards the depression center, so sandstone-mudstone became interlaminated. Superposition of better reservoirs and the giant anticline has formed a world-class giant oilfield.

LAKE DEVELOPMENT DURING THE EVOLUTION OF MONGOLIA

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Mongolia represents a case study in its own right on lacustrine diversity. Lake sediments can by identified in most geological periods from the Carboniferous to Recent.

By the late Paleozoic, following shoaling and emergence of a broad continental shelf, lakes began to develop in compressional basins. Emergence culminated in a large mountain range developing across Mongolia in the early Mesozoic. These mountains created a major Asian watershed. During the late Mesozoic and Tertiary, reactivation of inherited crustal weaknesses largely by strike-slip tectonics allowed lakes to develop in rift and strike-slip extensional basins. Extension and rifting episodes were intermittent and often incomplete. As a consequence, subsidence rarely outpaced sedimentation for long periods and so conditions suitable for long-lived 'permanent' lake sites were limited. This led to many lake basins being rapidly infilled and choked with sediment. Volcanic rocks were also responsible for infilling of the basins.

Most lake basins are small (<40,000km^2) and short-lived, and the lakes within them were small (<10,000km^2). The non-marine sequences that developed in the basins cover a wide spectrum. These include alluvial fan sequences rich in polymict conglomerates, braidplain sequences rich in sandstones, and meander plain sequences of interbedded sandstones, siltstones, mudstones and coals. Soil processes including caliche, gypcretes and extensive color mottling affect many of the alluvial sequences. Aeolian sequences comprised mostly dune sandstones and these contain world famous dinosaur skeletons, bones, and eggs.

Lacustrine sequences include algal rich oil-prone mudstones and also carbonates which are comprised of algal micrites, encrustations and oncolites together with chert, bivalves and gastropods. There are various other subaqueous lacustrine sandstones, siltstones and mudstones.

Many lakes were fringed with coal swamps and marshes, and in some basins coals developed in preference to lacustrine rocks. In some basins, reddened mudstones developed in playa lakes.

The early Cretaceous lake basins appear the most important in terms of generating and trapping hydrocarbons (Figure 1). Many of these basins accumulated oil-prone mudrocks and "oil shales". These have generated classic lacustrine oils characterized by medium to high gravity, low GOR, low viscosity, low sulfur, high wax, high nitrogen, high Ni/V ratios, and high temperature pour points. These oils have been trapped in interbedded lacustrine and alluvial reservoirs.

Volcanic rocks co-mingle with many of the alluvial and lacustrine sequences. These too cover a wide range of types including basalts (sometimes forming plateaux), rhyolites, and felsic volcanics, cinder cones, ignimbrites, chloritised and flow banded tuffs and tuffaceous sandstones. However, there appear to be no volcanic lakes.

The position of present-day lake basins in Mongolia is largely controlled by reactivation of crustal weaknesses under the influence of compression and strike-slip. These present-day "successor" basins contain lakes which range from fresh to highly saline developing in a region of arid to semi-arid continental interior climate which has extremely low humidity. In the winter, many lakes are frozen for more than three months.

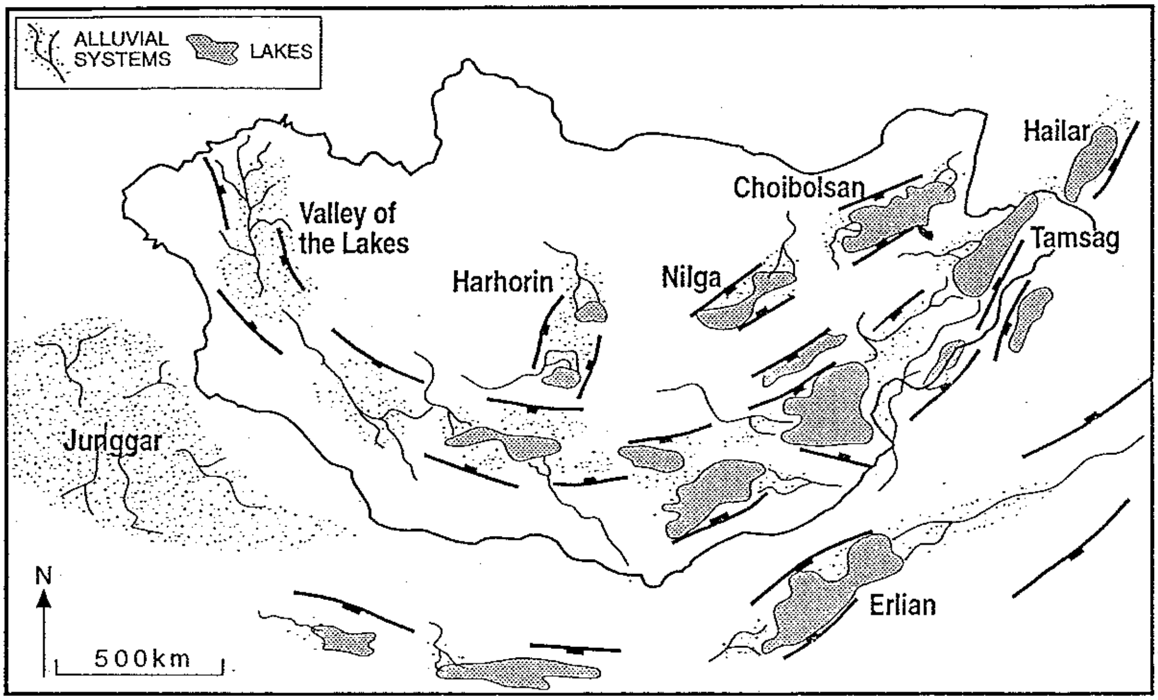

Figure 1: Late Jurassic-Early Cretaceous paleogeographic reconstruction showing alluvial systems tracts draining into a variety of lake basins

INTEGRATED STRATIGRAPHIC EVALUATION OF THE LOWER TERTIARY IN THE EASTERN SUBEI BASIN

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The Tertiary Subei Basin is composed of extensional halfgrabens separated by pre-Tertiary arches and uplifts. Traditional exploration targets ard Paleogene fluvio-lacustrine sandstones in fault closures charged from adjacent halfgrabens. A multidisciplinary synthesis integrating biostratigraphical and petrophysical well data with seismic has provided a clearer insight into the spatial and temporal distribution of key lithofacies (i. e. time/rock synopsis) and has improved the understanding of the Tertiary hydrocarbon potential in the eastern Subei Basin. Lacustrine system tracts can be recognized comprising of transgressive lake, lake maximum and lake lowstand units. The sequence stratigraphic model is calibrated by quantitative data on Palynofloras, Charophytes and Ostracods. This integrated approach has highlighted new exploration potential for stratigraphic traps in the Lower Tertiary.

HABITAT AND TYPES OF CENOZOIC HYDROCARBON ACCUMULATIONS IN THE PEARL RIVER MOUTH BASIN (EAST)

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The Pearl River Mouth Basin is an extentional basin developed since the end of Mesozoic. The sedimentary column is over 10,000 m and composed of mainly Cenozoic rocks. The basin is characterized by a structural pattern trending approximately northeast. The stratigraphic section consists of several subunits, which can be divided into two structural layers (faulting below and thermal subsidence above). Sedimentation was initially continental followed by marine deposition. This regional geological pattern has induced a unique habitat of hydrocarbon accumulations in the basin. The main source rocks are lacustrine shales in the Paleogene Wenchang and Enping Formations. The thick massive transgressive sandstone of the Lower Miocene Zhujiang Formation and the carbonate build-ups are the main reservoirs. The transgressive shale in the upper and middle part of the Zhujiang Formation provides the regional seal. Both short and long distance hydrocarbon migration (>40 km) exist in the basin. The traps which formed prior to the Middle Miocene are most favorable for hydrocarbon accumulation. The major types of traps in which hydrocarbons have accumulated include drape anticlines, rollover anticlines, carbonate build-ups and fault-seal traps.

STRUCTURE CHARACTERISTICS, RESERVOIR TYPES AND OIL AND GAS DISTRIBUTION IN JUNGGAR BASIN

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Junggar Basin is located within the Kazakhstan plate. It formed on a melange of overthrust belts along the southwestern margin of the Siberia plate and was adjacent to the Tianshan folded belt along its southern boundary. It was a rather steady terrain structure within middle-Asia. Its formation and development was directly controlled by the orogenic action caused by the contraction of a Paleozoic trough and the influence of Cenozoic Tethys structures. The Junggar basin is a typical complex-superposed basin with a central platform. Basement was formed by the amalgamation of two terrains, Manas in the south and Ulungu in the north. Each terrain displayed different characteristics and ages. The amalgamation period was from C_2 to C_3. The amalgamation belts were distributed along the Karameli ultrabasic rock belt which displays a northwestern trend along the axis of Sanggoquan uplifts. The formation period of basin was from C_3 to P_2. Basement amalgamation and overthrusting of orogenic melange terrains resulted in the formation of the basin. The basin evolved from an open marine basin to inland basin within a closed mountain-basin system. From P to Q time, the Junggar basin underwent four structure-sediment evolutionary stages: (1) foreland marine-relict marine basin (P_2); (2) foreland continental basin (P_2); (3) oscillating continental basin (T-E); and (4) foreland continental basin (N-Q). It was during the foreland development stage (Permian) that a series of structures was formed, and in which the rich hydrocarbon source rocks developed. During the oscillation stage, a series of reservoirs and caprocks were developed.

Rich hydrocarbon source rocks, developed in the Junggar basin. These rocks are present in numerous stratigraphic intervals (C_1, P_2, P_z, T_3, $J_{1\text{-}2}$, K_2 and E). The main hydrocarbon source rocks are Permian, with the Jurassic coal beds being of secondary importance. Main hydrocarbon generation of the Permian hydrocarbon source rock was from T to J, while the main stage of generation for the Middle and Early Jurassic coal beds was during the Cenozoic.

There are many types of reservoirs in the Junggar basin including conglomerates, sandstones, volcanics and peletic dolomites with each displaying different distributions and characteristics. Their distribution was controlled by such factors as structural evolution, sedimentary belt patterns and diagenesis. The Mesozoic was the main period for reservoir development.

Multiple hydrocarbon source beds, multiple episodes of oil and gas generation, multiple sedimentary discontinuities, multiple combination of reservoirs and caps, multiple trap types and multiple sets and periods of faulting controlled the distribution of oil and gas. These factors resulted in complex oil and gas accumulation belts. There exists autogenic reservoirs, external reservoirs, multi-mixed source reservoirs and others.

GENERATION AND ACCUMULATION OF COAL - FORMED HYDROCARBON IN TURPAN - HAMI BASIN

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The Early to Middle Jurassic Shuixigou Group in Turpan - Hami basin is a series of coal measure strata with a thickness of one to three kilometers. Coal and dark mudstone in the group have been proved to be the main source rock of the region's discovered hydrocarbon reserves. Sandstone in the Middle Jurassic Sanjianfang and Qiketai Formation above the coal measure strata are the main pay beds. It was estimated that 60% of the Jurassic oil and gas resources in the basin came from coal.

The maceral composition of the coal are vitrinite (50% to 80%), inertinite (10% to 25%) and exinite (5% to 15%). Both desmocollinite, which is hydrogen-rich in Turpan basin, and suberinite are the main hydrocarbon-generating macerals. Cutinite and sporophyte have also contributed hydrocarbons. Desmocollinite and suberinite generate a large amount of oil during the low - maturity stage (Ro=0.4% - 0.7%). Cutinite and sporophyte are the main oil - generating macerals later in the mature stage (Ro - 0.5% - 1.3%). In the early evolution stage with a vitrinite reflectance of 0.4% to 0.8%, the coal has best expulsion efficiency for hydrocarbons.

The coal in Shuixigou Group began to generate hydrocarbons massively in the late Jurassic. Three major phases of expulsion and accumulation occurred at the end of Jurassic, Cretaceous and Tertiary. The oil and gas migrated upward along the fault planes that cut through the coal measure strata to the traps in the Middle Jurassic forming accumulations. The Upper Jurassic red mudstone plays the role of a wonderful cap rock.

THE DEPOSITIONAL FEATURES AND CONDITIONS OF FORMATION OF THE UPPER JURASSIC OIL RESERVOIR IN LUJIAPU DEPRESSION

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The Lujiapu depression is located in the Nei Mongol Autonomous Region, northeastern China. Its area is about 2500 km^2. The depression which belongs to the Late Mesozoic rift system of northeastern China was developed and formed on Hercynian folded basement. It is a half graben-like depression with southern faulting and northern overlay.

The rift was developed and formed in the Late Jurassic and went through four stages which had different depositional features each: Yixian stage (initial extentional faulting stage) - thick beds of volcanic and pyroclastic rocks were deposited; Jiufutang stage (deep depression stage) - thick beds of semideep-deep lacustrine melanic shale were deposited in the center of the depression. Along the southern side of the depression, a series of inshore subaqueous fans were deposited, and some braided deltas were developed along the northern side; Shahai stage (steady depression stage) - hundreds of meter of shallow-semideep lacustrine pulverite was deposited; Fuxin stage (regression stage) - the water became shallower. Shallow water sediments and shore sediments of sand and shale were deposited in most areas. Shore marsh and sandwash occurred in local regions.

The oil source rock was mainly deposited at the deep depression stage (Juifutang stage), and it is a fairly good source rock with high organic matter abundance, good kerogen type and moderate thermal maturity. Oil generation and expulsion mainly took place at the end of Fuxin stage.

Subaqueous fans are the main reservoir beds. The lithological composition of the reservoir rock were sandstone and glutenite. Some characteristics of the reservoir beds are as follows: lower maturity, rich in volcanic materials, widespread distribution of carbonate cement, mesoporosity, low-ultralow permeability, etc.

Self-generating-trapping is the main type of source-reservoir-seal assemblage, and lower-generating-upper trapping comes second. The Cretaceous formation deposited at the down-warping stage is favorable regional capbed.

Structural traps are the main trapping type. Lithological traps are of secondary importance. Formation of oil traps was controlled by four factors:

1. The areal distribution of oil reservoirs was controlled by the location of the oil generative depression;
2. Syndepositional anticlines and monoanticlines formed at an early stage. These early structures were the most advantageous for oil and gas accumulation;
3. Where the middle subaqueous fan matched structure the highest enrichment of oil and gas occurs;
4. The regional caprock is a favorable barrier bed of oil and gas.

This regularity of oil and gas reservoir distribution is of universal significance for oil and gas exploration in the rift basins of eastern China.

FORMING CONDITION OF NON-ANTICLINE SUBTLE RESERVOIR IN MESOZOIC IN SHAN-GAN-NING BASIN

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The Shan-Gan-Ning basin formed during the Late Triassic. The basin contains 2000 meters of Upper-Triassic-Lower Jurassic sediments. The Upper Triassic Yan Chang Formation was deposited in a large stable inland lake basin. The basin contains large geologic bodies. Commercial accumulations are present in deltaic lithosomic bodies developed on both the eastern and western sides of the lake basin. One of these geologic bodies is the An Sai oil field which has proved oil reserves of more than 100 million tons and cumulative production of 1 million tons with both exploration and development activities increasing. The Yan An Formation of Jurassic age was deposited under lacustrine conditions. This material was deposited on weathered crust of the ancient landform of the Yan Chang Formation. The morphology was complicated and relief was large with an ancient highland unaka and river valley. Oil and gas from the Yan Chang Formation migrated along the ancient river valley to an unaka forming a series of non-structural, suttle ancient landform traps. Tens of small and medium-size oil fields have been proved and put into production with total productivity of 1.5 million tons per year. Two sets of oil-bearing formations have experienced exploration and development for more than 10 years and still have abundant potential resources.

GEOLOGICAL CHARACTERISTICS OF A CONTINENTAL BASIN IN WESTERN NEI MONGGOL AND ITS OIL-PROSPECT EVALUATION

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The basin in western Nei Monggol is one of the larger sedimentary basins in China but has undergone only limited exploration.

The sedimentary blanket of the basin is composed of fluviatile-lacustrine facies. The sediment is Jurassic-Cretaceous in age. The basement rocks around the margin of the basin are Precambrian-Paleozoic. The graben formed as a result of faulting during the Mesozoic-Cenozoic era.

Areal Geology of the Basin

The Jurassic-Cretaceous systems are in discordant contact with its basement rocks. The Jurassic sediments are also in discordant contact with the Cretaceous.

Longfengshan Formation which is lower Jurassic is composed of medium-coarse clastic sedimentary rocks with black rings. Qingtujing Formation which is Middle Jurassic is composed of gray-black, gray-green argillite pelite with lenses or medium thick beds of glauconite. Shazaohe Formation which is Upper Jurassic is composed of alternating layers of gray aleuritic-mudstone and grit with pebbles, medium-grained post stone aleurolite, and so on. The Lower Jurassic is fluviatile, the Middle Jurassic is lacustrine and the Upper Jurassic represents a fan delta.

Bayingebi Formation which belongs to Lower Cretaceous is composed of three cyclothems. They are clastic with some lacustrine carbonates. During the early stage of graben evolution basin fill was dominated by alluvial fan - anastomosed stream facies and by mudstone in lacustrine facies where the basin was filled with water. The sandstone and mudstone with carbonates were deposited as the lake basin evolved. The lake basin later was filled clastics. The lithologic association of Ularsuhai Formation which belong to the Upper Cretaceous include sandstone and alternating layers of sandstone and mudstone.

The basin includes six sags which are separated by some doming-up regions.

The Oil and Gas Possibilities in the Basin

Based on the available research, the oil-generating strata in the basin are the mela-mudstones and mela-shales which belong to Bayingebi Formation, (lower Cretaceous and Jurassic). The abundance of kerogen in outcrop samples is variable. Samples from a few of the sags contain high concentrations of organic matter. Some of the samples contain average quantities of organic material, while others are poor.

The abundance of kerogen in the subsurface, based on core material, is 6-9 times greater than in outcrop. The highest abundances of kerogen are in Jurassic-Cretaceous sediment.

The category of the kerogen in the oil-generating strata in the upper Bayingebi Formation is type II, and the kerogen in the middle Bayingebi Formation is type I. The category of the kerogen in Jurassic sections is type II.

The maturity of the oil-generating strata is low.

There are some oil shows in Jurassic-Cretaceous sequence.

The Oil Accumulation Condition in the Basin

There are favorable oil-bearing reservoirs in the Jurassic-Cretaceous sequence in the basin. The best potential oil reservoirs are the sandstones of the Ularsuhai Formation. These sandstones display favorable primary porosity with evidence of secondary porosity through dissolution.

Conditions for oil exploration within the basin are considered favorable.

LACUSTRINE SOURCE ROCKS IN THAILAND

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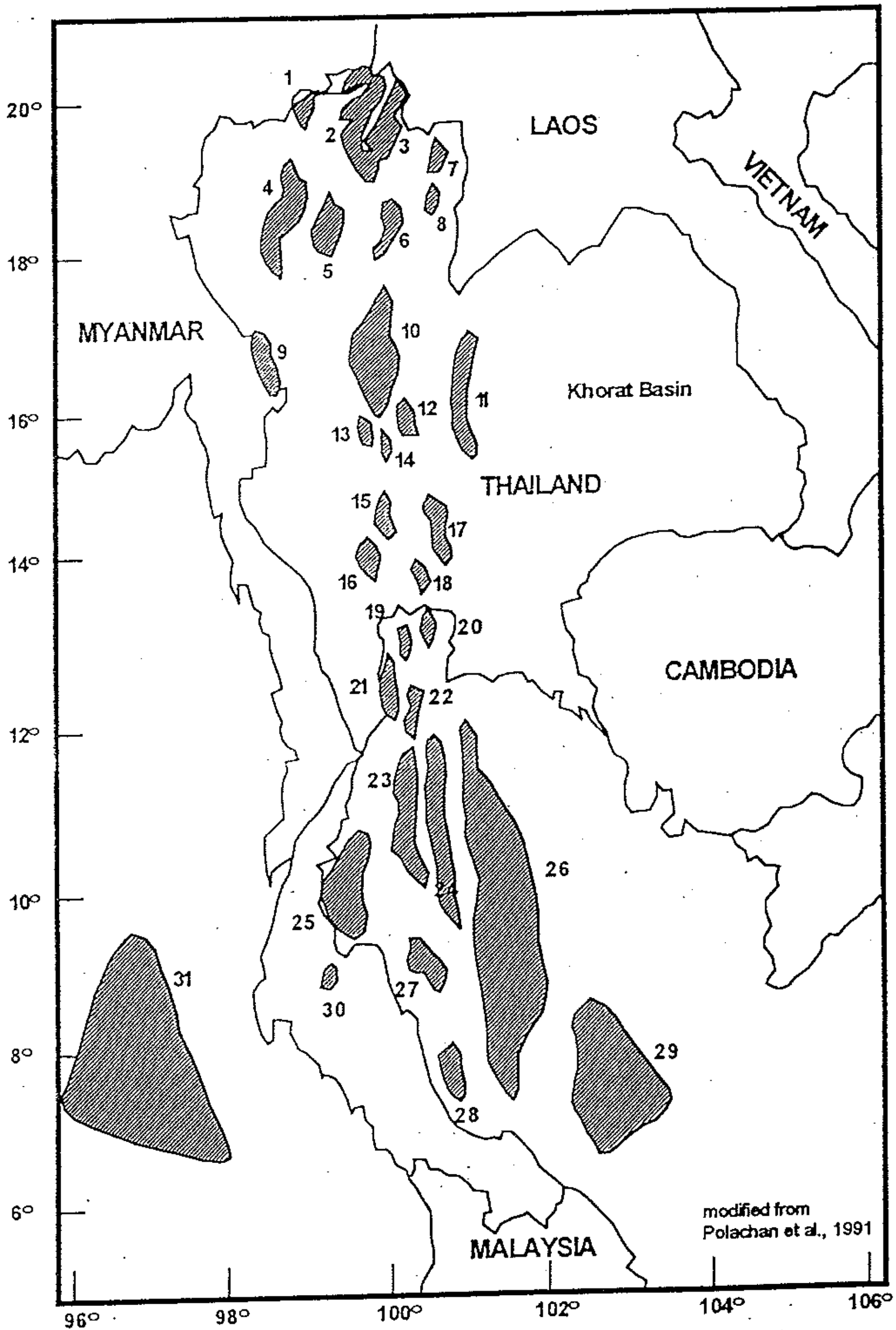
Thailand is located in Southeast Asia bordered by Myanmar to the west, China and Laos to the north, Cambodia to the east, and Malaysia to the south. Currently, four categories of petroleum have been found and proven in the Kingdom of Thailand, i.e. oil in the north and the western part of the Gulf of Thailand, oil and associated gas in the central plain, gas and condensate in the eastern part of the Gulf of Thailand and dry gas in the northeastern, Khorat Plateau, Thailand.

Petroleum basins in Thailand can be divided into two geological provinces: Tertiary and Pre-Tertiary. About 31 significant Tertiary basins have been identified onshore and offshore, of which 9 are proven petroleum provinces including Fang, Phitsanuloke, Phetchabun, Suphan Buri, Kamphaeng Saen, Chumphon, Pattani, Songkhla, and Malay Basins (Figure 1). Phitsanuloke Basin is the largest Tertiary onshore basin and Pattani Basin is the largest offshore basin. These are the main oil and gas producing basins in Thailand. In addition, more than ten pre-Tertiary Triassic basins have been mapped in the Khorat Plateau, northeastern Thailand.

Most of the Tertiary basins in the onshore and offshore western part of the Gulf of Thailand contain half-grabens filled with non-marine sediments. The offshore basins in the eastern part of the Gulf of Thailand are predominantly full grabens filled with non-marine sediments. Only the Mergui Basin in the Andaman Sea contains marine sedimentary rocks.

During the Eocene and Oligocene, high rates of sedimentation occurred in most of the Tertiary basins in Thailand. The sediments are comprised of alluvial fans and occasional lacustrine deposits (Unit I). Later, in the early Miocene, extensive lakes formed (Unit II) and were followed by fluvial depositional environments until the end of the middle Miocene (Unit III), which is

FIGURE 1. Cenozoic Basins of Thailand.



modified from Polachan et al., 1991

1 - Fang
2 - Mae Sui
3 - Chiang Rai-Payso
4 - Chiang Mai
5 - Lampeng
6 - Phrae
7 - Pua
8 - Nan
9 - Mae Sod
10 - Phitsanuloke
11 - Phetchanbun
12 - Nong Bua
13 - Lad Yao
14 - Nakhon Sawan
15 - Suphan Buri
16 - Kamphaeng Saen
17 - Ayutthaya
18 - Thon Buri
19 - Sakhon
20 - Paknam
21 - Hua Hin
22 - N. Western
23 - Western
24 - Kra
25 - Chumphon
26 - Pattani
27 - Nakhon
28 - Songkhla
29 - Malay
30 - Khiensa
31 - Mergui

Table 1. Source rock qualities of the Tertiary lacustrine sediments.

BASIN	TOC (wt.%)	Ro (%)	Source Richness	Maturity	Kerogen Type	Prone
Fang	1.63-2.67	0.36-0.44	Good	Mature	I + II	Oil
Mae Sot	3.36-8.80	0.27-0.33	Good	Immature	II + I	Oil
Phitsanuloke	1.10-42.0*	-	Good	Mature	I + II + III	Oil/Gas
Northwest	0.22-2.41	0.42-0.57	Poor Fair	Immature Early Mature	III + II	Gas/Oil

* Lignite Shale

Table 2. Source rock qualities of the Triassic lacustrine sediments.

BASIN	TOC (wt.%)	Ro (%)	Source Richness	Maturity	Kerogen Type	Prone
Hual Kum	0.20-6.60	1.60-2.50	Good Fair	Mature Very Mature	III + I	Gas/Oil
NaPho Song	0.20-2.20	1.20-2.20	Good Fair	Mature Very Mature	III	Gas/Oil
Nam Pha	0.14-2.00	-	Good	Mature	-	Gas/Oil
Lom Sak	-	-	-	-	I + II	Oil/Gas
Yang Talat	0.05-0.10	2.10-2.30	Poor Fair	Very Mature	-	-
Kuchinaral	0.10-0.30	4.10-4.90	Poor Fair	Over Mature	-	Gas Nonsource
Dao Ruang	0.15-0.74	0.99-1.17	Poor	Mature	III	Gas

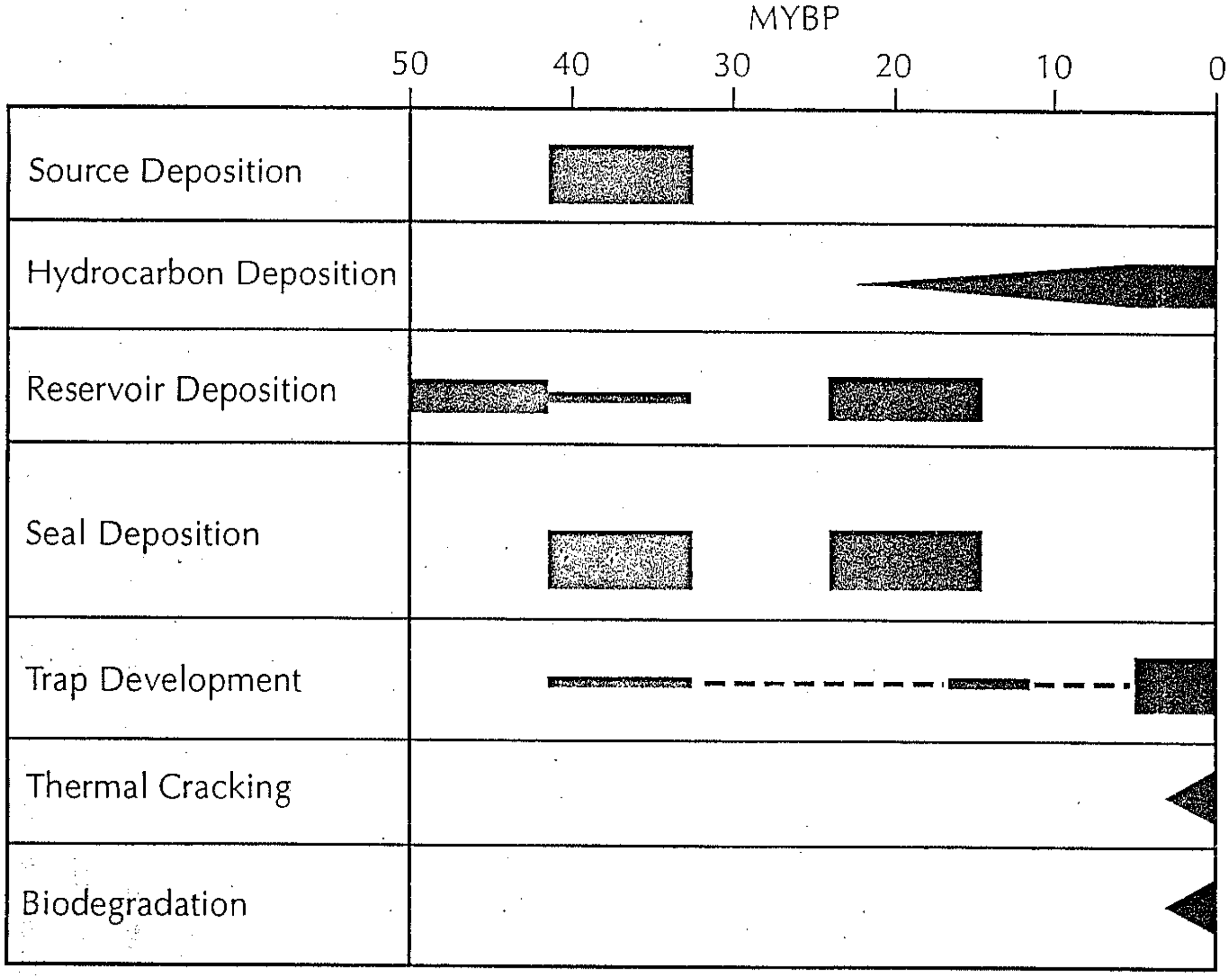
The establishment of the current level of thermal maturity within the Brown Shale is complicated by the general absence of vitrinite. Thermal maturity can, however, be modeled. Much work has been performed on the kinetics of hydrocarbon generation from Brown Shale kerogen. This work has established a narrow distribution of activation energies. Consequently, the transformation of kerogen occurs over a relatively restricted depth range. Thermal maturity of the Brown Shale is variable within and across the unit. This variability is caused by the variations in sedimentary overburden, the thickness of the unit, and the geothermal gradient (36 to > 90°C/km). Higher geothermal gradients are currently associated with uplifted basement blocks. The Brown Shale ranges in thermal maturity from immature to over-mature. Assuming current geothermal gradients, the main phase of hydrocarbon generation and expulsion may be encountered at depths as shallow as about 1100 meters or as deep as 2400 meters. These models also indicate that petroleum generation may have begun as early as the Lower to Middle Miocene. However, it is not clear when the current geothermal gradients were established. Arguments can be made that, unlike many rift basins, the current geothermal gradients represent near maximums and are the result of the more recent phases of tectonic activity (i.e., basin inversion), which permitted the establishment of the current subsurface flow regime.

Hydrocarbon migration displays both a vertical and lateral component. The half-graben, asymmetric character of the sub-basins results in larger gathering areas preferentially feeding the hinge-zone margin. Lateral migration distances appear limited largely as a consequence of the structural character of the basin. Vertical migration appears limited by the presence of Sihapas Group (Bangko and Telisa) shales, which provide the major regional seals.

The documentation of the various components of the source permits defining the timing (Figure 1) and areal extent of the petroleum system and its various sub-systems. An analysis of the petroleum system's timing diagram reveals that, within some of the various sub-basins, generation may have begun prior to the development of the primary reservoirs, associated seals and basin inversion structures. These early hydrocarbons would either have been trapped internally within the Pematang Group or would alternatively have been lost from the system.

With the establishment of the Brown Shale as the source, the hybrid character of the Central Sumatra petroleum system was also established, where the source rock is lacustrine and the primary reservoir is marine (Sihapas Group sandstones). Such hybrid systems are not unique. Within Southeast Asia and China many other hybrid systems exist. For example, the Wenchang-Zhuai (.) petroleum system of the Pearl River Mouth basin (South China Sea) shares a lacustrine source rock and a marine sandstone reservoir. These hybrid systems tend to share the benefits of both types of environments, i.e., the excellent source potential of the lacustrine environment and the higher lateral and vertical continuity, and higher reservoir potential, of the marine setting.

Pematang-Sihapas(!) Petroleum System



THE GENESIS AND DISTRIBUTION OF NATURAL GAS OF CENOZOIC AND MESOZOIC CONTINENTAL BASINS IN CHINA

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The continental basins in China can generally be divided into four types by their tectonic evolution: 1) the faulted-depressional basin systems in southern and eastern China Sea; 2) the rift basin systems in eastern China; 3) the depressional craton basin systems in Middle China; and 4) the composite basin systems of western China. Within each type of basins rich gas resources can be found.

The gas found in the Cenozoic and Mesozoic continental basins in China includes two types, abiogenic gas and organogenic gas. These two main groups can be further subdivided into six sub-types by the nature of the organic matter and their thermal evolution. These gas sub-types are abiogenic combustible gas (methane), abiogenic noncombustible gas (CO_2), organogenic biogas, sapropetic thermolysis gas and mixed thermolysis gas.

The gas pool types differ in the basin types. Structure and structure-stratigraphic gas pool are the dominant traps in all basins now. The stratigraphic gas pool reserves account for only a small percentage. The dominant reservoirs are continental sandstones. The big pools (fields) are usually present in the depressional basins, the medium-small gas fields are present mainly in the rift and extensional basins.

From a stratigraphic point of view, potential gas reservoirs are mainly distributed in the Tertiary and in descending order of importance Triassic, Cretaceous, Quaternary and Jurassic strata. But the gas is actually distributed principally in the Jurassic and Tertiary. Gas reserves can be viewed as a function of geographic districts: 1) the western oil district with rich gas (composite basins); 2) the middle gas district with oil; 3) the eastern oil district with gas; and 4) an offshore oil/gas district. Obviously, the strategies of China's natural gas exploration should be to strengthen the western, develop the middle, stabilize the eastern, value the offshore area.

TECTONICS OF MESO-CENOZOIC NONMARINE BASINS IN CHINA

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China is situated at the junction of three plates which strictly controlled the nature, distribution and evolution of basins. The difference in behavior and timing of their activities caused tectonic localization and zonation within basins.

The locations of basins, the styles of their tectonic activities and the degree of fault block tilting were influenced by basement characteristics and ancient faults.

Three major strike-slip faults, the Tanlu, Altun and Jinshajiang-Honghe faults, played an important role in basin formation and crustal deformation.

Nonmarine basins in China were controlled strictly by the regional stress field, that is, extensional, compressional and torsional stress fields. These stress fields created three major types of nonmarine basins in China, i.e. rifts, foreland basins and strike-slip basins. Each kind of basin is characterized by its own structural style and hydrocarbon pool type.

Multi-stage changes in the regional stress field created different basins which were juxtaposed vertically to form "China type" nonmarine basins with multiple series of hydrocarbon-bearing sequences.

marked by an unconformity formed by regional uplift marking the end of the rift phase. From late Miocene to recent, the Gulf has been marine (Unit IV) or post-rift sequence.

The petroleum of Tertiary basins both in onshore and western part of the Gulf of Thailand are generated from non-marine, lacustrine source rocks of Unit II, for example, Fang, Phitsanuloke, and Chumphon basins (Table 1). Petroleum source rocks of the basin in the eastern part of the Gulf of Thailand are mainly from non-marine lacustrine sediments of Unit I, for example Pattani basin (Table 1). Petroleum of Khorat basin, presently only dry gas encountered, was generated from two sources, shallow marine Permian strata and Triassic lacustrine sediments (Table 2).

Lacustrine source rocks can also be identified by the presence of high amplitude, low frequency seismic signatures on the seismic data.

Geochemical studies of most Tertiary lacustrine sediments in Unit II indicate that the level of organic richness is fair to good. These have been identified as potential and/or effective source rocks (Table 1) if the level of thermal maturity is suitable. The Triassic lacustrine source rocks are mainly gas prone and the organic richness is also fair to good. But the level of thermal maturity indicates that the section is mature to over-mature and only dry gas can be generated (Table 2).

MODELING SYSTEM FOR PETROLEUM GEOLOGIC PROCESSES AND ITS APPLICATION TO TWO BASINS IN CHINA

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The processes of petroleum geology are complex, dynamic processes. Oil and gas field formation is related to a trail of geological, physical and chemical processes, including tectonic subsidence, deposition, compaction, hydrocarbon generation, migration and accumulation et. al. According to various theories of information and geologic systems, boundaries and main events are determined in this study.

The models of various geologic process are built into this system. Compaction, a function of depth and grain diameter of sediment, is assumed to result in only partial elimination of porosity. The volume of grain matrix does not change with increasing burial depth. The main factor controlling abnormal pressure evolution is sedimentation rate. An elementary idea assumed that a mass balance exists during hydrocarbon generation for hydrogen between kerogen and petroleum. If the conditions of age and temperature are sufficient, the amount of petroleum generated within a time interval are calculated. Erosional thickness has been considered when residual petroleum present exceeds that which should be in the mature source rock. The "hydrostatic trap equation", is used to establish the maximum petroleum column height that a source rock can contain. Secondary migration is considered to determine whether entrapment or continued migration occurs.

This modeling system includes four parts: parameters input, the main assembly of models, mid-data chain, result output. The core part of the system is the main assembly of models. It consists of a restoring original thickness module, sedimentary compaction module, abnormal pressures evolution module, hydrocarbon generation module, and migration-accumulation module.

This system was applied to two typical basins - Qiuxi Basin, western China and Bohai Gulf Basin, eastern China. The results of this modeling provide a good match between model results and observations for the evolution of sedimentary compaction, abnormal fluid pressures, hydrocarbon generation, migration and accumulation. These models reveals important periods and processes for these two basins. The results further point out migration paths and the timing of entrapment in these areas, and show different characteristics of the processes of petroleum play development in different crustal stress environments. Such information is of direct benefit when exploring for hydrocarbons.

DEPOSITIONAL AND RESERVOIR FEATURES OF THE TERTIARY SALT LAKE BASIN, JIANGHAN, HUBEI, CHINA

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This paper presents the petroleum geology and hydrocarbon distribution of the Jianghan inland salt lake depositional basin. It is a Cretaceous-Tertiary inland salt lake basin formed after two tectonic cycles. Regional extension occurred following earlier thrusting. Strike detaching tectonic stresses were produced by the subduction of the Pacific plate towards the Asian plate during late Yanshanian to Himalayan time. The Tertiary depositional basin was developed on a marine basement of Sinian to Middle Triassic age and a coal basin of Late Triassic to Jurassic age. The alternation of arid and humid paleoclimates and the frequent shifting of salty and fresh water; resulted in several sedimentary rhythms of different orders. As a result of the single-directional water supply from the north, reservoirs, semi-cycle in shape, were mainly developed in the northern part of the depression. Whereas, carbonate, sulfate and potassium salts were deposited in a deep depression in a concentric circle pattern. High salinity water and the rapid sedimentation rate up to 80 mm/y was favorable for the preservation of organic matter and its transformation to hydrocarbons. These conditions created the large thicknesses of source rocks, the high transformation rate, the low degree of thermal maturity and abundance in oil reservoirs. Multi-cyclic (rhythmic) deposits create multi-assemblages of source, reservoir and cap rocks. Hydrocarbon accumulations are typified by structural traps related to the uplifting by salt flow and by complex lithology dominated traps. Oil and gas accumulations mainly formed around the inherited uplift surrounding the second order oil generative depression.

PETROLEUM SYSTEMS OF THE DONGTING BASIN, CHINA

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The Dongting Basin in Hunan Province is the southernmost basin of the East China Rift System, a group of north-south trending Mesozoic/Cenozoic rift basins. Reserves in these basins exceeds 20 billion barrels of oil, derived from non-marine source rocks and trapped in non-marine reservoirs. Although over 120 wells have been drilled in the Dongting Basin, no commercial hydrocarbon discoveries have been made. Oil shows are present in Tertiary dolomites indicating hydrocarbons have been generated. Lack of traps and poor reservoirs appear to be the limiting factors.

Present day, the Dongting Basin is a fluvio-deltaic basin with an elevation of about 30 m above mean sea level, surrounded by basement hills up to 1000 m in elevation. Three main rivers flow from the south and west into the basin with outflow to the north through the Jianghan Basin into the Yangtze River. Throughout much of its history the basin was a closed drainage basin; the present day outlet through the Yangtze River forming during the Late Oligocene-Early Miocene coincident with the opening of the South China Sea.

Climatic conditions throughout the Cretaceous and Early Tertiary were arid to semi-arid in the closed basin setting. Gypsum and anhydrite are commonly dispersed through the lacustrine shales and mudstones. During the Early Tertiary discrete gypsum, anhydrite and dolomite beds occurred interbedded with organic rich lacustrine black shales. With the opening of the South China Sea, sub-tropical to temperate climatic conditions were established.

Three northeast striking half-graben are present in the Dongting Basin, the Chang Tao, Yuan Jiang and Xian Yin, separated by the Mupinghu and Mahekou Arches. The Huarong Arch to the north, separated these graben from the adjacent Jianghan Basin until well into the Tertiary (age uncertain). In this paper the geology and geochemistry of the Yuan Jiang Graben are discussed in detail.

Seismic indicates the Yuan Jiang Graben consists of two half-graben compartments separated by a north to northwest trending accommodation zone. Graben geometry changes from a northwesterly bounded half-graben in the south to a southwesterly bounded half-graben in the north. The graben attains a maximum thickness of 4000 m and is characterized by the absence of an overlying sequence of transgressive marine "sag basin" sediments. The "sag phase" is represented by a continental sequence of mudstones of the Han Shou and Xin Hekou Formations.

These graben are dual cycle, as are many other graben in the East China Rift System. The first cycle is of Cretaceous age and the second cycle of Tertiary age. There is no apparent unconformity between the Cretaceous and Tertiary as defined biostratigraphically. However, seismic data show an unconformity near the top of the Late Cretaceous. Initiation of the second cycle is placed at the unconformity and is tectonically controlled.

The Cretaceous cycle consists of an initial rift-fill sequence of red, highly oxidized fluvial deltaic and floodplain sandstones and shales. The sandstones are lithic arkose to feldspathic litharenites. Porosities average about 15% (range 5-25%) with permeabilities in the 1-100 md range. A series of parallel reflectors onlapping the Cretaceous rift-fill sequence is interpreted to be a lacustrine source sequence, based on analogy to the basal Tertiary source unit. The overlying late Cretaceous fill sequence consists of red, highly oxidized fluvial to deltaic sands and shales, and shallow lacustrine to mudflat mudstones deposited in rhythmic cycles.

The Tertiary cycle begins with a 50-150 m basal-fill sequence of interbedded sandstones and shales of the Tao Yuan Formation. This is overlain by a lacustrine sequence of rhythmically alternating carbonates, anhydrites and oil shales. This lacustrine sequence was deposited in a large cyclic meromictic lake complex which varied tremendously in size in response to alternating humid and dry periods. The balance between water inflow and evaporative loss, combined with slow subsidence, apparently prevented formation of a large, deep lake. This

Tertiary lacustrine phase appears to be dominantly climatically controlled. These sequences are confined to the individual graben and represents the most arid climatic conditions encountered. Coalescence of the three graben occurred at the end of Yuan Jiang deposition and resulted in a larger depositional basin with the extent of the shallow lake becoming much larger than previous individual lake stages. The remaining Tertiary sequence is characterized by numerous mudstone/siltstone cycles correlatable basin wide and represents deposition in saline, shallow lacustrine to mudflat environments. Sandstone/shale ratio is very low, probably less than 0.05, with only very thin, discontinuous sands. The sandstones are litharenites to sub-litharenites with less than 25% feldspars. Porosities and permeabilities of the Tertiary sandstones are similar to the Cretaceous sandstones.

The cyclic nature of the oil shale-evaporite couplets is very similar to the cycles in the Tipton and Wilkins Peak members in the Green River Basin, Wyoming (Surdam & Wolfbauer, 1975). The playa-meromictic lake model of Surdam and Wolfbauer (1975) and Boyer (1982) is probably applicable to the Early Tertiary in the Yuan Jiang Graben. The Dongting Basin cycles may represent 100,000 year Milankovitch and shorter climatic cycles. The playa lake stage represents a lake lowstand with deposition of the carbonate, evaporate and mudstone layers. Increased precipitation resulted in lake expansion and stratification giving rise to a meromictic lake with fresh surface waters. Oil shales were deposited at this stage as a result of high organic productivity in the fresh surface waters and high rate of preservation in the saline anoxic bottom waters.

Geochemical analyses show that only the thin organic rich shales contain significant TOC contents (1.0 - 9.8 wt%), dominated by FA (47-85%) and NFA (0-38%) algal derived kerogen. The interbedded anhydritic mudstones are organically lean (<0.5 wt% TOC) and have HI values <200. Extract hydrocarbon contents of the organic rich shales range from 142-3334 ppm with HC/TOC ratios from 0.64-10.75. Low Pr/Ph (<1.0) ratios and low Carbon Preference Indices (0.95-1.16) indicate deposition in an anoxic evaporitic environment.

SEDIMENTARY CHARACTERISTICS AND PETROLEUM ACCUMULATION OF THE NEOGENE IN THE JIYANG DEPRESSION

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Jiyang Depression is an important depression of the Bohai Bay Basin. It consists of 4 hollows (Dongying, Huimin, Ghezhen, Zhanhua hollows) and 10 rises (Chenjiazhuang, Yihezhuang, Binxian rises, and so on). The area is about 26,000 square kilometers.

The thickness of the Neogene is about 1000 m in the Jiyang Depression. It consists of the Guantao Formation and the Minghuazhen Formations. The Guantao Formation and the Lower Member of the Minghuazhen Formation are the main producing formations in Shengli oil field. Based on the analysis of 1700 well logs, seismic sections, and core fossil data, we divided the Guantao Formation and the Lower Member of the Minghuazhen Formation into seven submembers (N_{g4}, N_{g5}, N_{g2}, N_{g1}, N^3_{mi}, N^2_{mi}, N^1_{mi}). A synthesis of geological, seismic, well logging, and chemical data, leads us to conclude that the Neogene section was deposited as alluvial fan-fluvial sedimentary system. The fluvial sedimentary stage is long and the range is vast. The fluvial facies is divided into four sub-facies (river bed, river embankment, floodplain and abandoned channel) and seven microfacies (sand bar, channel filling, natural barrier, etc.). In vertical section, the early period of the Guantao Formation belongs to the alluvial fan-braided river sedimentary stage, the middle - later period of the Guantao Formation belongs to the braided river-low-curvature meander river sedimentary stage, and the early period of the Minghuazhen Formation belongs to the high-curvature meander river sedimentary stage. On the basis of sand body distribution, heavy minerals, etc., we consider the main source of sediment of the Guantao Formation to be the Chengning Swell, with the Luxi Swell acting as a secondary source. The source of the Minghuazhen Formation is possibly from the eastern foot of the Taihang Mountains and the western foot of the Yanshan fold belt. The paleocurrent flowed from south-west to north-east, and finally to the Bozhong Depression.

The oil and gas pools are trapped in anticlines and fault blocks, as well as in stratigraphic traps. The reservoir rock is mainly arkose, which has undergone only mild diagenesis. Reservoir quality is good, but its heterogeneity is a serious problem. The caprock is mudstone, with good performance. Oil and gas was generated by the black shale of the Paleogene Shahejie Formation. The distribution of oil and gas is closely related to the structure and sedimentary facies. The oil is associated mainly with the river bed facies, while the gas is mainly associated with the river embankment and abandoned channel sub-facies.

SEQUENCE STRATIGRAPHY OF TERTIARY STRATA IN LIAODONG BAY, BOHAI BASIN

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Seismic stratigraphic studies of the Nanpu region, the Liaohe oil field, and offshore Liaodong Bay in Bohai Basin, have lead to the development of a large-scale sequence stratigraphic synthesis of the late Paleogene evolution of the basin. For the purpose of precise communication we have tied this synthesis to the reflector terminology used by the Chinese oil industry. Thus, the terminology T_2, T_3^3, T_5 etc. is retained as descriptors of regional surfaces (Shi and Qian, 1992). It is important to recognize that some of these surfaces are regional unconformities (sequence boundaries), whereas others are maximum flooding surfaces (and perhaps transgressive ravinements).

The Shahejie (Es) and Dongying (Ed) Formations in the Bohai Basin can be divided into three large-scale seismic sequences by the T_2, T_3^1, T_5 and T_6 unconformities and their correlative conformities (Fig. 1). We refer to these as "Vail Sequences" (Nummedal and Stuart, 1993). The reflector geometry, facies successions, and log signatures vary in systematic ways within each Vail sequence. The three large-scale sequences reflect major changes in stress regime affecting the tectonics of the rift. Superimposed on the Vail sequences are numerous high-frequency sequences probably driven by climatic oscillations ("Milankovitch sequences", Nummedal and Stuart, 1993).

Vail Sequence 1

Description-- The basal unconformity-bounded sequence comprises the Fourth and Third Members of the Shahejie Formation (Es4 and Es3; Fig. 1). In much (all?) of the basin the sequence overlies a regional pre-rift unconformity (T6 or T8), and consist of an overall upward-fining succession of conglomerates, sandstones and mudstones inferred to be deposited in fluvial(?) to lacustrine settings. Exact water depths are very hard to ascertain, but the overall trend is clearly one of upward deepening. The sequence is truncated by an erosional unconformity at the base of the second member of the Shahejie Formation (Es2).

Sequence 1 occupies a series of steeply-dipping and small half-graben basins, each with a typical width of a few km (Fig. 2A). The sequence ranges in thickness from several hundred meters in some wells to zero at the onlap margin against the basement unconformity. Seismically, Sequence 1 is characterized by basal onlap and overall wedge-shaped reflector packages.

Interpretation-- The early phase of extension in Liaodong Bay was apparently characterized by a large number of faults, each one taking up a small amount of deformational strain. This incipient phase of extension developed multiple, steep-sided, narrow basins. Some basins may have been isolated from regional drainage patterns and accumulated thick sections of very fine-grained sediments, others captured parts of the existing drainage and were filled with fluvial and shallow to deep lacustrine coarse clastics. The sequence appears to represent a general deepening trend, because of the overall upward fining and the fact that the few oil shale beds that do exist within Es3 are all in the very upper parts of the unit.

Sequence 1 is divided into systems tracts where the basal sandstones and conglomerates form a lowstand systems tract, characterized by log signatures that suggest aggradational (blocky log signatures) or slightly progradational (upward coarsening log signatures) stacking patterns. The top lowstand flooding surface is generally overlain by much finer-grained rocks; typically mudstones and shale with subordinate sandstone and conglomerate and rare carbonates. These intervals represent the transgressive and highstand systems tracts.

Vail Sequence 2

Description-- The second unconformity-bounded sequence comprises the Second and First Members of the Shahejie Formation and the lower member of the Dongying Formation (Fig. 1). There is a pronounced surface at the top of Es 1 against which overlying reflectors appear to downlap. This interpretation is also supported by sedimentological evidence that the surface is a maximum flooding surface rather than a sequence boundary. Therefore, the upper boundary of sequence 2 is the boundary between what we believe is the Lower and Upper members of the Dongying (Edl and Edu). There is a pronounced unconformity on structural high blocks at this stratigraphic level.

The geometry and distribution of depositional systems in sequence 2 is quite different from sequence 1. During deposition of sequence 2 the basins had become much larger and, although individual reflector packages continue to be wedge-shaped, they are much broader and therefore may appear tabular in short seismic sections (Fig. 2B). In most seismic sections it is very difficult to pick the Es2/Es1 boundary. Where seismic facies distinctions can be made they are based on reflector amplitude and continuity. The overall shape of the Es2+Es1 package is a very broad wedge tapering towards the top of the ramp side of 10 to 20-km-wide basins.

The lower unconformity is overlain by coarse or fine clastics, or carbonates of the Es2. This facies variation is controlled by elevation on the tilted fault blocks. These facies grade upward into Es 1, which consists of a diverse association of mudstone, sandstone, oil shales and carbonates. The oil shales mostly occur in the middle and upper parts of the Es 1 interval, and the relative abundance of oil shale to carbonate also increases upward. Overlying the downlap surface at the top of Es1 is an overall coarsening-upward package of mudstone, sandstone and pebbly sandstones.

The T5 unconformity (basal sequence boundary of sequence 2) demonstrates a dramatic basinward shift in facies (shallowing), because of superposition of inferred shallow water carbonates and proximal, coarse terrigenous clastic systems directly above deep-water, fine grained clastics in the upper parts of Es3 (Fig. 2B). Moreover, during the ensuing deposition of Es2 and Es 1, there must have been substantial topographic and bathymetric relief in the basin, because the Es2 is entirely absent on many structural high blocks.

Interpretation-- The upward deepening trend observed in Es3 implies that sediment accumulation was gradually falling behind a growing tectonic relief. The T5 unconformity, combined with overlying coarse clastics and carbonates, records an abrupt reversal in this trend. The T5 unconformity also represents a distinct increase in half-graben size, probably related to the concentration of strain on a few faults with larger offsets. When this happened, the greater tectonic denudation would cause greater isostatic footwall uplift, thus generating unconformities across most major structural highs, and local source areas for coarse lacustrine fans (Lambiase and Bosworth, 1995). The wide-spread occurrence of this unconformity throughout the Bohai basin, however, argues that its origin records a *basin-wide* event, rather than just a few footwall uplifts. We therefore propose that the T5 surface records isostatic uplift because of brittle, extensional thinning above a regional detachment surface (as in model by Wernicke and Axen, 1988). A similar mechanism is considered a plausible origin for the so-called "mid-clysmic" unconformity in the Miocene Gulf of Suez rift succession (Morley, 1995).

The lowstand of lake level that was induced by the basin-wide uplift that created T5 also changed the depositional systems in the lake. Carbonate production is very sensitive to depth, typically decreasing in an exponential way with increasing water depth. Also, carbonate formation is very sensitive to "poisoning" by suspended siliciclastics or high nutrient supplies. Therefore, a lake level drop may trigger carbonate production on some bathymetric highs which emerge into shallow water while other shallow water areas, that are close to the mouths of subaerial watersheds, may receive coarse terrigenous silciclastics (Fig. 2B). Finally, stratification may be present in deep lakes even during lowstand, thus providing local deeps for accumulation of organic rich mudstones in anoxic benthic layers. Lake floor turbidites may also accumulate in such places. The distribution and types of facies within the Es2 is consistent with its interpretation as a lowstand deposit.

Following deposition of the Es2 lowstand systems tract, there is ample evidence of rapid lake deepening through Es1. The upward increase in oil shales and decrease in carbonates (Fig. 2C) is the expected facies response to gradual drowning of the depositional systems described above. We interpret Es 1 as a transgressive systems tract, capped by a maximum flooding surface at or near the seismic downlap surface (T_3^3) that is used as the boundary between the Esl and the overlying Lower Member of the Dongying Formation. The Lower Dongying Member is the highstand systems tract of Vail sequence 2 (Fig. 2D).

T_3^3 probably records the deepest water conditions ever attained in Liaodong Bay, because of the best developed oil shales at this interval. Based on amplitudes of clinoforms in the overlying Dongying strata, the lake at this time may have been several hundred meters deep.

Vail sequence 3

Description-- The third, and topmost, unconformity-bounded sequence within the Paleogene section of Liaodong Bay comprises the Upper Member of the Dongying Formation (Fig. 1). The upper boundary of this sequence is the T_2 surface, which separates coarse-grained, fluvial sediments and basalts of the Miocene Guantao Formation above from coastal plain and sandy delta systems of the Upper Dongying Formation below.

The boundary between the Upper and Lower Dongying in seismic sections is essentially a seismic facies boundary, but there is, in fact, also an erosional truncation surface on structural highs at this level.

Interpretation-- The two Dongying members are composed mostly of fluvial, coastal plain, sandy delta and prodelta sediments with some coarse-grained, sublacustrine and proximal lake floor fans. The details of the sequence stratigraphic architecture is not nearly as well known as that of the Shahejie, to some extent because of lack of diagnostic well log signatures of the systems tracts. The large-scale, shallowing-upward facies pattern in the Edl, however, probably represents a thick highstand systems tract that formed in response to the gradual integration of drainage basins into larger systems with increasing discharge as the rift basin morphology matured. Overall, the Dongying records a series of oblique, southward-prograding depositional systems, thus signaling the gradual development of a through-going, axial sediment dispersal system. This is the typical pattern in all aging rifts.

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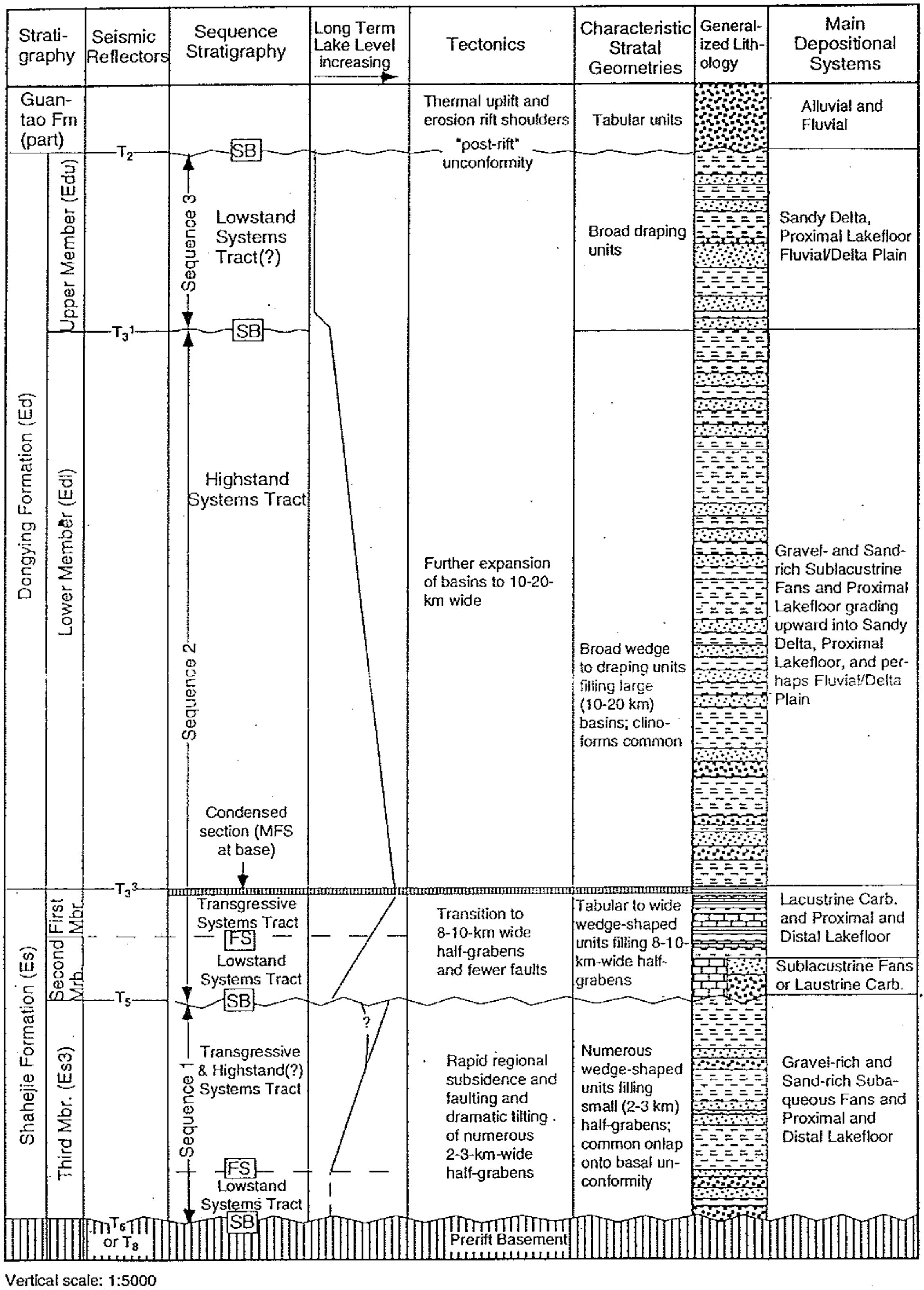
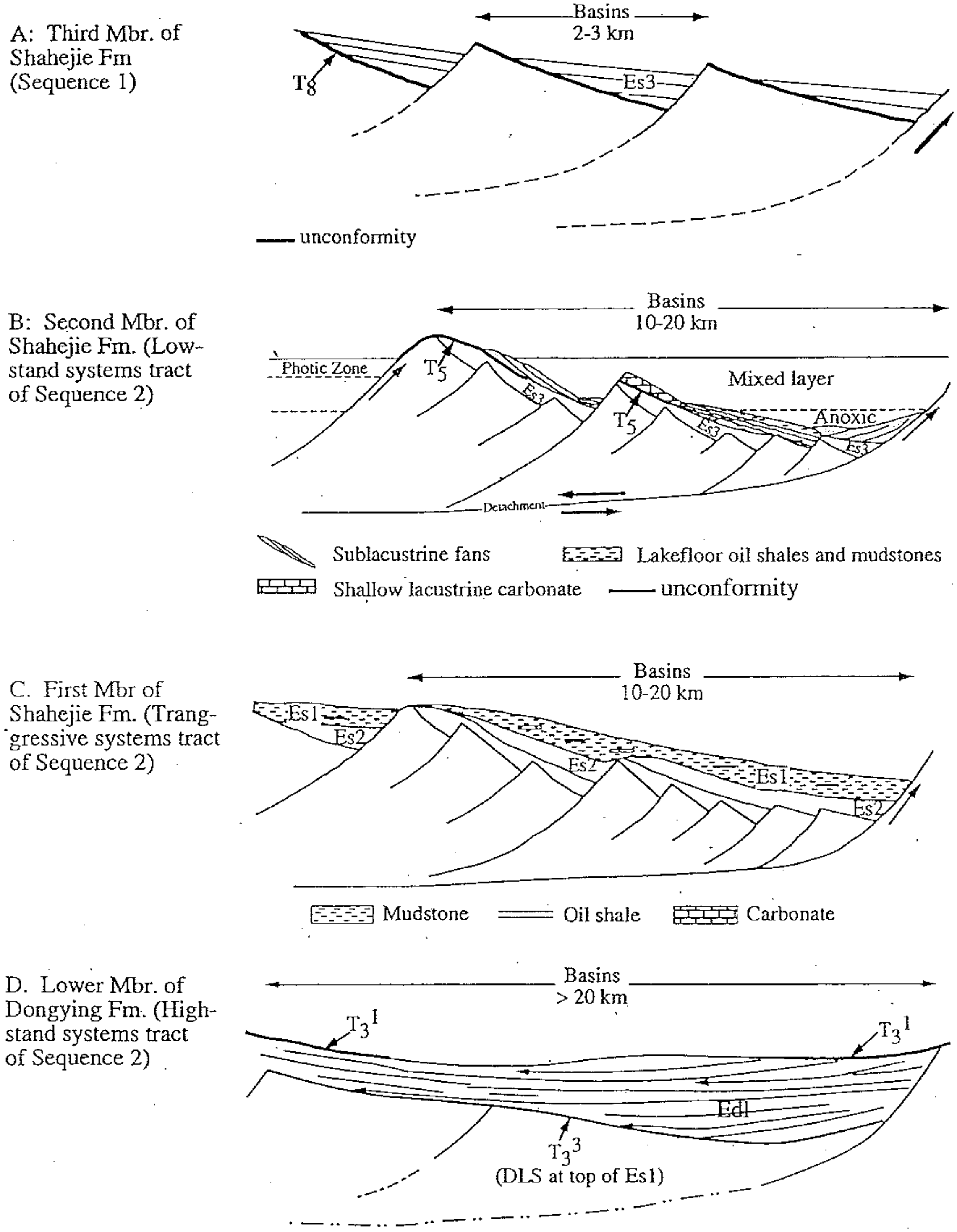


Figure 1. Summary of the stratigraphy, depositional systems, lake levels, and inferred tectonic events within the rift-fill sequence in Liaodong Bay, northern Bohai Basin, China.


A: Third Mbr. of Shahejie Fm (Sequence 1)

B: Second Mbr. of Shahejie Fm. (Lowstand systems tract of Sequence 2)

C. First Mbr of Shahejie Fm. (Trang-gressive systems tract of Sequence 2)

D. Lower Mbr. of Dongying Fm. (Highstand systems tract of Sequence 2)

Figure 2. Model illustrating the structural evolution and depositional systems in Liaodong Bay during Shahejie and lower Dongying time.

THE GEOLOGICAL FEATURES OF CARBONATE BURIED HILL OILFIELDS IN JIZHONG DEPRESSION

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The ancient buried hill oilfields in the Jizhong depression have their own unique geological features. The well developed and deeply buried pre-Tertiary basal buried hills are structures or traps which concentrate petroleum. The middle and upper Proterozoic carbonate rock, which were uplifted and weathered many times, became good reservoir units in which pores, holes and cracks are all mixed together. The Tertiary lacustrine mudstone, which covers the undulating basement serves as source rock. This combination establishes the petroleum reservoiring style of the buried hills, that is, hydrocarbons are generated in young formations and reservoired in old formations.

The wide occurrence of buried hill oilfields in Jizhong depression is closely related to the regional geological background. At the end of early Proterozoic after the Luliang movement, the North China platform began to deposit the middle and upper Proterozoic marine sediments which mainly consist of carbonate rocks. These deposits are extremely thick in the south of inner Menggol Axis, including Jizhong depression. During the Yanshan period, compressional movement formed an anticlinal structural landscape in Jizhong depression. At the central part of the anticlinorium, the middle and upper Proterozoic section had been exhumed. In the Cenozoic era, the structural movement in Jizhong depression changed into extension. Intense block-fault activity produced down-faulted sags and deeply buried faulted basement blocks. This geological framework was produced mainly by the these three episodes of structural movements and provided the conditions necessary for the occurrence of the buried hill oilfields.

HIGH-FREQUENCY, LACUSTRINE SEQUENCES OF THE NANPU OIL FIELDS, THE BOHAI BASIN, CHINA

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This paper examines the value of power spectral analysis as a tool in the study of cyclic lake sedimentation. The deposits we have investigated are the non-marine Shahejie and Dongying Formations of Eocene and Oligocene age in the Nanpu region of the Bohai basin of China. Both well logs and core descriptions reveal a distinct cyclic nature to the stacking pattern of successive lithologies. By applying spectral analysis, we can quantify the nature of the many superimposed cycles, and also test the idea that the cycles were caused by climatic and lake level fluctuations that had their ultimate origin in Milankovitch astronomical cycles (Fischer and Bottjer, 1991).

The Nanpu Depression

The Nanpu depression is a sub-basin of the large Bohai (or North China) rift basin. Regional rifting has recently been attributed to a decreased rate of convergence between the Eurasian and Pacific plates in the Eocene (Northrup et al., 1995). The Tertiary succession consists of up to 5,000 m of non-marine strata that are arranged in stacked sequences of varying scales. The overall succession ranges from basal fluvial deposits (the Paleogene Kongdian Formation), through lacustrine (Eocene Shahejie Fm. and much of the Oligocene Dongying), deltaic (mostly the Upper Dongying), and back into the extensive fluvial deposits of the Miocene Guantao and Minghuazhen Formations above the "post-rift" unconformity. This pattern of long-term rift evolution reflects systematic changes in the rate of rift-related subsidence, and has been widely recognized in rifts throughout the world (Lambiase, 1990).

The entire Tertiary basin fill can easily be subdivided into several sequences, bounded either by erosional unconformities or maximum flooding surfaces. In an accompanying paper (Nummedal et al. *ibid.),* we have divided the equivalent succession in the Liaodong Bay area of Bohai basin into four "tectono-stratigraphic" sequences, each one with a typical thickness of several hundred meters to a few kilometers and inferred durations of 5 to 7 million years. These, in turn, are composed of sequences on the scale of meters to 100 m. These high-frequency sequences are the subject of this study. Specifically, the objectives here are to document the characteristics of these small sequences, examining their stacking patterns, and build an understanding of the relationship between climatic cycles driven by the earth's orbital changes and Tertiary sedimentary sequences in the Bohai region.

Spectral Analysis

Spectral analysis is an objective, statistical method for detecting inherent cyclicity in time series data. A time series is a non-deterministic function x of an independent variable t. In "conventional" time series analysis $x(t)$ is a function of time, but in our case the independent variable is sedimentary thickness. The dependent variable, x, may be an attribute of the rocks easily measured in well logs, such as resistivity, density, gamma-ray intensity or SP. Because $x(t)$ is a function of depth, sequences will be expressed as repetitive well log patterns. These patterns are often referred to as *"log motifs",* and are often given such descriptive names as "bell-", "pagoda-", or "funnel-" shaped.

Time series analysis in this study was performed by calculation of the Fast Fourier Transform (FFT). The output of the FFT program is a plot of spectral energy (or total variance) against the frequency or thickness of the corresponding cycle (Figure 1). each spectral peak corresponds to a separate sequence thickness, and the degree to which the peak stands out from the background pattern is a measure of the statistical significance of that particular sequence. For example, the results of an FFT analysis of the gamma log of the Scientific Explorer Well (Gaocan-1) shows four distinct cycles at 11.9, 7.0, 5.2, and 3.7 m thickness (Figure1A). FFT spectra of the sonic log, resistivity, density, and neutron logs of the same well picked up the same spectral peaks (Figure 1B, C, D, and E).

In this complete study, Wu (1994) calculated energy spectra on a wide range of different well logs for the Scientific Explorer Well as well as selected logs from 13 different production wells in the Nanpu area. The spectra were analyzed and compared on the basis of their hierarchy, consistency, and energy levels. Peaks that were consistent in many wells and in several well logs from the same well were considered the ones that most probably recorded real climatically-induced cycles in the sedimentary record. Other peaks may either record allocyclic delta switching or "harmonics" of the major peaks.

Cyclicity in the Shahejie Formation

Spectra -- Spectra from the Shahejie formation interval on logs from the Nanpu producing wells revealed thickness cycles in the ranges of 18.2-28.6 m, 9.4-13.4 m, 6.5-8.1 m, 5.2-5.8 m, and 3.4-3.9 m. Radiometric dates on interbedded volcanics combined with log measures of interval thicknesses allowed us to calculate an average, post-compaction sediment accumulation rate of 0.3 mm/yr. for the Shahejie formation. The thicknesses just reported, therefore, correspond to time cycles of about 95, 41, 23, 19 and 12 ky, respectively. These correspond quite well to the known Milankovitch periodicities of 40 ky and 100 ky for changes in the eccentricity of the earth's orbit, the 40 ky cycles of obliquity changes, and the 23 and 19 ky precessional cycles (Fischer and Bottjer, 1991). The 12 ky peak is probably a harmonic.

When absolute time can be assigned to a succession of cycles, as done above, that is clearly the best way to test for the existence of Milankovitch cyclicity. If radiometric age calibration is impossible, or too poorly constrained, one can also test for the existence of Milankovitch cycles by looking for a consistent set of cycle thickness ratios. For example, precession cycles stacked within obliquity cycles should have thickness ratios of about 1:2, precession cycles within the short eccentricity cycles should stack 1:5, etc. Olsen (1986) applied this method with great success in a study of the Triassic Lockatong Formation of the Newark basin of northeast United States.

Changes in drainage basin climate, sediment yield, and lake levels were the drivers behind cyclic sedimentation in the Tertiary strata of the Nanpu depression. These changes had their ultimate origin in Milankovitch astronomical cycles.

Acknowledgments

We extend our most sincere appreciation to Mr. Xue Shuhao for his enthusiastic support and scientific discussion. This research was supported by the National Science Foundation Grant No. INT-8913154 to Louisiana State University.

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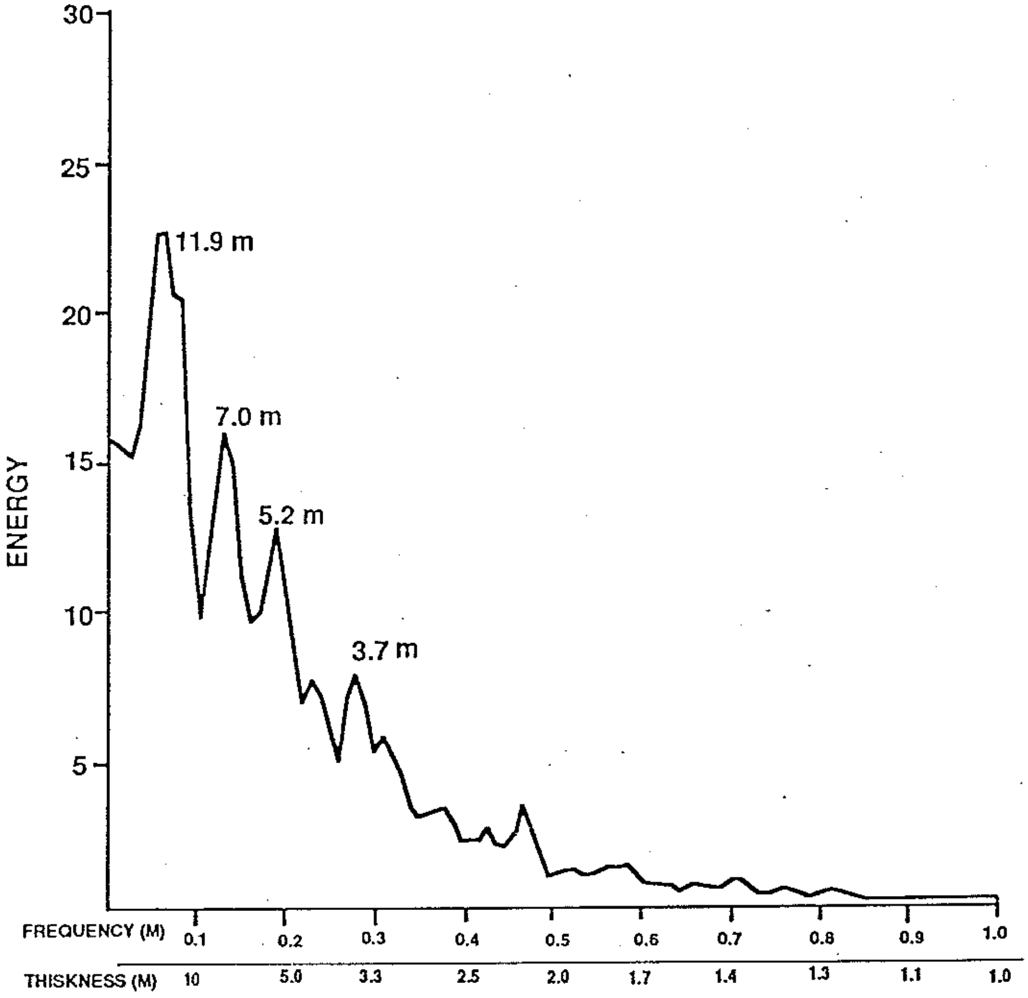

Fig. 1 . Power spectrum of the gamma log of the Scientific Explorer Well
The number of degrees of freedom is 10. The filter of TRIANGFIL (4) is used.
Four peaks are prominent.

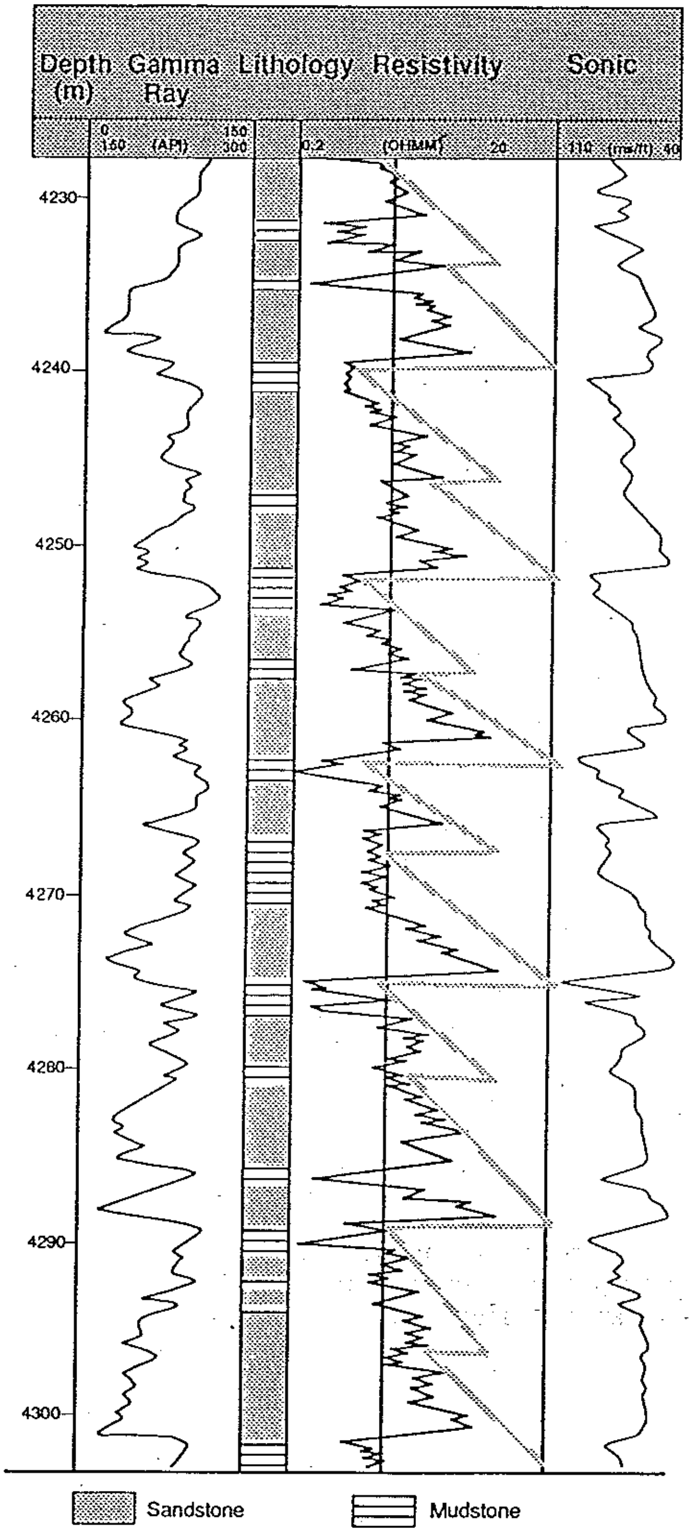

Fig. 2. "Twin cycles" in logs of the Scientific Explorer Well

SEQUENCE STRATIGRAPHY OF THE OLIGOCENE DONGYING FORMATION, LIAODONG BAY, NORTH CHINA (BOHAI) BASIN

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The North China (Bohai) Basin is a Tertiary rift, composed of half-grabens and intervening basement highs, that was filled with Eocene to Pliocene fluvial and lacustrine sediments. The Oligocene Dongying Formation was deposited during the late syn-rift phase, which was complicated by wrench faulting and local structural inversion. In the Liaodong Bay area (Figure 1), it is characterized by two stacked, shallowing-upward and then deepening-upward lacustrine successions. The lower one grades upward from deep lake floor shales and subaqueous sandy or conglomeratic fan deposits into forestepping and backstepping sandy deltas. The upper one contains the same succession, but the forestepping deltas eventually grade into delta plain and fluvial channel sandstones and mudstones. Dongying sandstones are important reservoir rocks throughout the North China Basin, and in Liaodong Bay contain significant hydrocarbon reserves in the JZ 9-3, JZ 20-2, JZ 2 1 -1 and SZ 3 6-1 fields. The shales have source rock potential, but are mostly immature. The objective of this study was to determine the distribution of the various Dongying facies using well and seismic data, and to develop a sequence-stratigraphic interpretation.

The overall sequence stratigraphic architecture of the Dongying Formation (Figure 2) shows two deltaic successions bounded by maximum flooding surfaces. Depositional sequence boundaries (unconformities) are contained within the sandstones. A third unconformity truncates the top of the upper Dongying, and forms the base of the Neogene Guantao Formation.

Stratigraphic nomenclature

The optimum method of subdividing a sedimentary rock succession is currently a subject of intense debate, with at least three different sequence stratigraphic approaches published within the past few years, in addition to allostratigraphic and conventional lithostratigraphic approaches. As described above, the Dongying Formation contains two mudstone to sandstone successions. We find it operationally logical to divide the Dongying into upper and lower parts at the maximum flooding surface (MFS) in the middle of the formation. Moreover, the lower boundary of the Dongying Formation is also a MFS. This division is applied here (Figure 2). By using maximum flooding surfaces as boundaries we are defining genetic sequences rather than depositional sequences.

Two alternative schemes have been previously used to subdivide the Dongying Formation (Figure 2). One is a lithostratigraphic scheme that divides it into two members, placing the boundary at the base of the upper (deltaic) sandstone. That boundary is clearly time transgressive. The other scheme divides the Dongying into three members, using a flooding surface near the top of the upper Dongying (as we have defined it) and the maximum flooding surface at the top of the lower Dongying as member boundaries.

The lower Dongying genetic sequence

The basal part of the lower Dongying genetic sequence is characterized by deep-water, varved shales and interbedded thin, sandy turbidites. These are interpreted to be early highstand deposits, which formed as deltas began to prograde at the basin margins. Coarser sediments were also transported into deeper water in response to delta-front slumping and river-initiated density underflows, forming lake floor fans that reached thicknesses of up to 200 meters. With time, the highstand deltas prograded farther into the basin, burying the lake floor fans. Some of these deltas prograded distances of several tens of kilometers.

A regional seismic line (Figure 3) demonstrates the forestepping and backstepping of the lower Dongying delta lobes. There is also good well log evidence for a backstepping set of high-frequency sequences at the top of this genetic sequence, implying that a regional transgression took place at this time. There is no conclusive seismic evidence of a lake level fall within the lower Dongying, but regional well log and seismic data suggest that there probably was one. Therefore, we have indicated a small fall in Figure 2.

The lower Dongying deltas are particularly well developed at the southern end of the Central Depression in Liaodong Bay (Figures I and 3), and are the main reservoirs in the SZ 36-1 oil field. Wells in this field encountered stacked delta fronts, which in the deeper half-graben areas reach cumulative aggraded thicknesses of up to 700 meters.

The upper Dongying genetic sequence

Upper Dongying prograding deltas are well developed in the northern end of the Central Depression, and their stratigraphic pattern is particularly well illustrated on the regional seismic line (Figure 3). At the base of the upper Dongying succession the reflectors are continuous, parallel, and of high amplitude. These probably represent distal lake floor mudstones, deposited at the time of maximum flooding. Overlying these in the proximal areas to the northeast are discontinuous, mounded features, that might represent lake floor fans. Farther landward, there are some sigmoid, aggrading reflectors that may represent deltas.

Higher in the section (at the center of Figure 3) there is an exceptionally well-defined set of clinoforms that first aggrade and then become successively more progradational. as the delta fronts regress more than 50 kilometers across the basin. The upper three of these progradational clinoforms show a pattern of offlap, i.e. successively younger strata extend less far landward than those below (the opposite of onlap). This is strong evidence of a relative fall in lake level and attendant subaerial erosion of the delta fronts. An apparent absence of the correlative delta front parasequences in the more proximal areas (see correlation of minor flooding surfaces, dashed lines, to the northeast in Figure 3) further confirms the presence of a major lake level fall associated with this surface. Because of the distinct seismic signature of this unconformity, we have indicated a major take level fall within the upper Dongying genetic sequence (Figure 2).

High-frequency (Milankovich) sequences

In contrast to the two genetic sequences described above, each of the reflectors traced in Figure 3 represents sets of smaller scale, higher frequency sequences. It is the stacking pattern of these higher frequency sequences that allowed the analysis of the lower and upper Dongying genetic sequences. In the SZ 36-1 oil field, where the higher frequency sequences are represented by a succession of stacked, prograding deltas separated by flooding surfaces, well-log correlations show a high degree of lateral continuity and consistently repetitive thicknesses. We suggest that a Milankovich climatic signal controlled their deposition. Global climatic oscillations due to Milankovich cycles are well known to have occurred throughout the Oligocene, and lakes are particularly sensitive to climate change. Both lake levels and fluvial sediment supply probably changed in response to a changing balance between water inflow and loss.

Lake depths

The water depths of the Dongying lakes has remained a controversial issue for some time. In this study we have addressed the issue by measuring the height of some of the inferred deltaic clinoforms on the seismic data, as illustrated in Figure 3, and decompacted them according to the standard techniques of backstripping analysis. For three different sets of clinoforms, using different assumptions for the sand-to-mud ratio, we calculated depths ranging from about 300 to more than 500 meters. The remarkable thickness of stacked delta front/flooding surface sequences in some of the wells, and the persistence of the minor flooding surfaces into even the proximal delta areas, suggests that lake levels fluctuated substantially (more than 100 meters?) during the each Milankovich cycle.

Summary

In summary, the Dongying Formation is composed of two shallowing-upward to deepening-upward cycles of lacustrine deposition, separated by maximum flooding surfaces. In the Central Depression of Liaodong Bay, the lower-cycle deltas are best developed at the southern end and the upper-cycle deltas are best developed at the northern end. This has led to miscorrelations in the past. In the case of both delta systems, the main direction of progradation was to the southwest, along the basin axis.

Analysis of the Dongying Formation in a sequence stratigraphic context has led to a greater understanding of the distribution of the depositional systems, and thus of the various reservoir and source rock facies. In future petroleum exploration and development, this understanding can be applied to our knowledge of the petroleum system, migration fairways and conventional and non-conventional trap-types.

THE FORMATION AND DISTRIBUTION OF NATURAL GAS FIELD IN DONGPU DEPRESSION

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Dongpu Depression is a rift sub-basin located at the southern end of the Bohai Bay Basin. The basement is crystalline metamorphics and layered Mesozoic and Paleozoic strata. Through Cenozoic extensional stress, the depression was gradually formed into the current rift basin, with the general tectonic framework of two deeps and one major structural high. The faults strike mostly NNE or NE. The overall structural configuration is very complicated.

Cenozoic sediment thickness in the eastern and western deeps are more than 9,000 m. The Eogene is dominantly fluvial and lacustrine sediment, which can be divided into two sedimentary cycles of E_k $E_{4\text{-}3}$ ES_2 lower and ES_2 upper ES_1 Ed, being the main source and reservoirs. As is common in terrestrial sediment, these deposits are characterized by multi-provenance and multi-depositional systems. They change fast in thickness, lithology and lithofacies, being vertically inherited and horizontally unbroken. The depositional cycle is alternating layers of sandstone and mudstone interbedded by a few sets of salt or gypsum-salt beds.

$ES_{4\text{-}3}$ is the main hydrocarbon source rock in this area. The kerogen present includes both sapropel and humic material. In general, the rocks contain a high abundance of organic matter. The high paleogeotherm under the thick gypsum salt bed and multiphases of volcanic activity are favorable to organic diagenesis and the generation of petroleum. Mature source rocks are widely dispersed over a large area. The sources have reached highly mature and post-mature stages in the deeps. Such conditions are favorable to the generation and preservation of natural gas. The Carboniferous and Permian coal measures are the second source rock in this depression. They have been preserved intact in the deeps, with a gross thickness of about 800 m, cumulative coal-bed thickness of 10-25 m, mela mudstone thickness of 188-222 m. The depth of coal measures is currently more than 4,000 m, having reached the stage of secondary gas generation. The two sets of source rocks are the material base for the abundant natural gas in Dongpu Depression.

The reservoir lithology is relatively fine-grained, most are siltstone and fine sandstones, some are medium sandstones and coarse sandstones. The distribution of sandstone has been obviously controlled by sedimentary facies, with individual layers being thin. The reservoir quality is variable. The reservoirs below 3500 m are usually less permeable and porous, because of deep burial diagenesis. Secondary porosity exists, however, even below 4,000 m.

The objective formation (Shahejie Formation) in this depression is a set of alternating sandstones and mudstones. This alternation appears favorable to the generation, migration and accumulation of hydrocarbon on the central uplift near the source deeps. The inherited structure provides a favorable target area for hydrocarbon migration. Various types of traps had been formed before hydrocarbon migration. Various types of traps had been formed before hydrocarbon migration. Fault-block traps dominate. The sets of gypsum-salt rocks which are widely distributed in Shahejie Formation have become good caprocks. Especially, the S_3^2 salt bed has been splendid caprock characteristics capturing oil-formed gas and coal-formed gas and mixed gas.

The distribution of gas reservoirs has been controlled by source, reservoir and structure, and types of trap formed. The shallow gas reservoirs have mainly been controlled by structure. These reservoirs mostly contain wet gas. The central uplift is a complex petroleum accumulation zone, in which various hydrocarbon reservoirs have vertically stacked up and have horizontally been continuous. The proven reserve and controlled reserve are mostly distributed in this zone. Addition to structure, deep-seated gas has also been controlled by the distribution of reservoir and diagenesis. The deep seated gas is generally condensed gas accumulating in wide non-anticlinal gas reservoirs including both stratigraphic and diagenetic traps.

THE DEVELOPMENT AND EXPLORATION OF QUATERNARY GASFIELD IN THE EAST PART OF QAIDAM BASIN

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A patch of high production Quaternary gas has been found in the east part of Qaidam Basin, Qinghai Province. It is very important to research and explore this shallow biogenic gas reservoir.

Located at the north-east of Qinghai-Tibet plateau, the Qaidam Basin developed as a result of the collision of India plate with the Europe - Asia plate. Within this special geologic and structural background a Quaternary lake facies formation, as thick as 3000 m was rapidly deposited. Beneath this Quaternary formation is 1500 m of dark mudstone source rock, sandwiched with fine sandstones of good quality. The fine sandstone have undergone ideal diagenesis. The growth structures provided good locations for gas migration and storage.

The author uses the methods of micropaleontology, paleontology, palaeomagnetism and the comparison of global geologic events, to establish the basin formation and depositional history, the transformation of organic matter to hydrocarbons and their migration and storage conditions within the Quaternary system. Described are the significant scale of the fast deposition and the formation of salt water which favored the habitation of early phase methanogenic bacteria. Also examined are the organic chemical reactions and the preservation of the organic matter and the problem of high porosity and permeability of cap rock. Some experiments and research have been carried out to define the theory of dynamic balanced accumulation formation.

Because of the speciality of Quaternary gas accumulation, there are many abnormal phenomena on seismic and airborne magnetic survey data. Such as low velocity, low frequency wave events, pull-down velocity sags and high frequency micromagnetic abnormal, etc. These phenomena provide reliable proof for the natural gas exploration and the gas field discovery.

FORMING OF CENOZOIC HYDROCARBON POOLS IN YINGGEHAI BASIN, OFFSHORE CHINA

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Yinggehai Basin lies in the South China Sea. It formed in response to transform - extensional tension. This Cenozoic basin contains over ten thousand meters of sediment. The geological characteristics of the basin are a high rate of deposition, high geothermal gradient, abnormal geopressures and mud diapirism.

There are three gas-prone sources in the basin confirmed by drilling, i.e., an Oligocene coal-bearing series, the middle Miocene and upper Miocene marine clays. Reservoirs are mainly present in the upper Oligocene, lower Miocene, top middle Miocene and top Pliocene. These potential reservoirs were deposited as deltaic sands, offshore bars, beach sands, and shelf sands. Regional seals are middle Miocene and Quaternary marine claystones spreading across all areas of the basin. Anticlinal and stratigraphic traps prevail. Faults and diapirs act as vertical migration paths. Some of the marine sands in several formations provide for lateral migration across the basin. Recently, some discoveries were made in the Upper Oligocene, top Middle Miocene and top of Pliocene sections. These pools contained mainly hydrocarbon gas but did include carbon dioxide and nitrogen.

THE THERMAL-TECTONIC EVOLUTION AND HYDROCARBON GENERATION HISTORIES OF DONGYING BASIN, EAST CHINA

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Dongying basin which contains the Shengli Oil Field is an extensional, pull-apart basin. Its formation and development, were controlled by the interaction between the western Pacific Ocean plate and Asian continental plate. The basin's history was controlled by the regional stress field and the influence of deep marginal faults. The basin's evolution can be divided into three stages: the rifting stage in late Cretaceous, the mainly extensional and pull-apart extensional stage during the Paleogene, and a thermal subsidence stage in the Neogene and Quaternary. The average sedimentation rate in Dongying basin is more than 100 m/my since the onset of the Tertiary.

1.5 - 22 HFU

The quantitative and qualitative studies of apatite fission tracks of 12 samples indicate that Dongying depression, on the whole, underwent cooling after its formation. Surface heat flow did rise between 20~30 Ma due to the uplift and erosion. But during this evolutionary stage, the temperatures of each stratigraphic unit were decreased about 10 °C as a result of erosion. Two-dimensional numerical modeling of paleo-temperature demonstrates that the heat flow after the basin's formation was about 79.5 mw/m^2, which decreased to 70.2 mw/m^2 before the uplift and erosion between the Oligocene and Miocene. After the uplift and erosion, the heat flow was about 73.8 mw/m^2, and decreased to 64.8 mw/m^2, which is very close to the present measured value of 65.6 mw/m^2.

Hydrocarbon generation by the source rocks within the basin was simulated using a geochemical dynamic method containing many parallel reactions. The simulation also included the rapid burial (with the average sedimentary rate about 100 m/my) and high heating rates (with the average of 3°C/my). The hydrocarbon generation histories of the main source rock - Es_3, are analyzed, and the results indicate that: 1-the main hydrocarbon generation stage of Es_3 was achieved in the Neogene thermal subsidence stage, although it had gradually reached the oil generation window beginning 32.8 Ma; 2-the hydrocarbon generation histories of the second-order units of the basin are different, the order of entry into the oil generation window are Lijing, Niuzhuang, Boxing and Minfeng areas; and 3-some areas had reached gas generation window beginning 11.2 Ma, so the exploration for gas resources must be emphasized.

THE STRATEGIES OF PETROLEUM EXPLORATION IN CHINA IN THE 21ST CENTURY

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Over the past 40 years, 82 Sedimentary basins (76 onshore, 6 offshore) in China have been explored gradually, and obtained very good results. Since 1991, the second assessment of petroleum resources in whole China indicates that the potential petroleum resources in China are very abundant. Many new targets both onshore and offshore are worth drilling; new concept and comprehensive exploration methods should be adopted to make a breakthrough in oil and gas resources exploration.

The concepts are mainly composed of the following four aspects:

1. Conduct more oil and gas exploration in which is considered as mature basins.
2. Invest in petroleum exploration in new prospective areas.
3. Pay more attention to the exploration regions and new oil-bearing reservoir layers formed by different Geotectonic background.
4. Integrate multidiscipline exploration methods to be proved as effective measures to enhance the successful rate of petroleum exploration.

To draw up the strategy of exploration for oil and gas resources based on the above concepts and is also the way to increase oil and gas production.

AN OVERVIEW OF LACUSTRINE BASIN PETROLEUM SYSTEMS IN CHINA, SOUTHEAST ASIA, AND INDONESIA

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The Far East is unique in that lacustrine facies play a dominant role in the petroleum systems of the region. It has be estimated that greater than 75% of the region's reserve base can be attributed to lacustrine source rocks. Individual accumulations can be quite significant falling into the "giant field" category. For example, the reserve estimates for Daqing (China) and Duri (Indonesia) have been placed at 8 and 7.1 x 10^9 barrels, respectively.

Although the lacustrine sources were deposited under varied conditions (salinity, water depth, etc.), the produced oils from these systems share many geochemical attributes (i.e. high pour points, high wax content, low sulfur content, etc.) and are chemically distinct from their marine counterparts.

A study of the stratigraphic distribution of these lacustrine source sequences reveals their presence from the late Paleozoic onward. Many, but not all, of these source rocks were deposited within rift basins which formed as a result of Meso-Cenozoic extension of continental crust and/or strike-slip movements associated with the readjustment of the Asian, Indian Ocean and Pacific Plates (e.g., Songliao, Bohai and Central Sumatra basins). Other lacustrine systems, particularly those of western China, formed in foreland basins which were the result of compressional tectonics associated with the docking of various microcontinents including the Indian Plate (e.g., Junggar and Tarim basins).

The nature of these source rock systems of these different basins varies significantly with respect to their volume (areal and stratigraphic distribution), the quantity (or richness) and quality (oil-proneness) of the organic matter. Among the best developed of the oil-prone lacustrine source rock sequences may be the Upper Permian, Lucaogoa Formation, of the Junggar basin where the net source rock interval may approach 800 meters. The effective source sequence has an average

TOC and S_1+S_2 yield of ~4.0 wt.% and 26 mg HC/g rock, respectively with hydrogen indices commonly in excess of 500 mg HC/g TOC. Other possible sources, such as the Eocene Maoming oil shales (Guangdong Province) may be richer and more oil-prone but are of more limited stratigraphic and/or areal significance. Yet other source units, such as the Oligocene Huagang Fm. and Eocene Pinghu Fm. (East China Sea) are largely coaly and dominated by gas-prone organic matter. To a large extent these variations in volume, quality and quantity of oil-prone source material are a function of the persistence of "deep" lakes, which is a function of the rates of subsidence and sedimentation and climate. The better established, more persistent the "deep" lake the better the oil source rock development. A secondary factor which also appears to assist with source rock development, particularly in shallower lakes, is salinity. More elevated salinities may result in the enhancement of organic preservation and better source rock development.

A further examination of the petroleum systems of the lacustrine basins of China, Southeast Asia, and Indonesia reveals the presence of both pure-bred and hybrid systems. For this discussion a pure-bred system is defined as a petroleum system in which both the source and the reservoir were deposited within a nonmarine environment (e.g., Qingshankou-Yaojia system of the Songliao basin, PRC). A hybrid system is defined as a petroleum system in which the source and reservoir were deposited in different environmental settings, i.e., one was deposited under marine conditions and the other was deposited under nonmarine conditions. In this region it is the source that was deposited within a lacustrine setting and the reservoir which was deposited under marine conditions (e.g., Pematang-Sihapas system of the Central Sumatra basin and the Wenchang-Zhuhai of the Pearl River Mouth basin).

Both the pure-bred and hybrid systems of the region share, at least in part, the geologic characteristics of their initial carrier (migration) network. In lacustrine basins both the lateral and vertical continuity of this network is often limited as a result of rapid facies variations. Consequently, secondary migration is commonly limited and hydrocarbon accumulations are in close proximity to the generative portion of the sedimentary basin. Commonly, a strong vertical migration component is associated with these systems, with the migration network being linked through a series of faults and fractures. These faults provide the primary conduits for hydrocarbon movement from the synrift lacustrine source to the post-rift marine reservoir. This migration network need not be associated with a single major fault, but actually may be a collection of more minor faults and fracture systems where the actual migration path follows a helical pattern. In those cases where there has been long-distance lateral movement vertical fluid flow has also played an important role.

The nature of the reservoir bodies within these systems is highly variable. In general the lacustrine reservoirs are more limited. This is particularly the case within the synrift tectonostratigraphic setting where sandstone mineralogy is typically immature and subject to porosity and permeability reducing diagenetic events. Within the lacustrine system the best developed reservoirs are often associated with delta complexes (distributary channels and mouth bars) and low-stand fan complexes. However, even within the more stratigraphically extensive fans reservoir quality is usually reduced because of poor sorting. Poor reservoir quality is also common within the beach and shallow lake features because of their normally fine-grained character.

Seal development within these systems is also highly variable. Excellent and laterally extensive seals often develop within the more axial portions of the lake setting. The stratigraphic continuity of these sealing facies decreases toward the lake margins as coarser-grained facies increase in importance. These more silty facies tend not to act as either seal or source but as a "thief" accumulating hydrocarbons which cannot be effective produced. Within the delta complex local permeability barriers (seals) develop both areally and vertically reducing the size of individual hydrocarbon pools. In those areas where fan development has occurred seal development is usually limited. In many instances favorable juxtaposition between reservoir and sealing facies is accomplished through changes in lake level which results in the migration of sedimentary facies. Further reducing the overall seal potential of many of these basins has been the interruption of beds by faults and fractures. It is the absence of a very effective seal in many of the basins within the area that has resulted in the upward migration of hydrocarbons into the overlying marine sequence .

METHODS AND RESULTS OF LOGGING SEQUENCE - ANALYSIS BY COMPUTER

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Subsidence, eustasy, sedimentary supply, and climate caused stacked sedimentary cycles which are recorded in well logs and can be placed in a sequence of stratigraphic framework.

The cycles can be established by applying spectral analysis and other methods to well log profiles. Profiles can be segmented into a series of stacked cycles by special series analysis technique. Generally, sedimentation rates could not match the change in accommodation space. Log character, therefore, records the depth of the water during the sedimentary cycle. The most shaley signatures in the cycles reflect the maximum flooding surfaces of the cycles. A special function was developed to correct the thickness of the logging data. After thickness correction of these cycles, curves can be plotted which present accommodation space versus well depth. Signal extracting techniques are then used to establish the subsidence and eustatic components based on their different frequencies. Sequences can then be automatically established and placed into the appropriate framework.

The method was used in a basin in western China. The oil resources correspond with mostly the transgressive systems tracts and to a lesser degree with high stand systems tracts in carbonate sections. A comparison of these automated results with that established through conventional analysis of seismic data, logging data and well cores was very favorable.

With the development of a computer system by our group this method can be used cautiously in different areas.

COMPOUND CONDENSED SECTIONS, STRENGTHENED REFLECTIONS, UNCONFORMITIES AND GIANT OIL FIELDS

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Strengthened events (or reflectors) usually occur in oil bearing basins. These events can be traced across the whole basin and are always considered stratigraphically equivalent boundaries. The results of sequence simulation show that the strengthened events are usually compound condensed sections. The stacking pattern simulations of different order sequences show that two types of compound condensed sections can be formed. The first type results from a second order base level fall and the connecting of third order sequences formed in the early and late stages of the second order base level cycle. The second type is formed by a continuous prograding of several third order sequences on a major unconformity surface after a widespread transgression. Nearly all giant oil fields are related to compound condensed sections because it makes an excellent condition for the formation of petroleum systems. Daqing and many giant oil fields in nonmarine sediments are examples. Studies show that two types of compound condensed sections, three types of giant oil fields and three orders of unconformities have to be recognized.

METHODS OF BASIN ANALYSIS IN FAULTED LACUSTRINE BASIS AND EXAMPLES STUDY

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The principles and methods of basin analysis have been developing since 1960's. McKenzie model, which has been used widely, is not satisfactory to the basin analysis of faulted lacustrine basins in east China. A systematic method, therefore, for the basin analysis of faulted lacustrine basins has been proposed, its major procedures are as follows: (1) research into basin genesis by the use of all kinks of available data; (2) stratigraphy through integrated analysis of the paleontologic, paleomagnetism and seismic stratigraphy; (3) identification of paleoenvironment using petrology, paleontology and geochemistry, etc.; (4) analysis of basin burial history by the use of back stripping method; (5) demonstration of tectonic development through the comprehensive uses of well logging, seismic data and tectonic modeling results; (6) indication of sedimentary filled history by the synthetical analysis of geological, logging and seismic data; (7) clarification of hydrocarbon evolution based on basin modeling; (8) identification of the types and occurrences of oil-gas pools according to the tectonic and sedimentary histories; (9) analysis of the types and evolutions of tectonic-lithofacies belts in terms of the second class tectonic units in a basin; (10) multipurpose analysis of the burial history, tectonic development, sedimentary filled history and hydrocarbon evolution, indication of the favorable targets for oil-gas exploration. Lastly, according to the methods mentioned above, the basin analysis of Dongpu, Dongying and Huimin basins, located in eastern China, have been completed, and the satisfactory results have been gained.

EXPLORATION FOR LACUSTRINE CARBONATE RESERVOIRS: INSIGHTS FROM AFRICA, BRAZIL AND CHINA

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Production from lacustrine carbonate reservoirs, some of which are giant fields, make them an important exploration target in many nonmarine rift basins. Modes of formation, both chemogenic and biogenic, and to some extent their distribution are fairly well understood, but from a petroleum exploration perspective, there are a number of key questions which have yet to be addressed. What conditions am required to develop carbonate deposits thick enough to be considered reservoir targets? What is the nature of the interplay between subsidence and lake level fluctuations which controls accommodation space for vertical accretion? What is the spectrum of facies types that can be considered potential reservoirs? How important are early and late diagenetic processes in producing and preserving reservoir quality in these thermally and tectonically active rift basins?

A significant amount of production in Asia comes from marine sections which are charged by deeper lacustrine source rocks. As exploration continues to mature, deeper drilling for lacustrine reservoirs juxtaposed with these source rocks will proceed in earnest. It is therefore very instructive to examine the various settings of lacustrine carbonate production worldwide to gain insight into the controls, problems and risks inherent in specific reservoir targets.

Cretaceous reservoirs of the Lagoa Feia Formation in the Campos Basin of Brazil are examples of a uniform prospective facies type with a complex structural and diagenetic overprint. Fields like Pampo and Linguado have produced over 170 and 110 MMBO respectively from cycles of pelecypod coquinas (grainstones, packstones and rudstones) which contain both primary and secondary porosity. Accumulations are controlled or influenced by updip facies and diagenetic changes and fault closures. Smaller fields in the trend like Badejo and Trilha have added another 40 MMBO from similar reservoir and trap types. The lesson learned from the Lagoa Feia is that some reservoir targets can have a fairly uniform productive facies type, but vary in lateral continuity, trap controls and compartmentalization.

Chevron's reservoirs of a similar age occur in offshore Cabinda, Angola. The TOCA formation (an old drillers term which stands for Top Carbonate) is highly productive in two of the four fields discovered and developed to date. These fields are distributed among three subbasins which have varied from connected to isolated at different times. Kambala Field is productive from two zones in the TOCA. The lower zone is a coated-grain grainstone/packstone shoal system with primary and secondary porosity. The upper zone is an algal biolithite which has been hydrothermally dolomitized resulting in secondary vuggy and intercrystalline porosity. Malongo West Field also produces from the TOCA, but here reservoir pore systems range from chalky microporosity dominated to vuggy karst related types. Nonetheless, this field has produced over 240 MMBO from these lacustrine carbonates and is still producing today. Both of these fields are trapped in different structural configurations of the rift basin tilted fault blocks. The lesson from Cabinda is that diversity in facies, diagenesis and trap type can be the norm in some nonmarine basins.

Lacustrine carbonates are a common reservoir type in the basins of the greater Bohai region, China. A good example occurs in the Jinzhou 20-2 fields of Liaodong Bay. The structural setting is dominated by rift tilted fault blocks with thick Eocene-Oligocene fill dominated by siliciclastics. The lacustrine carbonate reservoirs of the JZ 20-2 area are dolomitized gastropod-coated grain grainstones with excellent secondary porosity ranging between 8 and 30%. Traps are faulted anticlinal drapes over buried hills which are typical for many Chinese basins. However, the lesson from this region of China is that the details of structural style may exert a significant influence on areas of accumulation and preservation of potential reservoir facies.

Study of a diverse suite of lacustrine carbonate reservoir settings provides insight into understanding the controls on reservoir facies distribution and quality. It must be kept in mind that thick carbonate accumulations do not occur in all lacustrine basins. Examples include the Newark Basin in the U.S., the Doba-Doseo Basin in Chad and the Muglad Basin in Sudan.

Reconstruction of paleoclimatic conditions is critical since it may be the single most important factor controlling sedimentation and lake chemistry.

Excellent modern analogues exist from the Great Salt Lake in the United State and from recent work in the East African Rift. The Great Salt Lake is a shallow saline system of subbasins where ooid and algal biohermal facies form continuous trends around the lake margin and intralake highs. The East African rift lakes are a system of fresh deep lakes where skeletal facies form discontinuous trends, but in specific structural settings which could be identifiable on the seismic scale for applications in exploration. These analogues provide an understanding of how many of these reservoir targets can form, where they form and why. When applied properly they can significantly reduce exploration risk.

CHARACTERISTICS AND GENESIS OF IMMATURE OIL IN JIYANG DEPRESSION

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Immature oil is distributed widely in the Jiyang Depression. There are various types of accumulations (most of them within the Tertiary at depths of less than 2000 meters). Compared with the conventional mature oil in this depression, the immature oil is characterized by low concentrations of saturated hydrocarbons, low saturated/aromatic ratios and high nonhydrocarbon content. The saturated hydrocarbons are predominantly branched paraffins and cyclic alkanes. The aromatic fraction is dominated by condensed-nuclei aromatics. The steranes retain a high content of their original biological configuration ($\alpha\ \alpha\ \alpha$ 20R and 5 β), and a low content of isosterane in its geological configuration. Both diasterane and low-carbon number steranes occur in lower concentrations. There is no 17 β and 21 β terpane configuration. The total content of tricyclic terpanes is low, equivalent to 3~5% of the pentacyclic terpanes. All the above show the characteristics of primary transformation of organic matter.

According to the relative abundance of C_{27}, C_{28} and C_{29} steranes, gammacerane content and the pristane to phytane ratio, the immature oils can be divided into three types in this depression. The oil/rock correlation results show that the hydrocarbon source beds of these three types of immature oil are respectively from immature hydrocarbon source rocks in Es_1, Es_2 and Es_4 members of Shahejie Formation.

The author discusses the genesis mechanism of immature oil based on the comprehensive study of the palaeontologic assembly, paleoclimate and depositional environment of source rocks combined with the data of simulated tests. It is concluded that immature oil was generated from organic matter during early low-temperature evolution. It was the saline, strongly reducing environment which resulted in an oil source bed rich in lower planktonic algae that favored the generation of low maturity oil. This viewpoint provides the scientific basis for expanding exploration area and guiding exploration in the shallow section within this depression.

TECTONICS, LACUSTRINE FACIES DISTRIBUTION AND EXPLORATION STRATEGY IN EXTENSIONAL BASINS

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Accurate prediction of the occurrence, and distribution of lacustrine facies is essential for successful exploration in non-marine extensional basins. It is well established that the type and volume of lacustrine deposits determines the source rock potential of a basin. However, the size and geographic distribution of lakes also influence the geographic distribution of the associated lacustrine and non-lacustrine facies which ultimately may form potential reservoirs. Tectonics and climate have each been proposed as the primary control on sedimentation and, therefore, lake distribution in extensional basins. Clearly, both are important as lake occurrence requires a closed depression and a source of water which exceeds the evaporation rate; the present study focuses on the role of tectonics in controlling lacustrine facies distribution.

Six principal structural features strongly influence sedimentation patterns in extensional basins. These are: 1) topographically high accommodation zones which segment rifts into structural half-graben, 2) reactivation of pre-existing structural elements, 3) footwall uplift at main border faults, 4) gentle roll-over of topography on flexural margins, 5) breakup of the basin floor into elongate, basin-parallel fault blocks, 6) development of fault relay zones and transfer faults. Each of the six structural elements has its own specific affect on sedimentation, and consequently its own contribution to the basin's final stratigraphy. These controls operate in the present-day low latitude rifts of East Africa, where climate ranges from arid to humid and similar relationships have been identified in ancient basins.

Different structural elements, and the resulting sedimentation patterns, are prominent at different times during a basin's history. Recent models for the structural evolution of extensional basins indicate that there is a progression through four well-defined structural/stratigraphic stages and that a specific structural morphology is associated with each stage. Initially, rift-parallel fault blocks and transfer faults are the most important structures and topographic relief is limited. Sedimentation is dominated by fluvial processes; shallow lacustrine and paludal sediments also can accumulate.

During the second stage, the rate of structurally-induced basin-floor subsidence and basin shoulder uplift exceeds the regional sedimentation rate. Accommodation zones, footwalls, and flexural margins become positive topographic features, resulting in a half-graben morphology. The depositional patterns occur at the basin-wide scale, resulting in sediment starved half-graben. Large, deep lakes will develop in humid climatic settings and small lakes, rivers and deserts will dominate drier basins. On the basin floor, depositional patterns continue to be controlled by basin-parallel fault blocks and transfer faults.

Sedimentation rate eventually overtakes the rate of basin-floor subsidence and basin shoulder uplift. Basin-floor topographic features such as individual fault blocks and transfer faults are buried. Accommodation zones and basin shoulder topography continue to define the basin margins and to influence sedimentation. Maximum water depth in lakes is limited by the height of the lowest basin-bounding topography, which forces a decrease in maximum depth with time as the basin fills. Generally, accommodation zones are the topographically lowest basin-bounding features and are the next to be buried, converting the basin floor to a fluvially-dominated, linear plain without along-axis topographic barriers.

After accommodation zones are buried, uplifted footwalls and flexural margin rollovers continue to influence sedimentation until they are ultimately eroded. In some basins, this erosion is a result of isostatic uplift and is the final stage in the basin's evolution. Other systems become thermal sag basins that continue to subside as broad, regional depocenters.

The four structural/stratigraphic stages lead to a general stratigraphic succession that correlates well with the stratigraphy observed in numerous Phanerozic nonmarine extensional basins. It begins with a basal unit that is dominated by fluvial and alluvial sands. These are overlain by lacustrine deposits with an abrupt transition from the fluvial to lacustrine environments.

Progressively shallower water deposits occur upward through the lacustrine interval, culminating in a gradual transition to fluvio-deltaic sedimentation. Eventually, the transition to subaerial environments is completed, and subsequent deposits are primarily of fluvial and alluvial origin.

The tectono-stratigraphic model and the general stratigraphic succession have two important implications for exploration strategy. These are that: 1) lacustrine facies occur preferentially in specific stratigraphic units, and 2) while superficially similar, the stratigraphy of each half-graben develops quasi-independently. The first point indicates that the search for potential reservoirs and source rocks can focus on particular stratigraphic units, while the second indicates that the quantity and quality of source rocks and reservoirs can vary greatly in adjacent half-graben. Therefore, to accurately evaluate the source rock and reservoir potential of extensional basins, it is necessary to identify the number and geographic distribution of the original lacustrine depocenters and to test the facies associated with each. An efficient exploration program will first determine which depocenters contain lacustrine source rocks and then pursue potential reservoir targets in specific geographic and stratigraphic locations.

RECENT VOLCANIC ACTIVITY AND ITS RELATION TO HYDROCARBON MATURATION OF SYN-RIFT SEDIMENTATION IN THE NORTHERN SOUTH CHINA SEA

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The South China Sea contains substantial transitional crust that floors deepwater exploration targets within half grabens along its northern boundary. Though rifting initiated in the Cretaceous and was complete by the mid-Cenozoic, the thermal structure of the northern margin is 3-Dimensional and "spotty". There are several very hot locales that appear to be related to volcanicity that has continued from 5 to at least 1.5 Ma. Of course, there are active volcanoes on Hainan Island. Lamont has mapped several mini-basins filled with syn-rift sediments that have elevated thermal structures likely caused by buried volcanoes. Gravity and magnetic surveys support this interpretation. The elevated thermal histories near these volcanoes mature hydrocarbons in some of these mini-basins, whereas immature source rock is predicted away from the volcanic activity.

GEOTHERMAL RESOURCE AND ITS DEVELOPMENT IN HYDROCARBON REALM OF EASTRN CHINA

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It has been 2500 years since China discovered and began to utilige geothermal resource. In every federal dynasties of past ages, both royally and among ordinary people, hot springs have been widely used medically and for sightseeing as well.

In recent 10 years, China saw a rapid development and comprehensive use in the geothermal resource of both medium and low temperatures, which internationally, won the second place-geothermal heating systems covers $1.31 \times 10^6 m^2$; geothermal greenhouses $1.15 \times 10^6 m^2$; geothermal aquatic cultivation pond $1.6 \times 10^6 m^2$; 179 geothermal sanatorium and 594 geothermal bath pools. Great progress has also been made in geothermal exploration of high temperatrue in Tibet, Western Yunan and Taiwan. The geothermal power station in Well Yang—8, Tibet, has a yearly generating capacity of 25 million kW.

The Eastern China Hydrocarbon realm lies in the eastern margin of the Asian continental crust, which is getting comparatively thinner. Earthquakes and hot springs can be repeatedly found around this region because of the uneven and frequently—occuring upwellings, spurtings, riftings and nonhomogeneous deformations. There is a great prospect in geothermal exploration among the 400 rift basins and fault troughs within China, especially the 4 rift valleys and 12 basins in the Yellow River and the Huaihe River area, East China Sea, South China Sea and Xingan—Mongolian Region. The " geothermal fields "in Eastern China can be devided into 8 types according to their causes of formation, temperature, lithologic features and the salinity of the underground hot water, among which the " Buried Hill Type ", " Stratigraphic Type "and other 3 types enjoy great reserves, promising vistas and little risk.

It is advisable that the geothermal research on its distribution, evaluation and comprehensive exploration be widely carried out systimatically in China. Besides the openning up of " geothermal model bases ", relevant standards and regulations should also be drawn up to widen the scope of the utilization on geothermal resources, which in the near future, as a new source of energy, can make greater contribution to the national economy and construction.

SIMULATION OF HYDROCARBON MATURATION AND MIGRATION OF EOGENE SOURCE ROCKS IN JIYANG LACUSTRINE SUB-BASIN

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Jiyang lacustrine basin is located in the northeastern China, and is the onshore part of the Bohai Bay sedimentary province. A large volume of hydrocarbons has been discovered within the basin during the past three decades.

The major source rock in the basin is the lacustrine shale in the lower part of the Shahejie Fm (Eogene). Three-dimensional simulation of hydrocarbon maturation and migration, using specially designed simulator reveals three distinct stages of thermal maturation: the immature, mature, and high mature stages. The immature stage is characterized by low hydrocarbon concentration in the source rock (<200 ppm), low vitrinite reflectance (<0.3%), and low saturated/aromatic hydrocarbon ratio. The burial depth of the source rock is generally less than 2200 meters with temperatures being less than 93°C. The source rock in a mature stage has higher hydrocarbon concentrations. The temperature for this stage ranges from 93°C to 122°C, corresponding to burial depths of 2200-3000 meters. The high maturity stage is characterized by higher hydrocarbon concentrations, and higher vitrinite reflectance (0.9-1.0%). Burial depths range from 3000 to 3800 meters with temperatures of 122°C to 150°C.

The simulation demonstrates that, during five stages of sedimentary compaction, primary hydrocarbon migration occurs in the hydraulic fracture zone during the 2nd stage and is mainly caused by fluid displacement. Based on the simulation, a total of 46.5 billion tons of hydrocarbon were generated and 9 billion tons migrated out of the source rock. The volume of gas generated is about $5x10^{13}$ cubic meters, which gives a gas reserve of 555 billion cubic meters.

THE EVOLUTION AND HYDROCARBON POTENTIAL OF LACUSTRINE SYSTEMS IN THE MINLE AND CHAOSHUI BASINS OF THE HEXI CORRIDOR, NORTHERN CHINA

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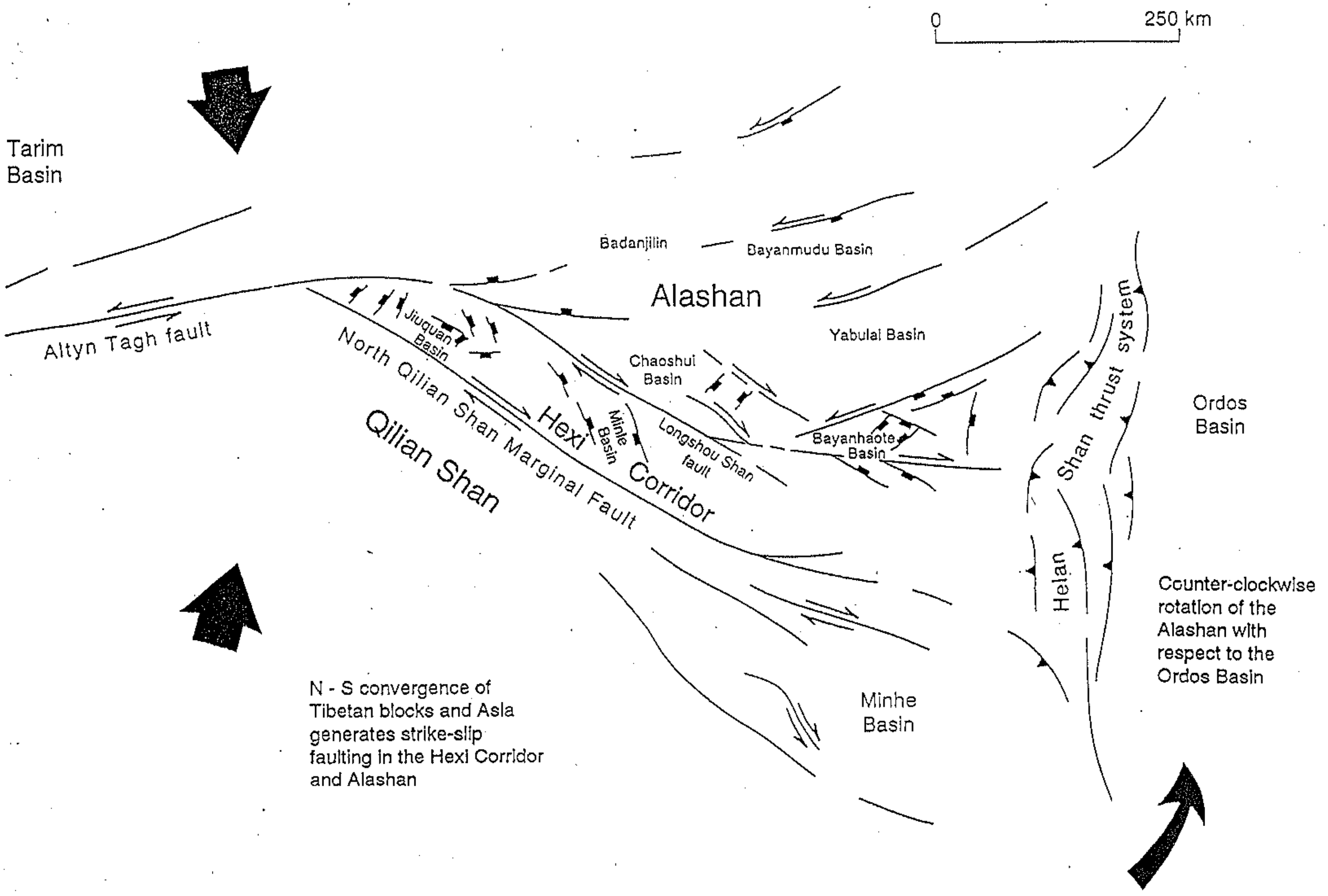
Over 90% of China's hydrocarbons are produced from Mesozoic and Cenozoic lacustrine deposits (1991 figures). International hydrocarbon exploration of Chinese basins is, however, hampered by the lack of available detailed studies on the structure and sedimentology of these basins. Recent CASP work in China has been aimed at overcoming this problem. This paper presents results from field-based work on the lacustrine systems within the Chaoshui and Minle basins of the Hexi Corridor which forms part of CASP's China Basins Project, that has studied the geology of China and its hydrocarbon potential since 1985.

The Hexi Corridor lies along the boundary between the cratonic basement of the Alashan, itself the western part of the North China Block, and the Paleozoic arcs and accretionary complexes that young southwards through the Qilian Shan and into the Kunlun Shan (Figure 1). The amalgamation of the Qilian Shan and Alashan took place in the Silurian. The next major collision in the area was between Tarim and the Alashan, possibly in the Late Carboniferous. Late Permian sinistral transtension affected much of northern China, but had little effect on the Hexi Corridor. Carboniferous sediments in this area are initially shallow marine, and pass into estuarine and shoreline strata. Permian sediments are fluvial. In Triassic times, much of northern China was in mild compression as a result of collision between the North China Block and the South China Block, and a compressive margin to the south of the Kunlun Shan. Well-organized fluvial systems flowed along the Hexi Corridor, but sedimentation was of limited extent.

The major phase of basin formation in the region took place in the Jurassic and Cretaceous. Pull-apart development in the Chaoshui Basin occurred somewhat earlier than in most areas, in the Early and Middle Jurassic. North-south trending normal faults controlled fluvial and lacustrine



N - S convergence of Tibetan blocks and Asia generates strike-slip faulting in the Hexi Corridor and Alashan

Counter-clockwise rotation of the Alashan with respect to the Ordos Basin

Figure 1. Geodynamic interpretation of Late Jurassic - Early Cretaceous basin formation in the Hexi Corridor, northern China, in response to strike-slip movements along marginal faults. From CASP report 14.

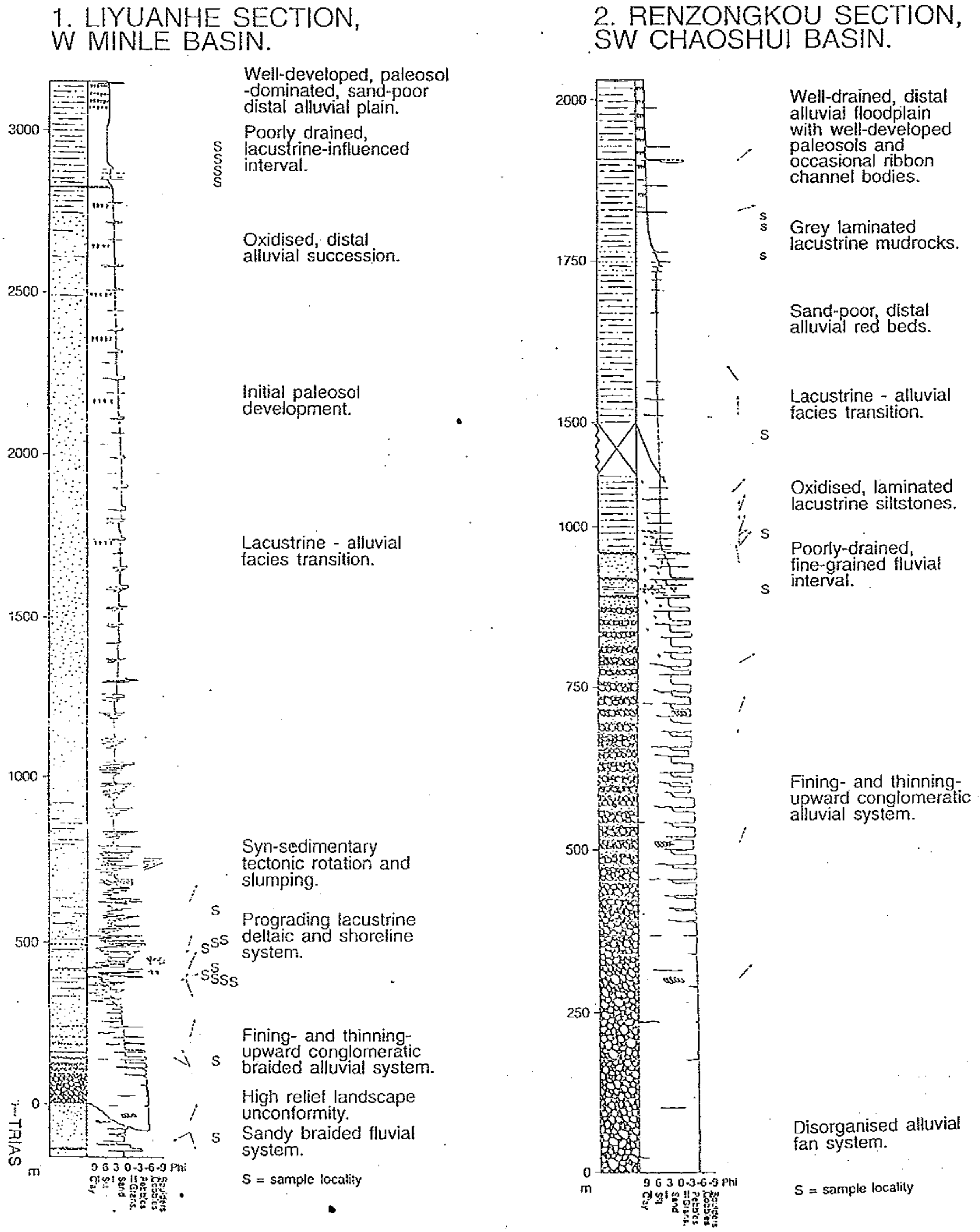
sedimentation in between major east-west trending strike-slip faults. Middle Jurassic conglomerates in the Minle Basin, to the south of Chaoshui, lie with a slight unconformity over Permian sandstones. The clasts in this conglomerate match the Proterozoic lithologies exposed in thrust sheets in the Longshou Shan - the elongate range between the Chaoshuli and Minle basins. Dextral(?) transpression uplifted the Longshou Shan at this time. The Late Jurassic marked the onset of major basin development in the Hexi Corridor. The basins formed between major strike-slip faults, and have geometries consistent with dextral pull-aparts, fault wedge basins and half-grabens formed as trailing imbricate splays (Figure 1). This occurred while the Tarim and Ordos basins to the west and east were under compression. Figure 1 reconciles these observations. North-south convergence to the west of the Hexi Corridor caused lateral transport of the crust within the Corridor to the east. There was no oceanic "free-face" to the east, but the Alashan was rotating counter-clockwise with respect to the North China Block, creating the space for the basins to extend.

The Mesozoic strike-slip related basins contain half graben and graben systems within which fluvial and lacustrine sediments were deposited. Mudrocks that accumulated during anoxic conditions in these lakes form the main hydrocarbon source rocks in the region. Oil has been recovered from the Jiuquan Basin at the western end of the Hexi Corridor since the 1930s, but the other basins are considerably less explored, and little is known about their depositional histories. One particular problem, with relevance for the Mesozoic basins throughout northern China, is to what extent source rock accumulation was controlled by large-scale tectonic effects, by local structures, or by climatic factors.

Fieldwork by members of CASP's China Basins Project during 1994 resulted in the collection of detailed sedimentological and structural data from the Minle and Chaoshui basins of the Hexi Corridor, northern China. This paper highlights data on the tectonic and climatic controls of Early Cretaceous sedimentation in the region which can be summarized by comparing two, approximately time-equivalent, logged sections; one from the Xinminbao Formation at the western margin of the Minle Basin, and the other from the Miaogou Group at the southwestern margin of the Chaoshui Basin (Figure 2). These graphic logs represent the products of two separate fluvial - lacustrine depositional systems, with the intervening Longshou Shan forming a subaerial sediment source at this time. Similarities in the sedimentology of these two areas are likely, therefore, to reflect large-scale, extrabasinal controls on facies development.

The Lower Cretaceous Liyuanhe and Renzongkou sections both record a retrogradational transition from coarse clastic alluvial facies upwards into lacustrine environments. Oxidized, fine-grained fluvial and distal alluvial sheetflood sediments then follow, and are capped by a succession of well developed paleosols (Figure 2). These large-scale trends are typical of fluvial - lacustrine systems developed within rift settings, with initial rift-margin clastics passing into deeper water sediments, prior to a slow-down in subsidence and the gradual infilling of the basin. Evidence for syn-tectonic rotation of Lower Cretaceous strata in the Minle Basin supports this analogy. Transpression along marginal structures to these basins is likely to have enhanced sediment source area rejuvenation prior to, or during, the Early Cretaceous. The thick accumulation of conglomeratic sediments within the Renzongkou section attests to its close proximity to the positive Longshou Shan structure, while the larger drainage area afforded the Liyuanhe system (derived from the proto-Qilian Shan) resulted in a better organized and longer-lived clastic sediment source.

Although the primary control on sedimentation within the Minle and Chaoshui basins is tectonic, both logged sections also include an upper lacustrine interval (Figure 2). There is no evidence for further episode(s) of rift-related subsidence associated with these intervals. Similarly, there is no indication of a lacustrine connection between the two basins, so that a direct base-level control is discounted. Instead, a climatically-induced period of increased precipitation, affecting the catchment areas of both basins, is thought to be the likely cause. If correct, this climatic signal (with the development of potential source rock lithologies) may well be present in other basins in the region. Further CASP fieldwork has just been completed in the Junggar Basin of northwest China (September 1995), one objective of this work was to attempt to identify this climatic signal in order to test this hypothesis.



1. LIYUANHE SECTION, W MINLE BASIN.

2. RENZONGKOU SECTION, SW CHAOSHUI BASIN.

Figure 2. Lower Cretaceous strata from the Minle and Chaoshui basins of the Hexi Corridor, northern China.

An analysis of the rift-related lower lacustrine mudrock interval indicates that the Liyuanhe section, located at the margin of the Minle Basin, contains early mature potential source rocks. The upper, climatically-controlled, lacustrine interval also contains potential source rocks. Isopach data indicate that significant thicknesses of equivalent strata are contained in the Central Minle Depression.

Since its initial collision at c. 55 Ma, the Indian plate has continued to move northwards with respect to Asia. Most of this post-collisional convergence has occurred within Asia, largely by crustal thickening north of the Indian indenter. Within northern China, the Qilian Shan has overthrust the southern margin of the Hexi Corridor, and sediment eroded from the range has been deposited in the adjacent basins. These are now subsiding under the combined load of the thrust sheets and these sediments. Paleocene and Eocene strata are almost non-existent, and Oligocene rocks are rare. Significant Cenozoic sedimentation in the Hexi Corridor began in the Miocene, and has continued since that time. Sandstones of the Miocene Baiyanghe Formation are the major reservoir rocks in the Jiuquan Basin; intercalated shales and evaporates form the seal. The major traps in this basin are growth anticlines that formed in the hanging wall of the Laojunmiao Fault.

Sinistral transpression has affected the Longshou Shan and the late Mesozoic basins within the Hexi Corridor. Thrusts diverge from the Longshou Shan towards the basins to the north and south. Some thrusts have broken up the structure of the interior of the Minle and Chaoshui basins, but Mesozoic normal faults exposed within the larger Cenozoic uplifts have escaped major inversion. A possible exception to this is the thrust at the northern margin of the Chaoshui Basin , that may have been a Mesozoic normal fault.

Although fields in the northwest of the Hexi Corridor, in the Jiuquan Basin, have been in production since the 1930s, other basins have been less-well explored. The Minle Basin in particular has potential, but any hydrocarbon reservoirs are likely to exist in more subtle traps than the known examples in Jiuquan.

CAN SOURCE ROCK OCCURRENCE BE PREDICTED, *DE NOVO*, IN A LACUSTRINE SETTING USING CLIMATIC MODELING?

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INTRODUCTION

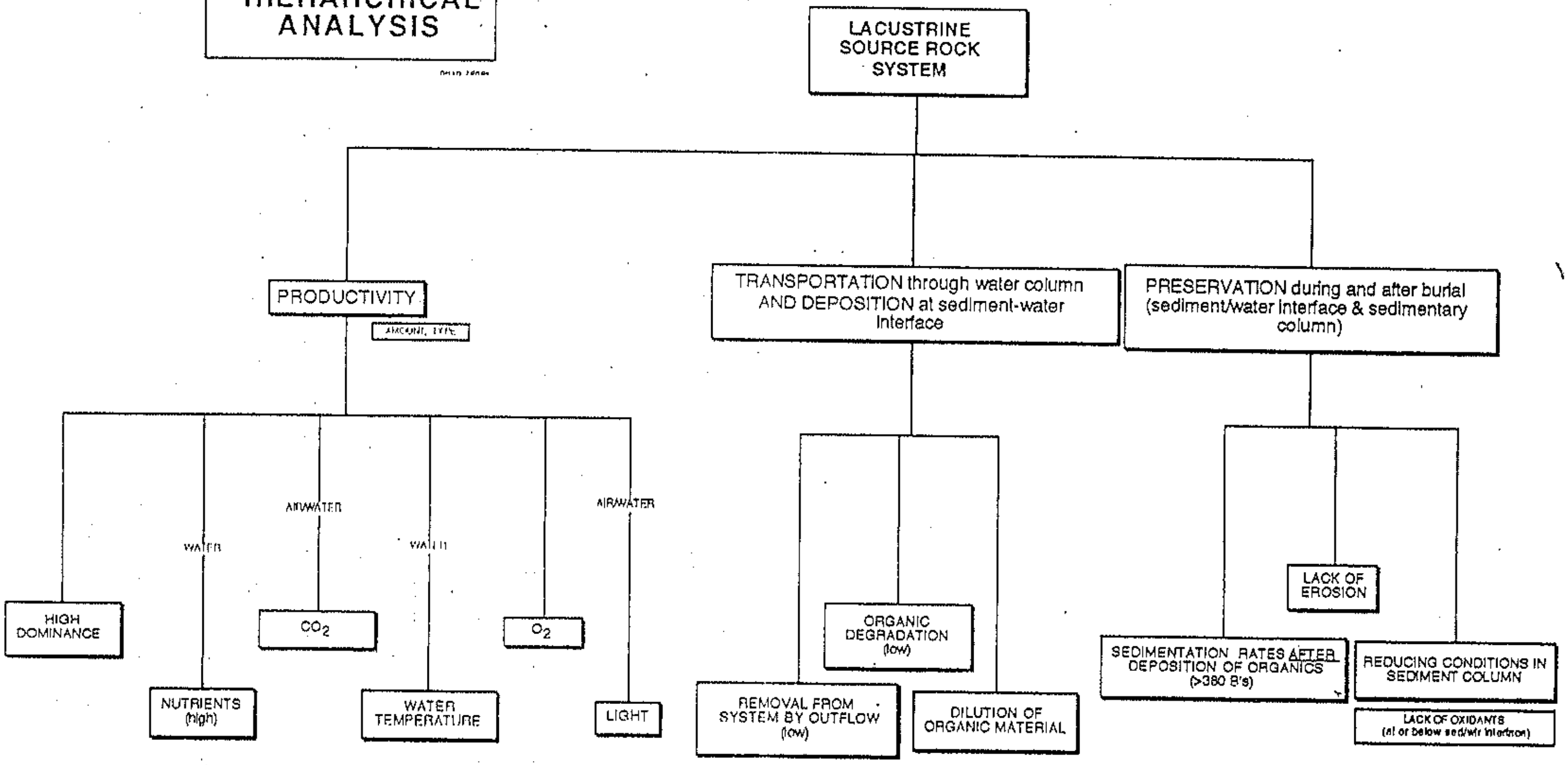
Geologists and geochemists have debated the conditions for formation of petroleum source rocks for several decades. In 1993, Unocal embarked on a modeling approach to this problem, utilizing hierarchical analysis and climate modeling to predict the occurrence of source rocks globally, at specific time slices. In this manner, we developed techniques to describe, from first principles (*de novo*), the critical factors involved in the development of hydrocarbon source rocks. In this poster, we present the results of that effort.

TECHNIQUES

We used a hierarchical approach to define and relate the critical factors in the development of source rocks. Whereas the defining conditions of source rock development are often measurable directly in the present-day (e.g., water temperature or atmospheric CO_2 content), proxies must be defined for these conditions in ancient sediments. The proxy (an observable, measurable or predictable characteristic of a natural system) is then used to define/predict the presence or absence of a condition. For example, $\delta^{18}O$ or alkenone distributions of certain components may be used as a proxy for water temperature.

The proxies represent the lowest level of our hierarchical analysis, and lead, ultimately, to prediction of the critical factors necessary for source rock formation. Figure 1 shows the first three levels of the lacustrine source rock system. At the highest level of the analysis, one supercritical factor (favorable basin development and morphology) and three critical factors (organic productivity, transportation and deposition, and preservation) are assessed. Within lacustrine systems, each of these critical factors is delimited by a set of natural conditions (e.g., nutrient level; organic degradation), each of which is predicted through a set of proxies (e.g., surface water runoff level; sedimentation rate).

LACUSTRINE SYSTEM HIERARCHICAL ANALYSIS



PRINCIPAL CONDITIONS DESIRED:
<u>Disaerobic Stratified Water Column</u>

Proxy Condition	Proxy values
1 Stable Climate	Low Seasonality, Low Wind Stress
2. Temperate Climate	Mean Temp between 15 and 25?
3. Positive Water Balance	
4. Long Duration	
5. Deeper Water	Colder bottom water, better chance of stratification
6. Source of Phosphorous(volcanic lake formation)	

PRINCIPAL CONDITIONS DESIRED
High Organic/Dilution Ratio

PROXY CONDITIONS
Subsidence
Net Inflow
Low Dilution source
Aridity

The success of the hierarchical analysis approach depends upon the availability of proxy measurements. This study relied upon climate modeling to define several proxy sets in both objective and subjective frameworks. A parametric climate model developed by Scotese and Ross was used to establish climate proxies, such as temperature, precipitation ranges and Eckman transport upwelling, for marine, deltaic and lacustrine settings. During the life of the project, complete modeling efforts, including ground truth verifications, were conducted for the present-day, Serravallian (mid-Miocene), Thanetian-Ypresian (Late Paleocene/Early Eocene) and Cenomanian-Turonian (Late Cretaceous) time slices.

RESULTS

Ground truth checks, using in-house information, regional contractor data and the published literature, indicated that marine and deltaic source rock predictions were successful for the Serravallian time slice, but less so for the Paleogene and Cretaceous time slices. This degradation in predictive capability with age probably results from the fact that the paleo climate model is calibrated to present-day data from a 'cold earth' setting; today's applicable proxies may not be useful as we proceed back through 'warm earth' times. Nevertheless, our success in the mid-Miocene confirms the validity of this approach.

Source rock depositional conditions in the lacustrine setting were predictable with varying degrees of success in the present-day and Serravallian. However, of the three depositional settings considered, proxy assignments for the lacustrine were the most problematic. We attribute this to the difficulty in assessing correctly the important influence of the lake's surrounding landmass on the critical factors. Whereas in the marine and, to some extent, deltaic realms the ratio of the water body to the drainage basin is large, in lakes this ratio is quite small. This magnifies the importance of various land-based critical factors for which proxies are uncertain, including topography, bedrock geology, aridity and tectonic configuration. Nevertheless, our (limited) success with lacustrine source rock prediction in present-day and Serravallian times suggests that continued development of this approach could lead to improved predictive capability.

The results of our predictive efforts will be presented as global and Asian basin maps of present-day and Serravallian continental configurations. The hierarchical approach for lacustrine critical factor definition will also be shown, along with the proxies defined for this purpose. Although the project at Unocal has now been terminated for budgetary and priority reasons, we suggest that climate modeling represents one of the best *de novo* methods of global source rock prediction. Furthermore, we anticipate that the development of more relevant proxies and sophisticated (ground-truthed) climate models will lead to greater success in the future.

HYDROCARBON MIGRATION AND ACCUMULATION ALONG FAULTS IN RIFT BASINS

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Large faults can be barriers or avenues of hydrocarbon migration. Whether small faults are sealing or non-sealing depends on the relation of the displacement pressures of their adjacent layers.

The large faults in sedimentary cover are usually sealing and can trap hydrocarbons in oil-generating sections when they are inactive, but the trapped hydrocarbons can quickly flow up along the faults and accumulate in shallow sections when active. The characteristics of the hydrocarbon distribution between primary pools and secondary pools are different.

The large faults whose one side is basement rocks and another is sediment are usually partially sealing or open. Hydrocarbons principally migrate along or across them, and accumulate in shallow traps or basement traps, in oil-generating sections, little or no hydrocarbons are trapped by them.

Although small faults are not avenues of vertical hydrocarbon migration, they are very significant in rift basins. The lateral migration of hydrocarbons across small faults leads to vertical migration. This style of migration includes "staircase" migration and "spiral" migration.

LITHOLOGIC, WELL LOG, AND SEISMIC FACIES OF LACUSTRINE RIFT-FILL SEQUENCES, BOHAI BASIN, CHINA

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The Bohai Basin in northeastern China formed by lithospheric extension during, the Paleogene. Syn-rift deposits of the Shahejie and overlying Dongying Formations consist of several kilometers of deep lacustrine to alluvial strata. An integrated subsurface data base consisting, of over 850 m of core descriptions from 18 wells, several hundred core photographs, well logs from over 30 wells, seismic reflection profiles, and published cross-sections were used to identify the lithology and well log and seismic characteristics of the major syn-rift lacustrine depositional systems in the Liaohe Depression and Liaodong Bay in northern Bohai Basin. This analysis provided the sedimentological framework for the tectonostratigraphic model for the Bohai Basin to be presented by Nummedal and others at this conference.

Lithologic well log, and seismic characteristics of major depositional systems

Fluvial/delta plain. Fluvial/delta plain deposits consist of mudstone, siltstone, sandstone, and rare conglomerate and coal that accumulated in a mud-rich, low-lying, coastal plain consisting of stream channels, levees, swamps, interdistributary flood basins, and perhaps delta plain ponds and lakes. The deposits occur in the Dongying Formation and have a tabular to broadly wedge-shaped geometry. Abundant carbonaceous debris, rootlets, thin coal beds, and unidirectional flow sedimentary structures, and common 5 to 10-m-thick fining-upward sandstones are the primary core-based distinguishing characteristics. Spontaneous potential, gamma ray, resistivity, and sonic logs through the system are characterized by irregular patterns indicative of frequent changes in lithology (Fig. 1A). Sandstone units exhibit blocky, sharp-based fining-upward, and less common coarsening-upward trends on the scale of 5 to 15 m. Fluvial/delta plain deposits are characterized by discontinuous, irregular, high to low amplitude seismic reflectors with numerous internal truncations, onlaps, and downlaps. There is no apparent pattern to internal stratal terminations. Fluvial/delta plain seismic facies can be distinguished from the sublacustrine fan seismic facies by the tabular geometry of the reflector sets. Fluvial/delta plain-

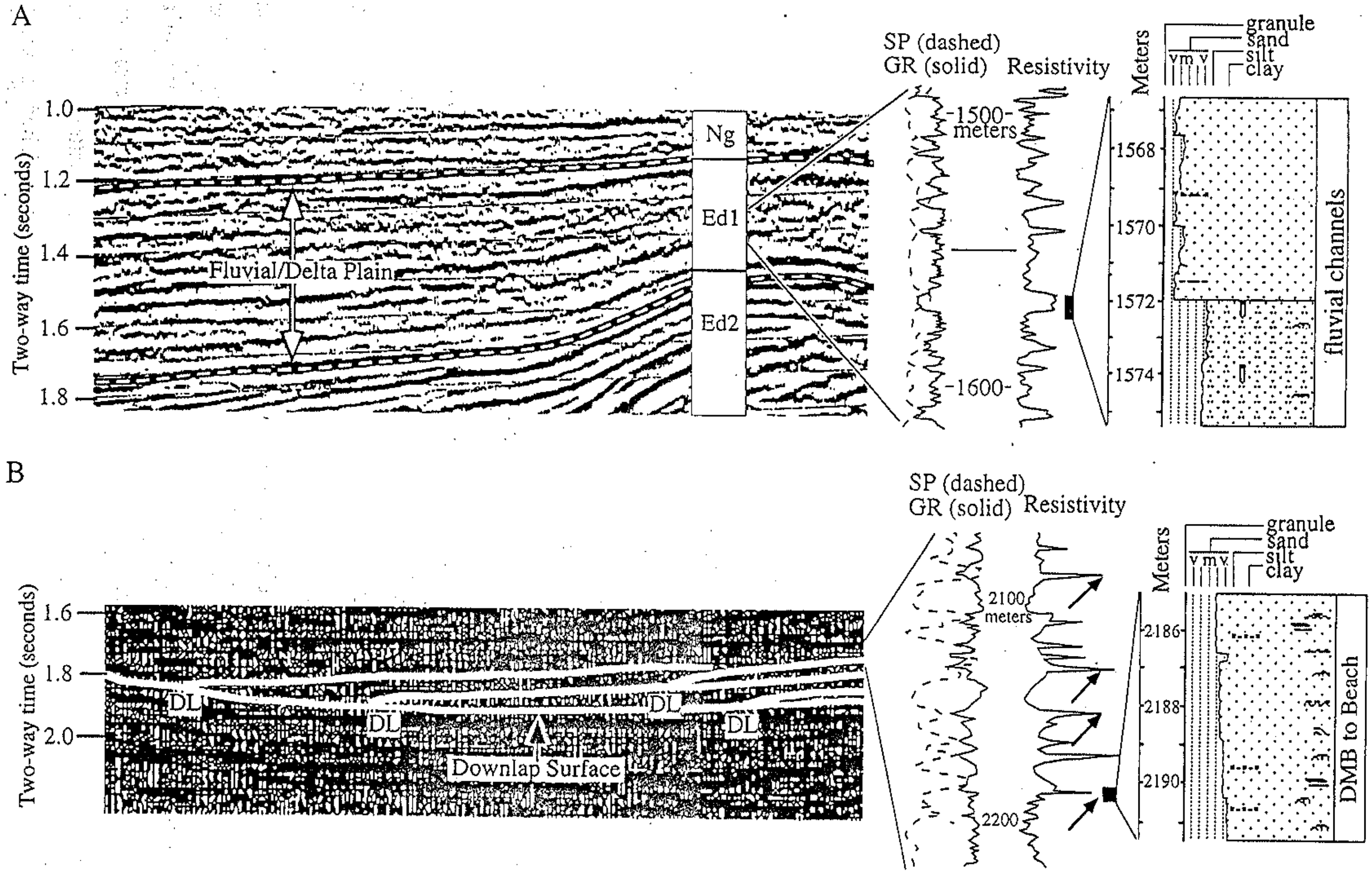

Figure 1. Typical seismic, well log, and lithologic charactersitics of fluvial/delta plain deposits (A), shallow-lacustrine delta mouth bars (B), sublacustrine fans (C), and lakefloor deposits (D) in the Shahejie and Dongying Formations. DL = Downlap; SP = Spontaneous Potential log; GR = Gamma Ray log; RES = Resistivity log; TD = Total Depth; Ng = Guantao Fm.; Members of Dongying Formation: Edu = Upper, Edl = Lower, Ed1 = First, Ed2 = Second, Ed3 = Third; Es = Shahejie Formation (Es1 = First Mbr., Es3 = Third Mbr.); Mz = Mesozoic; TD = Total Depth.

style seismic reflectors can commonly be traced down dip or overlie shallow lacustrine seismic facies.

Shallow lacustrine-- Shallow lacustrine deposits consist of mudstone, siltstone, and fine to medium grained sandstone that accumulated in a variety of relatively shallow nearshore settings. They are characterized by a mixture of unidirectional and wave-generated sedimentary structures, fine carbonaceous debris, and an absence of rootlets and other indicators of subaerial exposure. Delta mouth bars consist of coarsening-upward sandstone with well developed ripples, large-scale cross-bedding, and, in places, swash stratification (Fig. 1B). Lower shoreface and shelf deposits are characterized by well-developed rhythmic bedding or fine laminations, wavy to ripple laminations, minor burrows, and flame structures and other forms of soft-sediment deformation.

In places, sandstone units are relatively muddy and highly burrowed and exhibit ghost ripples, ghost laminations and clay drapes. Shallow lacustrine deposits are best developed in the Dongying Formation, where they form important petroleum reservoirs in Liaodong Bay.

Shallow lacustrine deposits can be distinguished from fluvial/delta plain deposits on the basis of sandstone well log signatures. Although some coarser-grained intervals have a blocky or well log pattern, the most common well log motif in shallow lacustrine deposits is 5 to 20-m-thick coarsening upward cycles (Fig. 1B). These coarsening, upward cycles are often arranged in progradational, retrogradational, or aggradational parasequence sets. In most wells the coarsening-upward sandbodies are separated by 5 to 20 or more meters of mudstone. In parts of the JZ36-1 oil field in Liaodong Bay, however, the sandstones are amalgamated, producing composite reservoir sandbodies over 50 m thick. On seismic reflection profiles shallow lacustrine deposits are characterized by strong, relatively parallel and horizontal reflectors that terminate by downlap. Downlap directions are generally consistent within a given set of reflectors. Individual seismic units (clinoforms) can be traced for 3-10 km in dip-oriented seismic profiles and several kilometers in strike-oriented profiles. The deposits can be distinguished from proximal and distal lake-floor seismic facies, which also exhibit strong

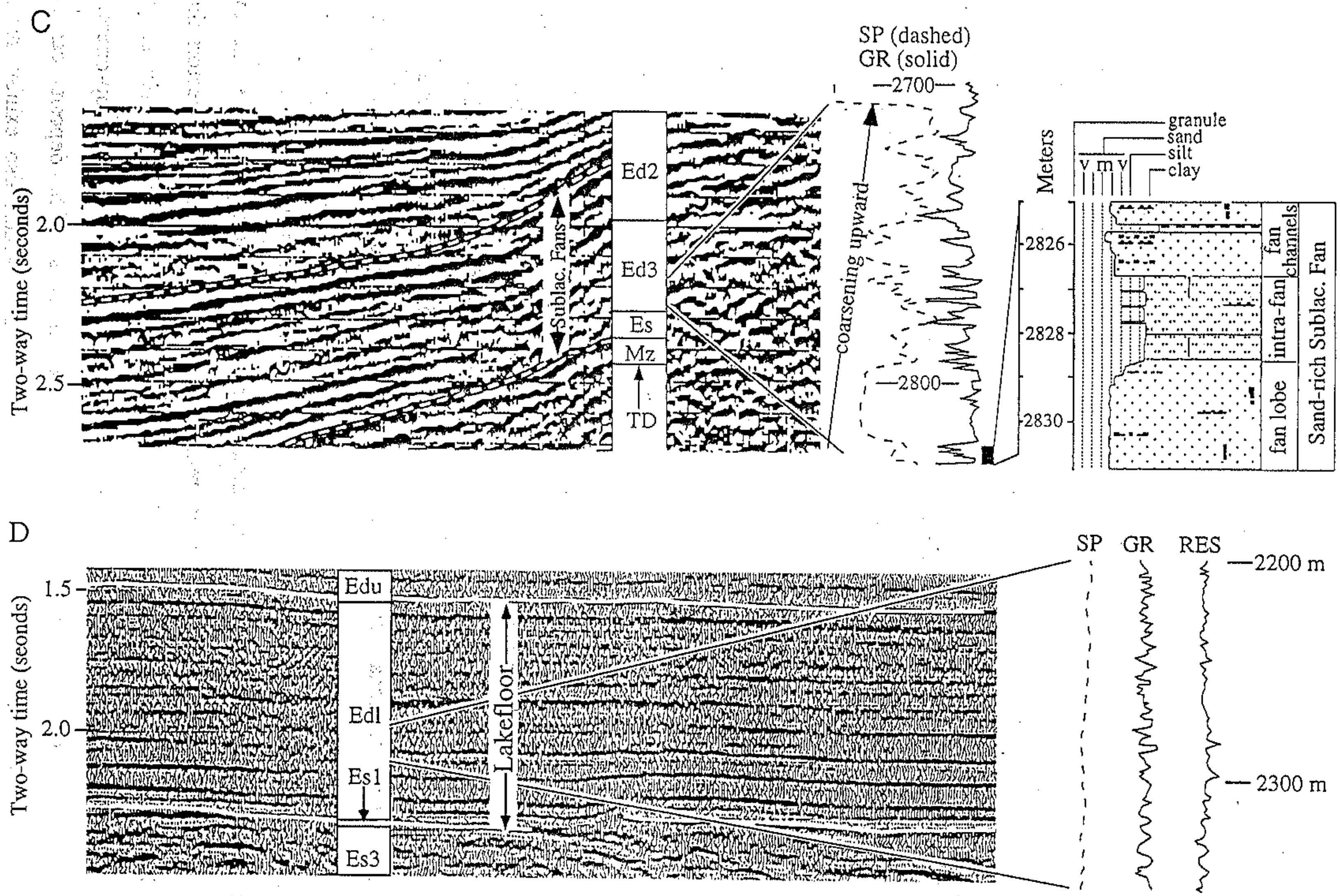

Figure 1. Continued.

parallel reflectors, on the basis of downlapping reflectors, common association with fluvial/delta plain seismic facies, and an absence of onlap onto older sequences or basement. The fact that sandy delta clinoforms are generally about 30 to 200 m thick, whereas coarsening upward delta mouth bars are generally less than 20 m thick, indicates that the clinoforms consist of several progradational units (parasequence sets).

Gravel- and sand-rich sublacustrine fans-- Sublacustrine fans are characterized by a wide variety of grain sizes, textures, and sedimentary structures, numerous scour surfaces, rip-up clasts, load features, and other evidence for rapid high-energy sedimentation, rapid changes in lithology (Fig. 1C), generally poorly developed traction-current structures in the coarser-grained sediment, common muddy and poorly sorted sandstone and conglomerate, and cohesive mudflow and other types of sediment gravity flow deposits. The rocks lack evidence for subaerial exposure and are commonly associated with lake-floor deposits. Water depths probably ranged from tens to hundreds of meters. Sublacustrine fans consist of proximal conglomerate-rich zones that grade rapidly down dip into sandy fringing fans. The sandy fans were probably fed by sublacustrine channels and valleys, a common feature in modern African rift lakes. Sand-rich sublacustrine fans may also have existed apart from gravel-rich fans in regions fed by sand-rich, gravel-poor rivers. Although high density sediment gravity flows have the potential for transporting coarse-grained sediment long distances, most sublacustrine fans in Liaodong Bay pinch-out rapidly into mudstone and fine sandstone within a few kilometers. However, the common occurrence of proximal lake-floor deposits (see below) suggests that low density turbidites and underflows were efficient mechanisms for transporting fine sediment away from deltaic and sublacustrine fan sources.

On well logs sublacustrine fans can be distinguished on the basis of the coarse grain size, rapid and commonly chaotic-appearing changes in grain size, and the presence of 10 to 20-m-thick fining-upward, blocky, irregular, and coarsening-upward well log motifs (Fig. 1C). The thickness of individual sand/gravel bodies ranges from a few meters to over 50 m. Mudstones within the fan systems exhibit irregular well log patterns, indicating that they contain variable, but generally high, amounts of sand and silt. Overall, the fans may either coarsen upward (Fig.

1C) or fine upward. Sublacustrine fans are characterized by irregular, discontinuous, strong to weak seismic reflectors that often dip at relatively high angles. Strong, continuous reflectors sometimes occur within the fans. Internally, reflector sets exhibit numerous truncations, onlaps, and downlaps. Sublacustrine fan seismic facies often exhibit rapid down dip transitions to lake-floor seismic facies. These fans have been identified by us in the Second and Third Members of the Shahejie Formation (designated Es2 and Es3) and in the lower Dongying Formation. Fan thicknesses range from a few meters to several hundred meters. Fans in the Es3 are typically wedge-shaped, fill numerous small half-grabens, and onlap onto graben-bounding faults or older Paleogene deposits. Fans in the Es2 and Dongying Formations are tabular to broadly wedge-shaped in geometry.

Proximal and distal lake-floor-- Proximal and distal lake-floor deposits consist of mudstone, shale, oil shale, interlaminated to thinly interbedded siltstone/very fine sandstone, and rare thin-bedded sandstone and conglomerate. Proximal lake-floor mudstones are massive or laminated light gray to black, and commonly contain fine carbonaceous debris, ostracodes, and pelecypod fragments. Interlaminated to thinly interbedded mudstone and siltstone/sandstone of presumed turbidite origin is a common proximal lake-floor facies. It commonly exhibits soft-sediment deformation, small scours, small burrows, and planar laminations and grain- to matrix-supported mudstone clasts in the sandstone. Distal lake-floor deposits are finer-grained than proximal deposits and are commonly organic-rich. Lake-floor depositional processes included suspension sedimentation, low-density turbidity currents, and traction currents. Although some of this sediment probably accumulated in shallow-lacustrine environments sheltered from influxes of coarser siliciclastics, most probably accumulated in poorly-oxygenated water below wave base.

Lake-floor deposits exhibit high gamma ray values and low spontaneous potential and resistivity values (Fig. 1D). These characteristics and the absence of thick beds of sandstone or conglomerate distinguish lake-floor deposits from other lacustrine facies. Lake-floor deposits have a distinctive seismic signature consisting of very strong to moderately weak, contiguous to semi-continuous, parallel reflectors that lack internal complexity and may be horizontal or thicken slightly into lows. Unlike sandy delta reflectors, lake-floor reflectors do not exhibit clinoform geometries. They may, however, onlap onto pre-rift basement or older Paleogene deposits. Fine-grained lake-floor deposits are the most common sedimentary rocks in the syn-rift sequence. They occur in the Shahejie Formation and in the lower and middle part of the Dongying Formation. These deposits are tens to hundreds of meters thick and are generally tabular in geometry.

Lacustrine carbonate-- Carbonate is a relatively rare component of the rift-fill sequence. Most carbonate observed in core is dolostone composed of well-sorted, grain-supported gastropods and ostracodes with sparse to abundant moldic porosity. The carbonates often contain sand or are interbedded with or directly overlie coarse volcaniclastic sandstone and conglomerate near or at the bottom of the rift-fill sequence. A second type of dolostone consists of tiny grain-supported pelecypod fragments. In the Paleogene sequence of Liaodong Bay carbonate occurs only in the Shahejie Formation, where it is most common in the Second and First Members. It is generally interbedded with mudstone, oil shale, and sometimes sandstone. Most carbonate units are a few meters thick. However, some wells exhibit carbonate accumulations that are tens to several hundred meters thick. Because of the thinness of most carbonate beds and the limited lateral extent of thick carbonate accumulations, the lacustrine carbonate environment probably cannot be identified on conventional seismic profiles. Although shell accumulations are known to occur in modern African rift lakes in water depths of as much as 100 m, the good sorting and absence of mud in the Shahejie grainstones suggest that they accumulated in relatively shallow high-energy environments that were sheltered from sources of siliciclastic sediment.

ACKNOWLEDGMENTS

This study benefited greatly from extensive discussions with UNOCAL personnel while describing core in Tanggu, during several data analyses meetings in Sugar Land, and in numerous phone conversation and fax exchanges. We would like to thank UNOCAL Corporation and the China Offshore Oil Bohai Corporation for permission to present the results of our analyses.

THE SEDIMENTARY FEATURES OF TRIASSIC TO JURASSIC LACUSTRINE, FORELAND BASIN IN KUCHE NORTHERN TARIM BASIN, CHINA

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Beijing, China

This paper discusses the sedimentary features of a lacustrine foreland basin and its sedimentary evolution, specifically the Kuche Triassic-Jurassic foreland basin.

The Kuche elongated foreland basin was formed by compression and shortening of the uplifted continental margin as influenced by Indo-China movement during the late Permian. The Kuche foredeep is filled mostly by lake facies deposits during the Triassic and Jurassic. The Triassic - early Jurassic strata record the early evolution history of Kuche foreland basin. During this period, major sedimentary facies were orogenic clastic wedges, fan-delta and turbidite deposits in a starved basin. With continued evolution of the basin, the foredeep was dominated by coastal-shallow lake and swamp lake facies into the late Jurassic.

The composition of the Triassic - early Jurassic sandstones is characterized almost exclusively as having been derived from a recycled orogen, where as most Late Jurassic samples were derived from either recycled orogens or continental blocks based on the provenance diagrams of Dickinson et al. (1983). Such a sand source is consistent with the erosion of Tianshan fold-thrust belt terrane and the evolution of Kuche foredeep. The composition of the sandstones obtained in Tianshan belt near Kuche foredeep are different from those in Taboi forebulge, showing the major recycled orogen and continental block provenance respectively.

Based on the data of geochemical analysis, the oil and gas that have been found in Tabei forebulge and Tianshan fold-thrust belt recently were considered to be mainly from the Triassic-Jurassic source rocks in Kuche foredeep. This suggests the importance of the starved foredeep as the oil and gas-generation area during the early evolution of the foreland basin.

The poster includes a regional geological (Triassic and Jurassic) sedimentary facies distribution figure, two provenance diagrams, and a sedimentary evolution pattern figure.

THE COMBINATION OF BIOMARKERS IN SOURCE ROCK OF TERTIARY LACUSTRINE BASINS IN THE EAST CHINA

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The majority of Tertiary lacustrine basins in East China possess 2-3 sets of source rocks, namely Lower Eocene, Upper Eocene and Oligocene. The biomarkers detected within the rocks and derived oils can be grouped into 4 combinations corresponding to different depositional environments. Firstly, a fresh-water deep lacustrine type which displays odd over even preference in *n*-alkanes, C_{27} sterane dominance over C_{29} steranes, medium Pr/Ph ratios (0.8-2), low gammacerane and abundant 4-methyl steranes with carbon numbers of 28-30. This type source rock, formed under strongly reducing conditions during a period of maximum lake expansion. The expansion occurred during the Tertiary in eastern China, namely Upper Eocene. These sediments are important and widespread. Secondly, a lacustrine-swampy type which is characterized by a high Pr/Ph ratio (>3) and odd over even predominance of alkanes, obvious C_{29} hopane and oleanane, C_{29} steranes dominating over C_{27} steranes. It originated from terrigenous organic matter related to coal formation during lake highstands and has limited occurrence in the Oligocene. The third type was deposited in a brackish-saline setting and displays a high gammacerane index and a low Pr/Ph ratio (<0.5), low concentrations of 4-methyl steranes and diasteranes, and abundant β-carotane. These sediments formed in coastal lake basins affected by sea water during the Oligocene. The fourth combination displays even over odd predominance of alkanes, C_{35} hopanes more abundant than C_{34} hopanes and abundant extended tricyclic hopanes. In general, these source rocks were deposited in a hypersaline water body during a lowstand in closed basins in a semiarid to arid climatic zone. These conditions existed in southeastern China during the Lower Eocene. With the exception of the second type of source rock system, all other three types of source rocks could be of high quality (I-II type kerogen) despite the Pr/Ph ratio. Moreover, the difference between the maturity of organic matter in the source rock provides additional variability among their biomarker characteristics. The Oligocene source rock and derived oils have immature-low mature features with low index of C_{29} steranes $\beta\beta/\alpha\alpha$

+ β β (often <0.2). In contrast, Eocene source rocks and oils show a high index (often >0.3). The combination of biomarkers represents different original organic input and indicates the change of climate and tectonism of the lacustrine basins.

PALAEOTOPOGRAPHY RECONSTRUCTION OF DONGYING LAKE AND ITS DRAINAGE BASIN DURING SHAHEJIE FORMATION DEPOSITIoNNAL PERIOD

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The reconstruction of topography and geology of the drainage basin is one of the important topics in palaeolimnology, also is it a new proposition posed in recent years. In this paper, the palaeotopography recostruction of Dongying Lake and its drainage basin during Shahejie Formation depositionnal period was experimentally made by introducing Mass—balanced Palaeogeography Reconstruction method raised by Hay et al. (1989).

In light of the method requirement and the distinguishing feature of Dongying Lake, the first step of the reconstruction process was the preparation of date sets documenting boundary conditions, including the definition of the range of the drainage basin, the selecting of the starting surface and its elevation data, the counting of the amount of the sediments, and the determination of the position of erosion base level for detrital sediment as well as the analyses of the possible source areas from which the sediments erosed etc. Afterwards, both the backstripping of the sediments from deposional areas and the replacement of sediments on the source areas were carried out. In addition, the isostatic adjustments and decompaction corrections were conducted. At last, the palaeotopography reconstruction maps were drawn out, which describe Dongying Lake and its drainage basin corresponding to eight time intervals of Shhejie Formation Depositionnal period.

These palaeotopography reconstruction maps macroscopically Pattern the palaeotopography and changing trend of Dongying Lake and its drainage basin during Shahejie Formation depositionnal period, which is in accordance with the course of structural and deposional evolution of Dongying Lake from rifting, packing to vanishing.

STABLC ISOTOPES FROM LACUSTRINE CARBONATES OF SHAHEJIE FORMATION AND ITS PALAEOLIMNOLOGICAL SIGNIFICANCE

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The stable oxygen and carbon isotopic compositions of lacustrine biogenic carbonates and lacustrine abiogenic primary carbonates can yield useful paleoenvironmental information. There are abundant lacustrine Ostracoda in Shahejie Formation of Dongying depression, but the lacustrine carbonates dominated by primary and/or early diagenetic dolomite only distribute in lst member and 4th member of Shahejie Formation. In this paper, stable—isotopic analysis of 29 lacustrine Ostracoda samples and 74 lacustrine carbonates samples have been carried out to reconstruct the palaeohydrology, palaeochemistry and palaeoproductivity of Dongying Lake during Shahejie Formation depositionnal Period.

The results show that both Ostracoda and primary carbonates from Es_1 and Es_4 display characteristic, highly correlated covariance between oxygen and carbon isotopic variations ($r=0.77, 0.99$ respectivily). It demonstrates that Dongying Lake is a hydrologically closed lake during Shahejie period.

At that time, the palaeosalinities are as follows: middle Es_4, lowerupper Es_4 > middle – lower Es_1 > upper ES_1 > upper upper Es_4, according to the changes of $\delta^{18}O$ values. The negative sift of $\delta^{13}C$ during Es_4 indicates a sulfate–rich, low productivity lake. The positive sift of $\delta^{13}C$ during Es_1 indicates a sulfate–poor lake.