ABSTRACTS OF PAPERS PRESENTED AT THE SYMPOSIUM ON GEOTECTONICS AND ENERGY RESOURCES IN EAST ASIA

The International Symposium entitled "Geotectonics and Energy Resources in East Asia" was held in September 1988, as a part of the Institute for Transfer of Industrial Technology Programme of the Agency of Industrial Science and Technology.

Thirteen experts in the field of geotectonics and resource assessment presented papers at the symposium. The abstracts of the papers are appeared in the following pages.

The result of the symposium will bear fruit in the near future as geotectonic maps and basin maps of East Asia in the course of the international activities conducted by CPMP (Circum-Pacific Map Project) and CCOP (Committee for Co-ordination of Joint Prospecting for Mineral Resources in Asian Offshore Areas).

GEOTECTONICS OF EAST ASIA

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The present structure of East Asia is a time section of the long history of the region from the Precambrian to Recent. It stems from the interactions among different plates. We have a wide variety of structures resulted from almost all the kinds of plate boundary tectonism in this part of the earth.

Surrounding the continental core, ocean-continent interaction constructed extensively island arc systems. We can see, besides these, local arc-arc and continent-arc collision boundaries, translational margins and others in the present East Asia.

Inside the continent, the geologic constitution is far from simple or clear-cut. The continent of Asia is a heterogeneous assemblage of paleoplates and fold belts, accreted successively by addition of new elements.

The primary structures of the constitutent elements are often secondarily modified by later deformation. Bent arcs, twisted mountains, fractured lands are not rare. Younger movements resulted in superposition of deformational features, making the structural analyses difficult.

Number of tectonic models have been presented already, in trying to interpret this complex history. Paleomagnetic study now in wide use, for instance, led us to the decomposition of apparently cohesive continent. It must be, of course, consistent with the data from the traditional but basic information of stratigraphy, geological structures and fossil records. It is eagerly wanted to organize all the available data for better understanding of the structure of this part of the earth.

The geotectonic maps of East Asia aim at summarizing such basic data in a form of map, which will be used not only for direct economic development but also for further tectonic meditation.

ACCRETIONARY TECTONICS IN JAPAN

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Before the Japan Sea was open in the Miocene, the Japanese islands had been situated at the eastern margin of the Asian continent. Along this continental margin, oceanic plates have been subducted since, at least, late Paleozoic time. Most of the geologic entities in the Japanese islands were caused by the accretion of trench-fill sediments, pelagic sediments, and fragments of seamounts, island arcs and microcontinents along the active continental margin during about 300 million years (Fig. 1). The following accretionary complexes are discriminated in Japan :

(1) continental fragments : the Hida terrane and the Southern Kitakami-Abukuma terrane,
(2) tectonically squeezed fragments of island arcs and Paleozoic accretionary complexes : the Circum-Hida Tectonic Zone and the Kurosegawa Tectonic Zone,
(3) Late Paleozoic accretionary complex : the Chugoku composite terrane comprising the Sangun, Maizuru, Akiyoshi and Ultra-Tamba terranes, and a part of the Chichibu terrane,
(4) Jurassic accretionary complex : the Mino-Tamba terrane, Northern Kitakami terrane and a part of Chichibu terrane,
(5) Cretaceous accretionary complex : the Northern Shimanto, Sorachi-Ezo, Hidaka, and Tokoro terranes,
(6) Paleogene accretionary complex : the Southern Shimanto terrane,
(7) Neogene-Recent accretionary complex : the Nankai trough.

Among them, the Hida terrane is considered to have constituted a part of the Sino-Korean Massif before the opening of the Japan Sea. The terrane consists mainly of polymetamorphosed gneiss and Jurassic granite. Rb-Sr radiometric ages of the gneiss and associated intrusive rocks are 1100, 700, 300, 240 and 180 Ma. These rocks are covered by Middle Jurassic to Early Cretaceous shallow marine to non-marine molasse-type sedimentary rocks.

The Circum-Hida Tectonic Zone extends along the southeastern margin of the Hida terrane. The zone is a heterogeneous assemblage of fragments of various rocks such as non-metamorphosed Ordovician to Permian shallow marine sedimentary rocks, chloritoid phyllite and schistose rocks (greenschist-

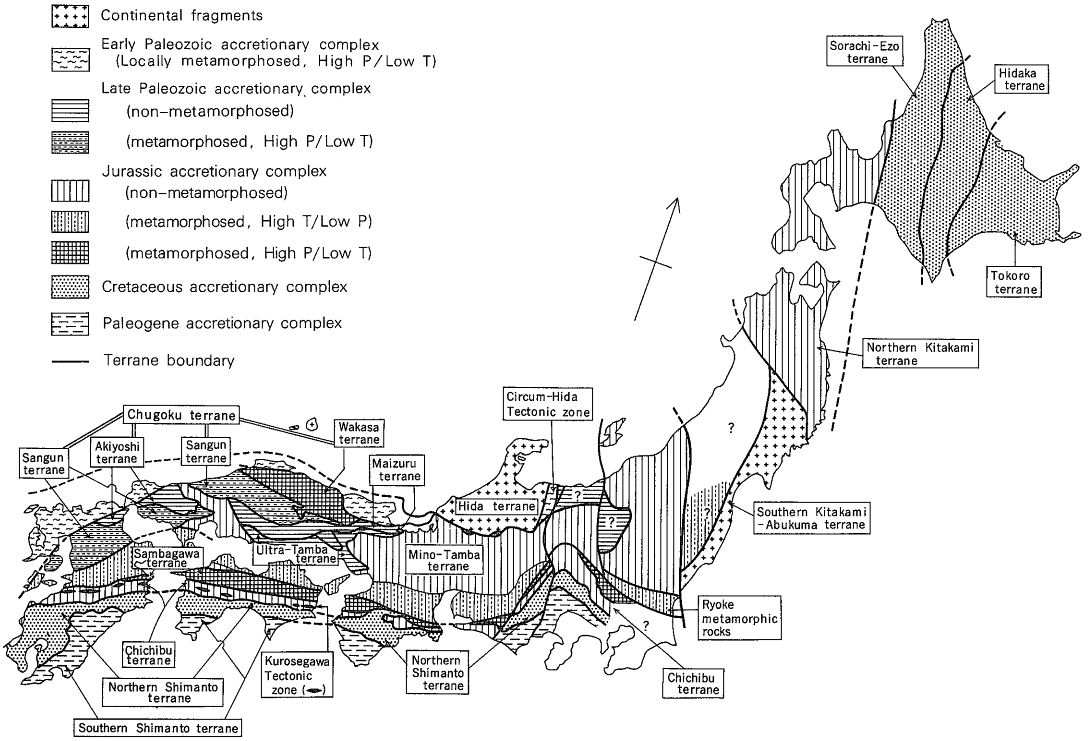

Fig. 1 Pre-Neogene tectonic units of Japan.

glaucophane schist facies) of 300–400 Ma. They are tectonically squeezed out and embedded in serpentinite. The assemblage is overlain by Lower Jurassic to Early Cretaceous shallow marine to non-marine molasse-type sedimentary rocks.

The Kurosegawa Tectonic Zone includes heterogeneous rocks which are tectonically squeezed out and embedded in serpentinite as well as the Circum-Hida Tectonic Zone. Early Paleozoic granite, volcanic rocks, gneiss and schist, and Paleozoic to Mesozoic shallow marine sedimentary rocks occur in the Kurosegawa Tectonic Zone.

The Paleozoic accretionary complexes are distributed in the Chugoku composite terrane (Sangun, Maizuru and Akiyoshi terranes). A considerable part of the Paleozoic accretionary complexes is affected by the high P/low T type metamorphism (Sangun metamorphic rocks). The non-metamorphosed part of the complexes is composed of chaotic mixtures of Middle to Late Permian trench-fill sediments, Middle Permian pelagic sediments and accreted remnants of Carboniferous to Permian seamounts. Radiometric dating shows that the metamorphosed part includes older elements than the non-metamorphosed part of Permian age.

The Jurassic accretionary complexes of the Mino-Tamba and Chichibu terranes consist mainly of Early Jurassic to Early Cretaceous trench-fill sediments, Permian to Jurassic pelagic sediments and accreted remnants of Late Paleozoic seamounts. These components were fragmentated and mixed each other, and often constitute melanges which are composed of numerous blocks of various rock types and ages embedded in muddy matrix. The complexes are locally affected by the high T/low P type (Ryoke metamorphic rocks) and the high P/low T type metamorphism (Sambagawa metamorphic rocks and a part of the Sangun metamorphic rocks.).

The Cretaceous, mostly non-metamorphosed, accretionary complexes occupy the Northern Shimanto, Sorachi-Ezo, Hidaka and Tokoro terranes. The Northern Shimanto and Hidaka terranes are composed mostly of Early to Late Cretaceous trench-fill sediments associated with pelagic sediments and accreted remnants of Late Jurassic to Early Cretaceous seamounts. The Sorachi-Ezo terrane is characterized by forearc sediments, ophiolite and melanges. The Tokoro terrane consists of accreted trench-fill sediments, pelagic sediments and seamounts. A part of the complexes in the Hidaka terrane is affected by the high T/low P type metamorphism, while a part of the Sorachi-Ezo terrane is affected by the high P/low T type metamorphism.

The Paleogene accretionary complex composed mainly of accreted trench-fill sediments constitutes the Southern Shimanto terrane. It is distributed along the Pacific coast in the Southwest Japan, and is in contact with the Neogene to Recent accretionary complex in the Nankai Trough.

Each of the Pre-Neogene accretionary events has been followed by complex strike slip and thrust faulting. Such multiple tectonic deformation and dislocation have disturbed the original arrangement of the individual accretionary complexes.

Non-marine to shallow marine intra-arc sediments have covered the previously accreted complexes since Mesozoic time. Igneous activities during the formation of the Jurassic accretionary complexes and the Cretaceous and Paleogene accretionary complexes were recorded in the Jurassic granite of the Hida terrane and in the acid plutono-volcanic rocks of the Northeast Japan and the Inner zone of the Southwest Japan, respectively.

The accretionary process is in progress in the Nankai Trough of the Southwest Japan still now, while tectonic erosion occurs in the Japan Trench of the Northeast Japan. The present collision of the Izu-Mariana arc to Japan is a symbolic manifestation of the accretionary tectonics in the Japanese Islands.

TECTONICS OF SOUTHERN KOREA

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As a whole, the Korean Peninsula comprises parts of the Sino-Korean Paraplatform, the Yangtze Paraplatform and the Cathaysian Fold Belt, which are extended from the eastern part of China. In contrast, the Peninsula is quite different in geology and tectonics from the Japanese Islands in that the islands form an active volcanic arc, which is situated along the Japan trench and is separated from the Asian continent by the development of a back-arc basin-Sea of Japan.

The southern part of the Korean Peninsula comprises NE-SW trending geologic provinces. They are, from the northwest to the southeast, the Precambrian Gyeonggi Massif, the age-controversial Ogcheon Folded Zone, the Precambrian Ryeongnam Massif, the Cretaceous Gyeongsang Basin and the Neogene Pohang Basin.

The Gyeonggi and Ryeongnam Massifs are protruding bodies of basement complex consisting mainly of Precambrian schists and gneisses, and subordinately Jurassic Daebo granite. The Gyeonggi Massif is partly covered by the Late Triassic to Early Jurassic fluvio-lacustrine Daedong strata. Between the massifs is the Ogcheon Folded Zone, which is occupied by the shallow marine and nonmarine strata of the Cambrian to Triassic Joseon and Pyeongan Supergroups in its northeastern part, and largely by the deeper marine sediments of the Ogcheon Group in its southwestern part. However, the age of the Ogcheon Group is a subject of strong controversy, being widely assigned to the Late Proterozoic to the Early Mesozoic. The Gyeongsang Basin is filled with a thick sequence of fluvial and lacustrine sediments. Volcanism and plutonism took place, at least, since the middle Gyeongsang time. The Pohang Basin corresponds to the western margin of the East Sea (Sea of Japan) Basin, which is a back-arc basin. The Neogene non-marine and marine strata in the Pohang area overlie the Cretaceous Gyeongsang strata and the associated volcanic and plutonic rocks.

Tectonic evolution of southern Korea is closely related to several times of igneous activities. During the Precambrian period, a few times of plutonism took place, although their influence to the pre-existing rocks became obscure due to overprinting by the Mesozoic orogenic movements and associated igneous activities. The mid-Triassic Songrim Disturbance and the Jurassic Daebo Orogeny ranging 200-140 Ma, both with plutonic intrusions, deformed and metamorphosed the pre-existing rocks, resulting in the severe folding and faulting of the Precambrian metamorphic rocks, the Paleozoic and age-controvercial strata in the Ogcheon Folded Zone, and the Late Triassic to Early Jurassic Daedong strata. During the Cretaceous Gyeongsang time, especially towards the end of the time,

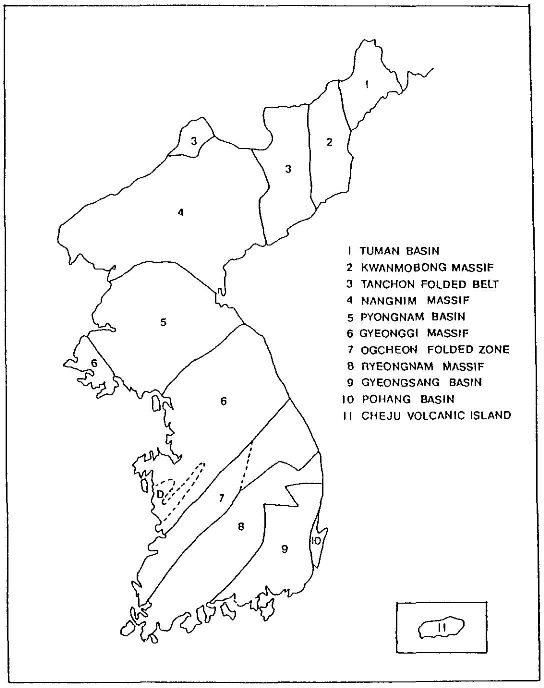

Fig. 1 Major geologic provinces of Korea.
Ogcheon Folded Zone (7) is divided into northeastern and southwestern parts. D is a representative area of Late Triassic to Early Jurassic Daedong strata (Modified after KIM, O.J., 1987).

GEOLOGIC PROVINCES	GENERAL GEOLOGY	STRUCTURAL FEATURES	REMARKS
GYEONGGI MASSIF	Precambrian metamorphic complex with areas of Jurassic to Early Cretaceous Daebo granites and Late Triassic to Early Jurassic nonmarine Daedong strata	Foliation varies from NW in western part to NE in eastern part. Most faults strike NNE, but some ones trend NNW.	Basement complex since at least Mesozoic time
OGCHEON FOLDED ZONE	Cambrian to Triassic shallow marine and nonmarine strata(Joseon and Pyeongan Supergroups) in northeastern part, and age-controversial metamorphosed marine sediments(Ogcheon Group) and Daebo granites in southwestern part. Daedong strata and Cretaceous nonmarine Gyeongsang sediments cover small areas.	Fold, fault, and foliation of schists strike NE in southwestern part.. Synclinoriums trend NWW to EW, but faults strike NNE in northeastern part.	Tectonic setting of basin development is unknown
RYEONGNAM MASSIF	Precambrian metamorphic complex consisting of granitic gneisses and schists, and Daebo granites. Enclaves of Cretaceous volcanic strata.	Foliation mostly strikes NE in southtwestern part and EW in eastern part. A few anticlinoriums and synclinoriums trending EW are recognized.	Basement complex since at least Mesozoic time
GYEONGSANG BASIN	Thick sequence(about 9,000m)of Cretaceous alluvial,fluvial,lacustrine strata. Volcanic sediments and flows are abundant in the middle and upper parts of the Gyeongsang sequence. Small granitic plutons are scattered.	Volcanism and plutonism were active towards the end of the Gyeongsang period. Eastward tilting and NNE-SSW trending faulting are recognized.	Graben-type continental basin
POHANG BASIN	Neogene marine and nonmarine strata overlying Cretaceous Gyeongsang strata and Bulgugsa granites.	Mostly homoclinal tilting to the east, with minor warping.	Western margin of East Sea (Sea of Japan)

Fig. 2 Summary of geologic and structural features of geologic provinces of southern Korea.

REGION / PERIOD		SOUTHERN KOREA		CHINA	
		TECTONIC MOVEMENT	IGNEOUS ACTIVITY (Ma)	TECTONIC MOVEMENT	IGNEOUS ACTIVITY (Ma)
CENOZOIC	Quaternary		Alkali volcanics	Himalayan	20-10
	Neogene				
	Paleogene	No sedimentation	Acidic volcanics (50-30)		
MESOZOIC	Cretaceous	Bulgugsa Disturbance	Bulgugsa granite & associated volcanics (130-50)	Yenshan	130-80 190-150
	Jurassic	Daebo Orogeny	Daebo granite (200-140)		230-190
	Triassic	Songrim Disturbance		Indo-Sinian	
PALEOZOIC	Permian			Variscan	260-230
	Carboniferous				300± 350±
	Devonian	Great Hiatus (in sedimentation)			
	Silurian			Caledonian	410-380
	Ordovician				460-430
	Cambrian				520-490

Fig. 3 Summary of tectonic movements and igneous activities during the Phanerozoic Eon in southern Korea. Tectonic and igneous activities of China are summarized for the comparison.

volcanism and plutonism were active in and around the Gyeongsang Basin. Due to the intrusion of the granitic rocks (Bulgugsa granite) ranging 130–50 Ma, the Gyeongsang strata are locally tilted, but neither folding nor metamorphism took place. Regardless of deformation age, the resulting folding axis and faults trend NE–SW. In detail, however, deformation pattern is more complex in the older geologic provinces than the younger ones.

The Mesozoic and Cenozoic basin development and igneous activities in southern Korea can be related directly and indirectly to the subduction of the Kula plate during the Mesozoic and the Pacific plate during the Cenozoic beneath the East Asian plate. However, plate tectonics of the Precambrian and the Paleozoic times are still uncertain.

THE GEOLOGICAL AND GEOPHYSICAL INVESTIGATIONS OF CHINA SEAS AND THEIR RESULTS

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The "Geological and Geophysical Serial Maps of the China Seas", with a scale of 1 : 2,000,000, have been constructed by Bureau of Petroleum Geology and Marine Geology, Ministry of Geology and Mineral Resources, People's Republic of China, since 1986. They are expected to be finished by the first quarter of 1989. After the final approval, they will be printed and published both at home (in Chinese) and abroad (in English).

The "Serial Maps", covering the area of 0°–42°N and 102°–140°E, are comprised of (1) topographic map, (2) free-air gravity anomaly map, (3) Bouguer anomaly map, (4) magnetic anomaly plane section, (5) magnetic anomaly map, (6) geomorphological map, (7) geological map, (8) geodynamic map, (9) geotectonic map, and (10) mineral resources map. Among them, (1)–(5) are the fundamental maps, (6)–(10) are the interpreting or resulting maps based on plate tectonic theory and comprehensive interpretation of geological and geophysical data. The "Serial Maps" are, therefore, the summation of marine geological and geophysical works run by Ministry of Geology and Mineral Resources, P.R.C., in the past 30 years.

GEOTECTONICS AND ENERGY RESOURCES OF THE PHILIPPINES

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The Philippine Archipelago, located at the junction of the Eurasian and Philippine Sea Plates, serves as a natural laboratory wherein processes leading to the accretion of terranes can be observed in action. This has attracted scientific investigators during recent years and has resulted in the recognition of terranes of island arc, oceanic and continental affinity.

At present, the Philippine Archipelago can be divided into two major structural provinces. The first lies west of the Manila–Negros–Cotabato Trenches which collectedly form the eastern Eurasian Margin. This province is less seismically active and is characterized by a NE–trending series of alternating basins and ridges.

The Palawan Ridge, which separates South China Sea from Sulu Sea, exposes continental crust of mainland Asia origin in the north and ophiolites and melange in the south. The Sulu–Zamboanga Ridge between the Sulu and Celebes Seas consist of volcanic arc material overlying ophiolitic and metamorphic (continental ?) basement. A common geologic history is believed to have been shared with the Cagayan de Sulu Ridge prior to the formation of Sulu Sea oceanic crust. The opening of marginal sea basins and processes associated with convergence are largely responsible for dispersion and accretion, respectively, in this province.

The rest of the archipelago, bounded by the Manila–Negros–Cotabato Trenches and the East Luzon Trough–Philippine Trench, the latter defining the western limit of the

Philippine Sea Plate is more geologically complex. This second province, known as the Philippine Mobile Belt, is subject to active seismicity and volcanism and to intense deformation.

Existing geologic and paleontologic data shows the presence within the mobile belt of structurally-bounded rock packages exhibiting a diversity in lithology, origin and age. These include metamorphics, ophiolites of Cretaceous and Eocene ages, melanges, and island arc material of Cretaceous through Neogene ages. The idea that some rocks in eastern Philippines might be of continental affinity has been suggested.

Paleomagnetic data suggest that these terranes have undergone translational and rotational displacements before being juxtaposed or superposed. More often, however, terrane boundaries are difficult to identify as they are made obscure by sedimentation, volcanism and later deformation. At present, these terranes are being rearranged as the Philippine Fault tears through the entire length of the archipelago. This feature, a major left-lateral slip, was generated in responses to the oblique convergence between the Eurasian and Philippines Sea Plates.

The distribution of energy resources of the Philippines can be explained by its geotectonic framework. The best potential for hydrocarbons is offered by the rifted microcontinental fragments although arc-related basins also serve as possible targets. Geothermal energy, on the other hand, is provided by Neogene volcanoes.

AN OUTLINE OF THE TECTONIC DEVELOPMENT OF THE INDONESIAN ARCHIPELAGO AND ITS BEARING ON THE OCCURRENCE OF ENERGY RESOURCES

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The geology and tectonics of the Indonesian Archipelago exhibit a typical tripple junction convergence, which is due to the tectonic movement of the northward moving Indo-Australian Plate, the westward moving Pacific Plate and the Southeastward moving Eurasian Plate. This tectonic configuration seems to have been developed since Neogene time.

Pre-Neogene tectonic development of the Indonesian Archipelago can therefore be divided into two different activities : i) tectonic convergence since Paleozoic in the western Indonesia and ii) tectonic divergence in Mesozoic time producing allochthonous terranes in the eastern Indonesia.

In Neogene time the tectonic convergence in the eastern Indonesia is dominated by a Tethyan type collision, in which continental fragments (micro continents) collided with subduction complex and/or island arcs.

The occurrence of the energy resources in the Indonesian Archipelago is related closely to the tectonic development of the region :

a. Hydrocarbon occurs in the Mesozoic continental shelf sequence in the eastern Indonesia and in the Tertiary back arc basin in the western Indonesia and some parts of the eastern Indonesia.
b. Coal occurs mostly in the foreland basin and some in the inter arc and/or transtensional basins.
c. Geothermal occurs typically in a sulfatara stadium volcanic belt.
d. Radioactive minerals occur mostly in the Mesozoic magmatic belt.

A SAMMARY OF TECTONIC UNITS OF PAPUA NEW GUINEA

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Tectonic units of Papua New Guinea, analized by recent workers, are summarised in terranes and major structural elements. Three composite terranes are Papuan, Solomon and Finisterre, punctuated with successor basins. These terranes represent continent and sedimentary overlap, oceanic crust and upper sedimentary layer, and island arc system respectively.

Their present location and structural

character are a result of middle Miocene–Pliocene uplift and deformation. Two tectonic divisions have been recognised as a result. Fly platform is an undeformed basin of mainly Mesozoic sediments which overly crystalline basement of Indo–Australian Plate. It is a foreland which preceeds New Guinea orogen. The orogen is a juxtaposition of Papuan and Solomon Composite terrane, thrust against by an arc–trench complex during late Tertiary.

Tectonic units of PNG compare with that of Appalachian Orogen. Individual tectonic units are characterized as follows :

1. Terranes

Four types of terrane, namely stratigraphic, disrupted, composite and metamorphic have been defined through the terrane analysis of Papua New Guinea.

(1) Papuan Composite Terrane

It is comprised of an amalgamation of Palaeozoic crystalline basement of the Indo–Australian Plate, and overlying sediments of the Papuan Basin overlap.

Crystalline basement is Carboniferous and Permian in age and consists of Fly–Stricland Granites, Kubor, Goroka and Papuan Plateaus. The overlying sedimentary sequence of mainly Mesozoic age rests unconformably on the basement. It is broken in Cretaceous Palaeocene, Eocene and Oligocene times. The terranes are exposed in the orogenic belt as thrust imbricates.

(2) Solomon Composite Terrane

It consists of an amalgamation of oceanic tholeiite and associated hemipelagic sediments. The tholeiites are largely transitional and range in age from Cretaceous to Eocene, except for the in situ Solomon Sea lithosphere, which had ceased rifting in Miocene and is currently a depositional basin.

Exposed terrane in the thrust belt includes Goropu and Lokanu. Goropu Terrane is older and metamorphosed.

(3) Finisterre Terrane

It is Palaeogene and younger island arc system. It comprises the Finisterre and Adelbert Ranges, and the New Guinea islands of Manus, New Ireland, New Britain and Bougainville.

The terrane consists mainly of calc–alkaline volcanics, subordinate plutonic equivalent, and derived sediments.

(4) Others

These include terranes which may be related to the terranes cited above, but protolithic relationship is uncertain.

i) *Torricelli Terrane* is Palaeogene in age and consists of an oceanic crustal affinity and pelagic sediments, together with elements of Maramuni Arc.

ii) *Landslip Metamorphic Terrane* is Cretaceous to Palaeogene in age and consists of schist to gneiss grade metasediments, amphibolite and metaultramafics.

iii) *Prince Alexander Metamorphic Terrane* is Mesozoic in age, and consists of medium grade metamorphics and tectonised granodiorite.

(5) Basins

The basins are Neogene and younger, and comprised of exposed mollasic basin overlap, and submerged rift–drift basin. The former unconformably overlies pre–Neogene terranes, and the latter intervenes the island arc.

2. Structural Units

Two tectonic division has been recognised in Papua New Guinea as a result of study by ROGERSON *et al.* (1987 a and 1987 b). The divisions are Fly Platform and New Guinea Orogen, and together they highlighted affinities of fore land thrust belts.

(1) Fly Platform

It is undeformed Papuan Composite Terrane of crystalline and Papuan Basin overlap. It is a foreland proceeding the fold and thrust belts and is separated from the New Guinea Orogen by the Papuan Thrust.

(2) New Guinea Orogen

This includes the New Orogenic Belt and Melanesian Arc. The Orogenic belt is comprised of fold and thrust belts of Papuan, New Guinea, Owen Stanley and Bogoro Thrust Belts.

i) *Papuan Thrust Belts* grades from tight folds in the south to thrust towards the northeast. It mainly consists of thrust sediments of the Papuan Basin overlap. Aure Trough Fold and Belt, situated to the northeast consist of deep marine sediments. The Papuan Thrust Belt represents a foreland thrust belt, and Valley and Ridge topography of the Appalachian Orogen. It is separated from the north by the Lagaip-New Guinea Thrust.

ii) *New Guinea Thrust Belt* is dominated by anastomosing subhorizontal thrust. Thrust imbricates include Papuan Basin sediments and oceanic crust interspersed with deformed granitoids and metamorphics. The thrust staggs are in turn underlain by the Australian crystalline basement. The unit represents Blue Ridge of the Appalachian Orogen. Strike-slip fault system of the Bewani and Torricelli Ranges marks the northern limit of the thrust belt.

iii) *Owen Stanley Thrust Belt* defines thrusting of Palaeo Solomon Sea Plate over mainly metamorphics of the Pauan Composite Terrane. However, towards the southeast thrust bifurcates. It is bounded by the Trobrian Trough and Bogoro Thrust.

iv) *Bogoro Fold and Thrust Belt* preceeds the Owen Stanley Thrust Belt, and mainly comprise of dismembered transitional tholeiite and hemi-pelagic sediments thrust over Papuan Basin sediments.

v) *Melanesian Arc* is represented by the Finisterre Terrane. It is bounded by Manus-Kilinailau Trench situated to the north, and Ramu-Markham Faults and Trobrian Trough situated to the south.

OUTLINE OF THE TECTONIC EVOLUTION OF THAILAND

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Thailand can be divided, based on the geological structures, into three major tectonic units. The Shan-Thai and the Indochina cratons are Precambrian craton-like blocks situated on the west and the east respectively. The Yunan Malay mobile belt, lying between these two cratons is subdivided in northern Thailand into the Sukhothai fold belt in the west and the Loei fold belt in the east.

In early Paleozoic, an island arc was formed above a west dipping subduction zone between the two cratons. In miogeosynclines, clastic to calcareous sediments containing local tuff intercalations were deposited on the Precambrian craton during Early Paleozoic. In Late Permian, a spreading ridge was developed in the ocean floor between the Shan-Thai and the Indochina, and a pair of subduction zones was formed subsequently. Both the mobile belt and the central parts of the cratons were uplifted by Hercynian movements.

During the Middle Triassic time the Shan-Thai was in contiguous to Indochina and South China. The continent-continent collision was a part of the Indosinian orogeny. The Indochina was tended to underthrust the Shan-Thai craton. This orogenic movement was associated with the intrusion of small granitic bodies.

After the collision, mountains were developed along the suture, particularly along the overthrusting Shan-Thai margin. At the sametime, granites were intruded to high levels in the sediments, and the extensive rhyolite were extruded on the land surface. Erosion of the mountain produced molasse deposits on both side of the suture. The molasse deposits are mostly developed in the Khorat Basin which was formed on the western side of underthrusting Indochina block.

Rifting of continental Southeast Asia and opening of the Gulf of Thailand by tensional regime during the Cretaceous to Tertiary times mark neotectonic stage of Thailand with subsequent rapid uplift of the present mountains during the Quaternary.

TECTONIC FRAMEWORK OF MALAYSIA

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Geologically Malaysia is made up of two widely separated regions. Peninsular Malaysia, on the west, is at the southernmost tip of mainland South East Asia and Sabah-Sarawak, on the east, forms the northern part of the island of Borneo. In this regional setting the geotectonics of the Peninsular region (at least after the Triassic) is related to that of a stable craton while that of Sabah-Sarawak largely that of a plate margin which is influenced by subduction at the Palawan and Sulu Trenches.

The main elements of the present day tectonic framework appear to have been established since the Jurassic, after the main Late Triassic orogeny when there was widespread emplacement of granitoids. On a more global setting, both Peninsular Malaysia and western Sarawak are located within the western and eastern margins of the Sunda Craton—a pre-Tertiary continental core made up of Burma, Thailand, Indochina, Sumatra, Java and Borneo with terrains accreted at its western and southern margins. This continental block forms the southernmost part of the Eurasian plate. The Peninsular Malaysia region is about 500 km east of the Sunda Trench, active since Mesozoic, where the Indo-Australian Plate is subducting under the Eurasian Plate in a cordillerian setting. Its geology after the Triassic do not appear to be affected by events at the trench and it behaved as a continental basement occupying a back arc setting. While the western part of Sarawak (west of the Lupar Line) forms part of the Northwest Borneo Basement, the larger part of it and of Sabah is within a huge accretionary complex welded on to this basement. This large accretionary complex stretching from the Rajang-Baram watershed in Central Sarawak to Sabah is related to spreading in the South China Sea Basin and subduction at the Palawan Trench. The source of the voluminous sediments is considered to have come from mainland South East Asia. Belts of accretion, successively younger toward the trench can be recognised in Sarawak but this pattern is obscured in Sabah where the effects of subduction at the Sulu Trench have complicated it. A large part of this accretionary prism is now uplifted and subduction at the Palawan Trench have ceased since middle Miocene when the Palawan block (a micro-continent) arrived at the trench. Very mild metamorphism have affected the rocks but the characteristics (flysch, turbidites, melange, ophiolites, ocean pelagites) of this accreted terrian are still evident. Some small isolated intrusives in west-central Sabah is thought to represent magmatic arc rocks and volcanics in the Semporna and Dent Peninsular part of the Sulu Island Arc system.

The paleotectonic framework, before the Jurassic, is difficult to interpret as the rocks are metamorphosed and intruded by granitoids. Various models have been proposed for Peninsular Malaysia. HUTCHISON (1973) postulated that the Lower Paleozoic saw the region in a plate margin setting with an easterly oceanic plate subducting beneath a westerly continental plate along what is today seen as the Bentong Geosuture. The Late Carboniferous to Triassic however saw it behaving as a small continental plate within and adjacent to two opposite facing arc trench systems with an eastward dipping subduction at a trench located along the axis of Sumatra and a westward dipping subduction at a trench located in the South China Sea. MITCHELL (1975) postulated that during the Triassic the Peninsular Malaysia region fused as a result of collision of two formerly distinct eastern (largely continental) and western (island arc and continental) blocks. METCALFE (1968) supported this hypothesis and named the eastern block as Manabor and western block as Sibumasu. TAN (1976) disagreed with the above models for the Triassic and proposed that during this time there was an attempt at rifting along the axial belt but this was aborted. All these models remain conjectural until several basic issues like tectonic implications of the granite and type of volcanism are studied. Whatever the paleotectonics it appears clear that after the Triassic the Peninsular Malaysia region behaved as a stable craton.

Based on the present tectonic framework outlined above, several major tectonic untis or tectonic elements are recognised (Fig. 1). The West Malaysia Basement forms the major part

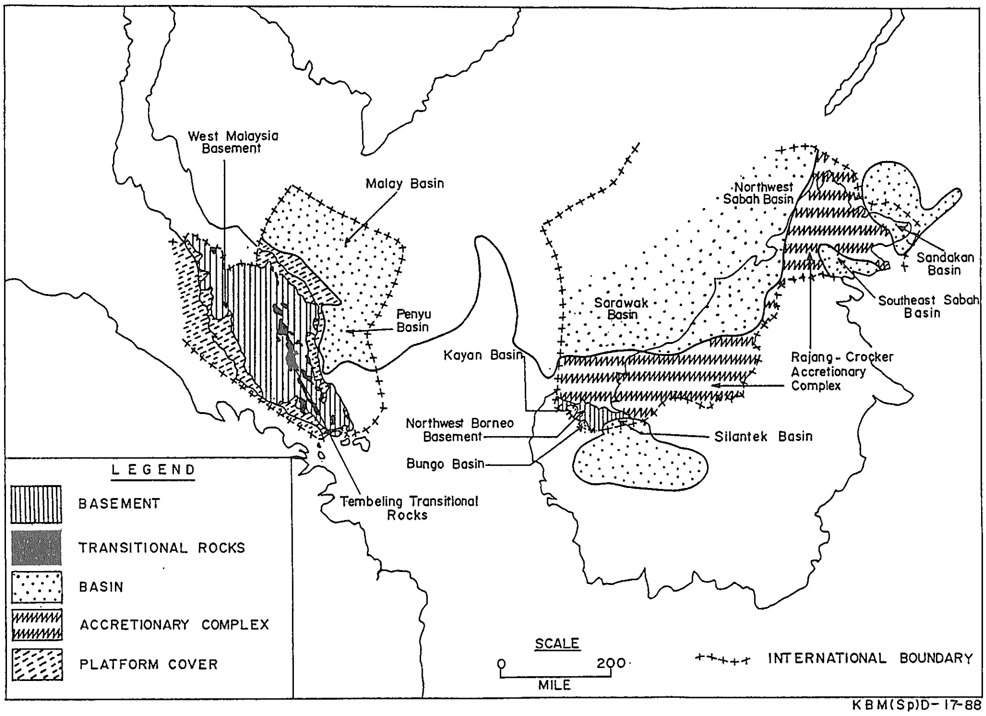

Fig. 1 Tectonic units of Malaysia.

of Peninsular Malaysia including the offshore areas. It comprises mainly of pre-Jurassic sedimentary, metamorphic and igneous rocks represented by the Machinchang Formation, Setul Limestone, Mahang Formation, Kubang Pasu Formation, Baling Formation, Singga Formation, Semanggol Formation, Kenny Hill Formation, Hawthorndon Schist, Bentong Group along the western part ; Gua Musang Formation, Semantan Formation, Gemas Formation along the axial part and Sg. Perlis beds, Kuantan Group along the eastern part. This basement is overlain by the Tembeling Transitional Rocks which are mainly Jurassic–Cretaceous molasse facies sediments lain down along the axial belt after the main Triassic orogeny. It is now represented by the Tembeling Group, Gagau Group, Bertangga Sandstone, Lesong Sandstone, Tebak Sandstone and Panti Sandstone. Also overlying this basement are several small Tertiary basins onland and the more important intracratonic Malay Basin and Penyu Basin offshore. Quaternary deposits confined mostly to the coastal zone and the offshore areas constitute which may be regarded as a platform cover. The western part of Sarawak forms part of the Northwest Borneo Basement. It comprises mostly of pre-Tertiary metamorphic and igneous rocks belonging to the Kerait Schists, Tuang Formation, Terbat Formation, Sadong Formation, Bau Limestone, Kedadom Formation and Pedawan Formation. The rest of Sarawak and of Sabah is underlain by the Rajang-Crocker Accretionary Complex represented by the Belaga Formation together with its Layar, Kapit, Metah, Pelagus and Bawang members. Overlying this accretionary complex are several forearc basins. The Sarawak Basin (represented by the Nyalau Formation, Setap Shale, Tangap Formation and Belait Formation) is continued through Brunei into the northwest Sabah Basin, which lies mostly offshore. The Sandakan Basin, lying mostly offshore, are represented onshore by the Bongaya, Kudat, Sebahat and Sandakan Formations. The Southeast Sabah Basin, which is continued into the Tarakan Basin of

Kalimantan, is represented by the Tanjong and Kapilit Formations. Three small basins, the Bungo, Kayan and Silantek Basins overlie the continental basement in West Sarawak. They are filled with the Kayan Sandstone, the Silantek Formation and Plateau Sandstone.

TECTONICS IN THE WESTERN PACIFIC

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The Western Pacific is in the one of the most enigmatic plate boundaries in the world forming many small plates, collisions and consumptions. This complication is a result of the northward movement of Australia since its breaking up from the Gondwana-Land in the Cretaceous. During their evolutions, most of them have associated with arcs. These arcs also have formed superimposing on the older exotic blocks of terranes.

Most of the terranes in the eastern Asia appear to be relics of arcs, oceanic islands and subduction complexes. They have collided and accreted from the inner (north western) side in China since the Silurian. They are characterized by three stages of the Pacific and Tethys evolution. The first collision is related to the Pacific domain in the Permian in which these movements are not clearly reconstructed. The second collision is related to the closure of the Paleo-Tethys in the Late Triassic to Early Jurassic. The third is related to closure of the Neo-Tethys and the subsequent collision of India in Tertiary.

There have occurred suture, arc and backarc basin formations in the eastern part following by the northward movement of Australia. The arcs facing toward the Pacific plate on the Western and Southwestern Pacific rim occur in a zone forming an arc chain from the Western Pacific tropics to the eastern margin of Australia. They are reconstructed since their initiation in the Eocene and Oligocene. They are associated with the formation and consumption of backarc basins. Reversal of arc polarities and renewed subduction has occurred in some of them.

The backarc basins associated with arcs of the Tertiary arc chain have same regular durations in their evolutions. The backarc basin forms 15 million years after the initiation of the arc. Several to 10 million years after the opening backarc spreading terminates. Approximately 20 million years after the cessation of the backarc spreading, the second phase of opening occurs in the backarc basin. In the case of arc collision, reversal of the arc polarity occurs, if there is the oceanic crust on the backarc side, and opening of a backarc basin occurs within several million years. These occurrences and durations for activities have a variation of plus or minous 3–5 million years.

From these reconstruction and regular durations which are observed in the Tertiary arc chain in the Western Pacific, the arcs and backarc basins in the Southeast Asia are evaluated and interpreted.

MESOZOIC AND CENOZOIC TECTONIC PROCESS OF NORTHWEST PACIFIC CONTINENTAL MARGIN

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The crustal movements which occurred in the Mesozoic and Cenozoic are distinctly developed in East China and its adjacent areas. In 1927, WENG Wenhao, a Chinese geologist, firstly named the term Yanshanian Movement for Jurassic-Cretaceous tectonism in China. In 1945, T.K. HUANG (HUANG Jiqing) put forth the term Indosinian Tectonism embracing the tectonic movements ranging from Middle Triassic to Early Jurassic and subdivited the Mesozoic and Cenozoic Alpine tectonic cycle into Indosinian, Yanshanian and Himalayan subcycles.

In recent years, the Indosinian, Yanshanian and Himalayan Tectonisms have been recognized as very important events in the tectonic process of the northwest peri-Pacific areas in East Asia.

I. Mesozoic Tectonic Zonation and Tectonic Process of Northwest Peri-Pacific Areas

1. Mesozoic Tectonic Zonation

On the basis of analysis of the formation and deformation of rocks at the Indosinian-Yanshanian stage, the peri-Pacific areas in East Asia can be divided into three tectonic zones (Figs. 1 and 2) :

(1) The eastern zone constituting a unified coastal mobile zone.
(2) The central zone constituting a unified mobile zone of continental margin.
(3) The western zone being an in-land stable zone.

2. Some Main Characteristics of the Indosinian-Yanshanian Movement

(1) Succession of tectonic deformation from the Yanshanian stage to Indosinian stage.
(2) Persistency of Mesozoic tectonic deformation.
(3) Episodicity of tectonism of Indosinian-Yanshanian stage.
(4) Repeated magmatic activity of Indosinian-Yanshanian orogeny.
(5) Oceanward gradation and migration of different geological processes.

3. Mesozoic Tectonic Process

During the Variscan or Variscan-Indosinian stage, the palaeooceanic or continental margin environment widely developed between

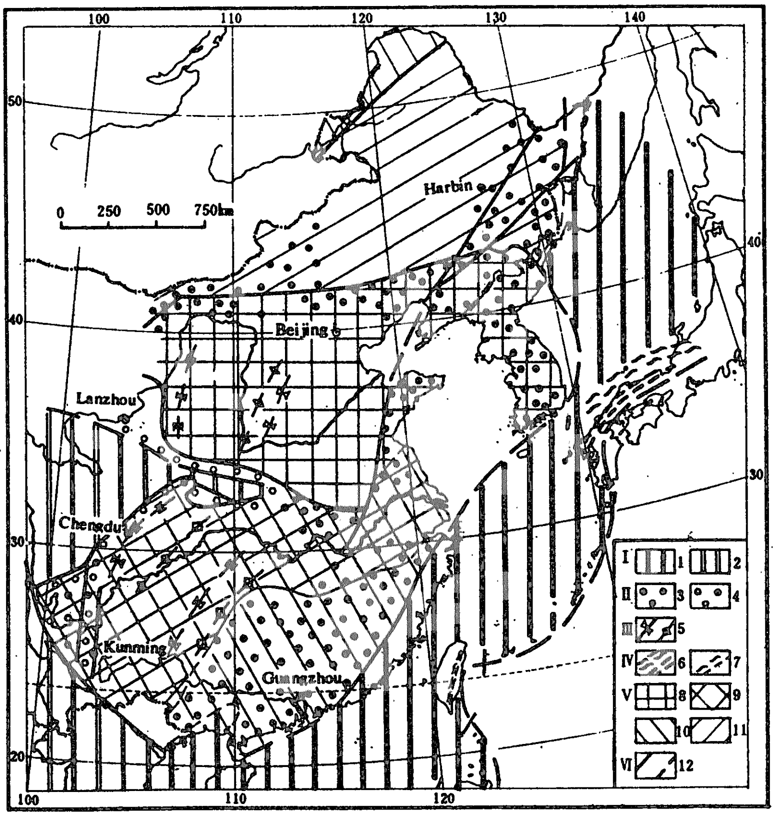

Fig. 1 Sketch map of the Indosinian paleotectonic setting in China's peri-Pacific belt (showing the present position).
1. Western peri-Pacific Hercynian-Indosinian fold zone ; 2. Tethys Indosinian fold zone ; 3. Mobile zone of the peri-Pacific continental margin ; 4. Mobile zone of the Tethys continental margin ; 5. Axial lines of uplift and downwarping in intra-continental stable zone ; 6. Indosinian paired metamorphic belt in southwest Japan ; 7. Yanshanian-Himalayan paired metamorphic belt in eastern Taiwan ; Pre-Indosinian Fold basement (8-11) ; 8. Lüliang and older ; 9. Jinning ; 10. Caledonian ; 11. Hercynian ; 12. Major fracture zones.

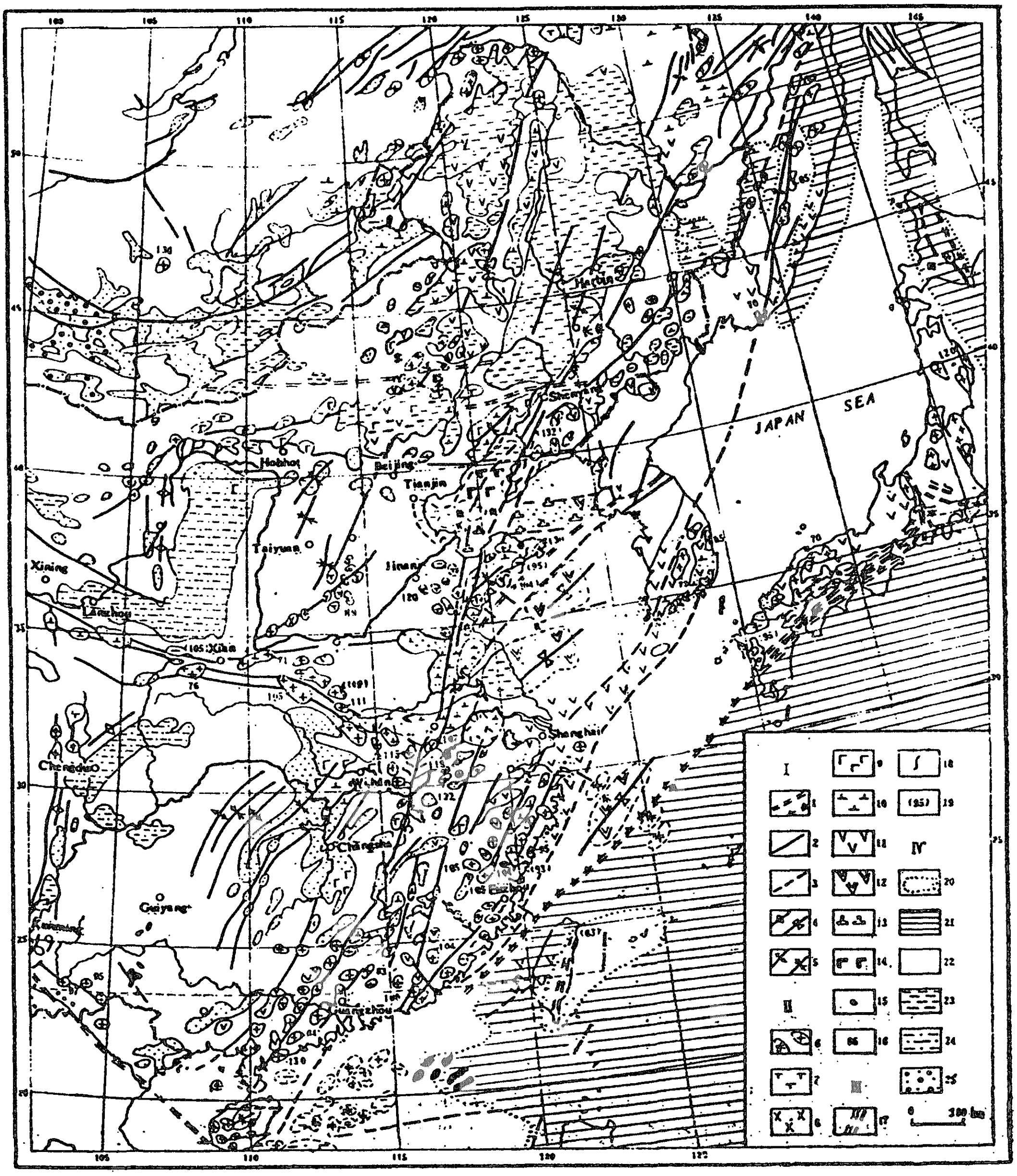

Fig. 2 Late Yanshanian paleotectonic map of peri-Pacific belt in China and its adjacent areas (showing the present position).

I. Tectonic deformation : 1. Suture between continent and ocean or gigantic fractured zone ; 2. Synorogenic fractures ; 3. Speculative synorogenic fractures ; 4. Synsedimentary anticlines and synclines ; 5. Synorogenic anticlines and synclines ; II. Magmatic activity : 6. Granites, Granodiorites ; 7. Diorites, Diorite-porphyrites ; 8. Syenites, Alkaline rocks ; 9. Basic volcanic rocks, 10. Intermediate-basic volcanic rocks ; 11. Intermediate-acid volcanic rocks ; 12. Early-Late Yanshanian acid volcanic rocks ; 13. Early-Late Yanshanian intermediate volcanic rocks ; 14. Early-Late Yanshanian basic volcanic rocks ; 15. Early-Late Yanshanian basic-ultrabasic rocks ; 16. Intrusion age (m.y.) ; III. Metamorphism : 17. Paired metamorphic belt (high-temperature belt, high-pressure belt) ; 18. Schistosity ; 19. Metamorphism age (m.y.) ; IV. Sedimentary formation ; 20. Boundary between sea and continent ; 21. Clastic formation or geosynclinal sedimentary formation ; 22. Old land or uplift ; 23. Oil shale and coal bearing formation ; 24. Red clastic formation ; 25. Red paramolasse.

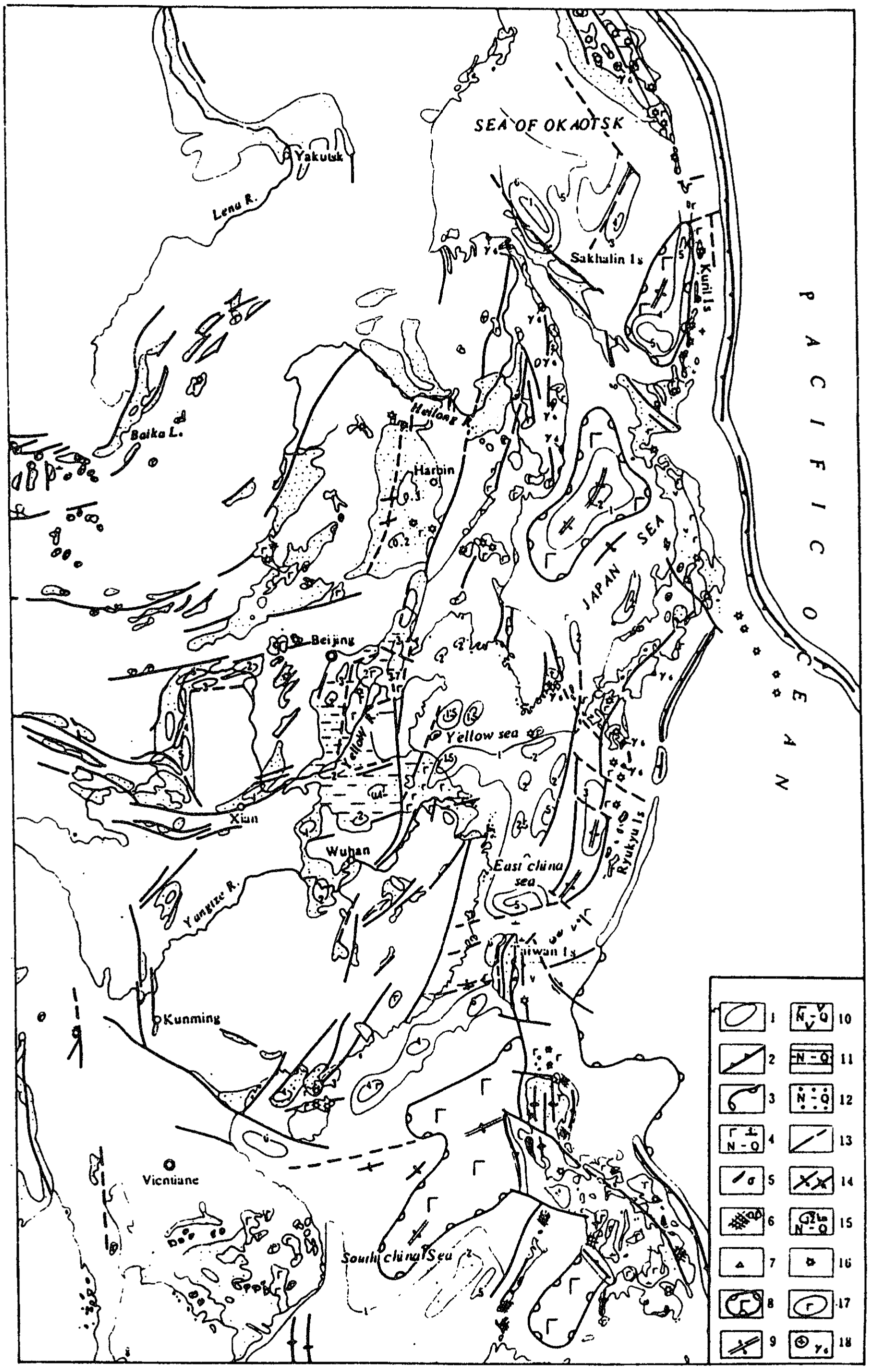

Fig. 3 Late Himalayan tectonic sketch map of peri-Pacific area in East Asia.

1. Trench ; 2. Subduction zone ; 3. Boundary of oceanic crust ; 4. Sedimentary and volcanic formation ; 5. Ultrabasic rocks ; 6. Ophiolite suite ; 7. Melange accumulation ; 8. Basins of marginal sea ; 9. Spreading axis ; 10. Basicultrabasic rocks and marine sediments ; 11. Sediments of marine-land facies ; 12. Sediments of land facies ; 13. Fracture zone ; 14. Anticlines and synclines ; 15. Isopac of sediments (N-Q) ; 16. Volcanic cone ; 17. Basalt ; 18. Granite.

the Siberia, Sino-Korea, Yangtze and Indo-China Precambrian massifs. The distribution of the palaeotectono-palaeogeographic framework and the uplift-subsidence belts are predominatingly of apparent E-W trend. As a result of the strong Late Variscan and Indosinian orogenic movements, these separate units coalesced into a unified palaeo-Asia continent.

The Indosinian tectonic cycle in East Asia may be divided from palaeogeographic and palaeotectonic features into the early Indosinian stage (T_{1-2}) and the late Indosinian stage (T_3), with two intervening regional orogenic episodes and the Yanshanian tectonic cycle into the early stage (J) and late stage (K) and several major tectonic episodes.

In the Late Triassic, the Indosinian Movement gave rise to a series of continental basins and tectono-magmatic zones having a main apparent NE-NNE trend in East China and the adjacent areas.

During the Yanshanian Movement, the apparent NNE trending Neocathaysian tectonic belt has developed all over the region, with their compounding on the older apparent E-W and NE trending tectonic belts in some area.

In summary, the Indosinian Orogeny acted as a turning point in the geological history, and the Yanshanian Orogeny has caused a fundamental change in the tectonic framework in East China and adjacent areas. In other words, the Indosinian-Yanshanian tectonism ushered in a new stage of the tectono-magmatic development in the western peri-Pacific areas.

II. Cenozoic Formation and Deformation Zonation and Tectonic Process of Northwest Peri-Pacific Areas

1. Cenozoic Formation and Deformation Zonation

From the present trench belt of the northwest Pacific areas to the west, there are distributed five gigantic Himalayan formation and deformation zones (Fig. 3) :

(1) Northwest Pacific trench-island arc zone.
(2) Basins zone of northwest Pacific marginal sea.
(3) Continental shelf subsidence zone from the East China Sea to the north part of South China Sea.
(4) Continental margin rift system zone of East Asia.
(5) Intra-continental rift system zone of East Asia.

2. Cenozoic Tectonic Process

From the analysis of tectonic evolution and the change of tectonic features, the Himalayan tectonic cycle in northwest peri-Pacific tectonic belt may be divided into early Himalayan stage (E or K_2-E) and late Himalayan stage (N-Q). By the end of early Himalayan stage and between the Late Tertiary and Early Quaternary of late Himalayan stage, two tectonic or orogenic episodes took place.

In the early Himalayan stage, there occurred the northwest peri-Pacific trough zone and continental shelf subsidence zone in the East and South China Sea. Some rift systems of the continental margin and intra-continent may be divided into uplift-erosion stage (K_2-E_1) and fault-subsidence stage (E_2-E_3 or N_1). In the late period of early Himalayan stage, the east trough zone was folded, and the South China Sea underwent sea-floor spreading.

In the late Himalayan stage (N_1 or N_2-Q), the rift system of continental margin and intra-continent, as well as the continental shelf zone experienced subsidence. A unified trench-arc system and epicontinental basin zone came into being from the Late Miocene and Late Pliocene.

HYDROCARBON RESOURCE ASSESSMENT METHODS AS APPLIED TO BASIN ANALYSIS APPROACHES IN SOUTH EAST ASIA

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Geological Survey of Canada

As a contribution to the IUGS sponsored Basin Analysis and Resource Assessment Project for South East Asia, Canada undertook a program of technology transfer wherein methods and computer software programs in resource assessment used by the Geological Survey of Canada would be transferred to participating countries within the project.

There are many options in estimating the hydrocarbon resource endowment of a given basin, and the methods selected depend largely on the requirements of the user for whom such assessments are made. Although the total endowment for a given basin is of interest for many users, our clients have been more concerned with the sizes and number of individual pools. To answer these questions the Geological Survey of Canada uses two approaches, both of which operate at the exploration play level. The two approaches are called, the discovery process model (statistical) and the subjective probability (geological) methods.

The discovery process model is a statistical approach used for established plays where there has been successful exploration resulting in discovered hydrocarbons. The underlying theory is that the discoveries represent a based sample of the underlying natural population of pools in the play. If the discovery process can be understood and modelled, then the method can predict both the size and number of remaining undiscovered pools. The method is particularly useful in treating stratigraphic plays where other methods are weak.

The subjective probability method is used mainly for conceptual plays where informed geological judgement is combined with whatever exploration data may exist to construct frequency distributions of both the reservoir variables and the number of prospects involved. An appropriate equation is formulated and the equation solved (several methods exist) to estimate th size and number of pools in the play.

THE GEOTECTONIC ZONATION AND DISTRIBUTION OF ENERGY AND RESOURCES IN VIET NAM

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The territory of Viet Nam and neighbouring regions belongs to the Southeast part of the Eurasian plate and is located at the junction of Pacific and Mediterranean tectonic belts.

On the basis of analysing geological, geophysical and remote sensing data, Viet Nam may be divided into the following tectonic elements :

—Precambrain continental crustal blocks : Indosinia block, its main part lies within the Indochina peninsula, consists of the Kontum uplift in the East and Khorat basin in the West, the Hoang Lien Son block lies in the North of Viet Nam.

—The Sino-Vietnamese folded belt, consolidated in the period from Early to Middle Paleozoic, consists of the Early Caledonian Vietbac, Late Caledonian Northeast Bacbo and Northwest Bacbo fold systems.

—The Vietnam-Laos folded belt, consolidated in the period from Middle to Late Paleozoic, consists of the Late Caledonian Danang-Sepon, Early Hercynian North Truongson and Late Hercynian Kampot-Hatien fold systems.

—The Indochina folded belt consolidated in the Early Mesozoic, consists of the Indosinian Makong and Songda (Black River) folded systems.

—The Mesozoic superimposed structures, which were mostly originated by rifting were filled with volcano-sedimentary formations. The Songhien, Anchau, Samnua, Ankhe, Tule rift depressions ; Hongai, Nongson coal bearing grabens and the Dalat volcano-plutonic margin.

—The Cenozoic superimposed structures are composed of Hanoi, Mekong and other continental rift depression and Taynguyen basalt plateau aureole.

—The sturctures of Eastern marginal sea comprise a deep sea basin of oceanic crust, peripheral zone with thinned granitic layer, continental crust massif of Hoangsa (Paracels) and Truongsa (Spratleys) slopes and shelves on the heterogenous basements.

The boundaries between the major fold belts are often marked by deepseated faults, which are associated with melange-ophiolite assemblages in connection with Paleo-Pacific type and Paleo-Tethys one.

The laws of distribution of energy resources are controlled by tectonic setting.

Anthracite has been found in upper Paleozoic covers of the Vietnam-Laos and Sino-Veitnamese folded belts. Tens of coal seams with great overall reserve are known in the Mesozoic and Cenozoic molasse formations, especially in the grabens and rift zones. Hydrocarbon occurs in the Devonian and Triassic breccia of the Northwest Bacbo folded system, especially has great potential in Late Oligocene-Miocene rift depressions and/or continental shelves.