# THE PRE-TERTIARY GEOLOGY AND MESOZOIC TECTONIC EVOLUTION OF EASTERN CHINA, SOUTHEAST ASIA AND ADJACENT REGIONS

A thesis presented to the Faculty

of the State University of New York

at Albany

in partial fulfillment of the requirements

for the degree of

Master of Science

Department of Geological Sciences

Michael P. Klimetz
1983

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ABSTRACT

Several orogenic belts transecting south-eastern Asia are the sites of former convergent plate margins although there have been varying interpretations of the collisional framework of individual continental blocks, styles of convergence at these zones and the timing of respective collisions. A comprehensive tectonic study of eastern China, Mongolia and the southern Soviet Far East indicates the collision of the South China Block with a combined North China-Northeast China Fold Zone Block in the late Triassic-early Jurissic their collective suturing to Eurasia in the late Jurassic-early Cretaceous, followed by the Sikhote Alin-Japan Block in the mid to late Cretaceous. The evidence is as follows: (a) A linear belt of late Triassic-early Cretaceous granites and granodiorites trends east from the Qinlingshan through the Dabieshan to the Huaiyang massif. Ophiolites, flysch, subduction zone mélange, a paired metamorphic belt indicating north-dipping subduction and marine strata of Carboniferous to late Triassic age from the Qinlingshan define the suture between the North and South China Blocks; (b) A sinuous belt of ultramafics, blueschists, silicic to intermediate magmatism and west- and north-vergent folds and thrusts trend from the west margin of the Ordos Basin through central Inner Mongolia and along the east Great Khingan Range to the Amur River. Coupled with a mid Jurassic-early Cretaceous unconformity a suturing of eastern Chinese blocks to Eurasia along this zone is suggested; (c) A fold and thrust belt with ultramafics, flysch, blueschists and subduction zone mélange along the Ussuri River in northeast China indicates the suturing

of the Sikhote Alin-Japan Block to Eurasia along a west-dipping subduction zone in the mid to late Cretaceous. Similarly, a comprehensive tectonic study of southern China and Southeast Asia has revealed a complex regional mosaic of suture-bounded terrains which nucleated about the eastern, western and southern margins of the Yangtze Craton during the late Triassic and early Jurassic. The evidence is as follows: (d) A north-south trending belt of ophiolites, blueschists, calc-alkaline volcanics and subduction mélange including granites, granodiorites and strongly deformed marine strata all of late Triassic age exposed in the Longmenshan of Sichuan merge with the Kekexilishan ophiolite zone into the Ailaoshan-Tengtaiohe ophiolite and blueschist belt in central Yunnan along which the Songban-Ganzi Complex and the Shan-Thai-Malaya Block join the Craton; (e) A southeastern prolongation of the Ailaoshan-Tengtiaohe belt bifurcates into the southeast-trending Konvoi zone of northern Vietnam and the north-south trending Pak Lay-Luang Prabang zone of Laos and Thailand. Zones of ophiolite, calc-alkaline volcanics and strong late Triassic deformation, they separate the Indosinia and Shan-Thai-Malaya Blocks from the Craton respectively; and (f) A northeast-southwest trending belt of ultramafics, pillow lavas and strongly deformed Triassic marine rocks extends from the Guangxi-Guizhou border to just south of Nanjing, on-strike with coeval porphyry copper deposits (the Kweichow Geosyncline of Fromagét, 1935) is considered by Hsü (1981) as a suture between the Craton and a strip of terrain herein known as the Cathaysian Arc .

These findings differ significantly from previous interpretations of a late Paleozoic consolidation of south-eastern Asia as well as the existence of a true Pangaea.

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# INTRODUCTION

The structural framework of the Eurasian continent can be characterized as composite, consisting of several continental and microcontinental blocks progressively accreted to the Siberian Craton from the latest Precambrian through the Tertiary (Dickinson, 1973, 1980; Burrett, 1974; Acharrya, 1978; Albany Global Tectonic Group, 1978; Roy, 1978).

Several orogenic belts transecting eastern China and Southeast Asia are interpreted as the sites of former convergent plate margins although there have been varying views on the collisional framework of individual continental blocks, styles of convergence at these zones and the timing of respective collisions.

The sites of pre-Mesozoic collisions are arranged in a roughly concentric, younging-outwards fashion about the southern, eastern, and western margins of the Craton. These in turn are framed by Mesozoic and younger orogenic belts which are more randomly distributed, more numerous and subsequently present a more complex tectonic picture. The structural edifice of the Tibetan Plateau for instance, appears to have evolved via a progressive late Triassic through early Tertiary southwards stacking of rifted northern Gondwana crustal elements against the southern margin of western China (Acharrya, 1978; Sengor, 1979; Bally et al., 1980; Li, 1980; Mitchell, 1981). Farther eastwards into Southeast Asia, western Indonesia and eastern China, at the former junction of the Tethys and Kula/Pacific Oceans, Mesozoic tectonic relations become more difficult to interpret.

Evidence supportive of major Mesozoic orogenesis (Tan, 1923; Teilhard de Chardin, 1924; Wang, 1928; Wong, 1929; Chao and Huang, 1931; Sun, 1934; Lee, 1938; Jiang, 1964; Jen and Chu, 1970; Workman, 1972; Huang, 1978) and the juxtaposition of Permo-Carboniferous Gondwanian, Cathaysian and Boreal-Pacific paleogeographic provinces (Sahni, 1935; Sze, 1942; Edwards, 1955; Kon'no, 1965; Hart, 1974) have long been recognized in southeastern Asia. Their explanation in terms of plate tectonics, however, has just recently been explored according to a variety of interpretative schemes (Hutchison, 1973; Ridd, 1976; Mitchell, 1977; Fan, 1979; Şengör, 1979; Bally et al., 1980; Feng, 1980; Ridd, 1980; Yin, 1980; Zhang, 1980; Duan et al., 1981; Li, 1981; Mitchell, 1981; Wang et al., 1981; Zhang et al., 1981; Klimetz, 1982).

The coverage, readability and subsequent reliability of data presented here has not been satisfactorially uniform across the entire area of study, however. The difficulties encountered in attempting to accurately translate foreign geologic documents written in nine languages in addition to English (including Russian, German, French, Mandarin Chinese, Japanese, Thai, Dutch, Vietnamese and Korean) have been formidable and may have resulted in the inadvertent omission or misinterpretation of certain critical pieces of information. Similarly, articles written by foreign geologists in their native language and then translated into English were usually difficult to read, poorly illustrated, poorly constrained, incomplete and presented interpretations based on obsolete, out-of-date concepts and analytical methods. Therefore, the author has tended to regard all the literature with a fair degree of justifiable skepticism, especially where stratigraphic thicknesses, interpretations of sedimentary facies and environments of deposition, isotopic age determinations of igneous rocks and ages of ophiolite and blueschist emplacement in suture zones were concerned.

There are major problems in East Asian Mesozoic tectonics that have yet to be satisfactorially resolved. The apparent paucity of Jurassic deep-water marine deposits and regional metamorphism (Miyashiro, 1982, personal communication) in central and northeastern China, the nature and extent of the southwestern prolongation of the Mongol-Okhotsk foldbelt in central Mongolia, the nature and significance of the Omeishan basalts of southwestern China, the post-Paleozoic (?) consolidation of the Yangtze Paraplatform (South China Block) and the size, nature, provenance and pre-Himalayan position of Southeast Asian-Indonesian crustal elements are just a few examples.

The following clearly demonstrates that the observed Mesozoic deformation, volcanism, silicic plutonism and occasional ophiolite emplacement are outgrowths of the consumption of Paleotethyan, Neotethyan and Kula-Pacific oceanic crust and the complex accretion to Eurasia of island arcs and continental blocks that bounded or lay within these areas. Several subduction zones were initiated along the former continental margins of southern Eurasia, southern Sino-Korea, southwestern Cathaysia (Yangtze Paraplatform) and western Indochina (Indosinia Block) during the late Permian. The earliest recognizable Mesozoic collision occurred during the late Triassic and the final assembly of southeastern Eurasia reached completion essentially by the late Jurassic-early Cretaceous. These findings, coupled with recent paleomagnetic investigations (McElhinny et al., 1981), differ significantly from previous interpretations of a late Paleozoic consolidation of southeastern Asia (Stroganova, 1975; Scotese et al., 1979; Ziegler et al., 1979; Ziegler, 1981) as well as disputing the existence of a true Pangea (Haile, 1981).

# CHAPTER I:

## THE EARLY SYNTHESES: SUESS AND ARGNAD

The Asian continental edifice is comprised of three main orographic units: the great southern peninsulas, the broad mountain belts that extend across the continent as well as the whole of eastern Asia and the northern plains which range from the high lands to the Arctic Ocean.

Suess (1904-1924) advanced a tectonic synthesis of Asia based on its classification into these three primary divisions. The southern peninsulas, comprising Southeast Asia and the peninsular part of India, were originally fragments of the ancient continent of Gondwanaland. The northern plains occupied the stable shield areas of Precambrian crystalline rocks peneplained by prolonged erosion, while the mountain belts to the south were being uplifted. The most important of these anicent, worn-down exposures was Suess' "Primitive Nucleus" which formed the foundation of Central Siberia, extending as far north as the Arctic Circle and encompassing Angaraland, Manchuria and Mongolia. The essential constituent of Suess' mountain belts were a series of parallel, subparallel and crescentic ranges, which extended from Asia Minor through Persia, Tibet, China and the East Indies. The primitive nucleus and the two southern peninsulas appeared to Suess to consist largely of ancient crystalline rocks with comparatively few marine exposures, whereas the mountain belts exhibited a varied series of the deposits of an ancient sea, the Tethys. The folding of the marine rocks deposited in the Tethys into mountain belts thereby joined the northern nucleus and the southern peninsulas and these comprised the Asian continent.

Gregory (1929) recognized that the main problem in unravelling the structure of Asia remained the nature of the earth movements which buckled the marine deposits of the Tethys between the northern nucleus and the southern peninsulas into the intervening mountain belts. The main line of the mountain belt included the Himalaya which, according to traditional opinion, are the equivalents in Asia of the Alps in Europe, but there have been several disparate hypotheses concerning their eastern continuation. According to Kropotkin (1904), the Himalayan line turns to the northeast across western and central China to the Khingan Mountains and the Bering Strait. Suess pointed out that the Khingan Mountains essentially are different from the Himalayas and in his view the Himalayan line bends back in a horseshoe course around Assam, turns southward through Western Burma and the Malay arc to the southern side of the East Indies. Suess also postulated that the Altai Mountains of Asia correspond to the Armorican-Varisian Mountains of Europe, and not with the Alps. He traced mountains of the same apparent character as the Altai through Asia and across Europe, through northern Africa and across the Atlantic to the eastern and central United States. He grouped these mountains into the Altaid mountain system whose best known Asian representatives includes the Tien Shan as well as the Nan Shan, central Kunlun Shan, Ala Shan and Tsinling Shan in China.

Suess' Altaids were the main girders in the structural edifice of Asia and dominated the structure of the continent; he did not accept any of these Asian mountain systems as equivalent to the Alps of Europe.

Suess' classification was subsequently challenged by Emile Argand (1924) who represented the structure of Asia as due to the union and contraction of various crustal blocks as the whole mass drifted southwards. This southern drift was regarded as the cause of the Alpine Cycle of mountain building in Asia which included both the Altaids and the eastern prolongations of the Alps. Suess regarded the Alps and their Asian equivalents as much younger than the Altaids. Both Argand and Suess recognized significant differences between the Alps and the Altaids. Suess attributed the differences to age with the Alps representing the summits of recent, and the Altaids the roots of ancient mountains. Argand's assessment of Asian tectonics involved a variety of earth movements which began in the Mesozoic, culminated in the midial Cenozoic and gave rise to the Alps as well as the Himalayas.

This phase of mountain building according to Argand essentially eradicated all previous structural relationships. A unique comparison of the contrasting views of Suess and Argand was presented by J. W. Gregory (1929) in his treatise on the structure of Asia: "Suess regarded Asia as like a building in which a Gothic roof has been built on Norman walls and perhaps over a Norman choir; according to Argand, Asia is like a building wholly of one period of architecture, the older materials used in its construction being stones that had been re-cut or lumps of masonry that had been incorporated in the walls or left in the foundation". The Asia envisioned by Suess was one that became enlarged through time, with each phase of expansion being duly recorded in contemporaneous rocks and structures. Argand considered that the effects of the Alpine deformations resulted in a complete reconstruction of the Asian structural edifice involving the obliteration of older structures and replacement by new. The existence of late Paleozoic, pre-Alpine cycle mountains was admitted by Argand, but he contended that the Asiatic Mountains produced during the Alpine Cycle deformations were created regardless of the late Paleozoic mountain-building. The whole of Asia was deformed by a "Tertiary paroxysm" Argand held, and modern folds were independent of ancient structures.

The essential difference between the hypothesis of Suess and Argand lay in Suess' belief that the trend and range of the Alpine Cycle mountains were pre-determined by the Altaids, whereas Argand regarded the Alpine movements as so overwhelming that their progress was not seriously interfered with by the Altaid blocks, which were passively pushed aside. Perhaps the most important difference of all between Suess and Argand lay in their respective fixist versus mobilist treatment of the ancient masses of crystalline rock. Suess regarded them as passive resistant blocks which affected the trend of the mountains when the weaker material became crumpled into folds by the contraction of the earths crust. Argand, however, viewed these ancient masses as the active agents whose relative displacements crumpled intervening areas into mountain chains as floes of ice plow beach materials into contorted drifts when driven ashore.

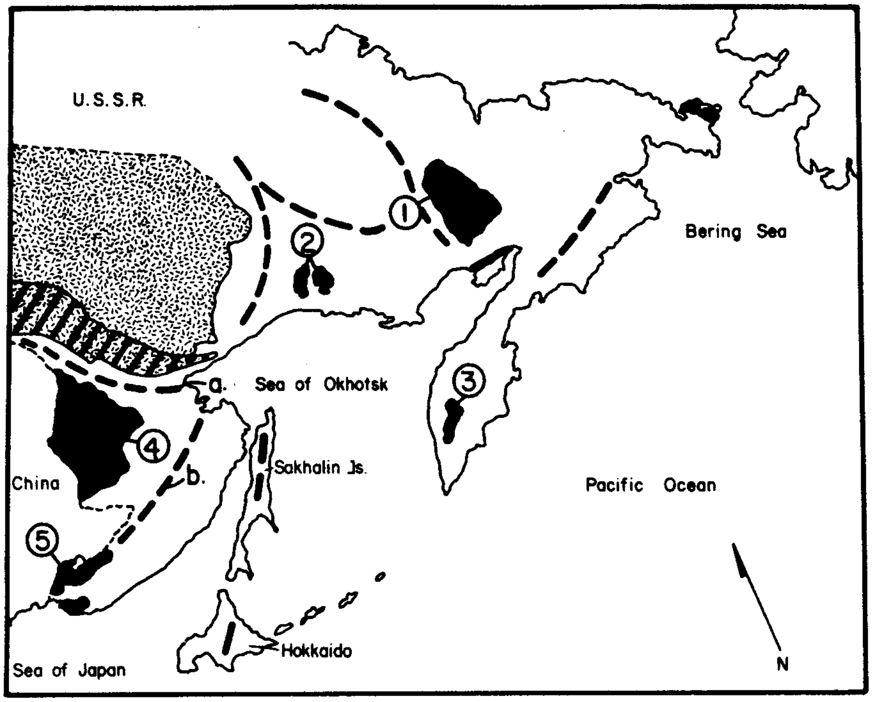
# CHAPTER II

# SOUTHERN SOVIET FAR EAST*

## 2.1 Precambrian

Precambrian rock complexes are widespread throughout the Soviet Far East. The principal exposures comprise (Figure 1): the Zeya-Bureya Massif which is areally extensive and includes the basins of the Zeya, the Selemdzha and the Bureya Rivers, and in the basins of the eastern part of the Stanovoy Range and in the southern Lesser Khingan Range; the Kolyma Massif and the Omolon Block; the Okhotsk Massif; the Chukotian Massif; in eastern Transbaikalia (the Gazimin-Nu-chinsk region); the southern part of the Sikhote Alin Range and near Lake Khanka (southern Primorye); the central Kamchatka Range; and the Sakhalin Range (Nalivkin, 1973). They form the basement of large, clearly distinguishable central massifs such as the Okhotsk, Omolon, Khankai and Bureya as well as smaller, elongated crystalline slivers in Proterozoic and Phanerozoic fold belts such as those exposed on the east Chukchi Peninsula, on the Taigonos Peninsula and in the Kamchatka and Sikhote-Alin Foldbelts. Compared with immense Precambrian shield areas such as the Siberian and the Canadian, the large central massifs and smaller exposures are of limited extent, occupying maximum areas of 150,000 and 10,000 square kilometers respectively (Parfenov et al., 1979). Cross-sections through the larger massifs usually reveal a mildly deformed late Proterozic through Phanerozoic sedimentary veneer which records multiple periods of intrusion by silicic plutonics, similar to the Archean basement complexes of the Siberian Craton. Parfenov et al. (1979) have divided the central massifs of northeastern Asia according to their association with deposits

*(See Plate X for locations referred to in this chapter)




(after Kosygin and Parfenov, 1977)

Precambrian massifs:

① OMOLON
② OKHOTSK
③ KAMCHATKA
④ BUREYA
⑤ KHANKA

Siberian craton (Aldan-Vitim shield)

Stanovoi (2.0 b.y.b.p.) foldbelt

Meso-Cenozoic foldbelts:

a. Mongol-Okhotsk  b. Sikhote Alin

FIGURE 1:

*Tectonic Sketch of the Soviet Far East* of platform facies (type "A") or deep water marine facies deposits (type "B"). This study is particularly concerned with the Bureya (Bureya'Zeya) and Khankai massifs, both of which belong to the type "B" category and are composed essentially of polyphase deformed amphibolites and low pressure granulite facies metamorphic rocks.

Exposures of the Bureya Massif basement are confined to the northeast-trending Gonzha and Maymin thrust zones located along its eastern periphery and to the eastern Lesser Khingan Range. The rocks comprise amphibolite facies biotite and biotite-hornblende quartzofeldspathic gneisses interlayered with marbles and quartzites. Quartzites form a fairly thick section in the northeastern part of the massif whereas a series of calccareous-silicate amphibolites with seams of gneiss and marble are dominant in the southeast. The age of the metamorphic series comprising the Bureya Massif has not been reliably established. Its upper age limit has been defined by a widespread medial Devonian basal conglomerate sequence (Parfenov et al., 1979). Unmetamorphosed early Cambrian archaeocyathid limestones resting on crystalline basement have been observed in exposures along the Urmi River the Zeya region of the massif (Nalivkin, 1973).

The rocks of the Khankai Massif consist of a two-part sequence. The lower part is composed primarily of marbles and biotite, biotite-cordierite, garnet-cordierite, and silimanite-bearing quartzofeldspathic gneisses, schists and quartzites. The upper series comprises biotite and biotite-hornblende quartzofeldspathic gneisses, amphibolites and calcareous-silicate schists. These rocks form the cores of several domed uplifts blanketed by aprons of thick sequences of late Precambrian and early Paleozoic clastics. K/Ar analyses of these rocks have yielded 450 to 830 million year (probable uplift) ages, whereas the U/Pb method has yielded a 1520 million year value.

Central regions of both the Khankai and Bureya Massifs have been extensively migmatized. An unmetamorphosed late Proterozoic, Paleozoic and early Mesozoic sedimentary veneer overlies both massifs, the total thickness of which may exceed 15 kilometers in central as well as marginal areas according to Parfenov et al. (1979) although the actual figure may be considerably less. They are fringed by marginal (peripheral) late Proterozoic through early Mesozoic basins capped by an edgeward-thickening apron of paralic and marine deposits of late Paleozoic through Mesozoic age. They have also been intruded by a variety of igneous rocks of various ages, dominantly by Devonian granites and Mesozoic island arc-type basalts and andesites.

## 2.2 Paleozoic Stratigraphy

Unless noted otherwise, the following is based primarily on Nalivkin (1973). Lower Paleozoic rocks are sporadically exposed throughout the southern Soviet Far East. At the bottom of Cambrian successions of eastern Transbaikalia lies a 200 to 300 meter thick section of basal conglomerates and sandstones which are succeeded by a 2100 meter thick section of marine archaeo cyathid limestones, dolomites and shales. These are overlain by the 1700 meter thick Altachian suite consisting of sandstones and shales interbedded with tuffs and limestones bearing medial Cambrian and Ordovician calcareous algae. There are no late Cambrian strata represented. The Altachian suite passes laterally into the 1600 meter thick shales of the Ushmanian suite. The Ordovician is represented by the 1500 meter thick Nerchinskozavodian suite comprising dolomites, limestones and shales bearing abundant bryozoans and algae. Similar sequences with an identical fauna have also been observed in adjacent Heilongjiang and Jilin provinces of northeastern China (Khodak, 1965).

Ordovician strata pass conformably upwards into the Silurian. Unconformably atop the Silurian are a 700 meter thick sequence of Devonian marine shales comprising the Blagodatskian suite.

Further to the east in Primorye, Cambrian sandstones and shales contain an abundant marine fauna. Exposures of archaeocyathid limestones are known from the lower reaches of the Uda River. Cambrian and Ordovician sequences are sparsely represented in Sikhote Alin. Exposures of early Cambrian rocks in the Ussuri River valley north of Vladivostok consist of a repetitive sequence of archaeocyathid limestones interbedded with siliceous shales in excess of 1500 to 2000 meters thick. At the base of these deposits there are layered Cambrian ironstones equivalent to those exposed in the Lesser Khingan Range (Khodak, 1965). These sequences are collectively overlain by a formation of coarse-grained conglomerate-breccias and sandstones of undetermined age.

The uppermost Precambrian to lower Paleozoic formations of the Lesser Khingan succession are similar to that of southern Primorye. Thick late Precambrian (Riphean) dolomites are overlain by phyllites, siliceous and calcareous shales, ferruginous sandstones, and banded iron formation. Further upwards in the sequence lie a thick series of limestones and shales tentatively assigned to the early Cambrian. Late Ordovician marine sediments have also been observed in the Lesser Khingan Range (Khodak, 1965).

Middle Paleozoic deposits of the southern Soviet Far East are more widespread than the lower Paleozoic, but are minor in comparison to upper Paleozoic and Mesozoic deposits. As a rule they are intensely deformed and strongly metamorphosed rendering accurate age determinations all but impossible. Those formations that have escaped tectonism and extreme metamorphism are, however, usually devoid of fossils.

The juxtaposition of two distinct zoogeographical provinces was discovered from the contrast observed between the faunal elements of early and middle Paleozoic sequences, respectively. The boundary between the two provinces, a northern and a southern one, trends along the Yablonovy and Stanovoy Ranges to the Sea of Okhotsk and towards the mouth of the Anadyr River. Silurian through lower Carboniferous faunas identical to those of western Europe, the Urals, Novaya Zemlya and the Taimyr occur in the northern zone. Faunas equivalent to those found in Kazakhstan, China and the southern part of North America are represented in the southern zone, particularly those of the Hamilton, Chemung, Kinderhook, and Helderberg limestones. The Silurian succession of the northern province is fairly complete while lowermost Devonian rocks are transgressively overlain by those of the Givetian. Further upwards a complete sequence of Frasnian stage rocks are present. Tournaisian and Visean deposits are usually absent and late Paleozoic strata lie directly on the Devonian. The absence of lower Carboniferous and in places the whole of the Carboniferous from the succession is a characteristic feature of this province.

Middle Paleozoic sediments of the southern province are best developed in the eastern Transbaikal and in adjacent Primorye. They are also fairly well-developed farther to the east, especially along the banks of the upper Zeya River valley and forming a continuous exposure to the Sea of Okhotsk. Silurian deposits consist of thick shales, limestones and sandstones bearing brachiopods and corals. Devonian rocks are well-represented and bear faunal similarities to equivalent age rocks in North America. Lower Devonian rocks consist of massive limestones overlain by dark grey shales and siliceous sediments interbedded with cherts and volcanics which attain thicknesses in excess of 700 to 1000 meters. The middle and upper Devonian strata consist of a succession of limestones overlain by Givetian and lower Frasnian sandstones and muddy limestones which in turn are overlain by Fammenian shales and limestones. The thickness of Devonian strata is in excess of 4000 meters and in the Zeya River valley Eifelian age rocks form a 1600 meter thick succession.

The Carboniferous strata of eastern Transbaikalia rest conformably on the Devonian and consist of a 3000 to 4000 meter thick section of limestones and shales bearing a Tournaisian fauna juxtaposed between the Lesser Khingan Range and the Okhotsk coast Devonian rocks similar to those found in eastern Transbaikalia and bearing the same fauna have been observed. Medial Paleozoic rocks of the Sikhote Alin Foldbelt are relatively unknown.

Middle and upper Carboniferous deposits are apparently of limited extent across northeastern Asia, perhaps being confused with and often obscured by widespread, relatively unfossiliferous overlying Permian deposits. They are fairly diverse, consisting of limestones, a variety of shales, sandstones and conglomerates with local interbeds of volcanics. They rarely exceed a few hundred meters in thickness and are most fully developed and best studied in the Sikhote Alin Foldbelt. Lower Permian strata consist entirely of homogeneous flysch deposits indicating depositional basin instability perhaps attributable to late Paleozoic tectonism. Permian deposits in general are most extensively developed in late Paleozoic and Mesozoic foldbelts. Eastern Transbaikalia, Primorye and the upper reaches of the Zeya River contain a 2000 to 3000 meter thick, laterally continuous section of marine shales and sandstones of Permian age. Lower and upper Permian strata are also exposed in the Sikhote Alin Foldbelt. Exposures near Vladivostok comprise a diverse section of shales, limestones and conglomerates.

The Permian of the northern late Paleozoic and Mesozoic foldbelts is divided into a lower, brachiopod-bearing marine division and an upper, coal-bearing division often containing the marine lammelibranch Kolimia. The greatest expanse of Permian rocks in the region occurs to the north of Khabarovsk, near the upper reaches of the Bureya and near the lower reaches of the Uda Rivers and consists of alternating marine and terrestrial facies sediments interbedded with thick intermediate volcanics (Bobrov and Kulikov, 1968).

The fullest Permian section is developed in the Sikhote Alin Foldbelt, especially in its southern part. The lower Permian of western Sikhote Alin consists of terrestrial facies shales and sandstones with plant remains. Eastern regions contain deposits consisting of alternating marine and volcanic rocks with siliceous shales and limestones bearing an abundant fauna characterized by Pseudofusilina and Cancellina in lower and upper sections respectively. Lower Permian strata pass without break to the upper Permian. Massive reef limestones are in excess of 200 meters thick and bear diverse marine forms such as Neoschwagerina, Richthofenia and Lyttonia. Further upwards in the section lies a 900 meter thick flysch sequence. This formation is succeeded by a volcanic and volcaniclastic sequence interlayered with sandstone and limestone beds containing Lyttonia. The Permian succession terminates with a 250 meter thick series of freshwater sandstones and coal-bearing shales.

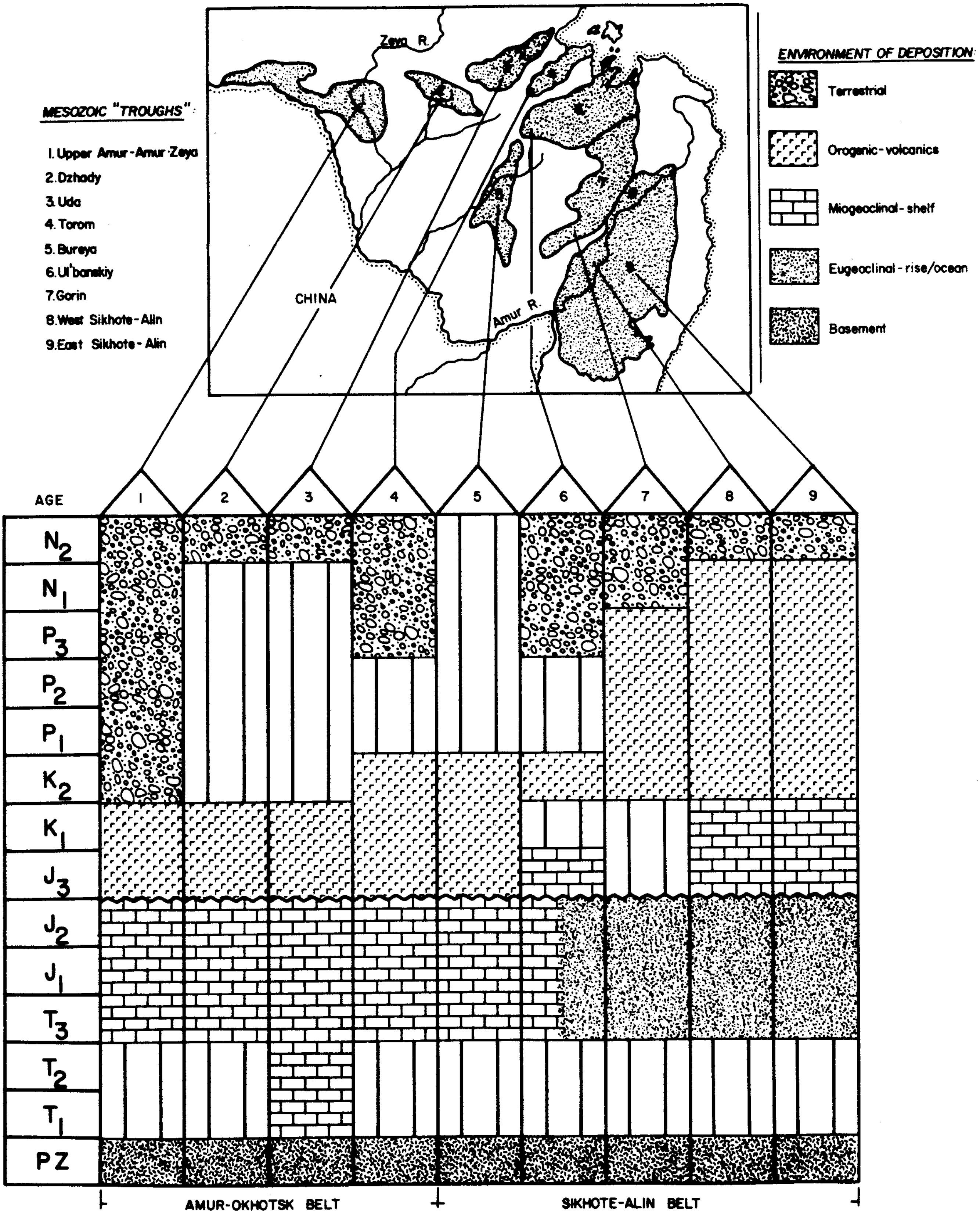
## 2.3 Mesozoic Stratigraphy

The Pacific Fold Belt Complex (Nalivkin, 1973) encompasses the far Eastern and northeastern parts of the Soviet Union. It has been subdivided into a variety of foldbelts ("geosynclinal areas"/ocean basins) that separate large masses of relatively stable continental crust ("median massifs"). Those which completed their development during the Mesozoic comprise the Mongol-Okhotsk and Sikhote Alin foldbelts. Those which continued their development during the Cenozoic are the Kamchatka-Koryak and Nippon (Sakhalin) Foldbelts (Beznosov, et al., 1978). During the Triassic and Jurassic, the Verkhoyansk and Chukotka foldbelts were separated by the Kolyma and Omolon Blocks (Seslavinskiy, 1969). The Okhotsk Block separated the eastern part of the Mongol-Okhotsk Foldbelt from the Verkhoyansk foldbelt. The Bureya Block divided the Mongol-Okhotsk foldbelt into two spurs, the western spur being separated from the southern part the Sikhote Alin foldbelt by the Khankai massif. The sites of the Verkhoyano-Chukotka and Mongol-Okhotsk oceans began their gradual demise and subsequent transformation into an orogenic belt from the end of the Upper Jurassic (Beznosov, et al., 1978). Unless noted otherwise, the following sections on Triassic, Jurassic and Cretaceous stratigraphy are based on Beznosov et al.(1978). See Plate X for detailed locations referred to in the text.

## Triassic

The most extensive occurrence of Triassic deposits in the Soviet Union occur in the Pacific Foldbelt Complex. The entire system is represented and rocks frequently contain an abundant well-defined fauna. There are gradual transitions from paralic to deep water marine deposits both within the system and within the overlying Jurassic. The Sikhote Alin Foldbelt contains thick sections of deep water marine cherts and mafic effusives. The Mongol-Okhotsk foldbelt was apparently the site of an ocean that extended sublatitudinally from the Sea of Okhotsk for approximately 3,000 kilometers, the deposits of which are preserved in the cores of a few tightly folded synclines (Kosygin and Parfenov, 1975).

FIGURE 2: Stratigraphy of the Lower Amur 'Mesozoic' basins.




(after Kosygin et.al, 1976)

Triassic deposits of the Transbaikal are found in the Onon River Basin and are represented by a 3000 meter thick section of littoral and deep water marine sandstones, grits and siltstones bearing Ophiceras, Gyronites and Neocalamites. Medial Triassic deposits are absent from most other regions of the Transbaikal. Upper Triassic deposits unconformably overlie the Paleozoic and are represented by sandy shales up to 3000 meters thick. Exposures along the upper reaches of the Zeya River near the Tukuringra Range and in the Uda Basin also contain upper Triassic shallow water marine sandstones and shales. These have a thickness of 4000 meters which decreases to approximately 1000 meters near Tugursk Bay.

Triassic deposits of the southern spur of the Mongol-Okhotsk Foldbelt are exposed in the northeastern foothills of the Lesser Khingan Range, the upper reaches of the Bureya River and in the Argun River basin. Lower and middle Triassic marine sandstones and shales bearing ceratites and marine pelecypods are exposed in the Lesser Khingan only, achieving a thickness in excess of 2000 meters. Upper Triassic deposits are exposed in the upper reaches of the Bureya River and in the Argun River basin. They are represented by conglomerates, sandstones and shales, and include a thick diabase sill overlain by siliceous shales which attain a collective thickness of 3000 meters. These deposits are similar to the Triassic deposits of the Sikhote Alin Foldbelt.

Adjacent to the Khankai Massif at the extreme southeastern part of the Sikhote Alin Foldbelt, lower and middle Triassic deposits unconformably overlie Paleozoic formations. They consist predominantly of shales interbedded with limestones, siltstones and sandstones bearing well-preserved ceratites and marine pelycypods. The thickness of the lower and middle Triassic exceeds 1200 meters. They are unconformably overlain by a 4000 meter thick section of upper Triassic deposits consisting of alternating coal-bearing and shallow water marine sandy shales.

The central and northern Sikhote Alin Foldbelt as well as areas adjacent to the lower Amur River contain extensive exposures of volcanics and siliceous shales of medial to late Triassic age with lenses of marine limestones as well as coal bearing shale horizons in excess of 3500 meters thick.

Jurassic

Lower and middle Jurassic marine deposits of the southern Soviet Far East rest conformably atop the Triassic. The sea occupied the Sikhote Alin, Verkoyano-Chukotka and Koryak-Kamchatka foldbelts and in a long embayment it advanced into the Mongol-Okhotsk Foldbelt and along the eastern margin of the Great Khingan Range. The maximum transgression appears to have taken place in the late Pliensbachian and the Toarcian. During the latter half of the medial Jurassic the size of the embayment into the Mongol-Okhotsk Foldbelt was considerably reduced and at various times during the late Jurassic marine sedimentation was partly replaced by terrestrial and paralic deposition. Unlike the Triassic, there was a much greater variety of deposits ranging from miogeoclinal in the lower Jurassic to those with a distinctly orogenic character in the middle Jurassic.

The Jurassic deposits of the Mongol-Okhotsk foldbelt occur in eastern Transbaikal, along the middle course of the Zeya River and in the Uda and Torom River basins. Lower Jurassic to Aalenian deposits are found in the eastern Transbaikal region between the Shilka and Argun Rivers. They accumulated in what appears to have been a narrow, restricted ocean basin, and are represented by grey marine sandstones and siltstones with subordinate conglomerates and shales in excess of 5000 meters thick.

Pliensbachian, Toarcian and Aalenian ammonites and marine pelecypods have been identified from these deposits. Exposures along the flanks of the foldbelt indicate that marine deposits are replaced by coarse clastic littoral and terrestrial deposits. Bathonian and upper Jurassic sequences fill a number of localized basins and are also of terrestrial facies accompanied by basalts, dacites and quartz porphyries.

A complete 4000 meter thick sequence of sandstones, siltstones and shales comprise the Jurassic of the upper Amur region. The lower Jurassic, the top of the middle Jurassic and the bottom of the upper Jurassic contain marine pelecypods, belemnites and some ammonite remains. The top of the upper Jurassic sequences consist dominantly of coal-bearing terrestrial facies deposits. The lower and middle Jurassic of the Uda and Torom River basins consists of sandstone and a variety of coarse clastics bearing a marine fauna. Transgressive Bathonian and lower Callovian deposits are composed primarily of shallow water marine sandstones in excess of 4000 meters thick, bear an abundant marine fauna including Buchia, Bureiyama, Pleuromya, Boreionectes, Modiolus, Amoeboecas, and Aulacosphinctoides (Sei and Kalacheva, 1977)and rest unconformably on older sequences. Areas north of the Uda basin contain exposures where the topmost section of the sequence is replaced by coal beds and silicic volcanics.

The lower and middle Jurassic deposits of the Sikhote Alin Foldbelt rest conformably on the Triassic and are comprised primarily of sandy shales, silicic volcanics and tuffs (Akmet'ev et al., 1967). The thickness of the lower Jurassic, Aalenian and Bajocian deposits varies but reaches a maximum of 6500 meters near the lower Amur River. Bathonian deposits rest unconformably on older sequences and combined with upper Jurassic deposits form a complex consisting of dominantly terrestrial deposits interbedded with silicic volcanics in excess of 3000 meters in thickness. A variety of well-defined Jurassic ammonites including Ataxioceras and Virgatosphinctoides have been described from these sequences. Information has recently appeared concerning the presence of marine deposits at the top of the upper Jurassic in northern Sikhote Alin, as the remains of Parodontoceras and Subplanites have recently been discovered (Sei and Kalacheva, 1977). The thickness of Jurassic deposits in southeastern Sikhote Alin reaches a maximum of 2800 meters and a variety of marine littoral and terrestrial facies sediments are present.

The Jurassic deposits of the "Nippon Geosyncline" (Beznosov et al., 1978) have been described from Sakhalin where a 2000 (?) meter thick section of siliceous shales and slates interbedded with porphyritic diabase are exposed. They are unconformably overlain by a 1000 (?) meter thick section of radiolarian cherts, tuffs and coralline limestones.

Cretaceous

Significant areas of the Sikhote Alin Foldbelt are occupied by marine Berriaisian-Valanginian deposits while Hauterivian and Barremian deposits are very limited and strictly of marine facies. Aptian-Albian deposits are of moderate extent and represented by both marine and terrestrial facies deposits. Contacts with underlying sequences are usually conformable with the only exceptions being near Komsomolsk-na-Amur and in the Tetyuke River basin. The Berriaisian-Valanginian deposits consist primarily of an alternating, 4500 meter thick sequence of sandstones, siltstones and shales with partings of siliceous shale, radiolarian cherts and lenses of limestone. These deposits bear a characteristic fauna including Buchia, Neocomites and Berriasella which occur only in southern

Primorye. The overlying deposits in Sikhote Alin consist of a 2500 meter thick section of late Hauterivian-early Albian sandstones and siltstones bearing Tetragonites, Deshayesites and Spitridiscus. Farther north, bodies of spilite and andesite are interlayered with these sequences. Towards the south, marine deposits are replaced by shales interlayered with coal seams.

The lower Cretaceous deposits of the Mongol-Okhotsk Foldbelt are manifest in a series of terrestrial, in places coal-bearing deposits which bear vertebrate remains at upper levels. Sporadic exposures of lower Cretaceous terrestrial deposits bearing a well-defined fresh water pelecypod and ostrocod assemblage are known from the upper Amur River and in the Zeya and Bureya River basins. Coal-bearing terrestrial deposits predominate in the Bureya River basin, while intermediate volcanics and volcaniclastics are the dominant deposits in other areas. Exposures of tuffs, sandstones and conglomerates interbedded with thick coal seams assigned to the upper Jurassic and lower Cretaceous are also known from the Lesser Khingan Range and the Songliao Basin of northeastern China (Arkhangel'skiy, 1959, Chen, 1980). Widely developed upper Cretaceous andesites, dolerites and quartz porphyries are also known from the upper Amur River, south of the Mongol-Okhotsk Foldbelt. Sections up to 1500 meters thick rest unconformably on Precambrian, Paleozoic, Jurassic or lower Cretaceous strata (Nagibina, 1959).

The lower Cretaceous (Albian) deposits of Sakhalin occur extensively in western regions and consist predominantly of terrigenous sandstones, siltstones and shales conformably overlain by Cenomanian sequences. Volcanics and siliceous clastics predominate in eastern Sakhalin and have been tentatively assigned to the Jurassic-lower Cretaceous.

The upper Cretaceous deposits exposed along the eastern portion of the Mongol-Okhotsk Foldbelt occur in small basins and in broad intermontane depressions. The lower Cretaceous deposits of the Amur-Zeya Basin are overlain by a transgressive 2000 meter thick sequence of sandstones, siltstones and shales assigned to the Cenomanian-Campanian. Further up in the sequence a 500 meter thick section of Maestrichtian-Danian sands and clays bearing reptile remains are in turn overlain by Paleocene clays. Predominantly terrestrial deposits of late Cretaceous age are exposed in the upper Primorye and Bureya regions while in the Lesser Khingan the upper Cretaceous consists of a 1000 meter thick deposit of mafic volcanics and volcaniclastics (Nagibina, 1959). Cenomanian-lower Senonian deposits of Sikhote Alin unconformably overlie the lower Cretaceous and comprise a 2000 meter thick section of siltstones interbedded with sandstones and conglomerates in excess of 2000 meters thick, while in Primorye they consist of tuffs and tuffaceous sandstones up to 2700 meters thick. At the base of the Turonian-lower Senonian (?) the deposits are predominantly tuffaceous sandstones bearing marine bivalves capped by a 1000 meter thick series of tuffs, porphyries and tuffaceous sandstones bearing abundant floral remains. They are succeeded unconformably by a 5000 meter thick post-orogenic sequence of molasse facies clastics and rhyolite and basalt flows of late Senonian to Danian age deposited in small intermontane depressions.

The Sikhote Alin Foldbelt appears to be the site of an active convergent/plate margin collisional suture during the late Cretaceous with clastic material being supplied to the Amur basins and adjoining areas from a rising volcanic arc to the west, the uplift of the Nadanhada Foldbelt of northeastern China and the emplacement of large ophiolite nappes near the Ussuri River (Mel'nikov and Golozubov, 1980).

## CHAPTER III

## MONGOLIA

### 3.1 Introduction

The first major work on the geology of Mongolia and the Gobi region was that by Berkey and Morris (1927), participating geologists in the Central East Asian expeditions of the American Museum of Natural History. Their tectonic subdivision of the Gobi district consisted of five distinct elements, three of which are essentially fault blocks, a fourth comprised a gently uplifted, bevelled mass which has been strongly incised and the fifth of intensely folded crystalline rocks which are presently low, maturely dissected hills. These folded and faulted mountains occupied most of Asia according to Berkey and Morris, and exhibit intense pre-Mesozoic basement folding and faulting accompanied by gentle or non apparent folding in the Mesozoic cover strata. Their traverses across the Mongolian Altai revealed an older, intensely folded Permo-Carboniferous greywacke and slate sequence intruded by huge granite batholiths, the Mongolian Granite. The older, folded sequences were found in fault contact with presumed Jurassic age redbeds that exhibited only gentle folding. The most significant of their observations was the remarkable parallelism of the successive post-Cambrian deformational events which contributed to the formation of both fault-type and fold-type central Asian mountain ranges which also appeared to be oriented in the same direction, regardless of age.

The Mongolian People's Republic occupies a unique position in the complex structural organization of central Asia. It is bordered to the north by the Siberian Craton, to the south by the Sino-Korean Paraplatform and the Tarim Block and in the east by the North China Fold Zone. Mongolia comprises a broad platform the tectonic framework of which is a composite of various arcuate crustal elements separated by major Paleozoic fold and thrust belts (Figure 3) (Ivanov, 1961; Nagibina, 1970, 1974a; Zonenshayn et al., 1978). The crescentic pattern of these major structural zones apparently reflects the adaptation of the constituent blocks to the shape of the southern margin of the Siberian Craton to which these units were successively accreted from the late Precambrian to the Permo-Triassic. The Mesozoic tectonic history of Mongolia is reflected in the reactivation of older, generally Paleozoic structures (Nagibina, 1970, 1974a; Lefeld, 1978; Zonenshayn et al., 1978), the deposition of molasse-type facies sediments in broad intermontane depressions, widespread Jurassic-Cretaceous volcanism and the closure of a restricted ocean basin.

Central and northern Mongolia are characterized by the occurrence of upper Proterozoic to lower Paleozoic geosynclinal deposits that were deformed and uplifted during the medial and late Paleozoic and subsequently block-faulted. Southern regions exhibit characteristic east-west structures and the prevalence of middle and upper Paleozoic "geosynclinal" formations (Amantov et al., 1970). The boundary separating northern and southern regions follows the Ih Bogd-Undershilin Zone, which trends along the southern boundary of the Mongol-Altay Mountains in the west, runs south of the Great Lakes area, the Hangay Mountains and the Valley of Lakes as far as the northern boundary of the East Gobi Depression in the east and the Great Khingan Range in China (Lefeld, 1978). There are several faulted Meso-Cenozoic basins superposed over an older, usually Paleozoic substratum of deep water Silurian, Devonian and lower Carboniferous deposits in both zones and especially in the late Paleozoic

Southern Mongolian Foldbelt Complex (Dornfeld, 1968). Mesozoic-Cenozoic sedimentary sequences are generally coarse-clastic, molasse facies basin fills intercalated with a few marine horizons of limited extent. By the end of the Permian, most of Mongolia was emergent, with marine deposition restricted to a few small terrestrial basins, marine embayments and a restricted, southwest-tapering ocean basin which cannot be accurately traced farther west than central Mongolia. This change in the structural configuration occurred during late Permian and early Triassic times and apparently corresponds to the collision of the Tarim Block and Mongolian Arc to southeasternmost Eurasia and the resultant shift of active convergent plate boundaries further east and south. Many Paleozoic structures were apparently reactivated in eastern Mongolia and the Transbaikal as a result of widespread Mesozoic tectonism (Nagibina, 1970) which exerted an even more profound influence on the tectonic development of the whole of eastern Asia including all of eastern and southern China, Southeast Asia and the Soviet Far East. According to Lefeld (1978), eastern Mongolia was affected by two main tectonic episodes, one during the Triassic-Jurassic and another during the Jurassic-Cretaceous. Late Jurassic-early Cretaceous sediments comprise a monotonous sequence of terrestrial facies deposits interbedded with minor marine horizons and mafic intrusives that were laid down in broad, fault-bounded basins. They rest with marked unconformity upon a Paleozoic and early Mesozoic substratum. Identical relationships have been observed in the eastern Transbaikal area, the Peri-Amur region and in northeastern China (Kimio, 1956; Lin, 1956; Lin, 1962; Kosygin et al., 1976). Upper Cretaceous sediments deposited following the late Jurassic-early Cretaceous unconformity comprise undeformed post-orogenic molasse-facies sequences (Gradzynski, 1970; Lefeld, 1978). Since the end of the Jurassic, large tracts of northern Mongolia became uplifted and eroded, while southern parts of the country received the detritus from these rising highlands.

## 3.2 Precambrian and Paleozoic Stratigraphy and Tectonic Subdivision:

Mongolia may be subdivided into two main tectonic domains, a northern, chiefly early to medial Paleozoic and a southern, mainly late Paleozoic domain. The following subdivision is based essentially on that of Amatov et al. (1970) and Lefeld (1978).

The northern area includes the Hövsgöl (Hubsugul) region, the western Hangay Mountains and the Great Lakes area and is comprised of four separate subzones: the North Mongolian, the Mongol-Altay, the Mongol-Transbaikal and the Central Mongolian (Figure 3). The Northern area comprises parts of Tuva and the southern Transbaikal of the U.S.S.R. and constitutes part of an early to medial Paleozoic foldbelt which frames the southern margin of the Siberian Craton (Aldan-Vitim Shield).

The North Mongolian Zone corresponds to the "Lower Caledonian Mega-block" of Yanshina et al., (1979) and is a continuation of the early Paleozoic Altay-Sayan and Selenga-Yablon foldbelts of southern Siberia. It comprises mainly Precambrian through early Cambrian sequences that were folded during the medial Cambrian which in turn are unconformably overlain by upper Paleozoic post-orogenic coarse clastics. Superimposed on this folded foundation are a variety of structures of Ordovician through Permian age including late Paleozoic silicic volcanics (Kepezhinskas et al., 1971). It is bordered to the north by the Tuvino-Mongolian Massif which consists of Proterozoic age crystalline rocks (Federov, 1971) which comprise an association of pre-Riphean gneisses and schists overlain by transgressive platform-type early Cambrian carbonates that have been metamorphosed to greenschist facies and occur in narrow basement infolds

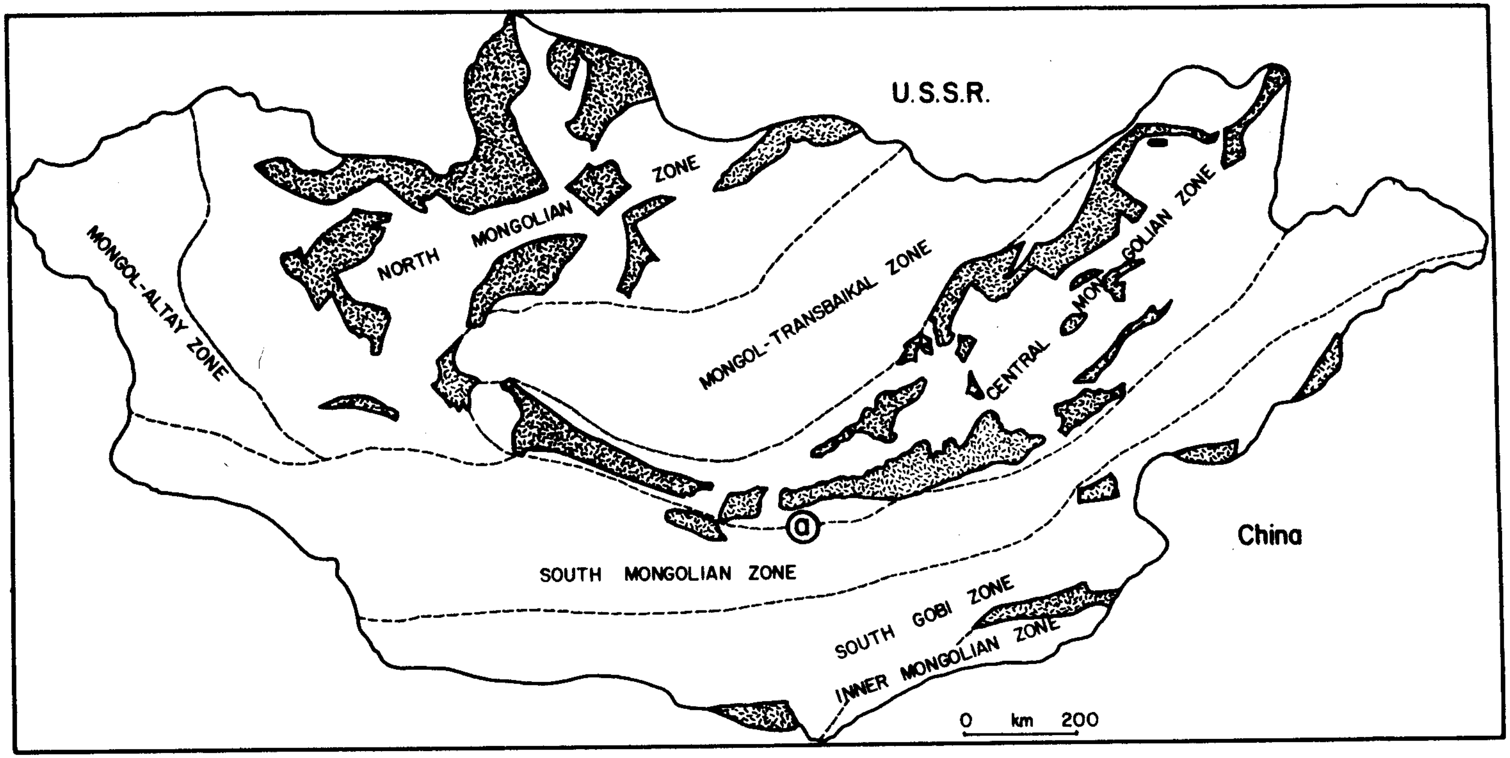



**Figure 3** :DISTRIBUTION OF PRE-CAMBRIAN (PRE-VENDIAN) STRUCTURAL COMPLEXES (EXPOSED IN THE CORES OF CRATONS AND AS BASEMENT SLIVERS IN PALEOZOIC FOLD BELTS.) and the MAIN TECTONIC SUBDIVISIONS OF MONGOLIA.

AFTER Amantov et. al.,(1970).

exposures of Precambrian

(a) Ih Bogd - Undershilin zone

(Il'in and Kudratsev, 1975). At the base of these cover sequences rest an association of rift facies terrigenous greywackes, sandstones and coarse clastics with spilites and diabases. This terrain also corresponds to the Dzhida Zone (Blagonravov and Zaytsev, 1973). Exposures along the southern and western margins of the North Mongolian Zone are the highly deformed remnants of the medial Paleozoic Ozernaya geosyncline, presently an imbricate fold and thrust belt bearing well-defined ophiolite complexes and deep water marine sediments (Zonenshain and Kuz'min, 1978).

The Mongol-Altay Zone is the southeastern extension of the Upper (Gornii) Altay and western Sayan foldbelts of far western Mongolia and comprise a broad belt of thick terrigenous, highly deformed sequences of medial and late Cambrian, Ordovician and locally of Silurian age. This zone bifurcates eastward into the Kharika and Mongol-Altay branches. Further into central and northeastern Mongolia this zone merges with the Mongol-Amur segment of the Mongol-Okhotsk foldbelt which eventually pinches out in the Hangay Mountains (Amantov et al., 1970). Its southern border is defined by the Bulgan overthrust which separates it from the southern (late Paleozoic) foldbelt complex further south.

The Mongol-Transbaikal Zone comprises a major segment of the Mongol-Okhotsk foldbelt (Dornfeld, 1968) which occupies the central and north-eastern parts of the country. It consists of deformed late Precambrian to early Paleozoic littoral marine deposits unconformably overlain by middle and upper Paleozoic deeper water marine deposits. They are exposed in both marginal and internal uplifts of the western and eastern Hangay Mountains and in the northern and southern Hentiy Mountains (Filippova, 1974; Zaytsev et al., 1976).

The Central Mongolian Zone borders the preceeding foldbelt to the south. The Precambrian through Paleozoic sequences of this zone are analogous to those of the Mongol-Transbaikal Zone. They have been broken up into several distinct blocks separated by narrow fold and thrust belts and have been periodically uplifted since the medial Paleozoic.

The Southern (late Paleozoic) Foldbelt Complex includes the Mongol-Altay Ranges, the eastern part of the Hangay Mountains, the Hentiy Mountains, the Gobi Tienshan and all of eastern Mongolia. It consists of three separate east-west trending tectonic zones: the South Mongolian, the South Gobi and the Inner Mongolian (Figure 3).

The Southern Mongolian Zone apparently forms the link between the medial Paleozoic structures of the Great Khingan Range in the east and the Zaysan and Dzungaria-Balkhash (Kazakhstan) foldbelts in the west (Amantov, et al., 1970). The late Paleozoic "geosynclinal" rocks within these foldbelts comprise Ordovician through Devonian and early Carboniferous formations.

The structures found in the South Gobi Zone are of medial and late Paleozoic age and are superimposed on an older deformed basement. The sediments exposed within the zone were apparently deposited in a Silurian ocean basin that have typically been telescoped as thrust sheets onto adjacent platforms which are especially well-displayed in the Mandal-Oba region (Figure 4) (Suyetenko, 1976; Suyetenko et al., 1978; Zonenshayn et al., 1978). Amantov et al., (1970) regard the South Mongolian Zone and Inner Mongolian Zone as subdivisions of the South Gobi Zone.

Only a small fragment of the Inner Mongolian Zone lies in Mongolia. Its northern boundary is marked by a zone of highly deformed deep water marine deposits and ophiolites known as the Solonker Zone in southernmost Mongolia (Plate 9) (Khasin and Borzakovskiy, 1967). Its westward extension comprises the eastern Kunlunshan Foldbelt (Huang, 1978) and to the

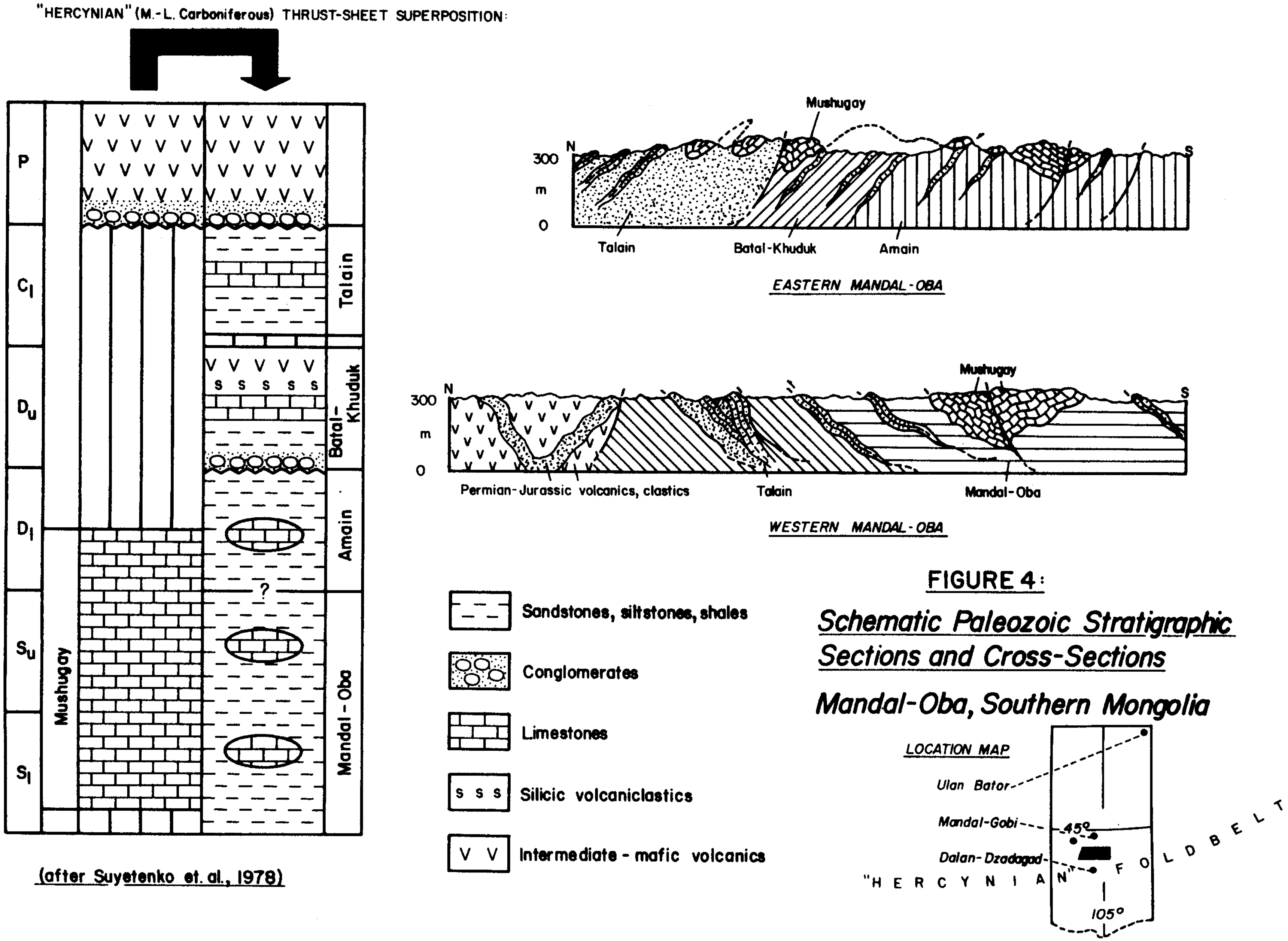



FIGURE 4:

*Schematic Paleozoic Stratigraphic Sections and Cross-Sections*

*Mandal-Oba, Southern Mongolia*

northeast it is known as the Suelün-Hegen Zone (Bally et al., 1980; Li, 1980). Its eastern termination is not known with certainty but is presumed to lie near the western foothills of the Great Khingan Range.

The late Paleozoic foldbelts of southern Mongolia therefore comprise the deposits and basement of a former ocean basin that have been characteristically deformed into repetitive sequences of imbricate nappes and thrust sheets. The nappes of the Southern Mongolian Zone also involve huge sheets of serpentinite of which the exposures in the Dzolen Range are the best known (Zonenshayn et al., 1975; Suyetenko, 1976). Dergunov et al. (1971) have also observed the involvement of Precambrian and Paleozoic formations in the thrust sheets that developed along the southeastern margin of the southern Mongolian "geosyncline," the latter of which are comprised mostly of middle Paleozoic volcanics and deep water marine clastics that have been metamorphosed to greenschist facies.

### 3.3 Mesozoic Stratigraphy

#### Triassic:

Triassic formations in Mongolia are confined mainly to northern and northeastern regions. Both terrestrial and marine facies occur though the former are clearly dominant. Terrestrial formations are exposed in two belts which trend roughly parallel to the late Paleozoic foldbelts. The northernmost belt extends from the Selenga River basin and Volcanic Belt along the southern border of the Hentiy Mountains to the Kerulen River basin. Triassic sequences in this belt consist essentially of a lower, 1,500 to 2,000 meter thick molasse sequence and an upper, volcanic sequence. The former are comprised mainly of locally derived, cross-bedded coarse sandstones and grits interbedded with siltstones, tuffs and conglomerates and contain abundant floral remains. This rests on a basal conglomerate consisting of weathered Permian volcanic detritus.

Despite the fossil flora, the exact age of the lower sequence is uncertain. While Triassic floras of Mongolia exhibit affinities to those of Kazakhstan, northeastern China and the southern Urals (Hart, 1974), the presence of some endemic forms however suggest that there may be a Mongolian subprovince (Lefeld, 1978). The presence of other floral elements suggest a late Triassic to early Jurassic age, but this determination is somewhat speculative (Balla, 1972a).

The upper, volcanic sequence covers large areas of the Selanga Mongol-Okhotsk volcanic belt and in eastern Mongolia southwest of Choybalsan and consist mainly of andesites, andesite and dacite porphyries and minor trachytes (Khasin, 1971; Borzakovskiy, 1971).

A complete Triassic marine sequence is exposed in the Dzhirgalantu River basin of northeastern Mongolia (Zonenshayn et al., 1971). Boreal marine pelecypods such as Eumorphities, Bakewellia, Posidonia and Myalina, and ceratite ammonoids such as Euflemignites, Anasibirites, Prosphinctes and Anashkimirites occur in a 400 meter thick, predominantly clastic sequence that concordantly overlies the Permian. The distribution of Triassic formations in northeastern Mongolia is rather unusual in that the marine deposits which occur in the Onon River basin are on strike with similar exposures in the eastern Transbaikal of the U.S.S.R. which in turn are rimmed entirely by terrestrial deposits, suggesting their accumulation in a long, narrow marine embayment or possibly an ocean basin.

A major late Triassic tectonic event in eastern Mongolia resulted in a highly variable basin and range topography. Newly formed intermontane basins became filled with coarse clastic deposits and the end of the Triassic was marked by intense silicic volcanism.

## Jurassic

Jurassic formations crop out over a much wider area than the Triassic. They are found in the Hövsgöl area, northwestern and central Mongolia, the eastern Gobi desert, the Hangay and Hentiy Mountains, southern Mongolia and the Nukut-Daban Range in the extreme east-southeastern part of the country. Stratigraphic correlation is fairly well-constrained in most areas, although the reliability of dating Jurassic Mongolian terrestrial sequences has been questioned by Balla (1972b). Generally, three main Jurassic type sequences may be distinguished. A solely terrestrial facies sequence occurs in northwestern Mongolia, in the Hövsgöl area, in central Mongolia and in the eastern Gobi desert. The two remaining sequences are sedimentary and volcanic and are exposed in the north and northeastern parts of the Mongol-Okhotsk foldbelt in the East Mongolian Volcanic belt. Jurassic units in the first four regions have been divided into a lower to middle Jurassic, generally grey-colored sequence and a middle to upper Jurassic sequence which consists predominantly of redbeds. The lower group is coal-bearing in some areas and the upper group conformably overlies the lower.

The lower and middle Jurassic terrestrial facies clastics exposed in the Dzhirgalantu Mountains are the most complete and best exposed sections. The fossil flora found in that section consists of Cladophlebis, Gingko, Pitophyllum and Coniopteris. An upper, coal-bearing sequence contains Ferganoconcha, Unio and Pseudocardiana and a similar mollusk assemblage has been found in many other lower and middle Jurassic sections in western Mongolia (Martinsson, 1961). Similar lower and middle Jurassic beds of the Great Lakes area are in excess of 600 meters thickness especially to the north of Har Us Lake. Coal-bearing sediments of the same age in northwestern Mongolia contain plant remains similar to those of the Kuznetsk basin, Tuva and the Irkutsk basin (Lefeld, 1978). A 1000 meter thick type section of the lower and middle Jurassic occurs at Bahar-Ula in the Gobi-Altay Mountains which also contain floral elements characteristic of the lower and middle Jurassic flora of central Asia (Shuvalov, 1970). The lower and middle Jurassic sequences of the Hangay and Hentiy Mountains comprise up to 3000 meters of trachyandesites and basalts as well as andesites. An interbedded sequence of conglomerates, sandstones and basalts contains lower and middle Jurassic flora as well. Contemporaneous sequences of northern Mongolia are divided into a lower, 250 meter thick terrigenous series, a middle, 500 meter thick volcanic sequence and an upper, 800 meter thick redbed sequence which collectively rest on eroded Triassic and Paleozoic formations.

Upper Jurassic redbeds unconformably overlie the lower and middle Jurassic or lower Jurassic formations of northwestern Mongolia, the Hövsgöl area, central Mongolia and in the eastern Gobi. They consist primarily of both volcanics and redbeds in northeastern regions whereas in the Hangay and Hentiy Mountains they usually comprise grey-colored clastics and coals. The upper Jurassic sequences of northwestern Mongolia are exposed in a broad belt at the foothills of the Gobi-Altay Mountains and consist of coarse conglomerates which vary in thickness between 250 and 1200 meters. Exposures near the Great Lakes are much finer grained, between 100 and 500 meters thick, unconformably overlie either middle Jurassic or Paleozoic rocks and contain Alaria, Throacia and Pleuromya which collectively suggest a Kimmeridgian age (Lefeld, 1978). The upper Jurassic sequences of the Gobi-Altay Mountains and the southern part of the Gobi desert consist of conglomerates, sedimentary breccias, shales and sandstones. Further upwards, sandstones interbedded with conglomerates and sandstones of fluvial and lacustrine origin become dominant (Shuvalov, 1970). Basalt horizons have been found in the upper part of coeval sequences along the Dzhirgalantu River of northeastern Mongolia and consist of 1700 meters of redbed conglomerates containing clasts of quartzite, granite and older conglomerates. These in turn are overlain by cross-bedded sandstones and sandy shales. The upper Jurassic sediments of the Hangay and Hentiy Mountains are exposed in small half-graben and consist of 80 meters of conglomerates and sandstones overlain by a 140 meter thick section of finer clastic rocks and coals bearing a medial to late Jurassic flora. The combined middle and upper Jurassic sequences of northeastern Mongolia and the eastern Transbaikal consist of andesites, basaltic andesites and liparites. Along the middle reaches of the Kerulen River, a 2000 meter thick tripartite series consisting of a lower sedimentary and volcanic sequence, a middle sequence comprised of rhyolites and andesites and an upper sequence of silicic volcanics is exposed. Farther to the northeast the lower member disappears and is replaced by a thick series of predominantly silicic volcanics. Isotopic age determinations of the lower member volcanics exposed at Tumen Tsogto on the Kerulen River yield 155 to 160 million year old values (Lefeld, 1978). Jurassic volcanic rocks unconformably overlie upper Paleozoic sections in southern Mongolia and the Nukut-Daban Range and comprise a series of tuffs and breccias between 300 and 500 meters thick.

The depositional pattern of the Jurassic and the character of the volcanic activity were inherited to a considerable extent from that of the Triassic. Volcanic activity was confined mainly to northern and northeastern regions, especially in the Mongol-Okhotsk region. Northeastern Mongolia was the only uplifted and denuded region during the Triassic but received coarse coal-bearing clastics during the Jurassic. The only marine incursion, one of fairly limited extent, occurred in the extreme northeastern part of the country (Arkell, 1956; Khrapov and Dambiynyan, 1980). Jurassic tectonism was particularly strong in southern and western Mongolia where the Mongol-Altay and Gobi-Altay systems were being uplifted. Less pronounced uplifts were observed in the Hangay, Hentiy and Great Khingan Ranges (Lefeld, 1978). Elongate depressions developed along reactivated Paleozoic structure trends which rapidly filled with clastic material shed from the surrounding highlands and was usually accompanied by mafic volcanism. According to Khrapov and Dambiynyan (1980), during the period from the late Triassic to the late Jurassic, the floral assemblages of northern Eurasia and China became monotypic.

### Cretaceous

Unless noted otherwise, the following section is based on Lefeld (1978). Cretaceous formations occupy extensive areas of Mongolia, particularly in eastern, southern and south-central regions. They are represented entirely by terrestrial facies clastic sequences which unconformably overlie the early Mesozoic or Paleozoic. Transitional beds between the upper Jurassic and lower Cretaceous are known in Mongolia as the Tsagaan-Tsab suite, the upper, tuffaceous part of which is assigned to the lower Cretaceous. Grey to greenish-grey clastic rocks of this suite are frequently intercalated with mafic to intermediate volcanics and tuffs. The overlying Dzuun Bayan suite (Hauterivian-Albian) consists predominantly of fine clastic sediments. Bituminous shales predominate in southern Mongolia whereas in the Eastern

Gobi desert a sandy, argillaceous series contains conglomerates at its base with a coal-bearing sequence at a higher horizon. The thickness of the Tsagaan-Tsab suite varies from 800 to 1800 meters with the thickest sequences occurring in the extreme eastern part of the country. A sequence of undivided uppermost Jurassic and Cretaceous sediments unconformably overlie Jurassic beds in the Great Lakes area of central Mongolia, and in some depressions adjacent to the foothills of the Mongol-Altay Mountains (Khosbayar, 1973). Upper Jurassic and lower Cretaceous sediments of western Mongolia are compositionally diverse, consisting mainly of terrestrial facies conglomerate, gritstone, sandstone, shale and marl with subordinate limestone, gypsum and hematite. Unlike the sequences in central and eastern Mongolia, the Mesozoic here is quite devoid of volcanics.

Cretaceous sediments younger than Albian mainly occur in the southern parts of the country, although exposures bearing well-defined Aptian-Albian faunas have been observed in central Mongolia (Nagibina and Badamgarav, 1972). Such sequences are usually separated by a sharp unconformity from the underlying folded Jurassic conglomerates and siltstones.

Cretaceous sediments younger than Albian are present only in eastern Mongolia where they disappear beneath Paleogene and Neogene formations near the Chinese border. Upper Albian to Cenomanian formations exhibit a more distinct redbed character than older formations and they are separated by an erosional surface from lower Cretaceous or pre-Cretaceous sediments. The type-section of the Upper Albian-Cenomanian Saynshand suite of eastern Mongolia also shows considerable variability in facies (Martinsson et al., 1969). The Saynshand sediments contain a characteristic ostracod and fresh-water mollusk assemblage which are only known from the alternating marine and terrestrial facies Albian and Cenomanian of Kirin (Jilin) northeastern China (Martinsson et al., 1969).

Younger Cretaceous formations are assigned to the 600 to 1200 meter thick Bayan-shire suite, which covers the uppermost Cenomanian to the Santonian and consist of reddish brown terrestrial facies clastics. They are best exposed in the eastern Gobi basin where the type section rests upon a basalt horizon with a slight disconformity.

Uppermost Cretaceous sediments have been referred to as the Baruun Goyot suite and overlie the Bayan-shire with a slight angular unconformity. The same name has been applied to the Campanian sediments of the Nemegt basin in the Trans-Altai Gobi Desert described by Gradzinski and Jerzykiewicz (1974).

The upper Cretaceous strata of Mongolia are found mainly in southern regions, occurring in large post-Oligocene strike-slip related half-graben. The rocks are exclusively terrestrial facies redbeds exhibiting marked lateral facies variability. Gradzinski and Jerzykiewicz (1974) have interpreted the Baruun-Goyot suite as a series of intertonguing and/or alternating dune deposits and sediments of intermittent lakes and streams. They consist of mega-cross-stratified sandstone units which show considerable lateral continuity and little variation of foreset dip and are thought to be buried transverse dunes. Gradzinski, Kielan-Jaworowska and Maryanska (1977) subdivided the Baruun-Goyot into three separate units consisting of the Djadokhta, Baruun Goyot and Nemegt formations. All comprise fluviatile, reddish-brown conglomeratic sandstones, siltstones and shales exhibiting cut and fill structures, fining-upward cycles, and caliche, interbedded with mega-cross-stratified aeolian deposits and containing an abundant vertebrate fauna.

The geomorphology of Mongolia appeared to be drastically altered after the late Jurassic. Northern districts experienced a general uplift while sizeable depressions developed elsewhere. The boundary between these two major morphologic zones follows the trace of the South Bayan Hogor-Ih Bogd-Undurshilin Zone (Lefeld, 1978). The extensive lake basins of the lower Cretaceous appeared to be interconnected, extending from north-central Mongolia to China. Coeval deposition was accompanied by a progressive tectonism which tended to accentuate the general basin and range topography as well as contribute to widespread silicic to intermediate volcanism.

Most of the Gobi district from the Great Lakes area to the Great Khingan were frequently covered by lakes during the Valanginian. An early Cretaceous subsidence maximum was reached in the East Gobi basin where a 1000 meter thick section of the Tsagaan Tsab suite accumulated. An apparent intensification in tectonism at the end of the early Cretaceous resulted in a localized diversification of deposition. Some basins disappeared while others changed position accompanying a gradual cessation of volcanism. The passage between the lower Cretaceous and the upper Cretaceous is marked by a slight erosional unconformity. Tectonic activity at this time resulted in a general uplift across the entire country. Deposition ceased entirely across most of northern Mongolia by the late Cretaceous. The Cretaceous sediments of Mongolia which may be considered typical molasse facies deposits range between 5000 and 6000 meters in thickness.

### 3.4 Mesozoic Magmatism

Mesozoic magmatism of Mongolia was typically of effusive character, silicic to intermediate in composition, confined mainly to central and eastern regions and of Triassic through Cretaceous in age. The Mongol-Okhotsk foldbelt of central and northeastern Mongolia and adjacent regions of the southern Transbaikal comprised the center of most igneous activity. Such activity in central and eastern Mongolia was simply a continuation of that established in the late Permian, following the suturing of the Qaidam-Alasian Block and Mongolian Arc to the Siberian Craton and the shifting of convergent margins further east and south as well as into the Mongol-Okhotsk region. Furthermore the last appearance of igneous activity migrated from west to east across central and eastern Mongolia during the late Jurassic and medial Cretaceous following the suturing of the North China Fold Zone behind the Mongolian Arc. The gradual eastward shift of Mesozoic igneous activity is a characteristic phenomenon of the whole of eastern Asia (Nagibina, 1970).

A group of granitic intrusions of isotopically-determined late Triassic (220 m.y.) to early Jurassic (180 m.y.) age are confined primarily to the batholiths of the Hentiy Mountains (Snirnov, et al., 1977; Lefeld, 1978), to small dispersed stock-like plutons in central Mongolia (Kapsamun, 1971; Khasin, 1971) and the granites and granodiorites of southeastern Mongolia (Khasin and Borzakovskiy, 1967; Borakavskiy, 1975).

A second group of intrusions, primarily of medial (175 m.y.) to late Jurassic (180 m.y.), age consist primarily of monzonites and syenites and are exposed in the southeasternmost Gobi. Intrusions of silicic plutonics, dominantly alaskites and granites, occur in central and eastern Mongolia and also in northeastern China.

After the end of the Jurassic, igneous activity was predominantly extrusive in nature, silicic to mafic in composition and confined to easternmost regions (Blagonravov and Saltykovskiy, 1971). A widespread late Jurassic to early Cretaceous phase of basaltic and trachyandesitic volcanism affected a significant portion of northeastern Mongolia and the northern Great Khingan Range in China (Soloviev et al., 1978; Khrapov and Dambiynyan, 1980). Such activity appears to be related to the subduction and eventual closure of two ocean basins, one located in the Mongol-Okhotsk foldbelt and the other to the east of the Great Khingan Range in northeastern China.

# CHAPTER IV

# CHINA AND KOREA

## 4.1 Pre-Sinian

Figure 5a illustrates the distribution of Archean and lower Proterozoic (Pre-sinian) rocks throughout the People's Republic of China. The principal site of Archean and lower Proterozoic rocks is the Sino-Korean Paraplatform which is comprised primarily of Archean high-grade metamorphics and is the oldest Precambrian terrain in China (Ma and Wu, 1981) and Korea (Reedman and Um, 1975). The early Proterozoic sequences of the Sino-Korean Paraplatform are characterized by belts of medium to lower grade metamorphic rocks unconformably overlain by a mildly deformed sedimentary veneer. Its basement took shape by the end of the early Proterozoic about 1.7 billion years B.P. Foldbelts marginal to the Tarim Platform expose Archean and early Proterozoic rocks. While it is considered to be one of the oldest platforms in China, its basement did not become completely consolidated until the late Proterozoic (Huang, 1978; Ma and Wu, 1981). Lower and middle Proterozoic rocks are also found in the exposed basement complexes of the Yangtze Paraplatform in central Yunnan and southern Sichuan and in the Chang Nan Geanticline, along the southwestern margin of the Bureya Massif in the Lesser Khingan Range, along the western margin of the Khankha Massif in the Nadanhada Foldbelt in the Ryeongnam Massif of Korea, as slivers in several Phanerozoic foldbelts and as isolated exposures in Shandong and Liaoning provinces (Figure 6) (Cheng et al., 1973; Geologic Map of Asia, 1975; Geologic Map of China, 1975; Reedman and Um, 1975; Huang, 1978; Bally et al., 1980; Wang, 1980; Ma and Wu,1981).

## DISTRIBUTION OF ARCHEAN-LOWER PROTEROZOIC ROCKS

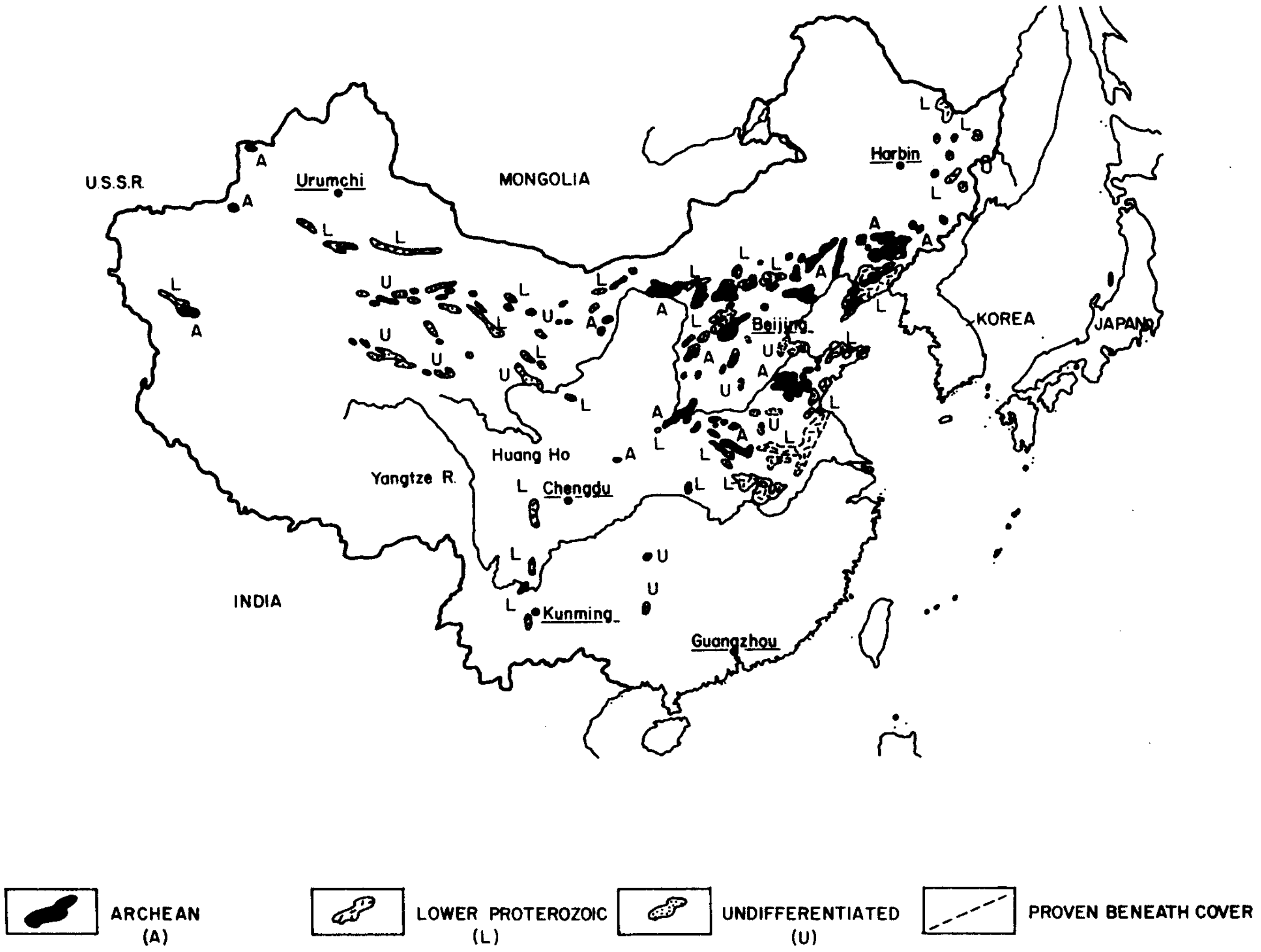
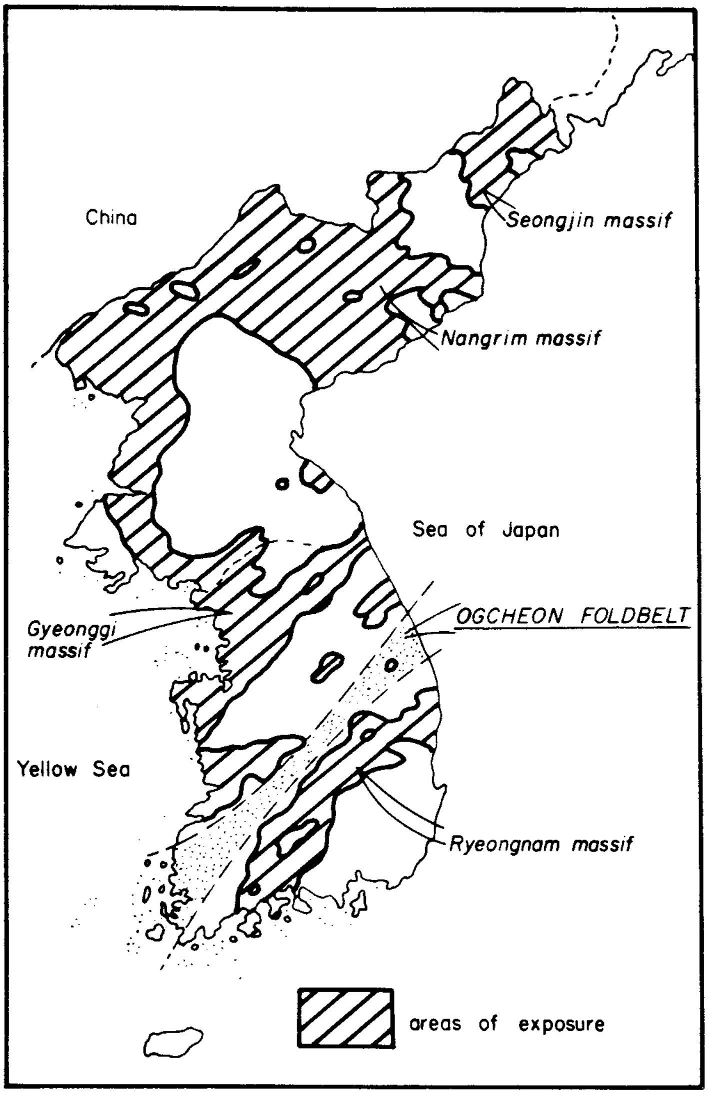



FIGURE 5a.

(after Ma and Wu, 1981)

The formation of the earliest sialic crust in China is still a matter of speculation. Recognizable patches of continental crust appear to have been in existence between 3.1 and 2.9 billion years ago, although their shape and size are indeterminate. By the end of the Archean large segments of crust comprising the cratonal nuclei of the Sino-Korean Paraplatform and the Tarim Platform had been created. Toward the end of the Proterozoic, stabilization and the formation of "proto-platforms" of subcontinental proportions occurred, and it was at this time that the tectonic framework of the main lithospheric blocks comprising eastern China began to acquire their present nature.

The pre-Sinian rocks of the southern part of northeastern China are exposed in the southern and central parts of Jilin and Liaoning provinces, extending in an northeast-southwest direction to the tip of the Liaotung peninsula. They comprise two distinct series of metamorphic rocks, the Anshan granulites and the Liaoho schists. Based on grade of metamorphism and apparent superposition, both are unconformably overlain by a Sinian sedimentary veneer. Pre-Sinian rocks are also exposed in Shandong province especially to the west of the Tancheng-Lujiang Fault Zone where they comprise the amphibolites and hornblende-granulites of the Taishan Group. The Anshan, Liaoho and Taishan Groups are strongly deformed, extensively migmatized and intruded by silicic, intermediate, mafic as well as alkalic intrusives ranging from late Precambrian to Cenozoic in age. Gneiss and schist complexes of Archean to medial Proterozoic age form the basement of the entire Korean peninsula and are widely exposed in the Nangrim and Seonjin massifs of northern Korea, and the Gyeonggi and Ryeongnam Massifs of southern Korea (Figure 5b.




(after Reedman and Um, 1975)

Figure 5b.:

Exposures of Archean to medial Proterozoic Rocks of the Korean Peninsula

## 4.2 Sinian

The Sinian suberathem comprises metamorphosed Proterozoic (1800 million year old to 570 million year old) marine and terrestrial facies sequences. They have been subdivided into a northern (Sino-Korean) and a southern (Cathaysian) type depending upon characteristic lithologic and faunal associations (Compilation Group of the Geologic Map of China, 1977).

Sinian deposits exposed in northern China occur in a broad region bounded by the Yinshan and Tienshan Foldbelts to the north and the central Qilian and north Qinling Foldbelts and the Shandong peninsula to the south. Type locality exposures in eastern Liaoning comprise a four-part series of thick, stromatolite and coelenterate-bearing marine and paralic facies sequences that are relatively unmetamorphosed. This well-defined series consists, from bottom to top, of the Changcheng, the Chihsien, the Qingpaikou and the Sinian systems respectively. The Sinian is best developed in marginal parts of the region, whereas in central regions the lower or middle Cambrian directly overlies the Qingpaikou. Numerous disconformities exist within and between the various systems and a marked unconformity between the Sinian and the pre-Changcheng sequences is ubiquitous.

The lower part of the Changcheng system consists of a series of transgressive neritic and littoral clastics intercalated with banded iron formation. This is overlain by stromatolite-bearing limestones and dolomites interbedded with mafic volcanics. The Chihsien system comprises a series of regressive neritic deposits containing algal limestones and dolomites overlain by phosphatic limestones and shales. The Qingpaikou system comprises a regressive-transgressive sequence of clastics and carbonates of limited development, confined generally to

FIGURE 6:

# TECTONIC SKETCH MAP OF EASTERN CHINA AND ADJACENT REGIONS

(after Huang, 1978)

central northern China. The Sinian system proper is limited to peripheral areas of northern China and is best developed on the Liaotung peninsula and in Gansu province on the flanks of the Sino-Korean Paraplatform. Lowermost sections consist of fossiliferous glauconitic sandstones and shales which in turn are overlain by neritic carbonates and clastics characteristically yielding a stromatolite fauna.

The Sinian suberathem deposits of southern China are confined primarily to the south of the Qinling-Dabieshan Foldbelt as well as the margins of the Tarim and Qaidam basins in northwestern China and consist of a two-part sequence divided by the regional Chinningian unconformity. The lowermost section consists mainly of slightly metamorphosed limestones, dolomites, cherts and clastics interbedded with mafic to intermediate volcanics and banded iron formation which collectively comprise the Panchi and Kunyang Groups of southern China. The 2000 to 1700 million year Huto Group of northern China contains similar lithologies and has been considered a correlative of the Panchi, Kunyang as well as the Szepao Groups of Hunan and Guangxi. Recent isotopic age determinations of 900 million years for the Kunyang and 1500 million years for the Szepao however, appear to have disproved any supposed correlation.

The Sinian system proper of southern China unconformably overlies the lowermost "Sinian" section and comprises an areally extensive fossil-bearing succession whose stratotype of two series and four formations have been defined in the Yangtze gorges of western Hubei. The lowermost series comprising the Matsaoyuan and Lientuo formations consist of terrestrial facies redbeds and volcaniclastics interbedded with algal limestones. The tillites (?) of the Changan formation underlie the Lientuo formation near the border region of Guizhou, Gangxi and Hunan provinces. The uppermost series is composed predominantly of fossiliferous neritic deposits characterized by glaciomarine conglomerates, sandstones and siltstones. The lowest part of the series is represented by tills of the Natuo formation and is in turn overlain by the glauconitic sandstones, shales, phosphatic rocks and carbonates of the Toushantuo formation. The highest part of the series is represented by the neritic-littoral Tengying formation of siliceous carbonates, evaporites and phosphatic rocks bearing an abundant fauna of sponges and hyolithids.

## 4.3 Paleozoic Stratigraphy

Paleozoic strata are well-developed, fossiliferous and fairly widespread throughout China. According to the Compilation Group of the Geologic Map of China (1977), the Paleozoic sequences of China can be best described in terms of their occurrence and facies with respect to eight specific tectono-stratigraphic subdivisions, namely, the Dzungaria-Khingan, Yangtze, Tarim, North China, Qinling-Kunlun, Tibet-West Yunnan, Southeast China and Himalayan domains (Figure 6). Although a few of the aforementioned domains are considerably west of the region of concern to this study, their Paleozoic sections are nonetheless important and a brief description of their stratigraphy is included in the following.

The Dzungaria-Khingan region extends north of the Yinshan-Tümen and Tienshan foldbelts from the Dzungarian to the Songliao basin. It is roughly equivalent to the Central and Southern Mongolian Zones (Amantov et al., 1970) (Figure 3). Cambrian and Ordovician sequences are rather sparse, confined to peripheral areas and consist primarily of metamorphosed fossiliferous marine clastics intercalated with limestones, dolomites, and volcanics which are in turn overlain with a marked angular unconformity by upper Silurian coarse redbeds. The upper Paleozoic sequences consist of marine and paralic facies clastics and volcaniclastics bearing a Boreal-Pacific faunal assemblage as well as Angaran floral remains. Upper Devonian terrestrial and shallow water marine sequences are widely developed across the region although equally widespread upper Permian deposits consist dominantly of terrestrial facies deposits with an Angaran flora with local intercalations of marine horizons.

The most complete Paleozoic sections of the Tarim are exposed predominantly along its margins in the foldbelts of the Kelpintagh, Kuruktagh and northern Kunlunshan. Subordinate exposures and decidedly less complete successions described mainly from drill core are known from the interior of the basin and display a characteristic late Ordovician through Devonian hiatus (Meyerhoff and Willums, 1976). Cambro-Ordovician sequences consist of shallow water limestones, dolomites and clastics intercalated with volcanics. Lower Cambrian phosphorites and bituminous shales, cherts, and limestones yield abundant trilobites, brachiopods, and cephalopods. Siluro-Devonian sequences are largely littoral and neritic facies red sandstones and shales with limestone interbeds, while the Carboniferous and lower Permian are composed primarily of paralic facies sandstones, shales and marls with occasional coal seams. The upper Permian are dominantly terrestrial facies clastics, rarely interbedded with marine horizons (Kretnikov, 1963; Roger, 1963; Hu et al., 1969).

The North China region, synonymous with the Sino-Korean Paraplatform of Huang (1960; 1978), is bounded by the Yinshan foldbelt to the north, the Qinlingshan foldbelt and the Huai River to the south and extends from the Holanshan at the western periphery of the Ordos basin to the Yellow Sea and includes the majority of the Korean peninsula. Cambro-Ordovician sequences are widespread and consist of relatively thin, shallow water platform-type limestones, dolomites, sandstones and subordinate shales

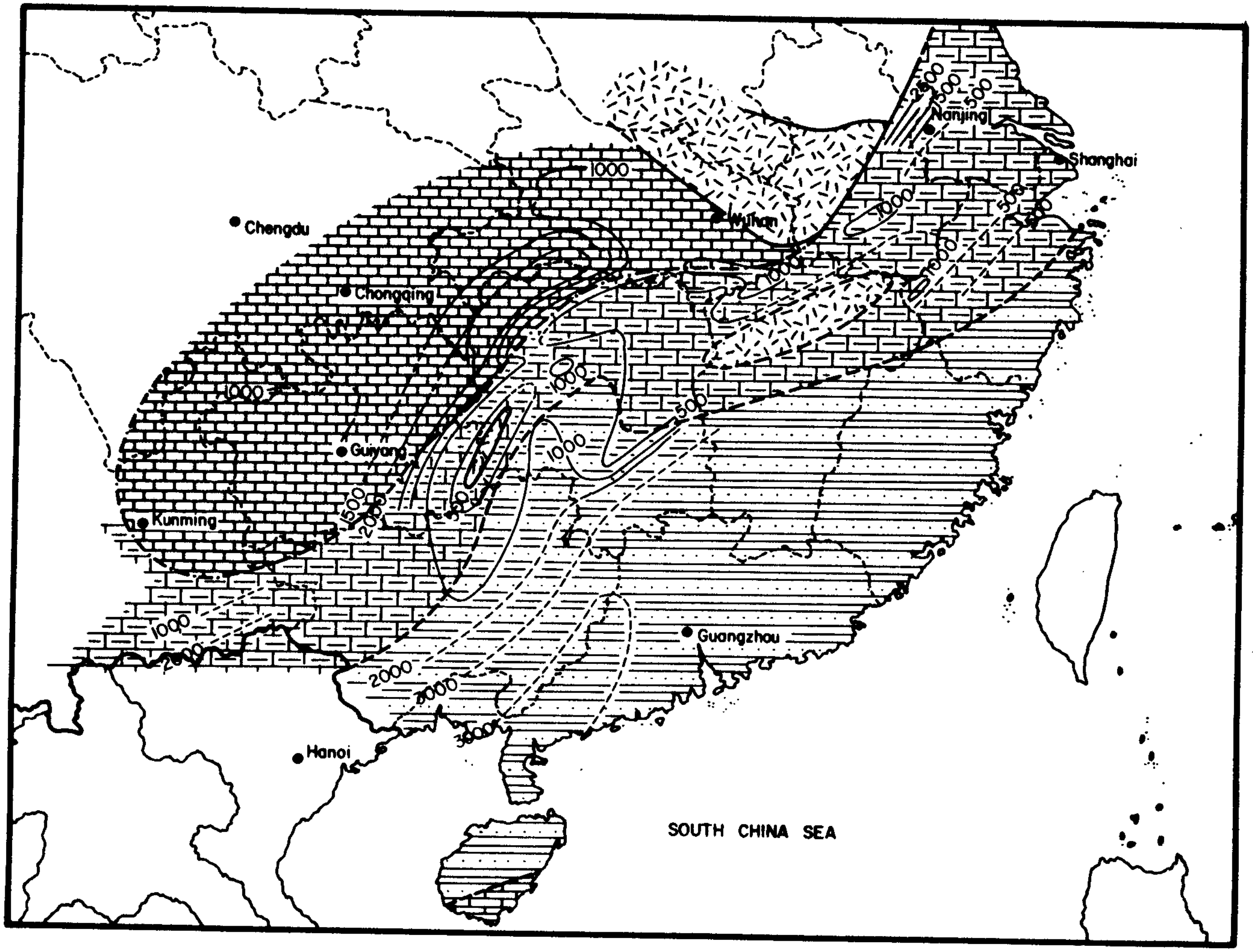



FIGURE 7: Cambrian paleogeography and isopachs of Southern China.

(isopachs in meters/ key follows figure 9/after Jen, 1968)

Klimetz, 1982

(Feng, 1979). Fairly complete and fossiliferous type sections are exposed in western Shandong, in the Yinshan and in the Western Hills of Beijing (Yin, 1920). Cambrian sequences characteristically contain abundant trilobites and Ordovician sequences bear several genera of actinoceroids. There is a ubiquitous hiatus spanning the upper Ordovician to the lower Carboniferous across the entire region and is an important criteria for the recognition of North China Paleozoic sequences in easternmost provinces which experienced significant post-Paleozoic dislocation. Middle, upper Carboniferous and Permian sections are best exposed near Taiyuan and Ningwu of Shaanxi province and in the Great Khingan Range. They are comprised mainly of terrestrial facies clastics interbedded with thin marine linstones containing productids and fusulines (Noda, 1956) and volcanic rocks. The uppermost Permian consists of redbed sandstones and shales evidently bearing a Cathaysian flora (Hart, 1974; Ziegler, et al., 1979).

The Qinlingshan-Kunlunshan region encompasses the Kunlun, Qinling and Qilian foldbelts which contain extremely thick "geosynclinal-type" sequences of Paleozoic age (Chao and Huang, 1931; Jiang and Chu, 1964; Xiao, 1978; Feng, 1979; Yin, 1980). Lower Paleozoic deposits consist of slightly metamorphosed fossiliferous marine limestones, dolomites, sandstones and shales intercalated with mafic and intermediate volcanics. The Nanshan series of northern Qilian foldbelt (Chilien Mountains Surveyors Group, 1963), the Naichihtai group of Buerhanbuda in the eastern Kunlunshan foldbelt and the Niutuoho group of eastern Gansu are lower Paleozoic "geosynclinal-type" deposits unconformably overlain by upper Silurian to Devonian molasse. The upper Paleozoic rocks consist mainly of alternating marine and paralic deposits. Upper Devonian through Permian deposits consist largely of terrestrial facies clastics that

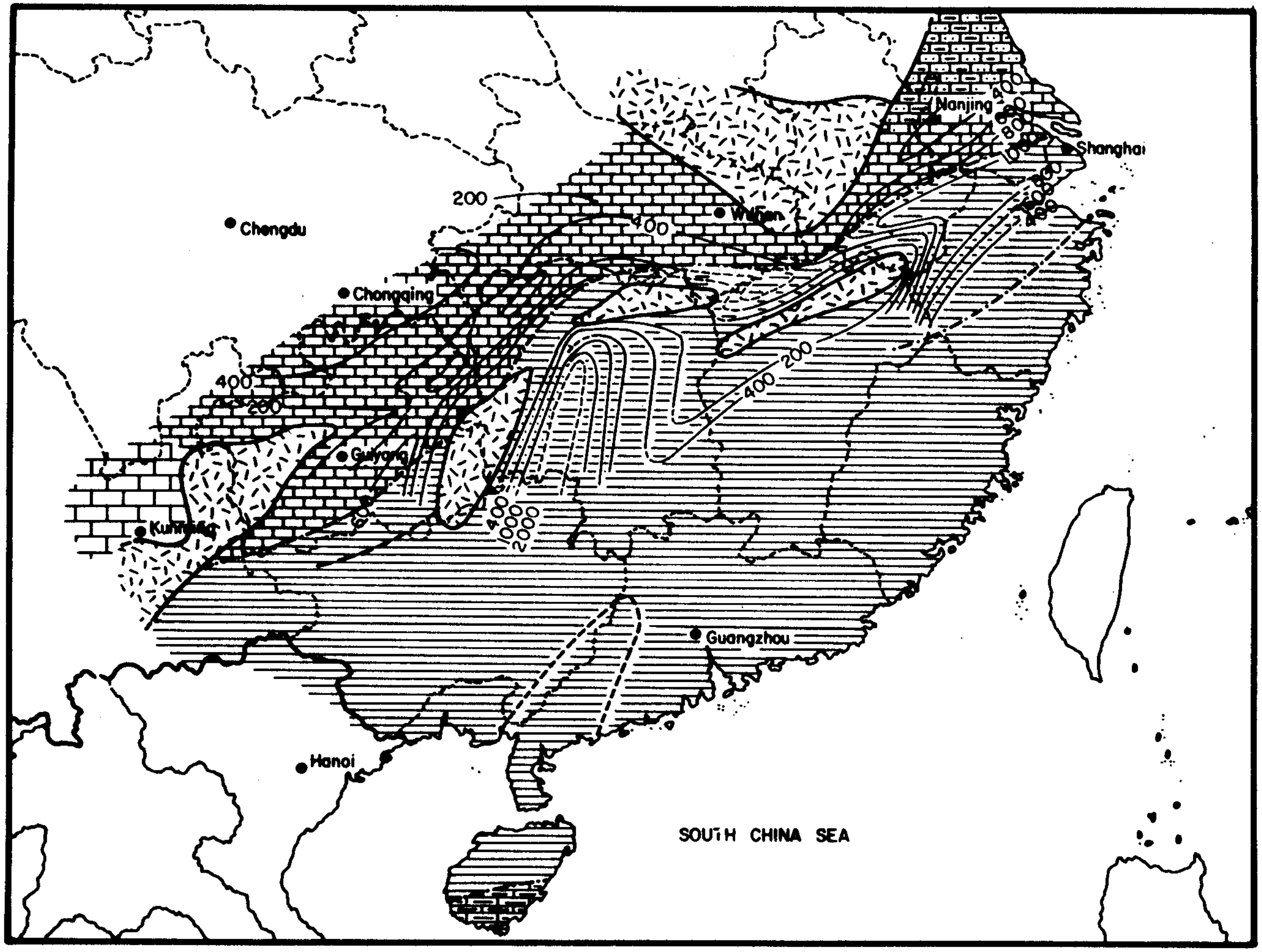



FIGURE 8: **Ordovician paleogeography and isopachs of Southern China.**

(isopachs in meters/ key follows figure 9/after Jen, 1968)

Klimetz, 1982

have been strongly deformed.

The Tibet-western Yunnan region encompasses a broad terrain bordering the western and southwestern margins of the Yangtze Paraplatform in Yunnan and Sichuan provinces and extends westwards into Qinghai and Xizang provinces. Extremely thick lower Paleozoic successions of western Yunnan consist mainly of Cambrian flysch, Ordovician and Silurian graptolitic shales and shelly limestones bearing cephalopods and corals (Elles, 1925; Gregory, 1925; Reed, 1925; Misch, 1945; Sun, 1945). Fossiliferous Cambro-Ordovician sequences of unknown thickness are also known from western Sichuan and eastern Tibet. Devonian through Permian deposits are widely distributed throughout this region and are comprised of marine facies sandstones, shales, limestones, and dolomites locally interbedded with mafic and intermediate volcanics and coal seams.

The Yangtze region, equivalent to the Yangtze Paraplatform of Huang (1960, 1978) (Figure 6) and the Yangtze Table of Cheng (1963) contain the best and most uniformly complete Paleozoic sections in China. Cambro-Ordovician sequences consist mostly of fossiliferous, shallow water marine limestones, sandstones and shales which in turn overlie a basal Cambrian horizon of phosphatic, bituminous shales and cherts. Cambrian sections yield abundant trilobites, hyolithids and archaeocyathids while Ordovician sections yield a variety of graptolites and characteristic Vaginoceras and Sinoceras cephalopods. The Silurian consists of graptolitic shales, shelly limestones and shales changing at upper stratigraphic levels to alternating redbed and marine facies rocks containing brachiopod and coral remains. Devonian and Carboniferous sequences are especially well-developed in the southwestern part of the region. Exposures in the Longmenshan of Sichuan province consist primarily of marine facies limestones, sandstones and shales

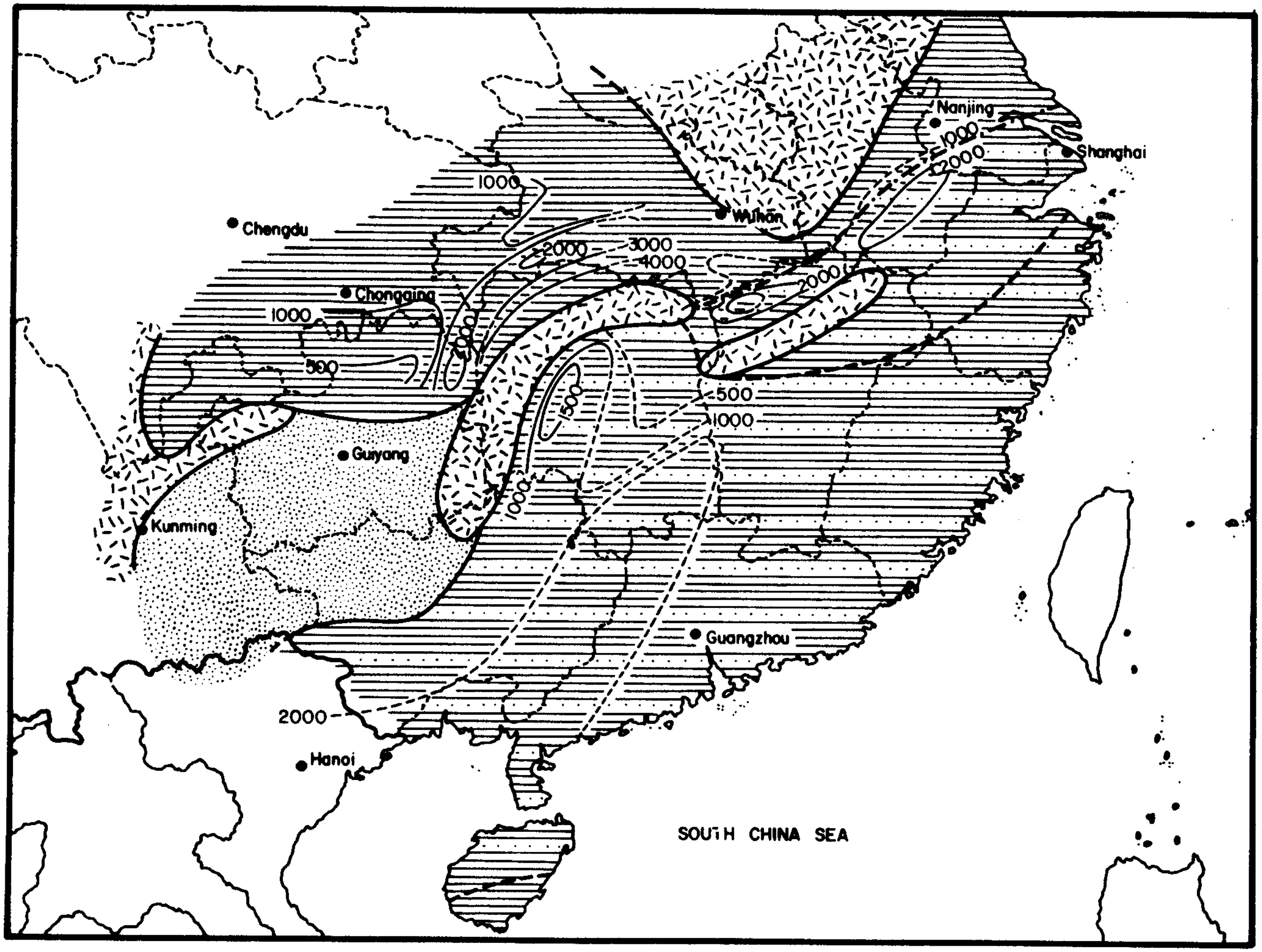



FIGURE 9: Silurian paleogeography and isopachs of Southern China.

(isopachs in meters/key on next page/after Jen, 1968)

Klimetz, 1982

locally intercalated with cherts and volcanic rocks whereas farther to the east, along the southeastern margin of the Sichuan basin, Devonian and Carboniferous sections are missing (Yang, 1981). Exposures of the Maoshan formation, confined to the lower reaches of the Yangtze River, consist predominantly of lower and middle Devonian paralic and terrestrial facies deposits bearing a well-described antiarch fauna, notably Bothriolepis. Devonian antiarch biostratigraphy in this and neighboring regions of southern China has recently been attempted by P'an (1981). Permian deposits are fairly extensive and consist of shallow water marine limestones overlain by paralic limestone and coals (Meng, 1948; Ting, 1966) and the areally extensive Omeishan (Emei) medial late Permian plateau basalt flows of eastern Yunnan (Misch, 1945; 1949; Tsao, 1958), Sichuan (Chao, 1929; Tan and Lee, 1932) and Guizhou (Huang, 1932; Ting and Grabau, 1933b) provinces. The Omeishan basalts are of variable thickness, in places porphyritic, and contain numerous interbeds of tuffs, intermediate volcanics and horizons of pillow lavas (Chao, 1942; Roger, 1963). At its type locality it reaches a thickness of between 300 and 400 meters and rests upon shallow water marine Moukou and Chihsia limestones (Heim, 1930; 1932). Exposures of intermediate and silicic volcanics are also known from central Guangxi. The upper Paleozoic sequences of this region are generally quite fossiliferous, regardless of facies. Devonian sequences contain a variety of marine and paralic fauna, including several genera of brachiopods, corals, ammonoids and antiarchs. The marine facies Permo-Carboniferous is characterized by abundant fusulinids (Thompson and Miller, 1935; Thompson and Foster, 1937), corals and brachiopods (Huang, 1932; Ting and Grabau, 1933a, b) while the terrestrial facies Permian contains the well-known Gigantopteris and other Cathaysian

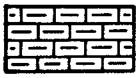
# *Legend to Paleogeographic Maps of Southern China*

(figures 7-9)

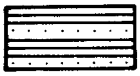
Emergent areas

## CAMBRIAN:

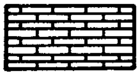
Yangtze Basin: limestone and dolomite (shelf)



Yangtze Basin: $\epsilon_1$ -black shale ; $\epsilon_{2-3}$-limestone



South China Basin: proximal/distal turbidites (rise prism)



Hainan Basin: deep water manganiferous cherts and limestone

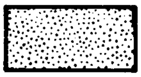
## ORDOVICIAN:

Yangtze Basin: $O_1$ -limestone and graptolitic shale; $O_2$-intertidal limestone; $O_3$ -black graptolitic shale

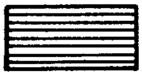
South China Basin: $O_{1-2}$- proximal turbidites and carbonates; $O_3$- distal turbidites and cherts

Hainan Basin: deep water limestone and shale

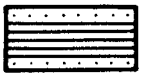
## SILURIAN:



Yangtze Basin: $S_{2-3}$- sandstone and shale



Yangtze Basin: $S_1$-graptolitic shale ; $S_2$-shale and coralline limestone; $S_3$-turbidites



South China Basin: $S_{1-2}$-turbidites; $S_3$ - terrestrial clastics

Klimetz, 1982

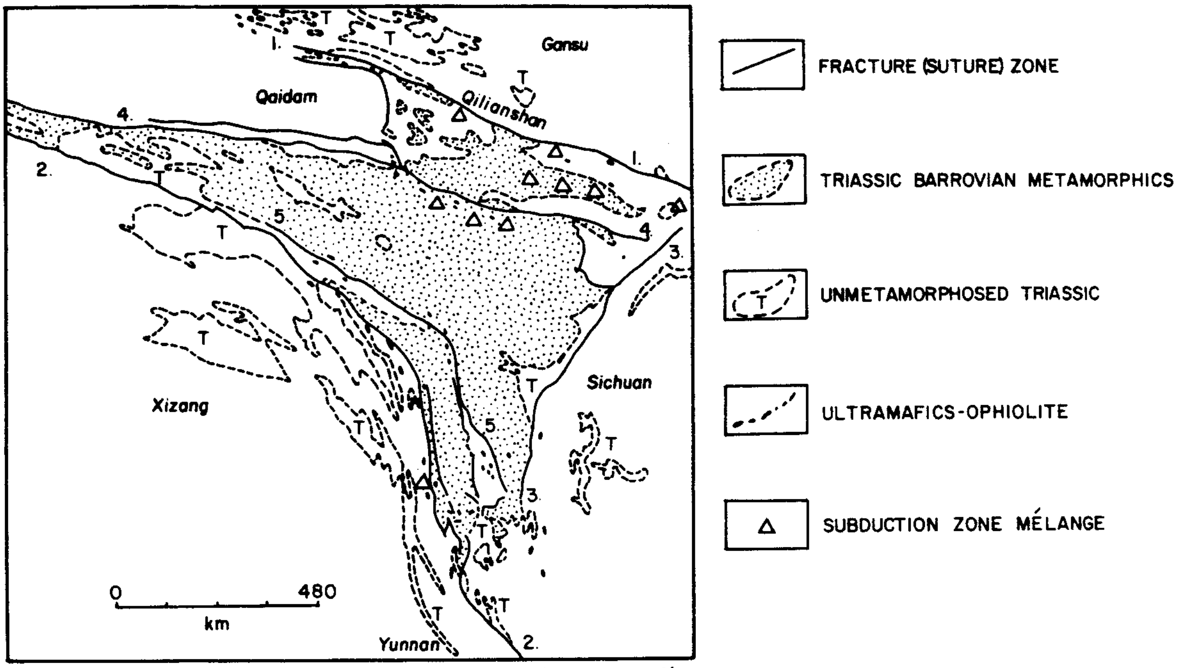
floral elements (Sahni, 1935; Edwards, 1955; Kon'no, 1965; Hart, 1974). It is interesting to note that Sze (1942) regarded the easternmost exposure of "Omeishan basalt" in eastern Yunnan, consisting of a 1000 meter thick section of pillow lavas and subordinate ultramafic rocks, as the boundary between the Gondwana (Glossopteris) and Cathaysian (Gigantopteris) flora in southeastern Asia.

The Southeast China region lies directly southeast of the Yangtze region and comprises the Southeast China and Southeast Maritime foldbelts of Huang (1960; 1978). Lower Paleozoic sections consist of a thick series of slightly metamorphosed marine rocks. The widespread Cambro-Ordovician Lungshan series of this region consists of flysch, graptolitic shales, cherts, occasional coal seams and an abundant fauna of mixed Atlantic and Australasian types (Compilation Group of the Geologic Map of China, 1977). Figures 7, 8, and 9 are Cambrian, Ordovician and Silurian paleogeographic and lithofacies maps of this region, modified from those in Jen (1968). Up until the Devonian, southeastern China appears to have been the site of a passive, Atlantic-type margin that accumulated fairly thick sequences of continental shelf and rise-prism sediments. A reversal of this situation commenced with the apparent development of a convergent margin in the Devonian which may have culminated in collision prior to the Carboniferous. Widespread intrusion of Siluro-Devonian granites, the deposition of coarse molasse facies clastics and an upper Silurian to middle Devonian depositional hiatus and angular unconformity are known throughout southern China. The upper Paleozoic is similar to that of the Yangtze region in both lithofacies and biotas. The Devonian and Carboniferous are comprised mainly of paralic deposits with molasse-facies coarse clastics while the Permo-Carboniferous contain abundant shales and coal seams.

The Paleozoic of the Himalayan region is fairly well-developed and consists primarily of fossiliferous shallow water marine sandstones, shales and limestones of Ordovician to Permian age (Wang et al., 1980b). A characteristic late Silurian to early Devonian graptolite assemblage comprised of Neomonograptus himalayensis and Monograptus thomasi discovered from the north slope of Jolmo Lungma Feng (Mount Everest) in southern Tibet are also present in the Mojiang region of western Yunnan, Guangxi and western Dzungaria (Compilation Group of the Geologic Map of China, 1977). More detailed studies on the pre-Mesozoic stratigraphy of the Himalayan region appear in Yin and Kuo (1978), Wang et al., (1980a) and Yin et al. (1980).

## 4.4 Mesozoic Stratigraphy

The Mesozoic stratigraphy of China and Korea for the most part consists of terrestrial facies deposits accompanied by huge expanses of volcanics and widespread silicic and intermediate plutonism. The Triassic and parts of the Jurassic and Cretaceous sections are marine, particularly in southern and western China and these are of often associated with bodies of ophiolite. Plates II, III and IV are a series of Permian through Paleogene stratigraphic columns for northeastern China, southern China and southwestern China-Indochina compiled principally from the Lexique Stratigraphique International for China (Roger, 1963), Manchuria (Kimio, 1956) and Indochina (Saurin, 1956) as well as from selected literature including Lin (1956) for northeastern China, Bally et al. (1980) for southwestern China, Tateiwa (1960), for Korea, and Matsumoto (1978) for Japan. A complete listing of specific location data by column number as well as data source appears in the appendices. Plate V is a correlation chart of the Mesozoic formations of




(after Yin, 1980)

SUTURE ZONES:

1. North Tsinling (Qinling)
2. Jinshajiang
3. Longmenshan-Kangdian
4. Buerhanbuda-Jishishan
5. Moli

FIGURE 10:

*Triassic Tectonic Sketch Map of the Songban-Ganzi Accretionary Complex* northeastern China based on that of Lin (1962).

Triassic

The Triassic strata of China are areally extensive and fairly well-developed. A facies boundary separating essentially terrestrial deposits to the north from dominantly marine deposits to the south can be traced along a line drawn from the western Kunlunshan foldbelt through the Qilianshan foldbelt then the Dabieshan foldbelt. The only exceptions to this are a small area of marine deposits exposed near the Ussuri River in far northeastern China and in northern Shaanxi (Yin, 1979).

Marine Triassic

Marine Triassic rocks are especially well developed in Tibet, Yunnan, Guizhou, Guangxi and Sichuan provinces of southern and western China. Wang et al., (1981) have recognized six regions and 23 separate districts of marine Triassic deposits in China, based largely on stratigraphic development, facies and characteristic faunal assemblages. They are approximately coincident with all but two subdivisions applied to the section on Paleozoic stratigraphy, namely the Dzungaria-Khingan and the North China regions. They include the Himalayan, Gangdese-Hengduan, Qilian-Bayanhar, Yangtze, Southeast China, and Nadanhada Ling regions.

An extensive area of entirely marine Triassic sediments spanning the Scythian to the Rhaetian is known from the Himalaya near Jolmo Lungma Feng and also in the Tibet-west Yunnan region. The sequences around the former consist predominantly of a monotonous succession of fossiliferous, shallow water marine miogeoclinal carbonates and clastics. Farther north, particularly near the Yarlungzangbo River, the upper Triassic becomes distinctly more orogenic in character, and consists of a complex association of deformed, deep water flysch and radiolarian cherts intercalated with mafic volcanics and ophiolites.

The Gangdese-Hengduan region consists of two east-west trending belts. The southernmost belt extends from northern Gangdese (Transhimalaya) to the Nainentanghlashan and contains a 10,000 meter thick section of fossiliferous sandstones, shales, cherts and limestone interbedded with tuffs, rhyolites and andesites. The northernmost belt occupies the Kunlunshan-Tanggula-Hengduan Ranges and extends from western Xinjiang to western Yunnan. It consists of a 6000 to 7000 meter thick series of sandstones, shales, cherts, limestones, intermediate and mafic volcanics interbedded with terrestrial facies deposits and coals in upper stratigraphic levels.

The deposits of the Qilian-Bayanhar region encompass the Bayankelashan, Tasuehshan, western Qinlingshan and the eastern part of the Tibetan plateau. They comprise the most widespread, best-developed and thickest sections of the Chinese Triassic, occupying the Sungpan-Kantze Fold System (Huang, 1978) also known as the Sungpan-Kantze Accretionary Complex (Şengör, 1979) (Figure 10). Recent stratigraphic and paleontologic studies in this region have determined that middle and upper Triassic deposits are the most widely represented, consisting primarily of metamorphosed and unmetamorphosed neritic and bathyal clastics, flysch and subordinate carbonates intercalated with intermediate to mafic and intermediate to silicic volcanics and ophiolites succeeded by paralic deposits at the very top of the section (Plate III) (Fan, 1980; Li, 1980; Yin, 1980; Wang et al., 1980). They contain a primarily Tethyan fauna with subordinate Boreal-Pacific representatives which consist of Claraia, Halobia, Daonella, Eumorphotis, Myophoria and numerous amounts ammonoids, brachiopods and hexacorals.

Deposits of the Yangtze (Changjiang) region are primarily platform-type sediments. Lower and middle Triassic sections are solely marine (Yin, 1963) while the Carnian and Norian are of mixed facies and become progressively more terrestrial in character with time. Several laterally equivalent facies belts have been recognized. Sediments of the southern Guizhou-northern Guangxi belt consist of shallow-water and thin bedded shales and limestones, shales, sandy shales, calcareous mudstones, siltstones and sandstones containing Daonella, Posidnia, Claraia, and several genera of ammonites. Deposits of the southwest Guizhou-southeast Yunnan, northwest Sichuan-southwest Sichuan and southeast Sichuan-west Hubei areas comprise a second facies belt. They consist primarily of shallow water marine and paralic sandstones, siltstones, shales, cherts and carbonates whereas in the neighborhood of the Sichuan basin unfossiliferous dolomites, limestones and evaporites dominate. The dolomitic character of the deposits decreases outwards from the center of the basin towards the south, east and southwest and is accompanied by a concomitant increase in the thickness of the limestone sequences and the rapid disappearance of evaporites. Arkosic sandstones and shales interbedded with coal seams occur at uppermost stratigrahic levels. Triassic evaporites and shales of the Sichuan basin served as an important décollement horizon in the Sichuan basin during Jurassic and Cretaceous tectonism (Bally et al., 1980; Hsü, 1981). The central Guizhou facies belt is transitional in character between the first two.

Triassic marine deposits of the Southeast China region consist of a suite of thin, shallow water platform-type sediments. None of the Triassic sequences represent a complete Scythian to Rhaetian section. The Scythian and Anisian usually consist of limestones, dolomites and shaly limestones interbedded with paralic and terrestrial facies clastics.

These in turn are overlain by alternating marine and terrestrial clastics intercalated with limestones, evaporites, black shales and coals. Claraia, Eumorphotis, Posidonia, Meekoceras and Ophiceras are known from lower stratigraphic levels whereas Unio, Podzamites, Dictophyllum, Neocalamites and Eustheria are known from upper levels. The best exposed sections are in the lower Yangtze, Hunan-Jiangxi and Nanling areas (Wang et al., 1981).

Located west of the Ussuri River and Sikhote Alin, the Nadanhada Ling region of Heilongjiang province contains a thick sequence of norian geosynclinal facies deposits. They are comprised of sandstones and shales intercalated with tuffs, diabase, chert, tuffaceous siltstones and ophiolites. Unlike the typically Tethyan faunal elements of southern regions, the fauna represented here are decidedly Boreal-Pacific in nature and include Entomonotis, Otapiria, Oxytoma and Pleuromya (Compilation Group of the Geologic Map of China, 1977).

The upper Triassic formations of Southern China are made up mostly of paralic deposits and include one of the most important southern Chinese coal horizons. The Anyuan Formation of Jiangsi, the Sucheaho Formation of northern Sichuan, the Hsiangchi Formation of western Hubei, the Hsiangyun and Yiping-lang coal series of Yunnan (Meng, 1948) and the Tumenglo coal series of Tibet are all late Triassic in age. Unconformities within the upper Triassic (Carnian to Norian) at the top of the Triassic or between the upper Triassic and lower Jurassic are widespread throughout southern China and are usually accompanied by a rapid facies change from marine to paralic to terrestrial facies sediments (Yin, 1963; 1980). Such occurrences have been observed from Kwangyun and Weiyuan, Sichuan (Huang and Yao, 1940; Compilation Group of the Geologic Map of China, 1977) western Yunnan (Jen and Chu, 1970; Bally et al., 1980; Duan and Zhao, 1981), the western Kunlunshan and Tarim (Roger, 1963; Hu et al., 1969), the Qinlingshan and the Longmenshan (Tan, 1923; Chao and Huang, 1931; Jiang and Chu, 1964) Anyuan, Jiangxi (Compilation Group of the Geologic Map of China, 1977) and the Sichuan basin (Liu, 1969; Meyerhoff and Willums, 1976).

### Terrestrial Triassic

The terrestrial facies Triassic occurs mainly in northern and northwestern China, including recently discovered exposures in western Jilin and Peishan, Gansu. Deposits consist entirely of molassic, intermontane basin-type and are exemplified by the complete succession present in the Dzungaria (Saidov, 1956) and Shen-Ka-Nang basins, and upper Triassic sections in the Qaidam, Chu-chuan, Ordos, Turfan, and Tarim basins (P'ang and Ryabukhin, 1964; Meyerhoff and Willums, 1976; Sun, 1980).

Lower and middle Triassic series terrestrial facies of these regions are usually conformable with the Permian. They consist predominantly of purple and red conglomerates, sandstones, siltstones and shales, locally intercalated with marine horizons, silicic and intermediate volcanics and coals which have in some places been strongly deformed. Upper Triassic series are composed primarily of sandstones and shales intercalated with coal seams. Lower and middle series yield a rare vertebrate fauna including Lystrosaurus chasmatosaurus and Kanneria while the upper Triassic series often contain the characteristic "Yenchang" floral elements, notably Danaeopsis and Bernoullia (Compilation Group of the Geologic Map of China, 1977).

### Jurassic

The Jurassic deposits of China consist predominantly of terrestrial molasse-type coarse clastics intercalated with volcaniclastics and silicic to intermediate volcanics. Subordinate marine sequences are confined to southern and northeastern locations, particularly to the Himalaya, Tibet-west Yunnan, eastern Great Khingan and Nadanhada regions.

Marine Jurassic

The marine Jurassic of Tibet and the Himalayan region consists primarily of limestones, shelly limestones, sandstones, and shales with an abundant Hettangian to Pliensbachian faunal assemblage of brachiopods, pelecypods, ammonites, belemnites and echinoids of eastern Tethyean affinity. The marine Jurassic of western Yunnan are best exposed along the Salween (Nujiang) River and comprise four distinct formations which lie unconformably on older sequences. The 1000 meter thick Mengga Formation consists mainly of purple and red sandy shales and sandstones intercalated with dolomitic limestones, dolitic limestones, gypsum and basalt flows. This is overlain by the 600 meter thick Liuwan Formation which consists of brachiopod-bearing limestones and shales. The 200 meter thick Longhai Formation conformably overlies the Liuwan and consists mainly of yellow shales and siltstones with abundant marine pelecypods. Lying disconformably on the Longhai Formation is the unfossiliferous, 285 meter thick Longkan Formation, chiefly composed of reddish-yellow quartz sandstones and conglomerates. The Liuwan and Longhai Formations are correlative with contemporaneous deposits of northern Tibet, southern Qinghai and with the Namyau series of the northern Shan States of Burma (Yin and Fang, 1973).

Jurassic deposits of the southeastern Maritime and Nadanhada Ling region comprise a thick series of highly deformed deep water shales, cherts and mafic volcanics with an abundant western Pacific foram and ammonite fauna.

Undifferentiated lower Jurassic marine deposits, ultramafic rocks (Lin, 1956) (Plate II) and "marine shell beds" (Lin, 1962) (Plate V) in the eastern Great Khingan Range are significant although their relationships to the regional tectonics of northeastern China and adjacent regions remains controversial. It is possible that they are correlative with coeval marine Jurassic sequences and ophiolites of the Mongol-Okhotsk Foldbelt of eastern Mongolia and the southern Soviet Far East (Kosygin and Parfenov, 1976; Misnick and Shevchuk, 1977, 1980; Besznosov et al., 1978; Lefeld, 1978) and formed under oceanic or para-oceanic conditions.

Terrestrial

Terrestrial facies Jurassic deposits occur in a number of large inland basins in China. Molasse-type facies lacustrine and fluviatile variegated clastics intercalated with coals typify the Jurassic deposits of the Tarim, Qaidam, Dzungaria, and Shen-Ka-Nang basins which lay north of the Qinlingshan and western Kunlunshan foldbelts. Redbeds predominate in basins south of the Qinlingshan and western Kunlunshan foldbelts, notably in the Sichuan (P'ang and Ryabukhin, 1964; Meyerhoff and Willums, 1976) and central Yunnan (Yuanmo) (Bien, 1940a, b, 1941; Misch, 1945) basins. Lower and middle Jurassic deposits of the Songliao (Sungari River) and Fushin basins of northeastern China consist principally of fluviatile and lacustrine deposits interbedded with coals, and intermediate to mafic volcanics. Upper Jurassic sequences consist of intermediate, silicic and subordinate mafic volcanics intercalated with volcaniclastics, lacustrine deposits and coals bearing an abundant and well-preserved plant, ostracod and fish assemblage (Lin, 1956; Lin, 1962; Meyerhoff and Willums, 1976; Chin, 1980) (Plate II and V).

North-vergent folds and thrusts of various Paleozoic sequences of the southern Tienshan Foldbelt over the lower and middle Jurassic exposed along the southern periphery of the Dzungaria basin have also been observed (Meyerhoff and Willums, 1976).

Cretaceous

Cretaceous deposits of China are widespread and consist predominantly of terrestrial molasse-type facies coarse clastics interbedded with volcaniclastics, volcanics and coals (Morris, 1936) (Plates II, III and V). Marine and paralic deposits occur only in the western Kunlunshan foldbelt (Krestnikov, 1963), the Karakorum (Roger, 1963), the Himalayas (Le Fort, 1975), Tibet (Bally et al., 1980; Organizing Committee, 1980) and as minor littoral horizons in the Tarim (Krestnikov, 1963) and Songliao (Chin, 1980) basins. A regional late Jurassic-early Cretaceous angular unconformity has been observed throughout most of China, especially in northern and northeastern China (Morris, 1936; Cheng, 1963; Roger, 1963; Chang, 1966; Meyerhoff and Willums, 1976) and adjacent regions of eastern Mongolia (Lefeld, 1978) and the southern Soviet Far East (Kosygin and Parfenov, 1977).

Marine Cretaceous

Cretaceous marine and paralic deposits of southern and western China consist mostly of shallow water sandstones, siltstones, shales and limestones containing abundant Tethyan ammonites, pelecypods and forams. Exposures along the Yarlungzangbo River comprise a thick series of deep water sandy shales, black shales and cherts yielding ammonites and belemnites (Bally et al., 1980; Organizing Committee, 1980). A glauconite and phosphorite horizon bearing a littoral pelecypod assemblage from the lowermost upper Cretaceous of the Songliao basin has been described by

Chin (1980) and Morris (1936) has described pre-Valanginian marine deposits with a Boreal fauna from the upper reaches of the Amur River near the China-U.S.S.R. border.

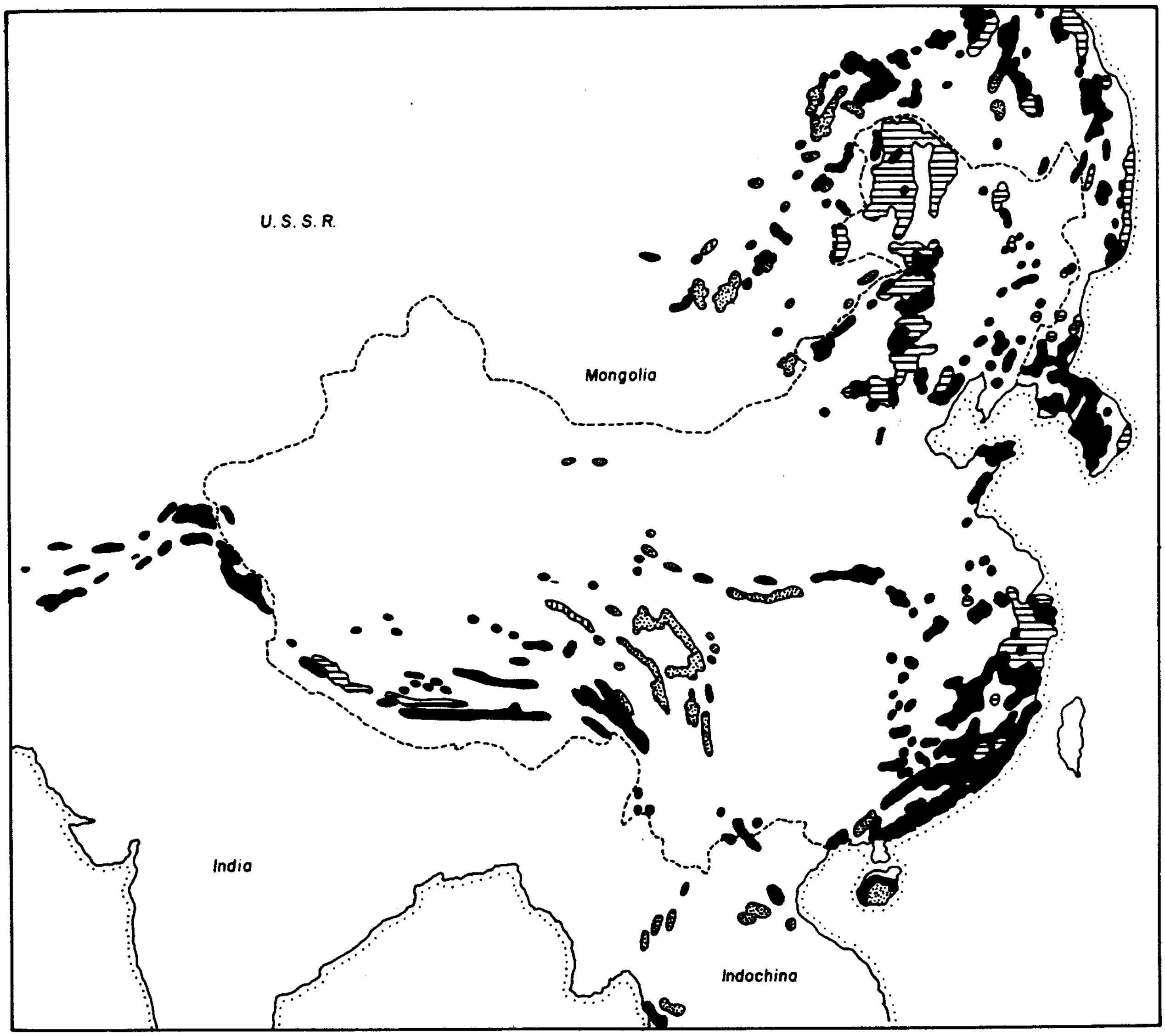
## Terrestrial Cretaceous

Terrestrial facies Cretaceous deposits occur in several central and western Chinese basins as well as the Songliao and neighboring basins in northern and northeastern China. They consist primarily of red conglomerates, sandstones and shales interbedded with evaporites and coals and containing an abundant fresh-water ostracod (Estheria) and fish fauna. Eastern basin sequences are also frequently intercalated with thick flows of silicic, intermediate and mafic volcanics, tuffs, tuff breccias and beds of volcaniclastics which increase in occurrence progressively eastwards. The principal accumulations of the terrestrial facies Cretaceous deposits occur in the Sichuan basin (Chao and Huang, 1931), near Guizhou (Hsieh and Chao, 1925), Zhejiang (Liu and Chao, 1927), western Fujian (Wang and Li, 1930), eastern Jiangxi (Kao, 1933), Gansu, Shaanxi (Yuan, 1925; Chi, 1931), northern Shaanxi (Teilhard de Chardin and Licent, 1924), Shandong (Grabau, 1928), the Western Hills of Beijing (Hsieh, 1933), Jilin and Liaoning (Tan, 1926; Lin, 1956; Lin, 1962) the Songliao basin (Meyerhoff and Willums, 1976; Chin, 1980), the Dzungaria basin (Saidov, 1956) and the Hulunchih, Tarim, Qaidam and Turfan basins (Meyerhoff and Willums, 1976). The Jurassic-Cretaceous transition occurs usually without interruption in some of the larger western and central basins although they are ubiquitously deformed, with the greatest intensity of deformation confined to the foldbelts that frame them and in the central Sichuan basin which is underlain by thick accumulations of Triassic shales and evaporites.

FIGURE II:

## Mesozoic Igneous Rock Distribution

: China, Mongolia, southern Soviet Far East




TRIASSIC ("INDOSINIAN"):

Granite

Volcanics

JURASSIC-CRETACEOUS ("YENSHANIAN"):

Granite

Volcanics

(after the Geologic Map of Asia, 1975)

## 4.5 Mesozoic Magmatism

Mesozoic igneous rocks are widespread throughout China and Korea and consist primarily of silicic to intermediate plutonics and volcanics with subordinate mafic and ultramafic rocks. They are divisible into two distinct associations based on age, relative position, mode of occurrence and overall extent (Figure 11). These associations are attributable to two major periods of tectonism, the late Triassic-early Jurassic "Indonisian" and the Jurassic-Cretaceous "Yenshanian" orogeneses. Coincident with such intense and widespread igneous activity was the initiation of several convergent plate margins, the consumption of oceanic lithosphere, intracontinental strike-slip faulting and continental collision. The "Indosinian" and "Yenshanian" orogeneses are important in that they mark those phases of continental nucleation which ultimately created the lithospheric framework comprising the eastern Chinese and Southeast Asian continental edifice.

### "Indosinian"

Late Triassic-early Jurassic magmatism was confined mostly to central and southwestern China and to adjacent regions of Southeast Asia, and was the apparent culmination of a range of igneous activity that commenced during the late Permian. Those igneous rocks distributed mainly in eastern Tibet, along the Ailaoshan and Longmenshan foldbelts of Yunnan (Misch, 1945, 1947) and Sichuan provinces, the western Kunlunshan foldbelt, the Qinlingshan, Kekexilishan and Nanling Ranges are composed primarily of granites, granodiorites and andesites which in places reach batholithic dimensions. They are accompanied by mafic and alkaline intrusive complexes and by the emplacement of ophiolites. They are intrusive into Triassic and older marine strata and are unconformably overlain by upper Triassic or lower Jurassic coarse clastics. K/Ar dates obtained from granite exposures in several areas yield 190 million year to 230 million year ages (Wang, 1982, personal communication), while the ages of eastern Qinling pegmatites range between 205 and 140 million years (Ninth Lab of Chengdu, 1973). Ages of between 90 and 190 million years from the granites of the Nanling have also been obtained (Li, 1969). Several bodies of Indonisian granite are also known from the Peishan of Gansu, the western Qinling, the Dabieshan and the Liuwantashan of Guanxi as well as the Great Khingan Range of northeastern China and adjacent eastern Mongolia (Plates I, II, III, IV and V) (Khasin and Borzakovskiy, 1967; Geologic Map of China, 1976; Compilation Group of the Geologic Map of China, 1977; Lefeld, 1978; Bally et al., 1980). The late Triassic-early Jurassic tin-bearing granites and granodiorites of Yunnan and southern Sichuan are undoubtedly correlative with coeval and similar metalliferous granites from adjacent regions of Southeast Asia (Mitchell, 1977).

"Yenshanian"

Jurassic-Cretaceous Yenshanian magmatism was apparently of much broader extent than the Indosinian (Figure 11), especially in the circum-Pacific regions of eastern China, in the Great Khingan Range as well as throughout all of southern China. Yenshanian intrusives are generally subdivided into two phases, roughly Jurassic (Yenshanian I) and a Cretaceous (Yenshanian II) phase (Wang, 1982, personal communication).

Early Yenshanian intrusives occur mainly in southeastern China, along the lower and middle reaches of the Yangtze River, northern and northeastern China as well as Tibet and Yunnan. They intrude Jurassic and older strata, are unconformably overlain by Cretaceous strata and yield isotopic age values of between 150 million years and 190 million years (Jahn, 1974; Compilation Group of the Geologic Map of China, 1977; Wang, 1982, personal communication). They consist principally of biotite granites, granodiorites and diorites. They are represented by the Nanling and Mufushan granites of the lower and middle Yangtze region, the Hsingtze granite of Lushan, the Huangshan granite of Anhui as well as several undifferentiated stock-like dioritic and granodioritic plutons in the Yenshan, Great Khingan and Yunnan regions. A variety of mafic and ultramafic-ophiolitic bodies occur within major thrust zones along the coast of Zhejiang and Fujian, along the lower and middle Yangtze, in the Nadanhada Ling and Great Khingan Ranges of northeastern China and in western Yunnan.

Late Yenshanian intrusives occur mainly in eastern China, Tibet and Yunnan. They are intrusive into Jurassic-Cretaceous sequences and are overlain by upper Cretaceous and Tertiary deposits and yield isotopic age values of between 80 and 130 million years (Jahn, 1974; Compilation Group of the Geological Map of China, 1977). Biotite granites, granodiorites, monzonites and a variety of small alkaline intrusives are known from southeastern China. Granite and granodiorite batholiths and associated alkalic intrusives are known from Shandong, the Liaodong peninsula, the eastern Qinling, eastern and southern Tibet and in the Karakorum. The Tanggula ultramafics-ophiolite suites of central Tibet were apparently emplaced during the late Yenshanian as well.

## 4.6 The Regional Structure of eastern China

Northeastern China may be subdivided into two tectonically distinct regions, the Sino-Korean (North China) paraplatform (Huang, 1978) and the North China (Inner Mongolian-Great Khingan, Jilin-Heilongjiang) Fold

Zone (Plates I and IX). Both regions appear to have had a long and complex history but are tectonically dissimilar in that the Sino-Korean Paraplatform behaved as a stable block throughout the Phanerozoic whereas the North China Fold Zone appears to have been fairly mobile, especially during the latter Paleozoic and Mesozoic. The structural discontinuity between them is the Yinshan-Tümen ophiolite zone (Bally et al., 1980; Li, 1980), a localized zone of deformation with a complex history of movement as a late Paleozoic suture and perhaps as a Mesozoic transcurrent fault zone. The dominant structural element comprising southern China is the Yangtze (South China) Paraplatform which comprises two distinct northeast-southwest trending regions, the Yangtze craton and the South China Fold System (Huang, 1978). Both regions appear to have been tectonized at various times throughout the Phanerozoic, although the Yangtze craton appears to have remained relatively stable in comparison to the South China Fold System which was subject to strong Siluro-Devonian and Jurassic-Cretaceous orogenesis. The structural discontinuity between them is the northeast-southwest trending Chang-Nan geanticline (Figure 6) (Jen, 1968; Wang, 1982, personal communication) which extends from eastern Yunnan to the Yangtze delta. A zone of moderate Siluro-Devonian "(Caledonian)" uplift and granite intrusion, it is the northwesternmost limit of late Silurian to early Devonian deformation in southern China. The Yangtze Paraplatform is bracketed entirely by Mesozoic fold and thrust belts.

The Sino-Korean Paraplatform comprises approximately one half of northeastern China, extending from the western margin of the Ordos basin in Ningxia Hui and Gansu provinces eastward through Shandong, Hobei and Jiangxi provinces to Korea and the East China Sea. It consists of an Archean to Proterozoic crystalline core unconformably overlain by a succession of Paleozoic marine platform-type sediments from which Upper Ordovician, Silurian, Devonian and Lower Carboniferous sections are absent. Uppermost Paleozoic and almost the entire Mesozoic sequence appear to consist largely of terrestrial facies sandstones, shales, conglomerates and evaporites, interbedded with thick coal seams. Upper Permian and Triassic sequences are also interbedded with tuffs and coarse volcaniclastics and the redbed facies Jurassic sequences contain thick andesite and rhyolite flows, tuffs and coarse volcaniclastics especially at upper stratigraphic levels. The entire succession is extensively intruded by Jurassic-Cretaceous granite. The most widely recognized unconformities are between the Triassic and the Jurassic and between the Jurassic and the Cretaceous (Plate II). Sequences of lower and middle Cretaceous strata have been involved in complex north- and northwest-vergent folds and thrusts along the northern and southern margins of the Ordos basin (Wong, 1929; Chang, 1966) (Plate I). "Yenshanian" magmatism appears most intense on the northern margins of the paraplatform where a thick sequence of late Jurassic andesites are followed by a thick succession of early Cretaceous rhyolites and rachytes. The southern edge of the paraplatform was also the site of considerable Mesozoic igneous activity, with granites and granodiorites of late Triassic to early Cretaceous age exposed in the Qinling-Dabieshan foldbelt (Figure 5 and 6; Plate IX).

The North China Fold Zone comprises the northeasternmost provinces of China including Heilongjiang, Jilin and parts of Inner Mongolia and Liaoning. It is not known with certainty to what extent the region is underlain by Precambrian crystallines. The only exposures of Archean and Proterozoic gneisses are sporadic outcrops along the Yinshan-Tümen zone, at Lake Khankha along the Ussuri River zone and in the Lesser Khingan. Most lithologies are late Paleozoic and younger and consist predominantly of Permo-Carboniferous granites, Mesozoic terrestrial and shallow marine facies sediments and Jurassic-Cretaceous intrusives and volcanics (Plate II). Upper Devonian through Permian deposits are sparse and consist of platform-type marine clastics and carbonates with an abundant littoral fauna. These in turn have been intruded by late Paleozoic silicic plutonics and in southeastern Inner Mongolia are associated with serpentinized peridotites. There is an absence of Triassic age rocks (Cheng, 1958; Lin, 1980) but Jurassic and Cretaceous terrestrial sandstones, shales, conglomerates, volcanics, evaporites and coals are locally interbedded with some marine limestones and other littoral horizons (Lin, 1956; Lin, 1962; Chin, 1980).

The Yangtze paraplatform comprises the entire of southern China from Yunnan and Sichuan provinces to the South China Sea. The northwestern half is presumed to be underlain by Proterozoic gneisses and schists which form the core of the Yangtze Craton. The extent of Precambrian crystallines in the southeast is unknown. The paraplatform cover consists of marine carbonates and clastics ranging from late Precambrian (Sinian) to the Triassic and earliest Jurassic with a characteristic Devonian and Carboniferous hiatus in Sichuan and northern Guizhou. Unlike the Sino-Korean Paraplatform there is a well-developed Silurian and Devonian sequence which includes widespread upper Devonian molasse that appears to have been derived from the Chang-Nan geanticline. The widespread medial late Permian Omeishan plateau basalts are ubiquitious in eastern Yunnan, southern Sichuan and western Guizhou and appear to be related to the initiation of a convergent plate margin. Jurassic, Cretaceous and Tertiary cover sequences are comprised primarily of terrestrial facies clastics. The boundaries of the Yangtze Paraplatform are framed by Mesozoic and Tertiary fold and thrust belts. The paraplatform cover is also characterized by an extensive décollement fold system involving its detachment from underlying Paleozoic shales and Triassic evaporites (Hsü, 1981). Major regional unconformities exist between the Silurian and the Devonian, the Permian and the Triassic, the Triassic and Jurassic and the Jurassic and Cretaceous.

# CHAPTER V

# INDOCHINA AND EASTERN THAILAND

## 5.1 Precambrian

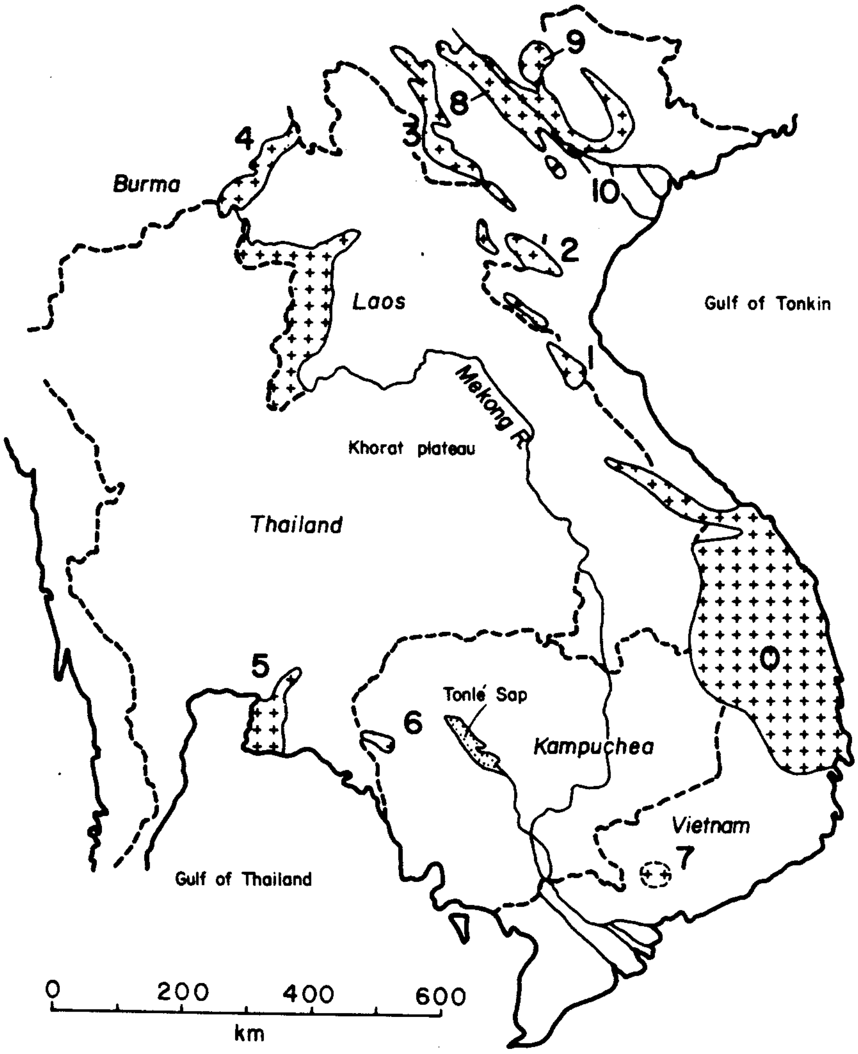
The principal areas of exposed basement rocks are shown on Figure 12 (see plate XI for locations not shown in Figure 12). They are as follows: the Kontum Massif of central Vietnam, extending into Laos at Tschepone; the Rao Ca and Song Ma Massifs located near the Laos-Vietnam border; the Chieng Saen Massif exposed along the Laos-Thailand-Burma frontier area; the Cholburi Massif of eastern Thailand and, the Pailin Massif of western Kampuchea. There is evidence of concealed basement at Bien Hoa, near Saigon (Ho Chin Minh Ville) as indicated by xenoliths of gneiss in bedded late Paleozoic tuffs (Workman, 1972).

The first of these, the Kontum Massif, is by far the largest with a estimated area of 60,000 square kilometers. The Kontum Massif constitutes the exposed part of a cratonic area which is believed to have formed a nucleus around which the younger fold belts were developed more or less concentrically (Postel'nikov, 1960; Workman, 1972). There is only a very generalized knowledge of the Precambrian of the Kontum Massif and very little can be said about the subdivision of basement complexes except in the broadest sense. Saurin (1953) presented a tentative grouping of the principal rock types, repeated in tabular form by Workman (1972).

The Song Ma and Rao Ca Massifs are comprised of Precambrian and lower (?) Paleozoic age metamorphic rocks which lie along a series of anticlinal structures extending from southern China across northwestern Vietnam and southeastward along the Vietnam-Laos border. Saurin (1956)

FIGURE 12:

**Exposures of Precambrian Massifs of Indochina**




| | | |
|---|---|---|
| 0 - Kontum | 2 - Song Ma | 3 - Song Ma |
| 4 - Chieng Saen | 5 - Cholburi | 6 - Pailin |
| 7 - Dong Nai | 8 - Fan Si Pan | 9 - Viet Bac |
| | 10 - Song Tay | |

(after Workman, 1972)

and Workman (1972) have identified an early Proterozic and an early Palaeozoic metamorphic series, the former consisting of mica and graphite schists with micaceous quartzites, marbles and granite gneisses and the latter comprised of micaceous arkoses, phyllites, quartzites, mica- and graphite-bearing calcareous schists and marbles.

The Chieng Saen Massif extends across eastern Burma and northwestern Laos and southwards into northern Thailand (Hoffet, 1934; Page and Workman, 1968). Exposures near northwestern Laos consist partly of coarse, non-foliated, leucocratic granite. There are tracts of gneiss, including augen-gneiss, and it may be that all the granitic rocks in that area either belong to the Precambrian basement complex or were accreted to it during Paleozoic and Mesozoic tectonism. Minor bands of crystalline schists occur both within the Chieng Saen Massif and elsewhere in northern Laos. The exposures at Pak Beng are comprised of schists and marble and in the frontier range of Phu Pha Moun, west of Pak Tha they are made up of biotite and amphibole schists.

The Cholburi Massif of eastern Thailand consists of quartzofeldspathic gneisses, migmatites and a variety of granites. Exposures extend from near Kabinburi in the north to the Gulf Coast at Cholburi in the west and Sattahip in the south (Figure 12) and to offshore islands in the Gulf of Thailand. Within and marginal to the granite-gneisses of this area are bands of low grade metasedimentary rocks speculatively assigned to the lower Paleozoic. There are also occurrences of non-foliated granites, granophyres and pegmatites which may be migmatized parts of the basement affected by younger tectonism.

The Pailin Massif has a comparatively limited exposure near western Kampuchea and the eastern Thai border (Figure 12) (Gubler, 1935). It may extend southwards under the western part of the Cardamone Mountains which are comprised of gently dipping Mesozoic terrestrial facies sandstones. The Pailin Massif seems to lie within both the late Paleozoic and early Mesozoic orogenic belts which extend across southeastern Thailand and southwestern Kampuchea. The metamorphic rocks of the Pailin area include granites, diorites and plagioclase and amphibole gneisses. There are also orthoamphibolites and mafic gneisses which grade into metagabbros and a variety of metamorphosed sedimentary rocks.

5.2 Paleozoic Stratigraphy

Unless noted otherwise, the stratigraphic data presented in this section is essentially that of Saurin (1953); Workman (1972), Fontaine and Workman (1978) and Luong and Bao (1979).

Very little is known about the Cambrian in the lower Mekong Basin. Paleontological evidence is restricted to the possible but unconfirmed identity of the Cambrian trilobite Asaphiscus aff. gregarious in sandy shales in north central Kampuchea, north of Stung Treng (Postel'nikov, 1960). The Ordovician and Silurian are known from northern Laos and the Silurian may be present in northeastern Thailand at the base of the Devono-Carboniferous Kanchaniburi Group.

The most extensive of the lower Paleozoic formations is the Dalat eries of southern Vietnam (Fromaget, 1944; Tri, 1979) and southern Kampuchea. An undated formation in west Cholburi province of southeastern Thailand may also be Cambro-Silurian with equivalents in Kampuchea and Peninsular Thailand. The metasedimentary cover complex of the Songma Massif of northeastern Laos may also be partly lower Paleozoic in age.

The Cambro-Silurian Dalat Series of Southern Vietnam occupies an important place in the southern Vietnamese "geosyncline" of Workman (1972) which also includes beds up to early Carboniferous in age. The series consists predominantly of shales, slates, phyllites and a variety of schists (Saurin, 1935). The Dalat contains no known fossils and is unconformably overlain by Devonian and Carboniferous formations. The Dalat series is not younger than Cambro-Silurian and the age of folding and metamorphism may be Siluro-Devonian according to Luong and Bao (1979).

Formations which resemble and are correlated with the Dalat Series occur over parts of south and west Kampuchea (Gubler, 1930; Saurin, 1935). Like the Dalat, they are overlain unconformably by the Devonian and Carboniferous.

The oldest known fossiliferous strata in Laos are Ordovician (Fromagét, 1941). No structural break is known between these beds and the overlying Devonian from which the Ordovician and Silurian are generally not separated. The principal area in which Ordovician and Silurian strata are exposed is the Phu Loi Massif which extends northwards from Ban Ban to beyond Muong Son. Beds attributed to the Ordovician and Silurian comprise shales, phyllites and sericite schists, greywackes, sandstones and thin-bedded limestones. The Ordovician is represented near Ban Ban by sercitic schists containing Trinucleus cf. ornatus. The Silurian fauna include Encrinurus punctatus var. laoensis and Lichas cf. scabra, and also Spirifer sulcatus (Gubler, 1935; Saurin, 1935).

The dolomitic limestones found on the island of Ko Si Chang in the Gulf of Thailand are speculatively correlated with the Ordovician limestones of the Thai-Malay Peninsula (Dept. Mineral Resources, 1964). Bands of lower Paleozoic phyllite, quartzite, and limestone are associated with the Cholburi Massif and appear to be partly folded into it.

Upper Paleozoic sedimentation commenced with widespread submergence in the medial Devonian (Duong and Thom, 1979; Tran and Bao, 1979). Prolonged and extensive marine sedimentation ensued, interrupted in places by emergence, erosion and periods deformation, but continuing regionally into the Mesozoic.

A break within the upper Paleozoic sequence, accompanied by the strong folding of the older sequences in some places, occurs about the middle of the Carboniferous during the Visean, Namurian and Moscovian. The Namurian is known only in the Annam Cordillera of eastern Laos.

The known Devonian rests unconformably on older rocks in almost all areas. Little is known about the lower Devonian. Widespread marine transgressions seem to have begun only at the end of the lower Devonian, reaching their maximum extent in the Eifelian but still leaving several older massifs such as the Kontum and Song Ma as emergent masses (Postel'nikov, 1960; Duong and Thom, 1979). Shallow, epicontinental seas remained through the succeeding Givetian and Frasnian stages but regressed in the Famennian (uppermost Devonian) leaving only a narrow gulf in central Vietnam and eastern Laos (Hué-Khammouane) within which sedimentation continued into the Dinantian (earliest Carboniferous).

The relationship between the Devonian and the Dinantian of southeast Asia is rarely visible. Exposures in eastern Laos and central Vietnam show a conformable passage between the Devonian and the Dinantian whereas in other areas there is a hiatus but not an angular unconformity.

Devonian through Dinantian sequences are exposed in the following areas. In eastern Laos and central Vietnam, the Annamitic Zone was the site of a northwest-southeast trending epicontinental sea extending from Khammouane on the Mekong to Hué, with a separate portion farther south at Attopeu in southeastern Laos. Towards the northeast, the

Annamitic zone passes into the oceanic facies belt in the Vinh Thanh Hoa region of Vietnam; in northern Laos, extending from Pak Lay to Xieng Khouang and beyond Xieng Khouang to Phu Loi the deposits comprise partly epicontinental and partly 'geosynclinal" facies; in eastern central Thailand, along the southern extension of the Pak Lay zone in Laos, and in Kampuchea and southern Vietnam where epicontinental and unfossiliferous terrestrial facies deposits are exposed (Duong and Thom, 1979).

The largest single expanse of Devonian strata is exposed in the Annamitic Zone of eastern Laos and central Vietnam, extending northwest of Hué as far as Khammouane (Fromagét, 1941; Duong and Thom, 1979). A series of fossiliferous marine and paralic beds lies along the northern margin of the Kontum Massif. No lower Paleozoic strata are known from this part of Laos, and the Devonian rocks rest with marked discordance on the Precambrian crystalline basement of the Kontum Massif (Saurin, 1953).

Devonian deposits along the western margin of the Kontum Massif are of littoral and paralic facies and consist mainly of sandy shale, marl and yellow sandstones with minor limestone interbeds which bear an Eifelian fauna (Hao et al., 1979 a, b). Reef deposits in eastern Laos contain the Eifelian coral Calecola (Fontaine, 1961) which is considered diagnostic as well as Favosites and Helialites. These deposits are succeeded by shallow water Frasnian sandstones bearing Spirifer and Dechenella.

Dinantian strata consist predominantly of fossiliferous limestones. Exposures of these limestones in the Annamitic zone of eastern Laos extend into the Moscovian and contain an abundant assemblage of corals, brachiopods, bryozoa, ostracods and forams. These limestones are in turn overlain by goniatite-bearing shales near Ban Phit in eastern Laos

(Fontaine, 1961). Further to the northeast, the Annamitic zone deposits become distinctly oceanic in character especially near Vinh in the Song Ca Valley (Fromagét, 1941). Sedimentation in this area appears to have been continuous from the Silurian to the early Devonian with an Eifelian to Givetian fauna confined to shales which eventually pass upward into quartzites, limestone, and radiolarites. They have been thrust southwestwards, over shallow water sequences, as the large Nam Nhuong nappe (approximately 220 kilometers long) apparently for a distance of 60 kilometers (Din Kat, 1972). Autochthonous Devonian sequences of the Annamitic zone are observed farther to the north near Thanh Hoa and comprise black shales, radiolarian cherts, marls and marbles. Still further north into Guangxi and Guangdong provinces of southern China this facies gives way to fossiliferous shales and limestones.

Devonian strata of northern Laos overlie the Silurian without any apparent discordance and pass upwards into the Dinantian without a break (Fromagét, 1941). This prolonged period of sedimentation ended with folding and emergence before the Moscovian, causing the appearance of a land mass (island arc?) in the central part of northern Laos. The principal exposures of Silurian, Devonian and Dinantian strata are found across this landmass which is only partially hidden by mainly horizontal Dinantian and younger sedimentary cover. Throughout the remainder of northern Laos, Permo-Carboniferous and Mesozoic strata cover older formations (Saurin, 1956).

Silurian, Devonian and Dinantian deposits are treated essentially as a single group, apparently due to the lack of detailed mapping. The Devonian section is a complete one, and fossiliferous strata are exposed principally in the Phu Loi (Muong Son) area, north of Xieng Khouang and southwest of the Tranh Ninh Plateau (Plain of Jars). Devonian limestones bearing Atrypadesquamata predominate near Phu Loi, while southwest of the Plain of Jars, shales, greywackes and sandstones containing brachiopods, corals and lamellibranchs dominate (Saurin, 1956).

West of Vientiane, Devonian strata are exposed mainly west of the Mekong River, and consist of limestone with cherts and an Eifelian-Givetian faunal assemblage including Heliolites porosus and Favosites styriacus (Bourret, 1925; Fontaine, 1961). Unmetamorphosed Dinantian shales and greywackes exposed near Pak Lay are overlain unconformably by upper Carboniferous and Permian strata equivalent to the Kanchanaburi Formation of western Thailand. Shales and greywackes comprise the Dinantian of eastern Laos and contain an abundant fauna of brachiopods gastropods, corals, bryozoa and foraminifera.

The Devonian-Dinantian stratigraphy of Thailand is poorly known, but two lithostratigraphic units have been defined to encompass strata of this age, namely, the Kanchaniburi (Silurian-Devonian) Formation and the Karny Krachan (Devonian-Carboniferous) Formation. Loei province and northern Thailand contain the only known fossiliferous Devonian strata in the entire country, and bear corals (Bourret, 1935) and graptolites (Jaeger, et al., 1968) respectively.

The Tanaosi Group covers large areas of Phetchabun and Loei provinces in east-central Thailand, and consists of strongly cleaved sandstones, siltstones, shales, greywackes, arkoses and tuffs with subordinate limestone, marl and bedded cherts. It is overlain unconformably by upper Carboniferous marine sequences of sandstone, shales and limestones or the Permian Ratburi limestone. The Tanaosi in Kanchanaburi province bear Tentaculites remains that are similar to those of the Shan States of Burma (Thein, 1978) and indicate a possible Silurian age. Medial Devonian corals have also been found in the Tanaosi Group of eastern

Loei province and late Devonian to early Carboniferous remains from this group have been discovered in western Loei province.

Devonian through Dinantian sequences of southern Vietnam exposed between Ho Chih Minh Ville and Nha Trang appear to be part of an oceanic assemblage of shales and cherts which unconformably overlie the lower Paleozoic Dalat Series and were strongly deformed during the medial Carboniferous (Saurin, 1935; Fromagét, 1941). The southern part of Kampuchea and the Transbassac region of southern Vietnam contain Devonian-Dinantian sequences comprised of shale, sandstone, limestone and chert with a few beds of marl.

Equivalent units crop out near Pailin in western Kampuchea and consist of a two-part unit (Gubler, 1935). The lowermost unit consists of shale, sandstone, marl, chert and the uppermost unit of shale and marl with sandy limestone.

Devonian-Dinantian units of southern Vietnam and Kampuchea are markedly unfossiliferous and regional correlations appear to be often based solely on lithologic similarity.

A stratigraphic and structural hiatus between the lower and upper Carboniferous (Dinantian to Moscovian) is ubiquitous throughout Indochina, with the exception being an occurrence of the Namurian in eastern Laos (Fromagét, 1941). This interval appears to be synchonous with a period of major folding and magmatism accomapnied by a low grade regional metamorphism.

Upper Carboniferous and Permian sedimentary facies consist of four laterally correlative types according to Workman (1972). The first group comprises terrestrial and paralic facies conglomerates, sandstones and shales with plant remains and coal seams. The second group are epicontinental clastic facies sediments comprised of relatively unfossiliferous shallow water marine shales and sandstones. The third group is also an epicontinental facies but consist mostly of shelf-type limestone with subordinate shales and sandstone, bearing an abundant fauna. The fourth group consist of relatively deep water graptolitic shales and greywackes.

Groups one, two and most of four comprise the "Indosinia Inferieures" of the Service Géologique de L'Indochine and groups two, three and four have a well defined, mutually interfingering and lateral replacement relationship.

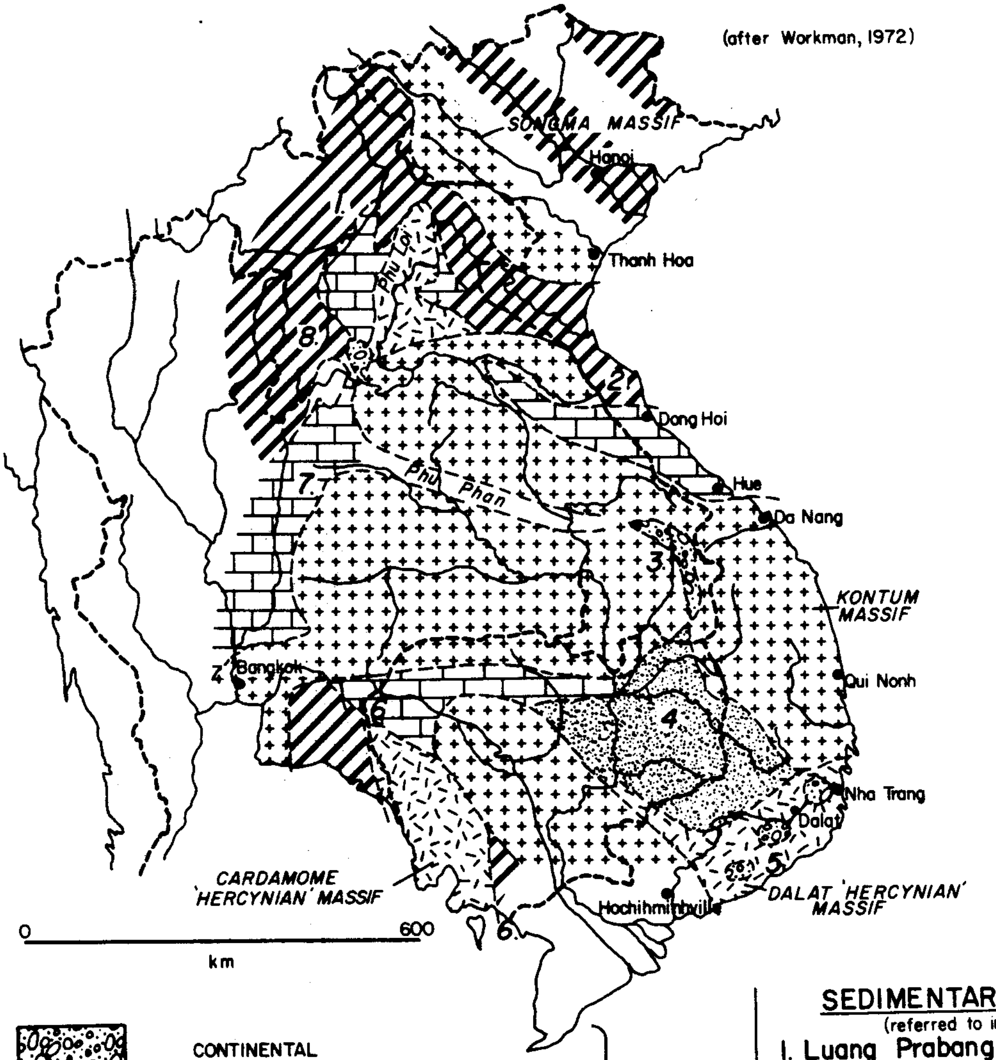
These upper Carboniferous and Permian complexes are exposed in eight distinct areas each of which represents a paleogeographically unique location according to Workman (1972) (Figure 13). They are: northwestern Laos (Luang Prbang Zone); eastern Laos and central Vietnam (Annamitic Zone); southern Laos (Saravane-Attopeu Zone); east central Thailand (Phetchabun Zone); west central Thailand (Pak Lay Zone); eastern and northern central Kampuchea; southern Vietnam and southern and western Kampuchea and southeastern Thailand.

Northwestern Laos during the Late Carboniferous and Permian was a broad zone of sedimentation with many local paleogeographic variations (Fromagét, 1941). The Luang Prabang Zone (Fromagét, 1935a), which encompasses the region north of Sayaboury contains a complete upper Carboniferous through Permian deep and shallow water marine succession. Throughout northwestern Laos there are exposures of upper Paleozoic reef limestones that pass laterally into thin bedded shales. The majority of them are Permian but Mesozoic age limestones are known from Phu Loi and west of Dien Bien Phu (Fromagét, 1941; Postel'nikov, 1960). Moscovian to Uralian limestones bearing Triticites fusilinids are known from the Pak Lay Zone, but most of the limestone in the Sayaboury-Luang

## FIGURE 13:

### LATE PALEOZOIC PALEOGEOGRAPHY OF INDOCHINA

(after Workman, 1972)




| | | |
|---|---|---|
| CONTINENTAL | DEPOSITION | |
| CLASTIC-SHALLOW MARINE | | |
| CARBONATE-SHALLOW MARINE | | |
| OCEANIC | | |
| HERCYNIAN DEFORMED MASSIF | EMERGENCE | |
| PRE-HERCYNIAN DEFORMED MASSIF | | |

**SEDIMENTARY 'REGIONS':**
(referred to in text)

1. Luang Prabang zone
2. Annamitic zone
3. Saravane-Attopeu
4. Eastern and north-central Kampuchea
5. Southern Vietnam
6. Southern and western Kampuchea, southeastern Thailand
7. Phetchabun zone
8. Pak Lay zone (western Laos)

Prabang-Muong Ngai district are Permian and contain a varied fauna including fusulinids, bryozoa, brachiopods, gastropods and corals (Workman, 1972). They are assigned to the Sakmarian, Artinskian and Kungurian stages, while the Kanzanian and Tartarian (late Permian) stages are dominantly non-calcareous sequences. Exposures of fossiliferous marine shales, sandstone and greywackes are much less numerous than those of the limestones. West of Muong Fuong along the Lik River, exposures of Uralian tuffs and sandstones are present. Exposures of Artinskian (early Permian) fossiliferous marine shales and sandstones are known from Phu Loi and the Beng River. Limestones of Kungurian age overlain by Kanzanian to Tartarian age clastics are exposed near Luang Prabang and contain brachiopods and plant remains. The upper Paleozoic succession exposed near Pak Lay consists mainly of grey to black shales with siltstones, fine grained sandstone and lenses of reef-type limestones (Fromagét, 1935a).

The Dinantian and Moscovian sequences of the Annamitic Zone consist of fossiliferous limestone (Hung, 1980), and marine deposition appears to be continuous from the Devonian to the Moscovian elsewhere in this zone. Permian deposits are relatively sparse and consist of marine sediments bearing fusulinids (Hung, 1980).

The late Paleozoic paleogeography of the Annamitic Zone (Figure 13) was marked by the transgression of a shallow sea across the northeastern margin of the emergent Kontum Massif and was manifest in the deposition of shallow marine pre-Moscovian sandstones, shales and limestones (Fromagét, 1941). Farther northeast, an ocean basin was developing during the Devonian and Carboniferous and filling with clastic sediments of the "Indosinas" facies (Luong and Bao, 1979). Basalt flows occur at the base of the upper Permian in far northwestern Vietnam and are probably correlative with the Omeishan (Emei) plateau basalts of adjacent southwestern China (Plate IV).

The upper Carboniferous deposits of the Saravane-Attopeu Zone of southern Laos consist principally of continental and epicontinental facies grey and black shales with plant remains, sandstones, grits and coal seams (Fromagét, 1941). The lower Permian consists of marine limestone and is only exposed in an area near Saravane.

Upper Carboniferous and Permo-Triassic strata occupy a wide expanse of north-central and eastern Kampuchea (Gubler, 1935; Saurin, 1935). They are mostly of shallow water facies, consisting of sandstones, shales and subordinate limestones and comprise a part of the "Indosinias Inferieures". These sequences were apparently deposited in a shallow epicontinental sea on a submerged portion of the Kontum Massif (Fromagét, 1941). The upper Permian "Indosinias Inferieures" facies passes upwards into similar sequences of fossiliferous Triassic and Jurassic age withou any major hiatus or structural discontinuity. Fossiliferous Permian limestones are very restricted in northern and eastern Kampuchea and occur as small, more or less lensoid masses in shales and sandstones.

The upper Carboniferous and Permian sediments of the region east of Ho Chih Minh Ville were deposited a southern extension of the emergent Kontum Massif which was itself uplifted during late Palaeozoic tectonism (Fromagét, 1941). The upper Permian sediments deposited in eastern Kampuchea may have been the erosional detritus shed from the Kontum. Within the confines of the Kontum massif, upper Carboniferous beds are found on the present day surface as a number of outliers, resting with marked unconformity upon folded Cambrian through Dinantian sedimentary rocks and medial Carboniferous intrusions. The upper

Carboniferous beds were probably deposited in separate intermontane basins, representing in part a terrestrial equivalent of the marine and epicontinental facies of eastern Kampuchea. There are no known marine strata of upper Carboniferous to Permian age northeast of Ho Chih Minh Ville but between the Dalat Massif and eastern Kampuchea is the "sillon cochinchinois" of Saurin (1935) which may represent the deposits of a deep water marine embayment that persisted from the upper Carboniferous to the lower Jurassic.

Upper Carboniferous and Permian deposits of southern and western Kampuchea and southeastern Thailand consist entirely of marine shelf facies comprised of highly fossiliferous massive reef limestones which are exposed in extreme southern and in northwestern Kampuchea (Gubler, 1935). They unconformably rest on folded lower Paleozoic to Dinantian strata and are interbedded with subordinate beds of sandstone, conglomerates and marl.

Upper Carboniferous and Permian sequences of east-central Thailand (Phetchabun Zone) comprise the well described Rat Buri Limestone Group which extends along the western edge of the Khorat Plateau from Sayaboury to Loei and in northeastern and southeastern portions of the country (Dept. Min. Res., 1964; Yanagida, 1964; Ridd, 1978). The Rat Buri Group succession in the Phetchabun Zone consists of massive limestones interbedded and grading into thin-bedded limestones, marl, shale, siltstone, and sandstone sequences. The limestones also comprise fine-grained clastics and pebble conglomerates in addition to accumulations of shell fragments and reef facies deposits. This facies is entirely clastic in the northwestern Loei area, consisting of marine and paralic facies deposits. The Rat Buri Group consists of two distinct facies sequences, a southeastern and a northwestern. The former consists of massive fossiliferous limestones and shales and the latter consists of unfossiliferous black shales and siltstones. The black shale-siltstone facies continues northwards to the Pak Lay Zone in Laos.

The Pak Lay Zone (Bourret, 1925; Page and Workman, 1968) is the northward continuation of the Phetchabun Zone of Thailand. Dark grey to black shales, siltstones and fine-grained sandstones without limestone comprise the upper Carboniferous and Permian of the southern parts of the Pak Lay; while shales interbedded with massive limestone beds increase in abundance to the vicinity of Sayaboury. North of Sayaboury, thin bedded shallow water shales and limestones become the dominant facies near the Luang Prabang Zone. West of Vientiane, there is a transitional zone between the supposed landmass (island arc?) of central Laos and the upper Paleozoic to Mesozoic sedimentary trough of Pak Lay.

### 5.3 Mesozoic Stratigraphy

The Mesozoic deposits of Indochina (Plate IV) consist of two major sedimentary facies groups. The first is a dominantly marine facies of early Triassic to Liassic age. The second is an essentially terrestrial facies of Triassic to Cretaceous age alternately referred to the Indosinias Group, Khorat Group, Terrain Rouge and Grés Superieures. There is a general vertical transition from marine to continental facies in a given stratigraphic section, but this transition was not synchronous across the entire region. There is a good deal of lateral variation in the marine and terrestrial facies groups, especially in the Upper Triassic and the Liassic (Plate IV). Nevertheless, there appears to be a gradual emergence from marine to a more terrestrial environment across the region in the upper Triassic and lower Jurassic.

The transition between the Paleozoic and Mesozoic is marked in many places, especially Laos and Thailand, by a stratigraphic hiatus between the Permian and middle or upper Triassic. There are also major discontinuities within the Triassic-lower Jurassic succession which apparently relate to Indosinian tectonism which spanned the late Permian to the early Jurassic with a period of major deformation occurring in the late Triassic (Norian-Rhaetian). Indosinian orogenesis affected an area from southern and western Kampuchea, east central Thailand, western and northern Laos to northern Vietnam and adjacent regions of southwestern China. Unless otherwise noted, the stratigraphic data presented in this section is based on that of Saurin (1953), Workman (1972) and Fontaine and Workman (1978).

## Triassic Marine

Marine formations of Triassic age are exposed in several locations across Indochina, including northern and east-central Thailand (?Scythian to Liassic), northwestern and northern Laos (Scythian to Norian), northern Laos (?Anisian to Norian) and eastern Kampuchea-southern Vietnam (Anisian to Liassic).

The marine Triassic succession in Thailand is referred to as the Lampang Group because of its type-exposure in Ban Thasi, Lampang province. Sequences equivalent to the Lampang Group have also been recognized in Phetchabun province, east-central Thailand (Workman, 1972). A detailed litho-stratigraphic description of the type-Lampang Group appears in Chapter VI. The lowest part of the Mesozoic succession in southeastern Thailand and adjacent Kampuchea consists of tuffs, breccias and unfossiliferous sandstone and coarse clastics of greywacke aspect which bear clasts of fossiliferous late Permian limestones. They are strongly deformed in several locations and are unconformably overlain by subhorizontal Jurassic and Cretaceous terrestrial facies sequences (Gubler, 1935).

Marine Triassic formations in particular are found over large areas of northwestern Laos (Plate IV) (Fromagét, 1935b; 1941). Their relationship to the Permian is unknown as no contacts have yet been observed. The major phase of folding in this region is of late Triassic-early Jurassic age (Indosinian orogeny) (Fromagét, 1941). The lowermost Triassic is represented by Scythian shales and sandstones exposed near Sayaboury. There is no Anisian and the Ladinian is known only sporadically. The principal marine formations are dominantly Carnian and Norian. Exposures of the Carnian are represented near Sayaboury and consist of shales and sandstones. These are in turn unconformably overlain by the "Terrain Rouge" redbeds and the "Indosinias moyennes", the basal sections of which are presumably late Norian in age. Carnian sequences north of Pak Beng are dominantly fossiliferous shales, marls and marly limestones. The Carnian-Norian transition is observed over a wide area of far northern Laos and consists of a distinctive marine black shale horizon that unconformably lies on strongly folded "Indosinas Inferieurs". The Norian consists dominantly of "Terrain Rouge" terrestrial deposits, but there are also several significant marine intercalations of Norian age as well. These consist of fossiliferous sandstones, shales and coralline limestones and are well-exposed throughout the Luang Prabang zone from northwestern Laos to Nam Khan, Nam Ngun, and Nam Beng (Workman, 1972). A medial Triassic marine transgression in northeastern Laos followed a period of late Permian emergence (Fromagét, 1941). Folding of pre-Triassic strata occurred during the early and medial

Triassic during the Indosinian orogeny and was accompanied by rholitic, dacitic and andesitic volcanism. Such activity persisted into the Carnian-Norian in far northern Laos (Fromagét, 1941). Carnian and Norian formations are very widespread and consist of marine shales, marls, sandy shales and sandstones with minor limestones. The marine Norian is partly overlain unconformably by and interfingers with the "Terrain Rouge" redbeds which appear to commence with the upper Norian as in northwestern Laos. There is a lateral transition in places to a lagoonal facies shale, marl and grit with a fresh and brackish water fauna.

The Triassic of eastern Kampuchea and southern Vietnam consist of a relatively unfossiliferous marine horizon within the Indosinias inferieurs, a formation that ranges from the uppermost Permian to the Triassic (Gubler, 1935; Saurin, 1935).

Jurassic Marine

Marine sedimentation throughout Indochina was drastically reduced at the end of the Norian, terminating at the end of the Liassic. Minor marine interrelations within terrestrial facies sandstone occur in eastern Kampuchea and southern Vietnam (Saurin, 1935). Marine marls, sandstone and limestone also interbedded with redbed type sequences of the "Indosinias moyennes" occur in the Attopeu-Saravane area of southern Laos and are assigned to the middle and upper Liassic based on their ammonite fauna. The youngest marine strata appear to be the sandstone and shale beds near Srepok, Vietnam which are of Toarcian (upper Liassic) age, based on the presence of Hildoceras quadretum and lantenoisi (Workman, 1972). Liassic marine sequences are also known from the Nong Son-Vinh Phuoc region of central Vietnam, and comprise a 150 meter thick succession of fossiliferous sandstones and shales with intercalations of limestone. They overlie terrestrial facies sandstones, conglomerates, and coal horizons bearing a Rhaeto-Hettangian flora and are subsequently overlain by "Indosinias moyennes" facies red beds.

Mesozoic Terrestrial

Mesozoic terrestrial facies deposits of Indochina are known as the Khorat group in Thailand and the "Indosinias moyennes et superieures," "Terrain Rouge" and "Grés Superieurs" in Vietnam, Laos and Kampuchea respectively. The thickest and most complete development of these terrestrial facies sediments is on the Khorat plateau of northeastern Thailand and in neighboring parts of central and southeastern Laos, northern Thailand, northern Laos and in the Cardamome Mountains of western Kampuchea (Gubler, 1935; Saurin, 1935). A complete description of the Thai Khorat Group stratigraphy appears in Chapter VI.

The "Indosinia moyennes" comprise mostly the "Terrain Rouge" sedimentary facies and can be correlated with the Phu Kradung formation of the Khorat Group of Thailand (Dept. Min. Res., 1964; Borax and Stewart, 1965; Hahn, 1982). The series consists of sandstone, sandy shale, red shale, marl, calcareous sandstone and conglomerate. Thin seams of coal and rock salt appear in the series near Phong Saly, northern Laos. The "Indosinias moyennes" are essentially flat-lying and rest unconformably on folded Triassic and older strata in all areas of exposure, the principal ones being in northern Laos. A well described section of the "Indosinias moyennes" from southwest of Da Nang consists, from bottom to top of 1000 meters of Rhaetic clastics and coals, 500 meters of Liassic clastics, 150 meters of Liassic marine deposits and 400 meters of "Terrain Rouge" sequences (Workman, 1972).

The"Indosinas superieurs"are correlative with the Phu Kradung, Phra Vihan, Khok Kruat and Maha Sarakam formations of the Khorat Group in Thailand and the"Gres superieurs"of Laos and Kampuchea (Workman, 1972). The 1000 meter thick lower section of the"Indosinas superieurs" consists of sandstone with intercalations of conglomerate, shale, sandy shale and marl and are roughly equivalent to the Phu Kradung and Phra Vihan Formations. They occur principally in the Cardamome Mountains, the Bolovens plateau and central and northern Laos. Along the Thai border in western Laos (Pak Lay) and in the Cardamome Mountains the upper section is on the order of 1000 to 1500 meters thick. An analysis of pollen samples has yielded an early Cretaceous age. (Fontaine and Workman, 1978). The base of the"Indosinias superieurs"is transitional, and is approximately of late Liassic age. The upper limits probably extend through the remainder of the Jurassic and into the Cretaceous. The"Indosinias superieurs"rest with slight angular unconformity upon the "Indosinias moyennes"in northern Laos.

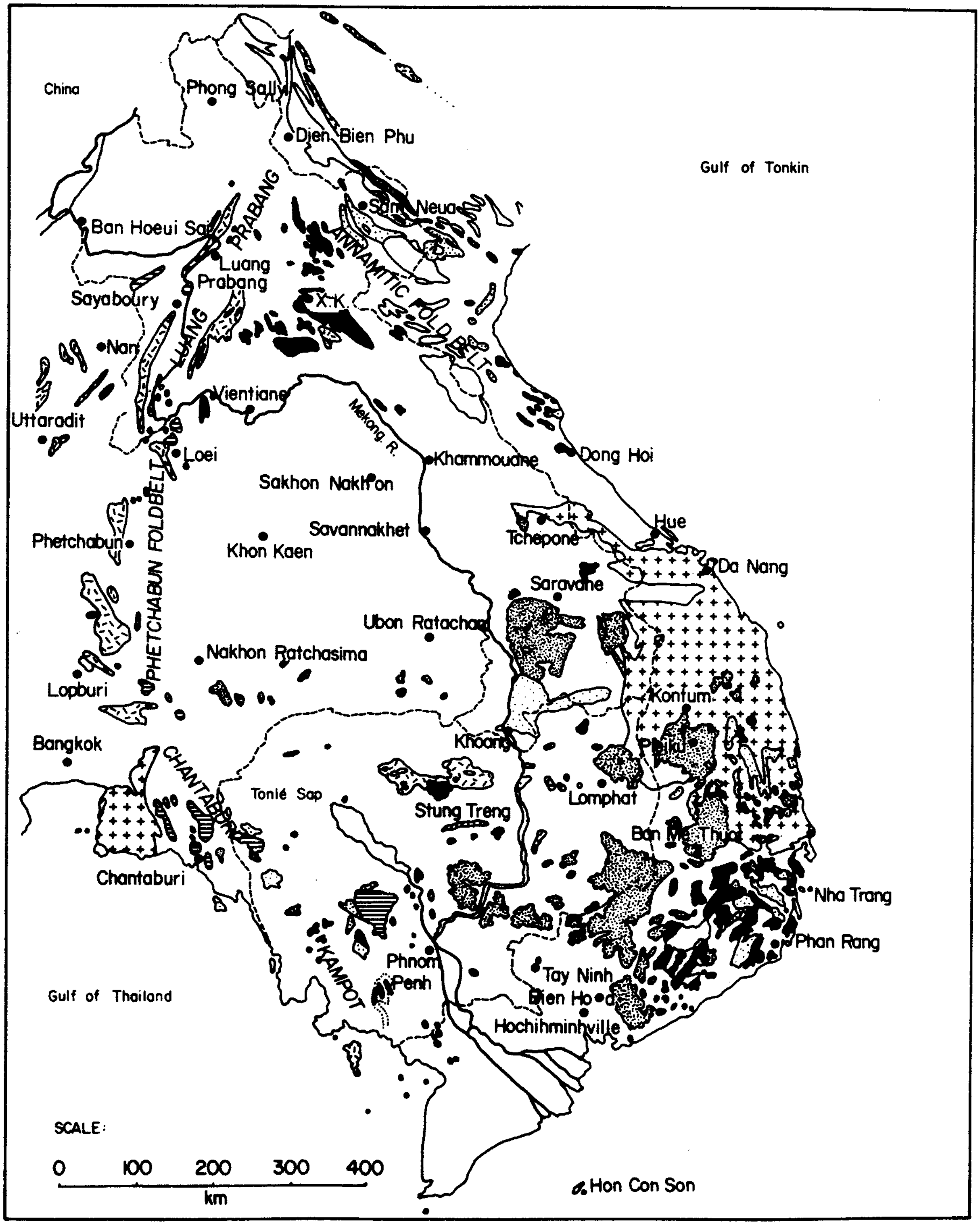
The upper, Cretaceous part of the"Indosinias superieurs"is equivalent to the Khok Kruat and Maha Sarakam Formations, and is restricted mainly to the Muong Phalane sequences east of Savannakhet. They are comprised of sandstones and shales bearing abundant plant and lamellibranch remains interbedded with thick marine evaporite horizons (Workman, 1972).

Near Song Da, Vietnam and Phong Saly, Laos, an upper Cretaceous red bed sequence varying between 300 and 1800 meters in thickness is exposed and has been dated by plant and fresh water lamellibranch remains. An exposure of late Cretaceous rhyolite is also present at Tu Lé, on the lower reaches of the Red River near Hanoi (Staritsky, et al., 1973).

FIGURE 14:

## Distribution of Crystalline Rocks of Indochina-eastern Thailand

(including location map/key on following page/after Workman, 1972)



## *Legend to Distribution of Crystalline Rocks of Indochina and eastern Thailand*

- Orthogneisses and paragneisses of Precambrian, early Paleozoic and granites and granodiorites of late Paleozoic age with minor mafic intrusives

- Andesites, trachytes and dolerites of pre-Cretaceous mostly upper Carboniferous to Triassic age

- Rhyolites, dacites and porphyries of pre-Cretaceous mostly upper Carboniferous to Triassic age

- Tertiary-Quaternary basalts

- Post-tectonic granites and granodiorites of "Indosinian" foldbelts (Triassic-Jurassic)

- Syntectonic and post-tectonic granites, granodiorites and monzonites of late Paleozoic foldbelts (medial Carboniferous)

- Ophiolites, ultramafics and serpentinites (undifferentiated, mostly Triassic-Jurassic)

## 5.4 Mesozoic Magmatism

The crystalline rocks of Indochina and eastern Thailand range in age from Precambrian to Quaternary. Excepting a few isolated exposures of Mesozoic volcanics and Tertiary to Quaternary basalts (Bourret, 1924), most igneous as well as metamorphic rocks appear to be confined to peripheral late Paleozoic and Mesozoic foldbelts and marginal basement uplifts of the Indosinia Massif (Figure 14). The plutonic rocks for the most part consist of stocklike bodies of silicic to intermediate composition which are frequently accompanied by shallow level mafic intrusives.

Workman (1972) recognized distinct late Precambrian, early Paleozoic late Carboniferous, Triassic to early Jurassic ("Indosinian") and Cretaceous episodes of granitic and granodioritic intrusion on the basis of stratigraphic relationships and isotopic age determinations. Phanerozoic ophiolites, undifferentiated ultramafic rocks and their serpentinized equivalents are ubiquitous and confined solely to late Paleozoic and Mesozoic foldbelts, occurring as narrow, elongate and highly dismembered masses usually associated with deep water marine clastics and radiolarian cherts (Saurin, 1953; Izokh and Van Tien, 1966; Hutchison, 1975). Alkaline intrusives are rare and the only known occurrences are of late Cretaceous to Paleogene age from the Red River fault zone of northern Vietnam.

The volcanic rocks of Indochina and eastern Thailand exhibit a similar range of composition but are of much greater areal extent and more restricted in age with respect to plutonic associations. There appears to have been major silicic to intermediate volcanism during the late Paleozoic, the Triassic to early Jurassic (Indosinian) and dominantly basaltic volcanism during the late Tertiary and Quaternary

(Bourret, 1924; Workman, 1972; Fontaine and Workman, 1978). Exposures of Cretaceous rhyolites are also known from the Red River-Tu Lé-Fan Si Pan region of northern Vietnam (Din Kat, 1975; 1978) and undifferentiated mafic effusives of medial(?) Cretaceous age are known from near Cao Beng in northwestern Vietnam (Fontaine and Workman, 1978).

Isotopic age determinations of Southeast Asian igneous rocks are few, poorly constrained and largely inconclusive. Hamilton's (1979) observation of the extreme disparity in values obtained from Malayan granites (Snelling, et al., 1968) as an outgrowth of altered elemental abundances created by younger orogenic events and further complicated by crustal? contamination should be kept in mind, especially in view of the prolonged history of tectonism through which this region has evolved. The values obtained by Burton and Bignell (1969), Hurley and Fairbairn (1972) and others, therefore, may not represent ages of intrusion at all.

Throughout the Triassic and early Jurassic a linear belt of granodiorites were intruded along the Dien Bien Phu-Luang Prabang-Phetchabun Pak Lay foldbelt of western Laos, northeastern and southeastern Thailand and southern Kampuchea (Figure 14). Exposures of late Triassic to early Jurassic ophiolites, deep water marine clastics, volcaniclastics, in the Luang Prabang (Hutchism, 1975) and Uttaradit (Thanasuthipitak, 1978) areas located west of the granodiorites appears to indicate the former existence of an ocean basin that was being consumed along an east-dipping convergent margin along the western periphery of the Indosinia Massif at this time. The apparent ages of the granodiorites appears to decrease from north to south along the trend of the foldbelt as well and is suggestive of diachronous convergence. These are also accompanied by trachytes, andesites and dolerites which also appear to exhibit the same diachronous age relationship (Workman, 1972; Bunopas and Vella, 1978; Chantaramee, 1978; MacDonald and Barr, 1978).

The early Triassic rhyolites of the Kontum Massif and northeastern Kampuchea are accompanied by Barrovian zone metamorphic rocks (Ngok, 1980) and appear to be the remnants of a late Paleozoic convergent margin and island arc collision along the Song Ma Arc in the Annamitic Zone of central northern Vietnam.

Exposures of lower Triassic granodiorites and associated serpentinites are also known from the Stung Treng area of northern Kampuchea in a zone of predominantly late Triassic and early Jurassic deformation (Workman, 1972; Hutchison, 1975; Fontaine and Workman, 1978). Although this association is strongly suggestive of having been produced along a Mesozoic convergent plate margin, the age and nature of the serpentinites and their surrounding sedimentary envelope remains unknown.

The medial Jurassic to early Cretaceous was a period of relative quiescence which was followed by a medial to late Cretaceous episode of granitic intrusion in southern Vietnam (Saurin, 1930; Burton and Bignell, 1969) and early Cretaceous eruptions of rhyolite at Tu Lé in northwestern Vietnam (Din Kat, 1978) and mafic alkaline volcanics near Cao Bang, Vietnam and southern Guizhou, China (Hutchison, 1975; Fontaine and Workman, 1978).

A total of several thousand square kilometers of southern Vietnam, eastern Kampuchea, the Bolovens plateau of southern Laos and southern offshore Vietnam were the sites of alkaline-olivine basalt eruptions during the Pliocene and Quaternary (Bourret, 1924) and were perhaps related to Neogene transcurrent faulting that have dissected much of the Southeast Asian continental edifice (Katili, 1970). Alternately, they may be related to late Tertiary and recent extensional phenomena in the Sunda Shelf, perhaps related to on-shore transforms or normal faults, because the ages of basalts decrease southeastwards from central Laos to southern Vietnam (Workman, 1972; Burke and Kidd, 1975; Fontaine and Workman, 1978).

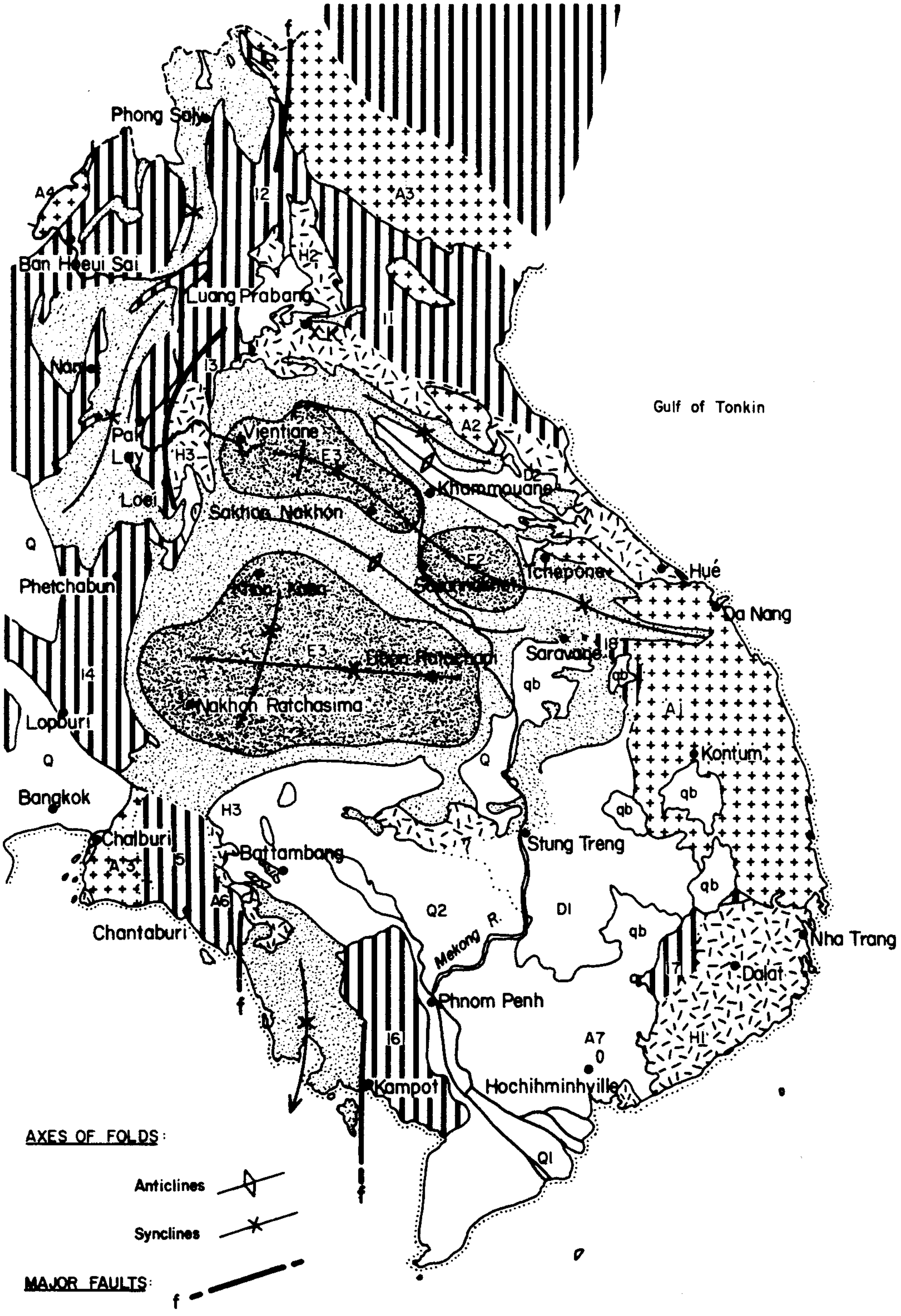
### 5.5 Regional Structure and Tectonics

The principal exposed elements of the regional geological structure of Indochina related specifically to late Paleozoic and Mesozoic deformation are shown on Figure 15 which is based on Workman (1972). A variety of unusual interpretive structural syntheses of the whole or specific parts of Indochina from a decidedly Soviet [and Southeast Asian] point of view including Din'Kat (1972a, b; 1970; 1975); Khoan (1980); Morgunov (1970); Postel'nikov (1960); Staritsky et al. (1973), Stroganova (1975) and T'yong (1980), have also been consulted.

The general structural plan of Indochina consists of a composite mosaic of rigid Precambrian crystalline massifs and the suture zones that outline them. The largest of these stable blocks is the Indochinese Craton (Indosinia Block), the largest uplifted and exposed portion of which constitutes the Kontum Massif of central Vietnam, northeastern Kampuchea and southeastern Laos. A narrow, northwest trending projection of the Kontum massif constitutes the Bak-Ma Spur (Postel'nikov, 1960) of crystalline rocks and extends from Touraine to Tschepone. Smaller massifs, peripheral to the Indochinese, exposed either as slivers in adjacent foldbelts, as stable blocks themselves on opposing sides of fold belts or as inferred massifs, include the Pailin Massif of southwestern Kampuchea, the Song Ma Arc of northeastern Laos and Vietnam, the Chiang Saen area of Laos and Burma, the Cholburi Massif of southeastern Thailand, the Bien Hoa "inferred" Massif of southern Vietnam and the Rao Ca inlier of the Annamitic (late Paleozoic) foldbelt of

FIGURE 15:

*OUTLINES of the REGIONAL GEOLOGIC STRUCTURE*




(key on following page/after Workman, 1972)

## Legend to the Outlines of Regional Geologic Structure

- Precambrian massifs
- Pre-Cretaceous terrestrial basin fill
- Cretaceous terrestrial basin fill
- Indosinian (Triassic-Jurassic) foldbelts
- Late Paleozoic foldbelts
- Flatlying Phanerozoic and Quaternary cover

*Major Structural Units*:

A. Precambrian massifs — A1: Kontum; A2: flatlying cover (inferred basement):

E1: Savannakhet basin (K); E2: Sakhon Nakhon basin; E3: Khorat basin (K);
D1: Kampuchean platform; D2: Khammouane platform

A3: Rao Co; A4: Song Ma; A5: Cholburi; A6: Pailin; A7: Bien Hoa

B. Hercynian foldbelts: H1: Dalat; H2: Laos; H3: Loei-Pailin

C. Indosinian foldbelts: I1: Annamitic; I3/I4: Luang Prabang-Phetchabun-Pak Lay; I2: Dien Bien Phu (converging); I6: Kampot; I5: Chantaburi; I7 "Sillon cochin-chinois"; I8: Saravane

D. Quaternary basins — Q1: Mekong; Q2: Great Lake

qb: Quaternary basalts

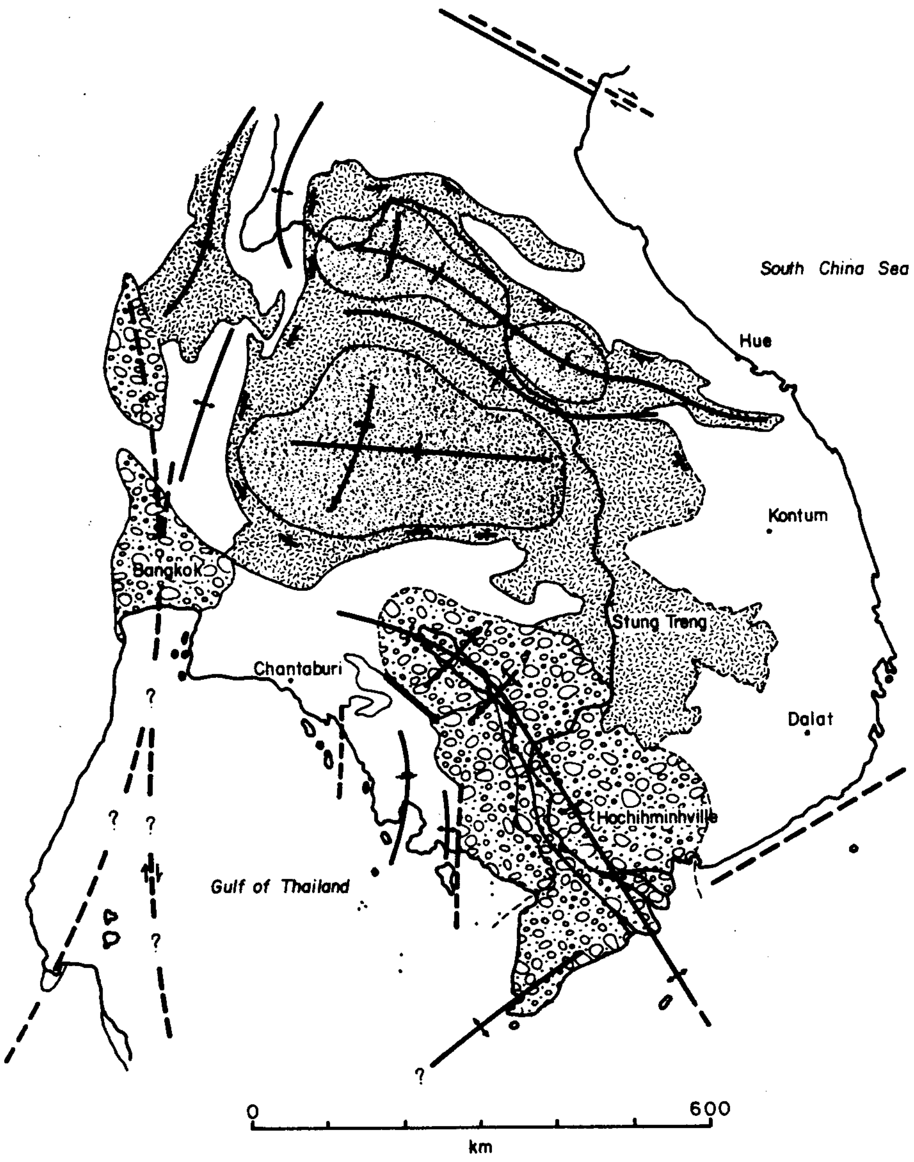
northeastern Laos and Vietnam (Figure 15). There has been considerable variation in nomenclature regarding the exposed and inferred parts of Indochinese and other massifs. The Indochinese craton, was referred to as the "Cambodian Mass" by Suess (1908) and the "Indochinese platform" by Fromagét (1939; 1941). The Kontum Massif has been retained from the original usage by Saurin (1935) for the exposed part of the Indosinia Massif but has been alternately referred to by Blondel (1929) as the "Central Indochinese Massif" and the "Annam Massif". The Song Ma Arc comprises "the Song-Tay Arch" of Fromagét (1939) and the "Northern Tonkin Massif" of Postel'nikov (1960) whereas the Pailin Massif constitutes the "Pursat Massif" of Postel'nikov (1960). The basement massifs of Indochina consist of polyphase deformed gneisses and schists which, according to Saurin (1935), are strongly overprinted by north-south and northwest-southeast fold and fault trends. They are accompanied by sub-parallel belts of silicic plutonics attributable to late Paleozoic and Mesozoic tectonism.

The westward extension of a continuous Indochinese Craton beneath flat lying medial and late Mesozoic cover rocks of southern Laos, eastern Kampuchea and eastern Thailand has been postulated by Postel'-nikov (1960), Morgunov (1970), Din Kat (1972), Workman (1972), Staritsky et al., (1973), Stroganova (1975), Fontaine and Workman (1978) and T'yong (1980). The centers of the Savannakhet, Sakhon Nakon and Khorat basins (Figure 16) consist of moderately flexed terrestrial clastics that rest upon strongly deformed Precambrian crystallines or flat lying Paleozoic sequences. Basin margins are limited either by late Paleozoic and Mesozoic fold and thrust belts outlining the limits of the craton itself or by superimposed anticlinal flexures which separate the basins from one another.

FIGURE 16:

## *Mesozoic-Tertiary Structures of Indochina*

(after Workman, 1972)




MEDIAL JURASSIC BASINS

LATE MESOZOIC BASINS

QUATERNARY BASINS

FAULT

ANTICLINE

SYNCLINE

DIP OF STRATA

The Khammouane anticline comprises the northeastern margin of the Sakhon Nakhon basin which is colinear with the Mekong River between Paksane and Khammouane (Workman, 1972) along which are exposed gently dipping Permo-Carboniferous limestones and Mesozoic terrestrial facies clastics overlying strongly deformed Devonian to Carboniferous strata.

Farther to the southwest, the Phu Phan anticline divides the Sakhon Nakhon and Khorat basins (Figure 16) and may or may not correspond to a hidden late Paleozoic foldbelt. The Khorat is the largest of the superimposed Mesozoic basins and may also be floored by Precambrian and Paleozoic rocks although no deep drill holes have yet fully penetrated Mesozoic cover (Borax and Stewart, 1965; Pitakpaivan and Chonglakmani, 1978).

Several distinct areas of exposed basement rocks in Kampuchea and southeastern Thailand may also correspond to exposed portions of the Indochinese Craton. The largest of these, the Kampuchean (Cambodian) platform, covers most of western Kampuchea and extends further west to the Great Lake (Tonlé Sap) Basin. It is covered by mildly deformed Paleozoic, early Mesozoic and few inliers of upper Mesozoic sediments and Quaternary basalts which collectively seem to have escaped the affects of any Phanerozoic orogenesis. The southern margin of the Kampuchean platform is obscured by the thick Quaternary deposits of the Mekong Delta, but the northwestern limit of the late Paleozoic Dalat foldbelt of southern Vietnam is roughly equivalent to the southeastern-most edge of the Kontoum Massif.

Workman (1972) and Fontaine and Workman (1978) have classified Indochinese foldbelts depending on whether they exhibit deformational features attributable to either late Paleozoic "(Hercynian-Variscan)", early to medial Mesozoic (Indosinian) or both phases of tectonism.

Workman (1972) has recognized two phases of Indosinian deformation, an Indosinian I (early Triassic) and Indosinian II (late Triassic-early Jurassic). The former is observed throughout southeastern Thailand, Kampuchea and northern Laos.

Late Paleozoic Foldbelts

Areas of Visean-Namurian folding that have escaped late Triassic-early Jurassic refolding include the Dalat foldbelt of southern Vietnam, the Annamitic foldbelt of north-central Vietnam and easternmost Laos, the Loei area of northeast Thailand, the Pailin massif area of extreme western Kampuchea and the Stung Treng foldbelt of northern Kampuchea (Figure 14, 17). These all appear to have been zones of Silurian through early Carboniferous sedimentation, with or without Carboniferous and Permian magmatism, and were deformed in Carboniferous and later times. These areas thus represent a growth of the craton through the peripheral accretion of late Paleozoic foldbelts.

The Dalat foldbelt is a northwest-southeast trending zone, which had undergone two Paleozoic folding episodes prior to the early Carboniferous (Saurin, 1956). Upper Carboniferous and younger formations resting on the Dalat massif are undeformed. A narrow zone of strong late Cretaceous to early Jurassic folding referred to as the "sillon cochichinois" (Saurin, 1935), is located along the northwestern edge of the Dalat foldbelt. This appears to be a zone of weakness inherited from the Carboniferous phase of tectonism and is perhaps an Indosinian suture joining the Indochinese craton and the Dalat Massif. Its participation in Indosinian tectonism is discussed in Chapter 11, Section 2.

North and east of the Indochinese craton, during the early Carboniferous in which is presently north-central Vietnam lay the Annamitic "geosyncline"also known as the Truong Son Zone, (Fontaine and Workman, 1978). By the Visean, igneous activity and large-scale southwest-vergent imbricate nappes consisting of"geosynclinal"deposits and crystalline rocks were thrust upon the northeastern, Atlantic-type margin of the Indochinese Craton. Along the Laos-Vietnam border east of Vientiane, Devonian and older sequences of the Annamitic "geosyncline" are expressed as the 200 kilometer long Nam Nhuong nappe which rests on Devonian through Carboniferous shelf deposits. Estimates of minimum displacement for the Nam Nhuong are about sixty kilometers. These rocks are in turn unconformably overlain by Permo-Triassic paralic and terrestrial facies sediments. The northernmost limit of these late Paleozoic deformed sequences is at Phu Loi, Laos. Beyond this point, Indosinian fold belts join from the west and the east to form the "North Laos Convergence" (Workman, 1972).

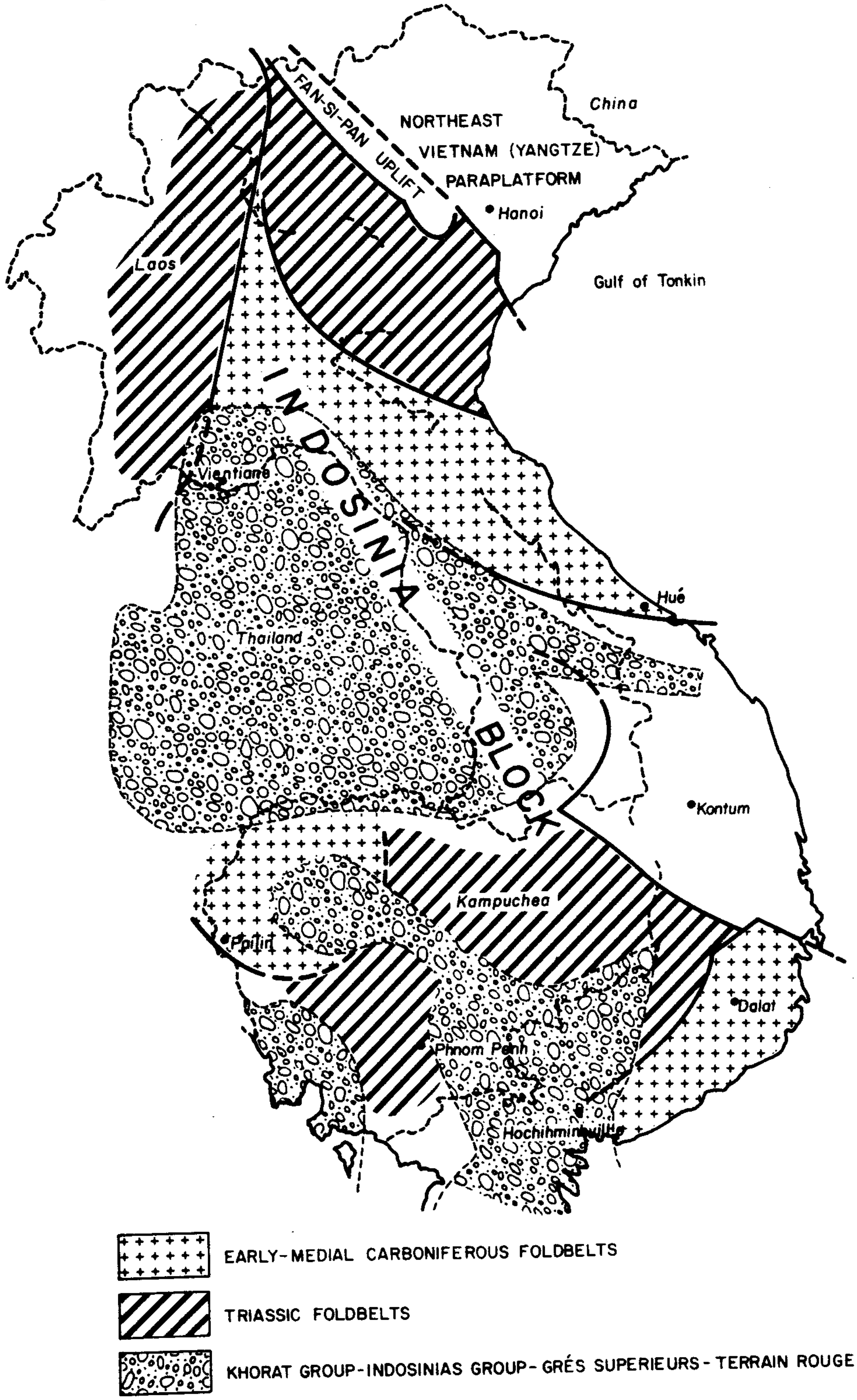
Exposures of strongly deformed lower Carboniferous rocks unconformably overlain by Permo- Carboniferous sequences are observed near Loei in northeastern Thailand. These exposures are separated from a zone of dominantly Indosinian deformation to the west by large Cenozoic strike-slip faults.

The Precambrian Pailin Massif occupies the extreme western part of Kampuchea and is believed to pass beneath both the Cardamome Mountains to the south and the Great Lake to the east. It appears to have been emergent and relatively stable during post-Carboniferous times. Permo-Triassic sediments resting unconformably on strongly deformed Carboniferous and older deposits along the northeastern margin of the Pailin are themselves only mildly dislocated.

The arcuate, late Carboniferous Stung Treng foldbelt of northern

FIGURE 17:

## PRINCIPAL TECTONIC ELEMENTS




(after Fontaine & Workman, 1978)

Kampuchea and southwestern Laos bears all the characteristics of a suture zone. It is associated with large expanses of andesitic lavas, granitic intrusions and bodies of serpentinite (Hutchison, 1975) that were emplaced prior to the Mesozoic.

Triassic-Jurassic (Indosinian) Foldbelts:

By the medial Carboniferous an enlarged Indochinese Craton occupied central and southern Vietnam, much of eastern and central Laos, the whole of northeastern Thailand and most of northern and eastern Kampuchea. It is shown on plate tectonic reconstructions as "Indosinia" (Annamia of Fontaine and Workman, 1978) and is believed to have remained essentially a stable block that occasionally received shallow-water marine and paralic deposits from medial Carboniferous time onwards (Fromagét, 1941; Postel'nikov, 1960; Workman, 1972; Fontaine and Workman, 1978) (Figure 17).

Peripheral to Indosinia, thick deep water marine deposits accumulated in zones which eventually became the loci of strong late Triassic to early Jurassic (Indosinian) tectonism. Folding, thrusting and igneous activity accompanied by the emplacement of blueschists and ophiolites are presently manifest as a pair of northwest-trending and northeast-trending linear belts that extend as one arc across northwestern Laos, central Thailand and western and southern Kampuchea, and as another arc across northeastern Laos and most of north-central Vietnam. They both converge in northern Laos at the northernmost tip of Indosinia (Figure 17).

The late Triassic - early Jurassic Chantaburi foldbelt is a northwest-southeast trending structural unit which extends across southeastern Thailand and northwestern Kampuchea and passes beneath the mildly tilted upper Jurassic sandstones of the Cardomome Mountains. Triassic and older rocks have been strongly folded about northwest-southeast trending axes and some tightly folded anticlines have been completely eroded exposing gneissic basement in their cores, particularly at Cholburi and Pailin (Workman, 1972).

The north-south trending, late Triassic-early Jurassic Kampot foldbelt is located to the southeast of the upper Mesozoic cover sequences of the Cardamome Mountains of southern Kampuchea (Figure 14).

The exposed western flank of this foldbelt consists of a north-south trending fault which is clearly expressed as the eastern escarpment of the Cardamomes, and has been inferred to pass just east of the Phu Quoc Island. According to Fontaine and Workman (1978), between Phu Quoc and Vietnam are numerous island exposures of deformed Paleozoic strata and igneous rocks which suggest the southward extension of the Indosinian foldbelt as far as the westernmost edge of the Mekong Delta.

The Dalat Foldbelt, also known as the "sillon cochinchinois" (Saurin, 1935) is a narrow zone Carboniferous and late Triassic to early Jurassic sedimentation and early Jurassic deformation located at the northwestern margin of the Dalat Massif. The results of recent work reported in Fontaine and Workman (1978) have demonstrated the existence of strongly deformed Triassic flysch beneath much of eastern and northern Kampuchea, in contrast to Workman (1972) who considered the dominant deformational episode in this region to be late Paleozoic.

The Saravane Foldbelt of southern Laos comprises a narrow arcuate band of deformed Paleozoic sequences that lies just west of the Kontum Massif. Farther west these sequences dip beneath flatlying Mesozoic sediments and Quaternary effusives. The Saravane Foldbelt exhibits some degree of late Paleozoic deformation although the dominant phase of folding occurred during the Triassic (Workman, 1972).

The Luang Prabang-Phetchabun Foldbelt of northwestern Vietnam, central Thailand and northwestern Laos is the exposed part of a north-northeast trending foldbelt whose eastern and western margins are almost entirely obscured by Upper Mesozoic cover sequences. While late Paleozoic and medial Triassic folding have been recognized throughout the zone, the dominant phase of folding appears to have been the latter which resulted in the isoclinal folding of pre-Triassic sequences and a strong unconformity with the overlying late Triassic redbeds. This foldbelt eventually converges with the various structural elements comprising the Indosinian foldbelt of northwestern Vietnam and northeastern Laos (Morgunov, 1970; Staritsky et al., 1973; Din Kat, 1975).

This relatively well exposed late Triassic-early Jurassic foldbelt that passes through northwestern Vietnam and northeastern Laos has received a great deal of attention over the years from French, Soviet, and Vietnamese geologists. It has been studied in sufficient detail so as to allow various workers to clearly recognize and subsequently subdivided it into distinct component tectonic zones. Figure 17, is an edited adaption of an illustration that appears in Fontaine and Workman (1978) who in turn had consulted the works of Morgunov (1970), Din Kat (1972) and Staritsky, et al., (1973).

Relatively stable platforms located in the central northeastern sector of Indochina were established by the end of the Carboniferous (Fromagét, 1941). These platforms were separated by a northwest-southeast trending foldbelt whose history of development ended with the Triassic. A pair of synclinoria within this foldbelt, the Song Da and Dien Bien Phu, were individual ocean basins by early Triassic and late Permian times respectively (Morgunov, 1970) and continued as such until the Carnian. The first episode of folding and uplift occurred in the early Norian and a second phase during the late Cretaceous. The former was accompanied by dominantly silicic plutonism and the latter by silicic as well as alkalic plutonism and volcanism. The Createceous granites appear to be concentrated along the uplifted age of the Yangtze Paraplatform known as the Fan Si Pan uplift. This foldbelt has been divided by Fontaine and Workman (1978) into six northwest trending tectonic zones extending laterally across northern Vietnam from China to Laos and are, from northeast to southwest, the Red River Fault zone, the Fan Si Pan anticlinorium, the Tulé fault zone, the Song Da Synclinorium, the Song Da Fault zone, the Song Ma anticlinorium, the Song Ma fault zone, the Sam Neua basin, the Dien Bien Phu synclinorium, the Phu Hoat massif and the Song Lamm fault zone (Figure 17).

All these features extend across the entire width of northern Vietnam from the Gulf of Tonkin (Bacbo) to the Laotian border where they abut and are somewhat truncated by the Pak Lay-Luang Prabang-Phetchabun foldbelt near Dien Bien Phu. This apparent truncation is thought to be the result of post-Triassic transcurrent dextral slip faulting in excess of 100 kilometers of displacement along the Pak Lay-Luang Prabang-Phetchabun Foldbelt (Din Kat, 1972). By the close of the Triassic both foldbelts simply merged with one another into a single foldbelt which continues on a northwesterly trend into southwestern China (Jen and Chu, 1970). The Indosinian foldbelt in China eventually bifurcates itself and continues as both the Ailaoshan-Tengtiaohe-Jinshajiang-Kekexili (Red River) suture of Yunnan and Qinghai provinces and the Longmenshan suture of Yunnan and Sichuan provinces (Plate IX) (Huang, 1978; Bally et al., 1980; Duan et al., 1981; Li, 1981; Zhang, et al., 1981).

Jen and Chu (1970) observed a major Carnian-Norian unconformity in the Lanping-Simao region of Yunnan, southwestern China, with the strong folding and thrusting of a Permo-Triassic sequence of deep water marine sediments. According to Fan (1978) and Duan et al. (1981) there is evidence of a still later folding episode in southwestern China, either latest Triassic or Jurassic, along the Red River Zone adjacent to the Yangtze Paraplatform involving inverted deep water marine sediments and the Jurassic emplacement of ophiolites and glaucophane schists. This younger deformational event most likely corresponds to the collision of the northern extremity of a Shan-Thai-Malaya Block with the western margin of Indosinia along the Pak Lay-Luang Prabang-Phetchabun foldbelt and the Yangtze Paraplatform along the Ailaoshan-Tengtiaohe suture in the early Jurassic.

## CHAPTER VI

## THAILAND

### 6.1 Mesozoic Stratigraphy

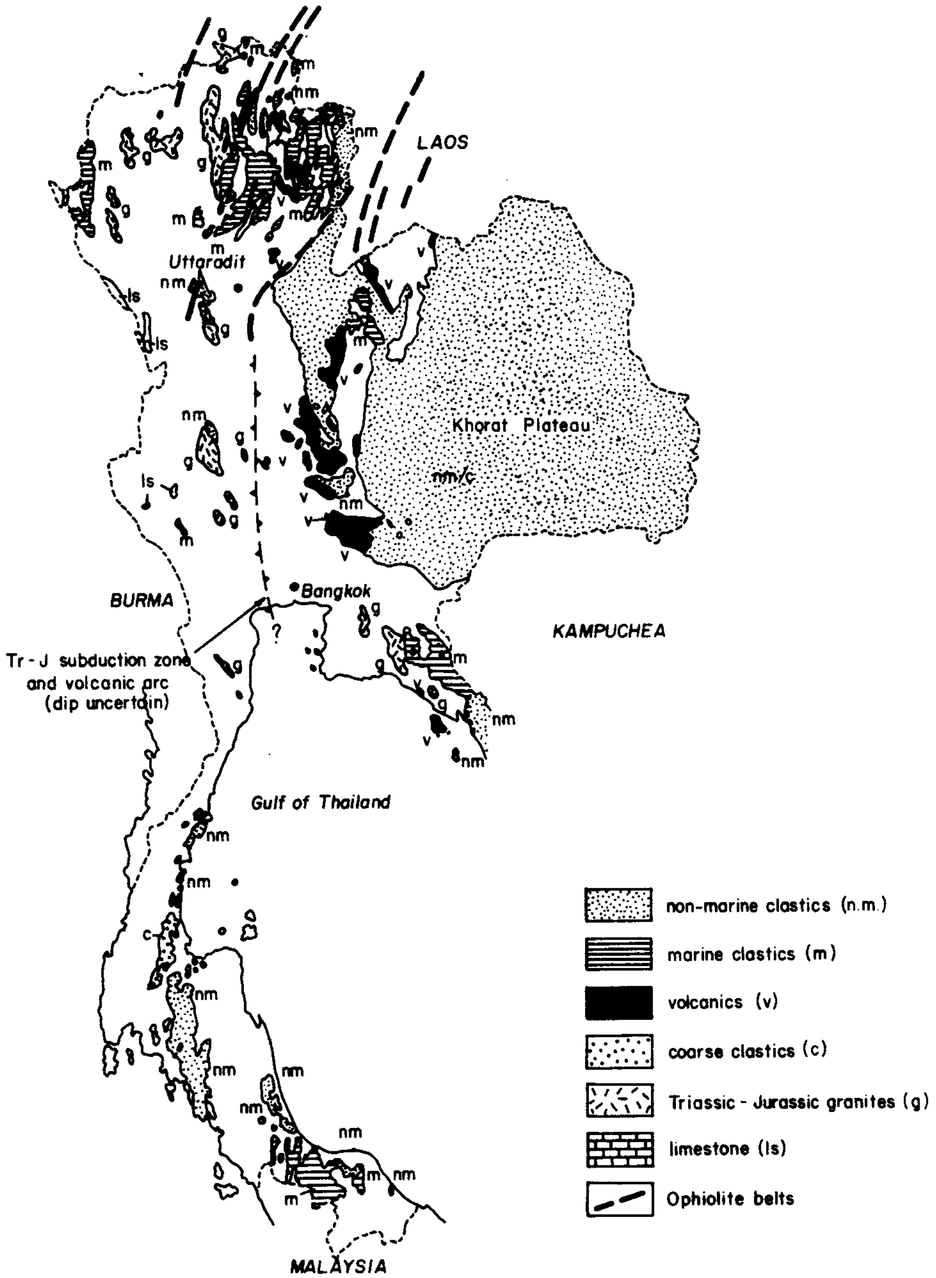
All three of the Mesozoic systems are represented in Thailand, cropping out extensively over the northern and northeastern sections of the country and in scattered exposures in the west, southeast and on the Thai-Malay peninsula. They appear to overlie an essentially continuous Paleozoic succession and are only locally concealed beneath Tertiary and Quaternary deposits (Figure 18). (See Plate XII for a detailed location map). Excellent reviews of the Paleozoic stratigraphy of Thailand can be found in Hamada et al. (1975) for the Cambrian through the Devonian and in Toriyama et al. (1975) for the Carboniferous and Permian.

#### Triassic

The Triassic rocks of Thailand consist predominantly of marine clastics and are exposed primarily in northern Thailand and referred to as the Lampang Group. Sequences of similar facies occur southeast of Bangkok and on the Thai-Malay peninsula. They are essentially flyschoid in the sense that they are pre- or syn-orogenic, marine and consist of a repetitious sequence of alternating sandstone and mudstone beds. (Gregory, 1929; Brown et al., 1951; Pitakpaivan, 1955; Kobayashi and Toriyama, 1951; Piyasin, 1972; Chonglakmani, 1972; Koch, 1973; Ridd, 1978; Hahn, 1981). At its type locality, the Lampang Group consists of a sequence of entirely marine fossiliferous shale, sandstone, limestone and conglomerate exposures at Ban Thasi, Lampang Province situated near the Laotian border (Workman, 1972). The group ranges in

FIGURE 18:

## MESOZOIC ROCKS OF THAILAND




(after Ridd, 1978; MacDonald and Barr, 1978; Thanasuthipitak, 1978; Chantaramee, 1978; Bunopas and Vella, 1978) age from Scythian to Rhaetian-Hettangian (Chonglakmani, 1972; Workman, 1972), attains a thickness of 2950 meters and was first described by Piyasin (1972). It has been subdivided into five formations which are, from bottom to top, the Phra Tat, Pha Kan, Hong Hoi, Doi Long and Pha Daeng (Workman, 1972). The Scythian-Anisian Phra Tat formation consists of fossiliferous sandstone, shale, calcareous shale and conglomerate with clasts of rhyolite and andesite and usually rests unconformably on Permian strata. The base of the Phra Tat is usually a basal conglomerate and rests on Permo-Triassic rhyolites, andesites or Paleozoic sediments. It is conformably overlain by the massive grey limestones of the Anisian-Ladinian Pha Kan formations which bears abundant coral, crinoid, gastropod and brachiopod remains. It reaches a thickness of 260 meters near the Laotian border and thins to a feather-edge in the Lampang area, 75 kilometers to the southwest (Ridd, 1978). This is overlain by the thickest units of the Lampang Group, the Ladinian-Norian Hong Hoi Formation, which reaches a maximum of about 1900 meters (Chonglakmani, 1972). It consists of a rhythmically alternating sequence of grey shales and graded tuffaceous sandstone or greywacke with some interbeds of conglomerate, shale and shaly limestones containing a varied marine fauna including ammonoids and the pelecypods Halobia and Daonella (Pitakpaivan, 1955). The next unit is the Rhaetian Doi Long Formation which consists of 230 meter thick massive limestone and limestone conglomerate containing peleypods, gastropods, ammonoids and brachiopods, which in turn is overlain by the Rhaetian to Hettangian Pha Daeng Formation of marine to paralic sandstones and shales (Workman, 1972). Rocks coeval with the Lampang Group in eastern and southeastern Thailand have been studied by Baum, et al. (1970) from which Scythian conodonts were obtained (Fontaine and Vachard, 1981). In summary the sequences pass upwards from a basal conglomerate into shaly and sandy sediments which are interbedded with limestone and chert. These chert and limestone horizons become progressively thicker westwards, and the Lampang Group as a whole becomes distinctly red-colored further eastwards.

Southeast of Bangkok, the Triassic Chantaburi Group consists of unfossiliferous rocks mapped by Ridd (1978), and forms a southeast trending belt that crosses into Kampuchea. It comprises a monotonous assemblage of deformed, locally overturned greywackes and sandstones intruded by granites. These rocks usually rest unconformably on Pre-Permian sequences. To the southeast, it is overlain by the mildly deformed Khorat Group of latest Triassic to Cretaceous age.

Triassic successions in Peninsular Thailand are exposed near Songkhla and Nathawi and consist of massive, 2000 meter thick sections of deep water marine sandstone, conglomerate, mudstone, siltstones and chert (Ridd, 1978). They are intruded by granites and appear to rest conformably upon the Permian Ratburi limestone. Exposures occur on the western side of what is assumed to be a synclinorium. Carnian Daonella has been collected from these rocks by Kobayashi, et al. (1966) and Halobia and Posidonia have been observed further south (Kobayashi and Toriyama 1959). Marine Triassic pyritic sandstones, shales and limestones mapped by Ridd (1978) on the west side of the peninsula near Kantay are apparently correlative with the Triassic Kodiang limestones of Malaya (Burton, 1973; Tamura, et al., 1975).

## Triassic-Jurassic, Jurassic and Cretaceous Marine Sequences

Near the northern Thailand-Burma border, a 1000 meter thick tripartite succession of late Triassic-Jurassic marine limestones are exposed.

They consist, from bottom to top, of the late Triassic Kamawkala limestone, and are unconformably overlain by the Aalenian age Ban Yang Puteh and Ban Hui Fon marly limestones (Sato, 1975). Koch (1973) has described a similar sequence farther to the south near Sri Sawat where the lowermost unit consists of an Anisian limestone conglomerate resting unconformably on Permian (Ratburi) limestones.

The relation of the Triassic and Jurassic carbonates of western Thailand with the terrigenous clastics of eastern Thailand is presumably an inter-fingering one (Ridd, 1978). The regional work of Baum, et al., (1970) indicates a proportional westward increase in the carbonate content of Triassic successions.

Non-Marine Clastics

Non-Marine clastic rocks of Late Triassic to Cretaceous age are by far the most areally extensive of all those in Thailand. They consist predominantly of reddish brown to grey sandstone, mudstone and conglomerates with local marine limestone interbeds. They are largely post-orogenic molasse-facies terrestrial sediments which contain plant remains, non-marine pelycypods, ostracods and, rarely, marine pelecypods and vertebrates (Iwai et al., 1975). These sequences, collectively known as the Khorat Group, attain a thickness of 4500 meters in northeastern Thailand and occur in the gently downwarped and flexured Khorat-Phayao basin in a region known as the Khorat Plateau (Plate XII). These rocks have been described in detail by Kobayashi (1960), Borax and Stewart (1965), Iwai et al., (1975), Pitakpaivan and Chonglakmani (1978) and Hahn (1981; 1982). They comprise a well-defined eight-unit succession ranging from upper Triassic (Norian) to Cretaceous.

The basal contact of the Khorat Group in the type locality is an angular unconformity. Locally developed above this is the Huai Hin Lat Formation which consists of a 140 meter thick conglomerate unit containing clasts of Permo-Triassic limestone, chert,rhyolite and shale interbedded with shale, siltstone and calcareous sandstone. Plant remains yield a Rhaetian to early Jurassic age.

This is overlain conformably by the 1500 meter thick Nam Phong Formation consisting of pale red conglomerates, sandstones and siltstones exhibiting cross-bedding and large scale fining-upward cycles. The top-most unit consists of a hard calcareous sandstone and siltstone. The presence of reworked Euestheria mansuyi at lowermost stratigraphic levels suggests that the Nam Phong Formation has been derived from Norian terrestrial deposits.

The 900 meter thick Phu Kradung Formation consists of pelletal, micritic dolomitic limestones of apparent lacustrine origin. Mostly siltstones and cross-bedded sandstones occupy the upper sections. Non-marine peleypods, marine reptile, teeth and plant remains have been reported from this formation.

The Phra Vihan Formation comprises a resistant, regionally continuous unit, consisting dominantly of cross bedded sandstone with intercalations of conglomerate, siltstone and carbonaceous shales. The thickness of this formation varies between 55 and 135 meters and it is essentially unfossiliferous.

The Sao Khua Formation consists predominantly of grey - red and brown siltstones which vary from 405 to 700 meters in thickness. Marine pelecypods, icthyosaur teeth and plant remains have also been described from this formation.

The Phu Phan Formation consists predominantly of unfossiliferous cross-bedded conglomerate and sandstone with a thickness varying between

80 and 185 meters.

The 700 meter Khok Kruat Formation consists mainly of siltstone with gypsum beds at upper stratigraphic levels. Non-marine pelycypods and land plants suggest a late (?) Cretaceous age.

The 1000 meter (?) thick Maha Sarakam Formation comprises the uppermost unit of the Khorat Group and consists of a variety of soft siltstones and mudstones with, in places, thick sequences of halite, gypsum, and anhydrite. It is unfossiliferous but has been tentatively assigned a late Cretaceous to early Tertiary age as a result of its relationships to the underlying Khok Kruat Formation.

The Khorat Group or at least its correlatives are present in other regions of Thailand. Redbed conglomerates and sandstone disconformably overlie the Lampang Group in northern Thailand. Rhyolite flows are often found between the Lampang and Khorat Groups, lying above the disconformity.

Further west the Khorat intertongues with marine Jurassic limestones (Baum, et al., 1970). Nearly flat lying sequences of the Khorat Group have been mapped by Ridd (1978) on the island of Ko Kut near the Kampuchea border, southeast of Bangkok where it unconformably overlies highly deformed Triassic (?) sequences. Similar sandstone, mudstone and conglomerate successions have been observed on the peninsula where they unconformably overlie Permian Ratburi limestone and older units (Ridd, 1978).

### 6.2 Mesozoic Magmatism

Silicic magmatism dominated Mesozoic igneous activity and a variety of intrusives and extrusives of this age range are distributed throughout Thailand (Figure 18). Most exposures are intrusives of stock and batholithic dimensions and consist of granites, granodiorites, tonalites and monzonites. They trend generally north-south and reach lengths in excess of 100 kilometers. Klompé (1962) recognized two distinct suites of Mesozoic plutons, a Triassic non-tin bearing one and a Cretaceous tin-bearing one, although it now appears as though the vast majority of them are late Triassic in age with a few minor exceptions (Ridd, 1978). Triassic sedimentary rocks in western Thailand have been intruded while lower sequences of the Mesozoic Khorat Group apparently have not. Isotopic age determinations of these rocks have, as with the Malayan intrusives, yielded inconclusive results. Burton and Bignell (1969) derived Permian and Cretaceous ages for southeast Thailand suites and Jurassic-Cretaceous ages for peninsula suites based on whole rock Rb/Sr analyses and on field relationships. Beckinsdale et al. (1979) and Ridd (1981) viewed the youngest granites as late Triassic and any younger dates were due to isotope resetting via tectonism. Considering the active post-Triassic tectonic history of regions immediately to the west of Thailand as well as Southeast Asia in general, it is not unlikely that a good many of these Jurassic-Cretaceous ages are of questionable significance. It is possible that isotopic resetting of older granites may have occurred purely by tectonism.

Mesozoic extrusive rocks consist principally of island arc andesite and rhyolite and in northern Thailand exhibit a bimodal age distribution: late Permian to early Triassic and late Triassic. The latter are much more widespread and occur at the base of the Khorat Group, disconformably overlying the Lampang Group (Baum et al., 1970; Chantaramee, 1978; Thanasuthipitak, 1978).

Dismembered late Triassic ophiolites and undifferentiated serpentinized ultramafic rocks are known from the Uttaradit area of central northern Thailand and also near Cheng Rai (Thanasuthipitak, 1978) and are associated with deep water marine clastics, cherts and volcaniclastics.

# CHAPTER VII

# MALAY PENINSULA

The tectonic history of the Malay Peninsula and the southern part of Indochina are recorded in the rocks and structures produced during late Paleozoic and Mesozoic deformation and magmatism. The major tectonic components and a detailed location map of the region are shown in Figure 19 and Plate XIV, respectively.

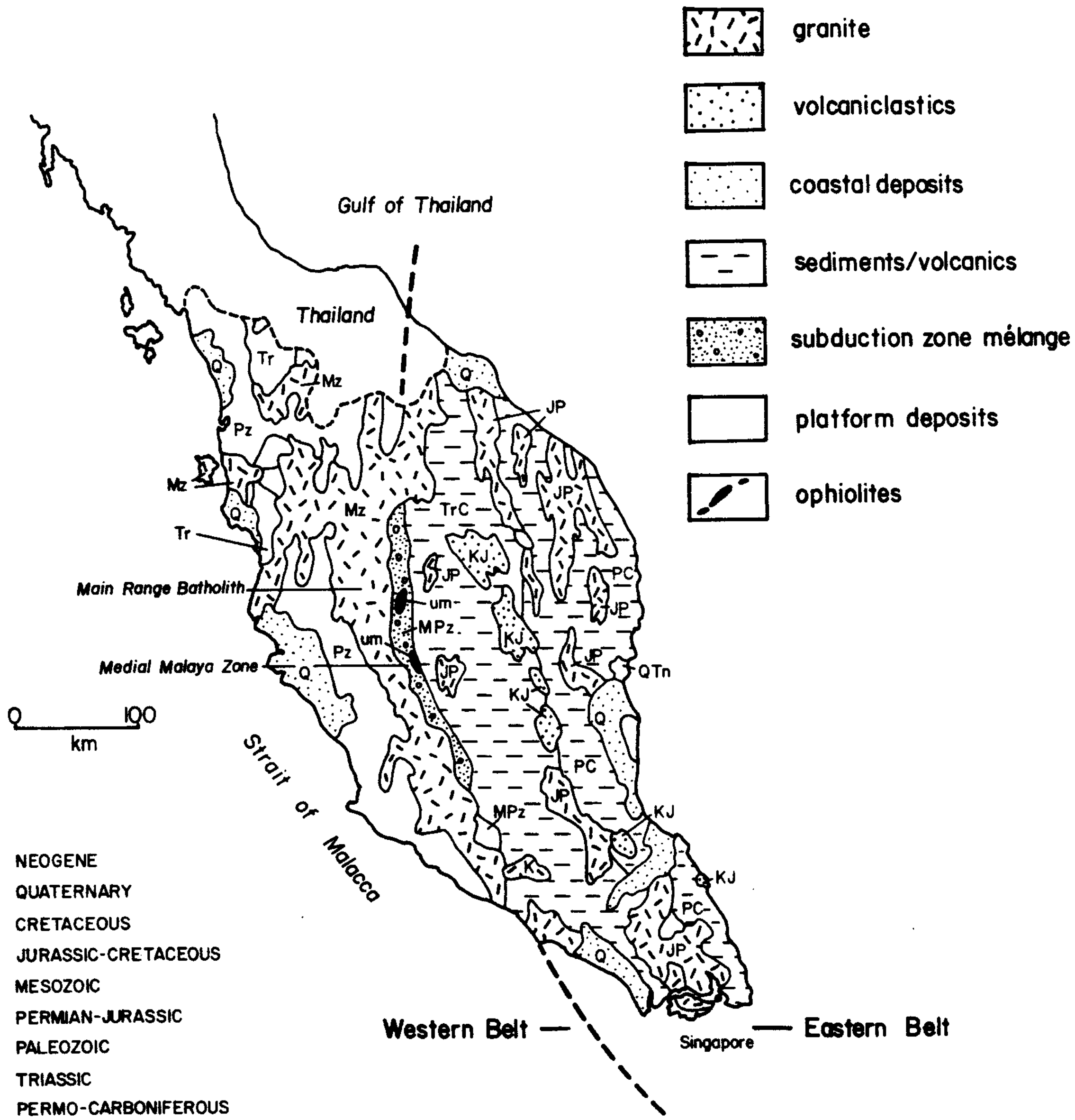
Exposures on the Malay Peninsula consist mostly of polyphase deformed Cambrian through Triassic sediments, Permo-Triassic volcanics and Carboniferous or Permian to Cretaceous granitic rocks. Several broad paleoenvironments have been recognized via sedimentary facies analysis. A relict subduction zone/suture zone complex of Paleozoic to Mesozoic age appears to be present in the Medial Malaya Zone (Hutchison, 1975; Albany Global Tectonics Group, 1978; Hamilton, 1979; Mitchell, 1981). Granitic rocks appear to become younger from east to west across the peninsula.

## 7.1 Precambrian through Mesozoic Stratigraphy

Basement rocks presumably of Precambrian age are present at shallow depths in far northwestern districts and are known only from drill core. Paleozoic strata occur as contrasted eastern and western facies belts divided by the meridional granite batholiths of the Main Range (Figure 19). The Paleozoic sequences west of the Main Range comprise fossiliferous Cambrian through Permian shallow water platform deposits. Magmatism was not apparent in this region until the Mesozoic. East of the Main Range, Paleozoic rocks are dominantly island arc volcanics and volcaniclastics.

FIGURE 19:

*Geologic Sketch Map of Peninsular Malaysia*




| | |
|---|---|
| QTn | NEOGENE |
| Q | QUATERNARY |
| K | CRETACEOUS |
| KJ | JURASSIC-CRETACEOUS |
| Mz | MESOZOIC |
| JP | PERMIAN-JURASSIC |
| Pz | PALEOZOIC |
| Tr | TRIASSIC |
| PC | PERMO-CARBONIFEROUS |
| TrC | TRIASSIC-CARBONIFEROUS |
| um | OPHIOLITE |

(after Hamilton, 1979)

Western Facies Belt

Lower Paleozoic shelf sequences are known from northwestern Malaya and peninsular Thailand southeast of the Marui Fault and consist primarily of 2000 meter thick Cambrian to lower Ordovician sandstones, quartzites and shales overlain by 1500 meters of Ordovician, Silurian and lower Devonian limestones (Jones, 1968, 1973; Ridd, 1971). Farther southeast, Silurian and lower Devonian strata comprise the Mahang black shales, suggesting a greater water depth in this region (Jones, 1968; Burton, 1970). Still farther east, a correlative series of unfossiliferous limestones, sandstones, shales and tuffs is exposed (Jones, 1968). Fossiliferous Silurian limestones are known from yet farther south and a low-grade metamorphism terrain consisting of lower Devonian slates and phyllites is known (Gobbett, 1973). Upper Devonian and Carboniferous shelf deposits are replaced by turbidites to the northwest. West of the central part of the Main Range in Malaya, middle Devonian to middle Permian shallow water dolomites, limestones and shales in excess of 1700 meters thick are exposed. The equivalent middle Devonian to lower-middle (?) Carboniferous sections in northwestern Malaya consist of sandy marine shales in the east which become diamondiferous, rift-facies mudstones, pebbly mudstones, siltstones, greywackes and conglomerates of the Phuket Formation (Gobbett and Hutchison, 1973; Ridd, 1976). A 2000 meter thick turbidite facies unit which rests unconformably on the shelf sequence has not been recognized northwest of the Marui Fault of southeastern peninsular Thailand. It appears to consist of westerly-derived continental detritus (Ridd, 1971).

A clastic wedge consisting of westerly-derived middle Devonian to lower Permian sequences which have been superimposed on an older continental shelf appear to be the fill of a foreland basin. An unidentified Devonian orogeny apparently affected a dominantly continental region which lay west of the present western limit of continental crust (Ridd, 1971). Overlying the Devonian and basal Permian strata through west-central and northwestern Malaya and peninsula Thailand and Burma is the shallow-water, richly fossiliferous Ratburi limestone of Permian age. This limestone has been interpreted as representing a series of patch and barrier reefs rather than a widespread continuous sheet. The abundant tropical faunas present in exposures of this formation in south-eastern Thailand are suggestive of equatorial latitudes. Faunally dated medial and late Triassic rocks west of the Main Range occur in north-western Malaya and adjacent Thailand and consist of marine sandstones, shales, cherts and towards the west, limestones and conglomerates (Burton, 1973). Jurassic and Cretaceous terrestrial and paralic facies sedimentary rocks are only marginally represented in this facies belt.

The Paleozoic and Triassic age deposits are highly deformed and intruded by swarms of granitic plutons. Field relationships and the presence of the widespread Rat Buri limestone indicate that none of the granites are of Permian age (Hamilton, 1979). The existence of a major medial Paleozoic orogeny has been disputed. The abrupt change observed in northwestern Malaya and peninsula Thailand from the platform conditions of the early Devonian to the beginning of the deposition of the clastic wedge in medial Devonian times is indeed suggestive of orogenesis, but the absence of any degree of regional metamorphism is a puzzlement. Only minor exposures of volcanic rocks are known with certainty to occur within the Paleozoic and Triassic sections of western Malaya. Carboniferous, Permian and Triassic strata in Thailand north and north-east of the Malay Peninsula also occur as contrasting non-volcanic facies in the west and volcanic and sedimentary facies in the east.

### Eastern Facies Belt

Malaya east of the Main Range was subjected to widespread silicic plutonism during Carboniferous, Permian and Triassic times. The region consists of sedimentary and volcanic formations of early Carboniferous to late Triassic age and also of granites (Burton, 1973; Gobbett, 1973; Chand, 1978). Sedimentary rocks exposed in the eastern portion of the region are mostly Carboniferous but include the Permian. Those in the remaining western portion are Permo-Triassic with Permian rocks dominating in the North, and Triassic in the south. They consist of mildly metamorphosed but highly deformed shales, sandstones, siltstones, arkoses, conglomerates and interbeds of fossiliferous limestones bearing a well-defined shallow water marine fauna.

Silicic volcanics consisting of tuffs, flows and breccias of rhyolite, rhyodacite and dacite composition are also abundant (Hutchison, 1973). Similar volcanic rocks are present in the eastern, Permo-Carboniferous facies belt. Batholiths were intruded coeval with Carboniferous, Permian and Triassic sedimentation and volcanism. Gently folded Jurassic (?) and Cretaceous fluviatile, deltaic and lacustrine clastic sedimentary rocks, consisting of red conglomerates and quartz sandstones rest unconformably on the eastern Malaya Triassic and Paleozoic rocks (Paton, 1959; Burton, 1973) and are interbedded with silicic volcanics and tuffs indicating coeval magmatism and deformation.

## 7.2 Mesozoic Magmatism

Mesozoic igneous activity was widespread throughout the Malay Peninsula, characterisitically of silicic composition and basically a continuation of magmatism that commenced in the region at the end of the Paleozoic. The late Paleozoic and Mesozoic granite batholiths of the Malay Peninsula typically form north-trending mountain ranges separated by regions of low relief eroded from early Paleozoic sediments (Scrivenor, 1921). The great Main Range Batholith runs the length of the Malaysian sector of the peninsula, just west of its centerline, and smaller batholiths are dispersed throughout the remainder of the region. The granitic rocks are on the average highly silicic and potassic, consisting predominantly of biotite-quartz monzonites (Hutchison, 1973) with subordinate hornblende-biotite granodiorite, quartz monzonite and quartz diorite. More intermediate rocks appear to be confined to a broad belt of small plutons east of the Main Range.

Malayan granites east of the Main Range yield concordant K/Ar mica ages and Rb/Sr whole rock and mineral ages. Data presented in Hamilton (1979) suggest that three major phases of silicic magmatism occurred in this region, at about 250 million years (latest Permian-early Triassic?), 220 million and 200 to 190 million years (late Triassic). These ages are apparently in accord with stratigraphic evidence as Permo-Triassic silicic volcanics are widespread in eastern Malaya.

Rb/Sr isochrons determined for medial Malayan (Main Range) granites are inconclusive, depending upon the choice of an initial $Sr_{87}/Sr_{86}$ value. Ordovician Silurian (440 million years), late Carboniferous-early Permian (295-275 million years), Triassic (243-200 million years) and Cretaceous ages have been derived. K/Ar mica data yield bimodal values of 210-130 million years (late Triassic to early Cretaceous) and 100 to 80 million years (late Cretaceous). Similar discrepancies between Rb/Sr and K/Ar dates have been reported from peninsular Thailand by Burton and Bignell

(1969). An extended discussion of the problems of central Malayan granite geochronology and petrogenesis mostly concerning magmatic assimilation of radiogenic strontium is presented by Hamilton (1979).

The presence of upper Paleozoic granites in medial and western Malaya (Hutchison, 1973) is difficult to reconcile with regional stratigraphic evidence indicating a Cambrian to middle Permian platform and shallow marine deposition devoid of volcanics. Hamilton (1979) has suggested that in medial and western Malaya the determination of Paleozoic ages from granitic rocks via whole rock Rb/Sr methods is not justified, that no granitic rocks older than the Triassic are represented and most of the granites are of late Triassic to early Jurassic age. It is interesting to note that the late Triassic-early Jurassic inferred ages of the medial Malayan granites also correspond to the dominant Mesozoic granite-forming episode in eastern and central Southeast Asia and southwestern China.

According to Hamilton (1979), several small southern Malayan granites have yielded Cretaceous Rb/Sr and K/Ar ages, and the granites east of the Main Range have been assigned an inclusive Permian through Jurassic age, a span that satisfies all the K/Ar and some of the Rb/Sr determinations as well as the stratigraphic ages of the various Permian and Triassic volcanics. Major magmatism decreased considerably by the beginning of the Cretaceous, but apparently continued to some degree further to the west. Jurassic and lower Cretaceous strata of eastern Malaya are only little deformed. Neither volcanism nor plutonism has been proved for the Carboniferous. Both K/Ar and Rb/Sr ages indicate that the hornblende-biotite-quartz monzonites and granodiorites of the western part of eastern Malaya are largely of Triassic age, whereas the biotite-quartz monzonites of the eastern part are Permian as well as Triassic. The granitic rocks of Malaya within and further west of the Main Range and of southeastern Peninsula Thailand have been broadly age categorized by Hamilton (1979) as undifferentiated Mesozoic. There does appear to be a general westward-younging trend in the ages of latest episodes of granitic magmatism in the Thai-Malay peninsula as well as across central and eastern Southeast Asia as a whole (Geologic Map of Asia, 1975).

## 7.3 The Medial Malaya Zone

A north-south trending belt of rocks transecting central medial Malaya along the eastern foothills of the Main Range has been inferred by Hamilton (1979) to consist of Paleozoic age subduction mélange. Referred to as the Bentong Group, the rocks comprise a chaotically interspersed and thoroughly sheared assemblage of clastic marine sediments, radiolarian cherts serpentinites, greenschist facies metamorphics and amphibolites that have been intruded (?) by the Main Range Batholith along its westernmost exposures. Sediments included within the complex or that supposedly lie unconformably on top of it within the belt have yielded Silurian, Devonian and early Carboniferous age faunas. Whether or not the late Paleozoic fossils occur within this mélange or in strata unconformably overlying it has yet to be determined. The Bentong Group is older than the Triassic (?) Main Range Batholith and may or may not be older than the upper Paleozoic strata within the belt. Intuitively, Hamilton's (1979) late Triassic-early Jurassic phase of silicic to intermediate magmatism is coeval with and perhaps genetically related to contemporaneously subduction and the eventual collision of eastern and western Malayan continental blocks along the Medial Malaya

(Bentong-Raub) Zone.

Until the full age range of the Medial Malaya mélanges is known with certainty, the termination of subduction and the timing of collision remains at best only speculative. It is interesting to note that the Medial Malaya Zone is on strike with the Dien Bien Phu-Luang Prabang-Phetchabun-Pak Lay Foldbelt across the Gulf of Thailand to the north (Albany Global Tectonic Group, 1978). A possible offshore link between these two zones may lie along the trace of the Thai Basin.

# CHAPTER VIII

# BURMA

## 8.1 Introduction and Tectonic Subdivision

The geology of Burma (Plate XIII) is critical for an understanding of the Mesozoic tectonic evolution of southeastern Asia. The outer arc ridge of the Sumatra-Andaman-Nicobar subduction system comes ashore in Burma as the Arakan, Chin and Naga Ranges, which comprise its pr-Eocene relicts. The western part of the Irrawaddy lowland, corresponding to the western trough of Mitchell and McKerrow (1975), appears to be the onshore extension of the outer-arc basin (Hamilton, 1979), but is interpreted as a north-south trending strip of suture-bounded continental crust whose basement is exposed as the high-grade metamorphic rocks of the Kachin State of central northern Burma and its equivalents in western Yunnan.

The Burmese structural units appear to follow broad, concave eastward, roughly concentric arcs. The mountainous Eastern Highlands and the eastern periphery of the Shan Plateau consist of Paleozoic and Mesozoic sediments and Mesozoic (?) intermediate and ultramafic igneous rocks that in part have been strongly deformed and metamorphosed as well as crystalline exposures which are equivalent to those of the Malay Peninsula and Thailand. The western edge of these highlands displays a belt of upper Mesozoic subduction zone mélange containing, among many other constituents, gneisses and undifferentiated ultramafic rocks (La Touche, 1912), eclogite, serpentinites, jadeite, glaucophone schists, and fossiliferous marine rocks of Jurassic age, Chhibber's (1934) Mandalay Line (Hutchison, 1975; Hamilton, 1979). West of the

Eastern Highlands are the 200 kilometer wide Irrawaddy (Central Burma) lowlands herein referred to as the West Burma Block. At the western periphery of the West Burma Block lay the Arakan, Chin and Naga Ranges, varying between 50 and 150 kilometers in width. The rocks of these mountains have been described by Brunnschweiler (1966) as consisting of wildflysch blocks of greywackes, gabbros, serpentinites, pillow basalt, radiolarian chert, glaucophane schist, jadeite, and other assorted sedimentary rocks chaotically intermixed in a sheared pelitic matrix. Undoubtedly a subduction zone mélange, this diverse assemblage involves fossiliferous Cretaceous and probably lower Eocene rocks in the east and upper Eocene rocks in the west. Steeply dipping Eocene, Oligocene and Miocene shallow water marine strata lie unconformably on eastern exposures of this sequence. Much of Burmese geology can be explained by a plate tectonic model involving the growth of Southeast Asia relatively westwards throughout the late Jurassic (?), Cretaceous and Paleogene as the result of the accretion of a series of arcs and northern Gondwana microcontinents, upon a earlier allochthonous foundation of Gondwana blocks that collided with each other and the southwestern periphery of the Yangtze (South China - "Cathaysia") Paraplatform in the late Triassic - early Jurassic (Indosinian). East-dipping subduction zones and accretionary prisms were situated near the western edge of what is now the Shan Plateau (the western fringe of the Shan-Thai-Malaya Block) during Jurassic and early Cretaceous times, along the eastern part of the Arakan-Chin-Naga Yoma terrain in the latest Cretaceous, Paleocene, Eocene and also along the western part of this terrain in the latest Eocene. The southward prolongation of these zones into the Malay Peninsula and far western Indonesia allow a reasonable interpretation of regional

Mesozoic and Cenozoic tectonics.

The Eocene mélange of the Arakan-Chan-Naga Yoma Belt projects directly to the Andaman Islands marine ridge along which coeval mélange sequences are exposed (Hamilton, 1973, 1979). The Neogene subduction zone to the west of the Arakan-Chin-Naga Yoma belt has its equivalent in the contemporaneous Andaman-Nicobar-Sumatra trench. The late Jurassic to early Cretaceous mélange belts along the western periphery of the Shan Plateau (Mandalay Line-Mogok Belt) project southward along the outer part of the continental shelf and Mergui terrace (Hamilton, 1979).

The four major Mesozoic and Cenozoic tectono-stratigraphic regions of Burma comprise the Shan-Tennasserim, Central Burma, Arakan-Chin-Naga Yoma and West Arakan basins (Thein, 1978) (Figure 20 and Plate XIII). They are large, north-south trending sedimentary regions, the first two divided from one another by the Eastern Highlands foldbelt and the third comprising the Arakan-Chin-Naga Yoma Ranges themselves (Nyunt and Saing, 1978). All four are clearly separable from a tectonic, depositional as well as geomorphologic viewpoint. The pre-Cenozoic sedimentary sequences of the Shan-Tennasserim and Central Burma basins can be thought of as comprising the autochthonous cover of two individual tectonic elements that behaved essentially as a rigid block throughout the Mesozoic and Tertiary. It is proposed here that these individual blocks comprised former Tethyan (northern Gondwana?) microcontinents that became accreted to the western margin of Southeast Asia from the late Jurassic-early Cretaceous to the late Eocene.

## 8.2 Precambrian and Paleozoic Stratigraphy

The only confirmed occurrences of Precambrian and Paleozoic rocks

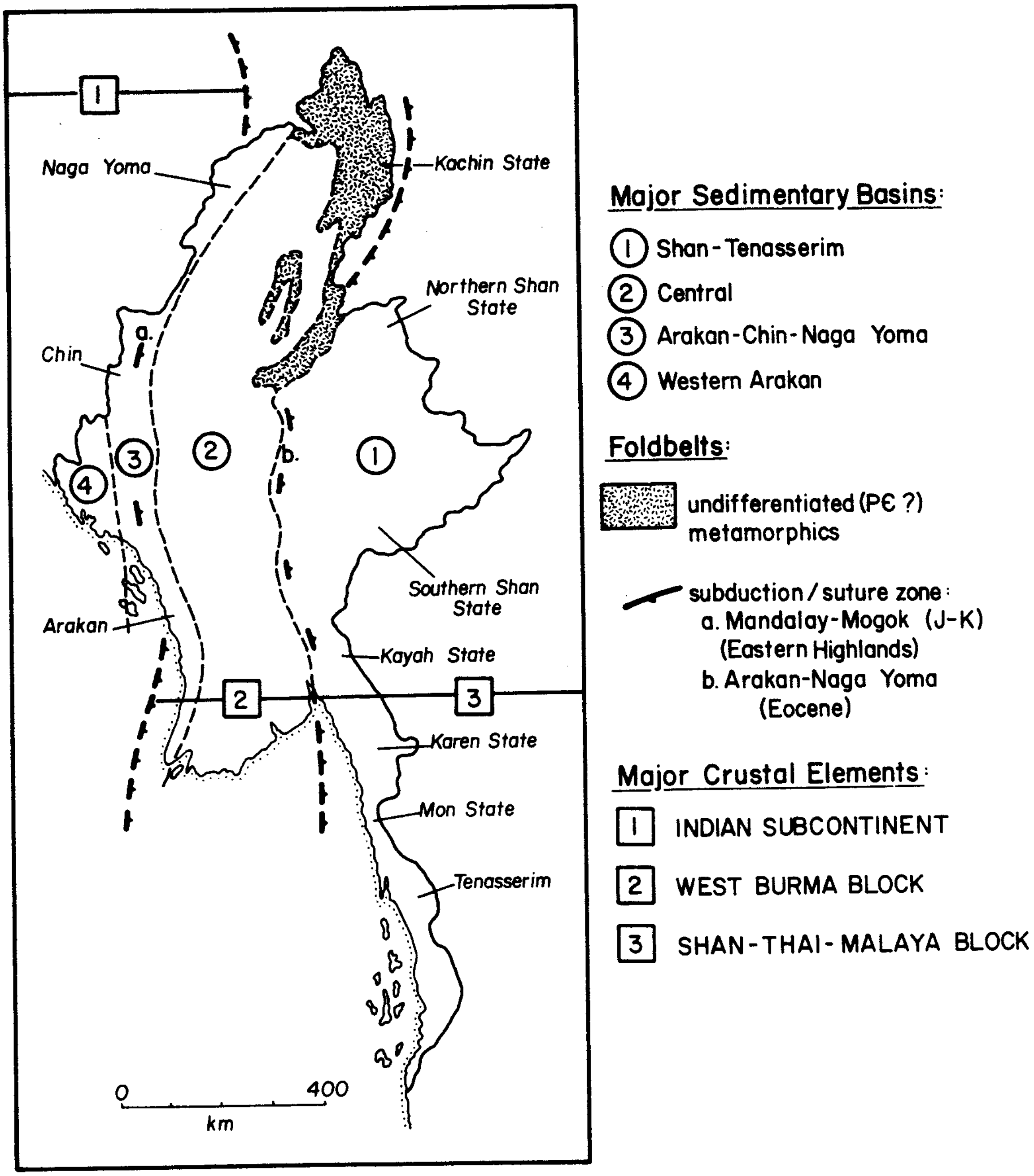



FIGURE 20:

## Principal Tectonic Elements of Burma

(after Nyunt and Saing, 1978)

Klimetz, 1982

are those of the Shan-Terrasserim (Shan-Thai-Malay) region. The Paleozoic stratigraphy for the southern Shan-State is based on the work of Thein (1972), for the northern Shan State and Karen State on that of La Touche (1913) and Brunnschweiler (1970) and for the lower Paleozoic of the entire region on Garson, Amos and Mitchell (1976).

Due to the age span and pronounced north-south variation in depositional history of the Shan-Tennasserim region, the Precambrian and Paleozoic stratigraphy of three separate regions will be discussed and include a northern region which comprises the northern part of the Shan State, a central region which corresponds to the southern part of the State and a southern region which encompasses the Kayah-Tennasserim area (Figure 20).

Precambrian and lower Paleozoic sequences are thicker and more complete in the northern regions of the basin whereas the Upper Paleozoic is better represented in the central region.

The metasediments comprising the Precambrian Chaung Magyi Series are unconformably overlain by the 800 meter thick upper Cambrian micaceous sandstones, shallow water marine quartzites and dolomites comprising the Molohein group in the center of the basin and by the lower to middle Cambrian 400 meter thick Bawdin intermediate volcanics in the northern part of the basin. Exposures of strongly metamorphosed Mogok gneiss underlie the Chaung Magyi Series in very northernmost regions and this gneiss is assumed to be Archean (Thein, 1978) but no isotopic age determinations have yet been done. The Bawdin volcanics are in turn overlain by the 600 meter thick upper Cambrian Ngwetaung sandstone and Pangyun Beds which consist of sandstone, quartzites and dolomites and bear a saukiid trilobite fauna identical to that of the Molohein group of the central part of the basin. The Molohein group is overlain by the shallow marine Naung Kangyi limestones, marls, siltstones and sandstones (La Touche, 1913) and Pangyun sandstones (Thein, 1978) which in turn are overlain by the 1500 meter thick shales, limestones and dolomites of the Pindaya Group. The lower and middle Silurian are represented by the 300 meter thick shales and phacoidal limestones of the Linwe Formation of the central region and by the Naungkow limestones of the northern region which are composed of Michelinoceras-bearing pinkish grey limestone interbedded with graptolitic shales and slates. The 150 meter thick upper Silurian Wabya Formation of the central region and 100 meter thick Pang-hsa-pye Series of the northern region are essentially graptolitic shales.

The lower Devonian is present only in the northern region and consists of the 70 meter thick shallow-water marine Tentaculites-bearing limestones and Zebingyi siltstones and shales. The regionally extensive 4,000 to 5,000(?) meter thick Plateau Limestone Group of the northern region encompasses the upper Devonian to the Permian whereas in the central region it ranges from the upper Carboniferous to the middle Triassic where it overlies the thick, lower to upper Carboniferous greywackes and clastics of the Lebyin Group (Thein, 1978). The upper Carboniferous to Permain Moulmein limestone and the Triassic Kamawkala limestone of the southern region have been correlated with the Plateau Limestone of the central region by Thein (1978) and overlie the greywackes and associated clastics of the Mergui Series. The Lebyin Group of the central region, (Nyunt and Saing, 1978a and b) the Mawchi series of Kayah State, the Martaban

Beds and Taungyo Series of northern Tennasserim are apparently quite similar and consist of shales, slates, quartzites, greywackes and mudstones. Faunal evidence from the Lebyin Group indicates a Carboniferous age. The Martaban Beds have been assigned to the Permian (Thein, 1978).

8.3 Mesozoic Stratigraphy

The 75-meter thick upper Triassic Panngo evaporites and 250 meter thick marine Napeng shale and mudstone beds of the northern region of the Shan-Tennasserim Basin have no equivalents in the central region of the basin. The Jurassic is represented by the 2,000(?) meter thick lower to middle Jurassic marine clastics of the Loi-An Group and the 800(?) meter thick lamellibranch-bearing (Reed, 1936) middle to upper Jurassic paralic facies clastics of the Namyau Group in central regions (Thein, 1978). The Cretaceous is represented by the alternating marine and terrestrial facies, cephalopod-bearing (Fox, 1936) siltstones and conglomerates of the Kalaw Red Beds of the central region, and their equivalents in the southern region.

The central basin is the second largest basin in Burma and occupies the north-south trending central low-lying valley located between the Arakan-Chin-Naga Yoma Ranges to the west and the Eastern Highlands to the east, and whose sediments comprise the cover of the West Burma Block. The northern boundary of the basin is defined by the exposures of undifferentiated granite-gneiss in the Kachin State whereas its southern boundary appears to be submerged beneath the Gulf of Martaban. The sequences of rocks in the central basin are folded and faulted, extremely thick late Cretaceous to Pliocene marine and terrestrial facies clastics (Nyunt and Saing, 1978). Lower Cretaceous shallow water marine Orbitolina-bearing limestones are known from the northern part of the basin, especially in the Jade Mines (Mandalay) area. These are overlain by the upper Cretaceous Kalaw Formation which consists of shallow to deep water marine sandstones, shales and limestones and is confined it is exposure to the western periphery of the Central Basin. Tertiary formations consist largely of molasse facies sequences locally interbedded with marine limestone.

The north-south trending Arakan-Chin-Naga Yoma foldbelts lie immediately west of the Central basin and comprise thick sequences of strongly deformed flyschoid, mainly indurated dark grey slaty shale with thin interbeds of grey sandstone. A few deep water limestone beds are present but their exact stratigraphic position is problematical. Upper Cretaceous complexes also occur as exotics of limestone in black, shaley Eocene mélanges. Paleontologic evidence indicates that sedimentation in the Arakan-Chin-Naga Yoma region commenced in the middle Triassic, judging from coeval exposures comprising the Daonella and Halobia-bearing shales and slates of the Thanbaya Formation of the Chin Hills. Deposition was not continuous however, as is indicated by a widespread Jurassic-Cretaceous hiatus (Nyunt and Saing, 1978a).

The stratigraphic sequence in the northern part of the foldbelt consists of four major units; the Kanpetlet schists, the Thanbaya Formation (Triassic), the Rangfi Formation (Cretaceous) and Eocene flysch. The thick sandstones, shales and limestones of the Thanbayo unconformably overlie the Kanpetlet schists. Deposition of deep water radiolarian cherts, pelagic limestones, sandstones and shales of the Rangfi Formation were subsequently replaced by the deposition of flysch during the Eocene.

CHAPTER IX

BORNEO

## 9.1 Introduction

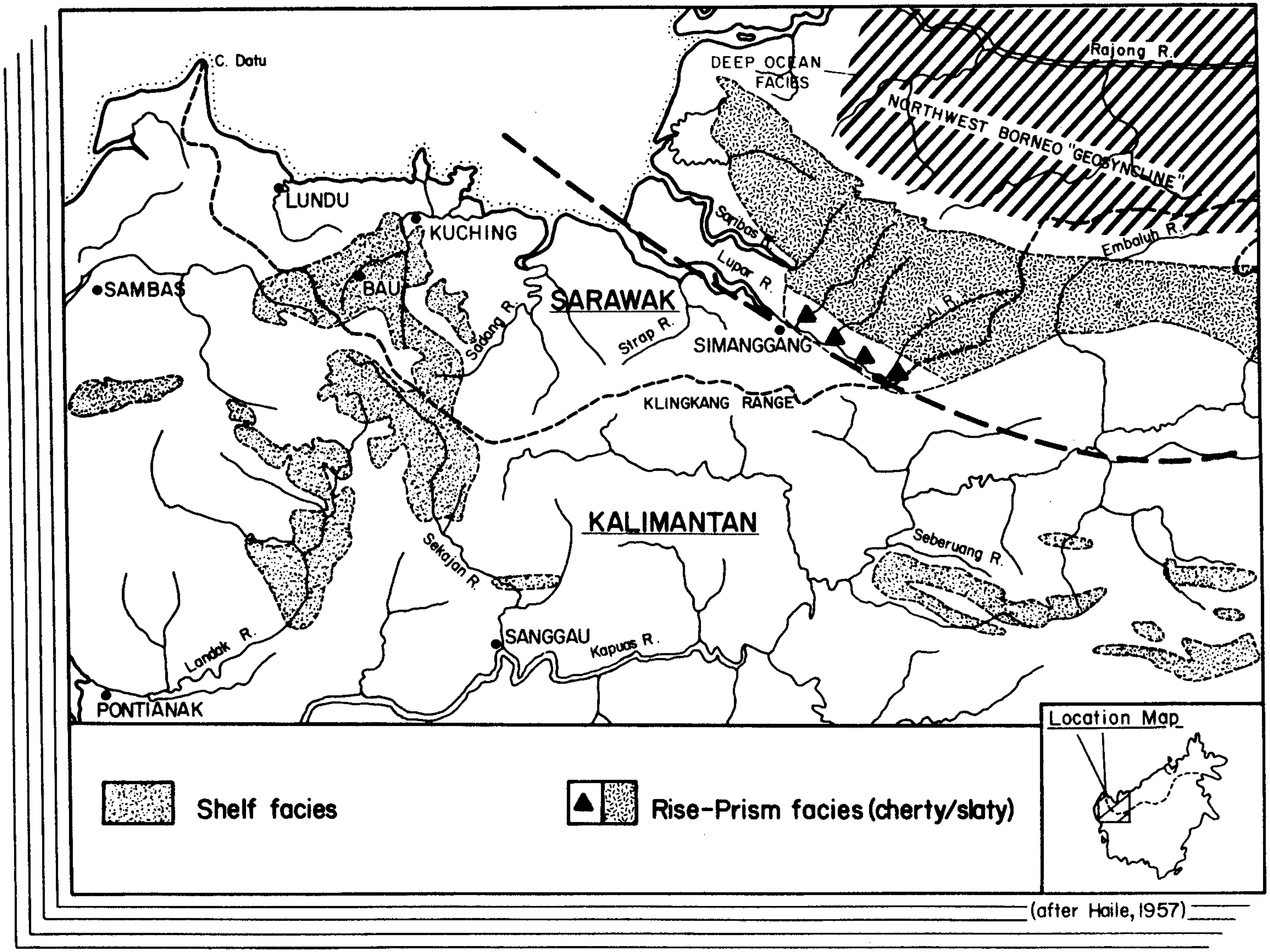
Variably deformed and metamorphosed Precambrian(?) Paleozoic and Mesozoic sedimentary and volcanic rocks and Mesozoic granitic plutons comprise most of western and central Borneo (Plate XIV). These rocks have been studied via systematic reconnaissance observations in far western Sarawak (Haile, 1957) but they are known only from very widely separated observations and traverses in the vastly larger region of Kalimantan (van Bemmelen, 1939). Subduction zone mélange, largely or wholly of Cretaceous age (Hamilton, 1979), occurs in both northwestern and southeastern Borneo, on opposite sides of a broad terrain dominated by Cretaceous igneous rocks. Some of this intervening terrain was apparently of continental character before Jurassic times. Permo-Carboniferous coal horizons, containing elements of the Glossopteris flora have long been known from the formerly exploited works of Labuan, Brunei (Tennison-Woods, 1885).

## 9.2 Pre-Cenozoic Subduction Complexes and Ophiolite Belts

The pre-upper Cretaceous rocks of the coastal part of far western Sarawak are interpreted by Hamilton (1979) as consisting of Jurassic to late Cretaceous polymict subduction zone mélange deposited in what had once been referred to as the Northwest Borneo Geosyncline (Haile, 1957; Brondijk, 1963). The material has been described as the "slaty conglomerate" of the Serabang Formation, dominated by deformed blocks of greywacke and sub-greywacke in association with sheared lenses of greenstone, dismembered ophiolites, ultramafic rocks, greywackes and other refractory rock types in an extremely sheared, argillaceous matrix (Hamilton, 1979). The southernmost limit of this mélange zone comprises the Lupar ophiolite belt (Hutchison, 1975). Tectonic lenses seen in outcrop reach several meters in length and those inferred from map relationships reach lengths of several kilometers. The shales contain undated abyssal foraminifera and radiolaria of Jurassic to Cretaceous age occur in white to red-colored exotic blocks of manganiferous chert. The mélange is intruded and contact metamorphosed by quartz monzonite plutons from which late Cretaceous K/Ar ages have been obtained. These in turn are overlain by latest Cretaceous sandstones which are not as strongly deformed. Mélange of the same age may be present in a broad terrain of deformed polymict formation located in far eastern Sarawak which had formerly been assigned to the Paleogene (Hamilton, 1979). South of the mélange belt, in far western Sarawak, conditions were apparently shallow marine prior to mélange emplacement and the exposed rocks consist of polyphase deformed shales, sandstones and silicic to intermediate volcanics with subordinate limestones that have been contact metamorphosed near granitic intrusions (Haile, 1957). Shallow water marine invertebrates have been discovered in upper Carboniferous to lower Permian limestone clasts in an upper Triassic coarse clastic sequence (Haile, 1957). These coarse sequences are also intercalated with intermediate volcanics. These in turn are overlain by upper Jurassic through upper Cretaceous (Orbitolina-bearing) shales, sandstones, tuffs and limestones (Haile, 1957; Chen and Lau, 1978; Hamilton, 1979). Individual exposures of Paleozoic clastic, volcanic or granitic rocks have not yet been positively identified in northwestern Borneo but

FIGURE 21:

## FACIES DISTRIBUTION OF THE JURASSIC-CRETACEOUS, N.W. BORNEO




(after Haile, 1957)

evidence of Permo-Carboniferous limestones has been presented by Haile (1957). Triassic (?) volcanic rocks in one area are comprised dominantly of island arc(?) basalts, andesites, and rhyodacites (Hamilton, 1979). Redbed conglomerates, arkoses and coals from continental crystalline sources are known from a few Triassic and Cretaceous sections but the precise area of provenance is not identifiable (Haile, 1957). One granodiorite pluton is overlain by unmetamorphosed upper Jurassic strata and is perhaps correlative with the upper Triassic volcanics. The other plutons are mostly of biotite-quartz monzonite and intrude strata tentatively assigned to the Jurassic and upper Cretaceous, and have yielded Cretaceous K/Ar determinations of about 75 million years for three plutons and 100 million years for one other (Hamilton, 1979). Rocks as young as late Cretaceous have been metamorphosed. Uppermost Cretaceous and Paleogene continental strata unconformably overlying these sequences are gently to severely deformed and contain intercalations of intermediate and silicic volcanics and small intrusions as well. According to the facies analysis of western Borneo by Haile (1957), far western Sarawak appears to have been a north-facing Atlantic-type margin prior to the initiation of Cretaceous subduction (Figure 21).

Most of western Kalimantan consists of deformed and variably metamorphosed clastics and silicic volcanics which are intruded in many places by a variety of granitic plutons from which whole rock K/Ar and single mineral K/Ar isotopic analyses have yielded 76 to 115 million year and 127 to 154 million year values respectively (McElhinny et al., 1977). Fission track ages from two samples yielded 77 million year values. The southwest Borneo granites thus may be largely of Cretaceous age. Cretaceous ages have also been determined from K/Ar analysis of samples from islands and drill cores to the south and west of Borneo. Haile (1973) found abundant medial Cretaceous pollen in steeply dipping sandstone and shale in a section that includes massive volcanics which have been intruded by granites.

Hamilton (1979) presumes these igneous complexes to be paired to the Cretaceous mélange complexes that occur in both northwestern and southeastern Borneo. The granitic complexes exposed in western Kalimantan are in general more potassic in the south than in the north, suggesting that the bulk of these complexes formed in response to south-dipping subduction but this exposed terrain represents only the northern half of the full width of the granite-dominated region known offshore further to the southwest.

Subduction mélange involving Cretaceous sediments and the ophiolites of the Meratus-Bobaris belt (Hutchison, 1975) occurs in several areas of southeastern Kalimantan which are in turn overlain by Eocene strata. The Meratus Mountains provide the largest outcrop area. This terrain consists of a variety of materials including polymict breccias, ophiolites, glaucophane schists, greenstones, peridoites, serpentinite, radiolarian cherts and deep water clastics and carbonates bearing pelagic, middle Cretaceous foraminifera. These are chaotically intercalated at all scales from the outcrop to a regional level in steeply-dipping, highly deformed complexes. Biotite-quartz monzonites and hornblende andesites also occur in the pre-Eocene complexes of the Meratus Mountains (Hamilton, 1979).

The basement terrain comprising northeastern Kalimantan is also inferred to consist largely of subduction mélange formed in Cretaceous times. This terrain is known only from extremely sketchy reconnaissance work and consists of low grade metaclastics, quartzose greywacke, serpentinite, peridotite, spilite, radiolarian chert, diabase, basalt and greenstone chaotically intermixed in a thoroughly sheared, argillaceous matrix (Hamilton, 1979).

### 9.3 Mesozoic Paleogeographic Position

An interpretation of the Mesozoic position of Borneo by Ben-Avraham and Uyeda (1973) suggested that Borneo moved southwards during the late Jurassic along a north-south transform fault located at the eastern margin of Indochina, from a position between what is now Hainan and Taiwan islands at the southern margin of mainland China. Audley-Charles (1978) however, contended that all available evidence appeared to indicate that there have not been any major post-Permian displacements between the island of Sumatra, Java and Borneo (the "Sundaland plate") and the western part of the South China Sea, although it did not exclude the possibility of lateral movements on large transcurrent faults.

Paleomagnetic vectors determined by McElhinny et al., (1977) on Cretaceous igneous rocks of between 80 and 90 million years old from southwestern Borneo indicate that the Cretaceous terrain apparently has undergone a net rotation of 45° counterclockwise or 135° clockwise, in the last 80 million years but has not changed latitude.

Audley-Charles' (1978) view of a major Sundaland plate comprised of Malaya, Indochina, Borneo, southwestern Sulawesi, Sumatra and Java has been further disputed by paleomagnetic evidence presented by Haile (1981) which suggests a 34° clockwise rotation of Sumatra since the Oligocene as well, although this does not appear likely.

## CHAPTER X

## PALEOMAGNETIC CONSTRAINTS

The acquisition and synthesis of paleomagnetic data for East and Southeast Asia is still in a developmental stage and consists primarily of scattered reconnaissance surveys that by and large have yielded inconclusive and often conflicting results. Some exemplary works have provided needed constraints on some of the more important regional geotectonic problems.

### Peninsular Malaysia

#### Early Paleozoic

Results derived from an analysis of Ordovician rocks from the Malay Peninsula by Haile (1981) indicate a 43° paleolatitude of undetermined but presumed southern polarity.

#### Late Paleozoic and Mesozoic

McElhinny, Haile and Crawford (1974) have demonstrated that the late Paleozoic positions of the Malay Peninsula and Indochina were totally different from that of Gondwana. Their studies indicate that Malaya in particular lay near 15° latitude at this time and not adjacent to the eastern coast of India as formerly thought by Burton (1970). The oldest rocks studied comprise a suite of lower Carboniferous sediments from central Malaya. Two other small suites of Malayan samples paleomagnetically analyzed were assumed Permian age rhyolites from the southeast of Malaya and a Triassic rhyolite and redbed sequence from a west-central district. The magnetic orientation of these rocks is similar to that of the lower Carboniferous sedimentary rocks but

Hamilton (1979) has questioned the validity of such results, citing the uncertainties involved in dating Malayan igneous rocks due to their incompatibility with presumably better constrained paleomagnetic reconstructions of a former Australia-New Guinea-Sumatra-Malaya continent which has been placed by McElhinny and Luck (1979) at 10° S. latitude in the early Carboniferous and at 40° S. latitude during the Permian and early Mesozoic. Sumatra-Malaya is presumed by Haile (1981) to have lain adjacent to what is presently central New Guinea in the Permian and Triassic and to have become detached from it prior to the medial Jurassic. If the Permian and Triassic age determinations from McElhinny, Haile and Crawford's (1974) Malayan samples are correct, then this orientation is obviously incompatible with a New Guinea attachment. Inverting the paleolatitudes does not clarify the problem as a 180° rotation of Sumatra-Malaya would be involved, thus placing Sumatra farther from New Guinea than Malaya. The suites studied and reported on by McElhinny, Haile and Crawford (1974) therefore could very well have been Jurassic or Cretaceous, their results indicating an acceptable position for Malaya at this time. Recent evidence from Sumatra cited by Haile (1981) seems to refute previous evidence of its participation in the aforementioned Permo-Triassic continent defined by McElhinny and Luck (1970).

Cenozoic

Paleomagnetic studies of late Cretaceous-early Tertiary basalt flows from southeastern Malaya by McElhinny, Haile and Crawford (1974) have yielded questionable 10° to 20° N. paleolatitudes implying that a southward movement and a clockwise rotation of Malaya on the order of 15,000 kilometers and 45° respectively have occurred since the Cenozoic.

## Thailand

### Paleozoic and Mesozoic

The presumed equatorial character of the fauna from the middle Permian of northern Peninsular Thailand has recently been confirmed by the 30° N. paleolatitude determination of McElhinny, Haile and Crawford (1974) and a 25° S. value obtained by Hamilton (1979) from coeval rocks of the region. A reconnaissance paleomagnetic survey of Jurassic Khorat Group Redbeds from northeastern Thailand (Haile and Tarling, 1975) have yielded a pole only 18° removed from the Juassic pole derived from analyses of similar lithologies from southwest China (Lee Chuan-ti, 1963).

## Western Indonesia and Sarawak

Haile, McElhinny and McDougall (1977) and Haile (1978) have postulated that the Malay Peninsula, western Borneo and southwestern Sulawesi appear to have comprised parts of the same continental piece in Cretaceous times while central and eastern Sulawesi and most of Sumatra appear to have been parts of different plate systems. Results from western Sarawak indicate that the rotation of a West Borneo microplate was largely completed by the Miocene (Haile, 1981). However, rotation of northwest-central Sulawesi was still occurring in medial Tertiary times, having previously gone through a 35° rotation between the Paleocene and Miocene. Results from Sumatra reported in Haile (1981) indicate a clockwise rotation since the Mesozoic. Most pre-Cenozoic sites show inclinations indicating a paleolatitudes of less than 26° and Haile's (1981) results suggest a 12° northward drift since the late Triassic accompanied by a 40° clockwise rotation, only 6° of which was accomplished by the Oligocene. It appears that Sumatra southwest of the Sumatran Fault Ssytem was not part of a continuous Sundaland "plate" comprising Borneo, Malaya, southwestern Sulawesi, Sumatra and Java as envisioned by Audley-Charles (1978) until the Oligocene-Miocene (Page et al., 1979).

## China, Japan and the southern Soviet Far East

A recent contribution by McElhinny, Embleton, Ma and Zhang (1981) is significant in illustrating that Permian rocks from the two major eastern Chinese cratons, the Yangtze (South China) Paraplatform and the Sino-Korean (North China) Paraplatform show disparate paleomagnetic vectors. This supports the view held by Klimetz (1982) that in the Permian they were separate from each other and from the remainder of eastern Asia based on tectonic evidence. Despite the fact that the results obtained from the southern Chinese samples may not necessarily be representative of the entire region, the results are encouraging nonetheless.

# CHAPTER XI

# MESOZOIC TECTONICS AND PLATE TECTONIC INTERPRETATIONS

## 11.1 Late Permian-Early Triassic

Figure 22 represents a schematic late Permian-early Triassic reconstruction for southeastern Asia. Due to space limitations only the Siberian Craton, North China Fold Zone, Sino-Korean Paraplatform and Yangtze Paraplatform have been shown. It should be kept in mind that this and following reconstructions are schematic. The relative distribution and positions of these blocks have been illustrated for convenience only and are not to be considered reflective of their actual positions at this time. The placement of the Siberian Craton in this and subseuqent figures has been shown in its present longtidinal orientation (note present-day north arrow).

Late Permian paleolatitudes and north-arrows determined by McElhinny et al., (1981) have been superimposed on each block. According to their interpretation, to restore the paleogeographic orientation of the Yangtze Paraplatform for this time would require an approximately 100-degree counter-clockwise rotation from the orientation depicted in this figure relative to the Siberian continent. Similarly, a 60-degree clockwise rotation of the Sino-Korean Paraplatform and the North China Fold Zone and a 65-degree anticlockwise rotation of the Yangtze Paraplatform, respectively, would restore the remaining elements. Despite these rotations it is significant that the Yangtze Paraplatform, Sino-Korean Paraplatform and North China Fold Zone lay near the equator and apart from the remainder of Eurasia which lay at considerably higher latitudes. The late Permian

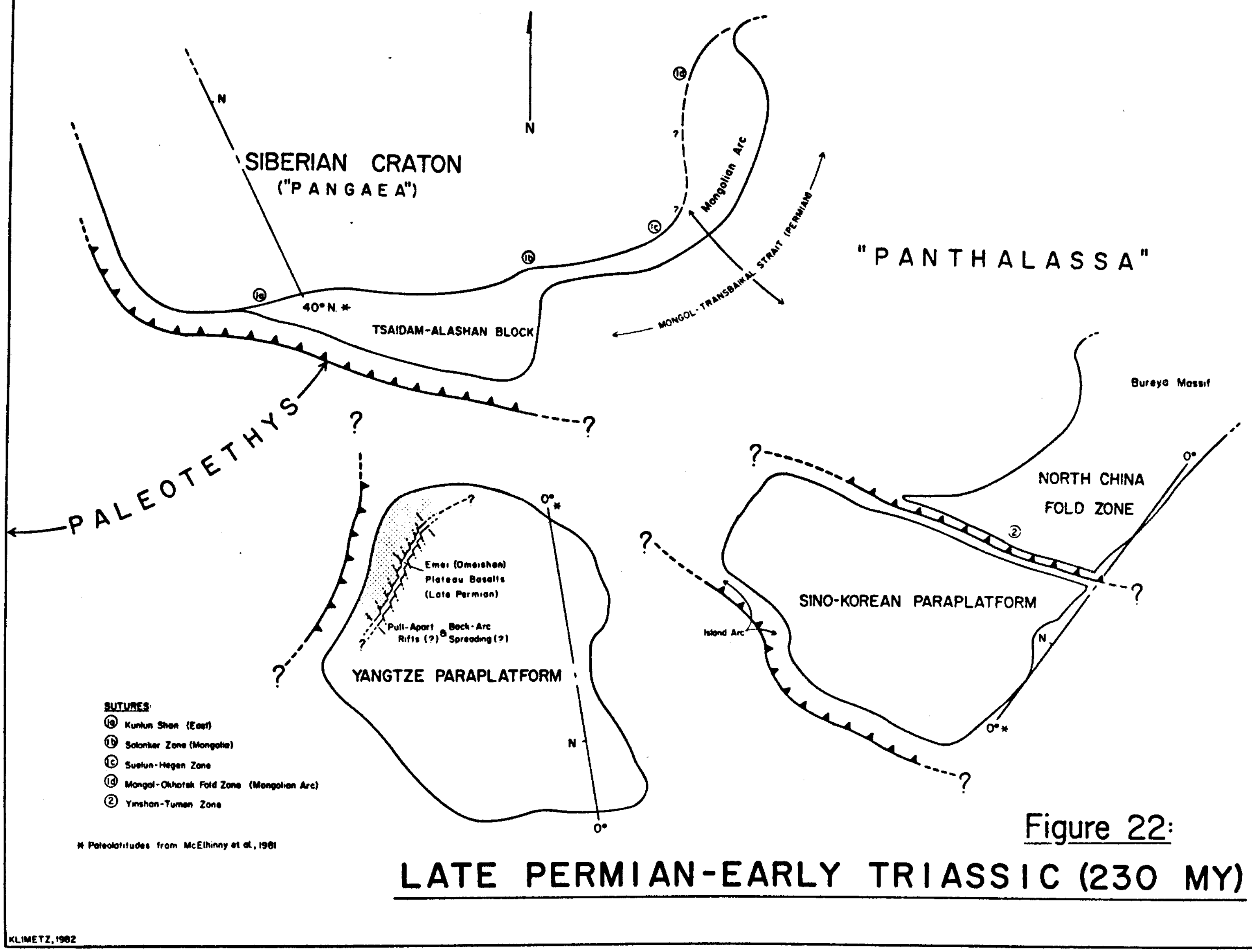



Figure 22:

LATE PERMIAN-EARLY TRIASSIC (230 MY)

positions of the Southeast Asian and Sikhote Alin Blocks have been placed between 20° and 40° north latitude by McElhinny et al., (1981) although the well-defined tropical marine fossil assemblages of the late Permian Rat Buri and correlative limestones of Thailand and Indochina (Workman, 1972; Fontaine and Workman, 1978) suggest that Southeast Asia occupied more equatorial latitudes.

The geometry of the southeastern margin of the Siberian Craton had become altered from that created during the medial Carboniferous via the medial to late Permian accretion of the Qaidam-Alashan Block and a small strip of continent known as the Mongolian Arc along the eastern Kunlun, Solonker (Khasin and Borzakovskiy, 1967; Borzakovskiy, 1970) and Suelün-Hegen suture zones (Bally et al., 1980; Li, 1981). These three zones (Figure 22) comprise a remarkably continuous belt extending from the southeastern Tarim Basin and the southernmost tip of Mongolia to its easternmost termination near the Great Khingan Range. Thrust sheets comprised of dismembered ophiolites, calc-alkaline island arc volcanics and strongly deformed Ordovician through lower Permian marine sediments have been described from the entire length of the belt. The eastward limit of the Suelün-Hegen zone is not known with certainty but appears to trend northwards, west of the Great Khingan Range to the Mongol-Okhotsk foldbelt at the junction of the Amur, Argun and Shilka Rivers.

The consumption of Paleotethyan ocean crust at this time along the Tarim-Qaidam-Alashan portion of the southeastern Eurasian Margin is indicated by coeval calc-alkaline magmatism along the western Kunlunshan and Buerhanbuda-Jishishan zones (Plate V) (Geologic Map of China, 1976).

The closure of an ocean basin along a north-dipping subduction zone and the subsequent collision of the Sino-Korean Paraplatform and the North China Fold Zone had nearly reached completion by the beginning of the Triassic along the Yinshan-Tümen zone (Bally et al., 1980; Li, 1981). Dismembered ophiolites, glaucophane schists, granites, granodiorites, silicic to intermediate volcanics and the strongly deformed Paleozoic Manmo Group marine sequences of up to late Permian-early Triassic age (Kobayashi, 1971) are exposed along an east-west trending, 1800 kilometer long belt from Inner Mongolia to the Tancheng-Lujiang Fault Zone. Basin closure was accompanied by a widespread Permo-Triassic regional unconformity corresponding to the Akiyoshi Orogeny of Kobayashi (1971), which synchronously affected large areas of Asia including the southeastern Northeast China Fold Zone and the Sino-Korean Paraplatform.

The consumption of oceanic crust between the Yangtze and Sino-Korean Paraplatforms along a north-dipping subduction zone located at an island arc somewhat removed from the southern margin of the latter apparently commenced during the late Permian (Feng, 1980; Yin, 1980). Similarly, the consumption of oceanic crust between the southwestern margin of the Yangtze Paraplatform and the Indosinia (Southeast Asia) Block also commenced during this time, and resulted in a strong Permo-Triassic regional unconformity corresponding to the "Tungwu Movement" of J.S. Lee (1938). The medial late Permian Omeishan (Emei) plateau(?) basalts of Yunnan, Sichuan and Guizhou provinces are undoubtedly a consequence of this convergence and have been interpreted by Fan (1978) as back-arc volcanics. They cover an extensive area bracketed by Mesozoic ophiolite complexes which have also been referred to as Omeishan basalt by most workers. An association of pillow lavas, radiolarian cherts, greywackes and shales of Triassic age have been described by Huang (1932) near the village of Chü-Chang in Guizhou province at the easternmost limit of Omeishan exposure. Exposures of ultramafic rocks are also known from this area (Geologic Map of China, 1976; Hsü, 1981). Oceanic or at least para-oceanic conditions therefore appear to have existed much farther island of the presumed southwestern edge of the Yangtze Paraplatform than was formerly thought, and the Chü-Chang ophiolites are interpreted as the locus of a late Permian back-arc basin which subsequently closed during the latter part of the Triassic. The Omeishan plateau basalts proper, which are themselves in part pillow lavas, were erupted onto a shallow water carbonate platform that existed across much of the southern Yangtze Paraplatform at this time. The southern fragment became rifted from the Paraplatform following the initiation of subduction in the medial late Permian (Figure 29). Judging from the position of these ophiolites with respect to the dominant early Mesozoic regional structures, facies belts and the eastern most exposures of Omeishan basalt, the back-arc basin appears to have been oriented northwest-southeast extending from the southern edge of the Sichuan Basin to the South China Sea. The paleomagnetic vectors determined from the Omeishan basalts by McElhinny et al., (1981) therefore may not necessarily be representative of the Yangtze Paraplatform as a whole, but a rifted and reaccreted portion of it.

The rifting of the Cimmerian Continent from northern Gondwanaland and the opening of Neotethys behind it also coincided with, and was perhaps attributable to, the subduction of Paleotethys beneath Eurasia (Şengör, 1979) as well as the eruption of the late Permian Panjal

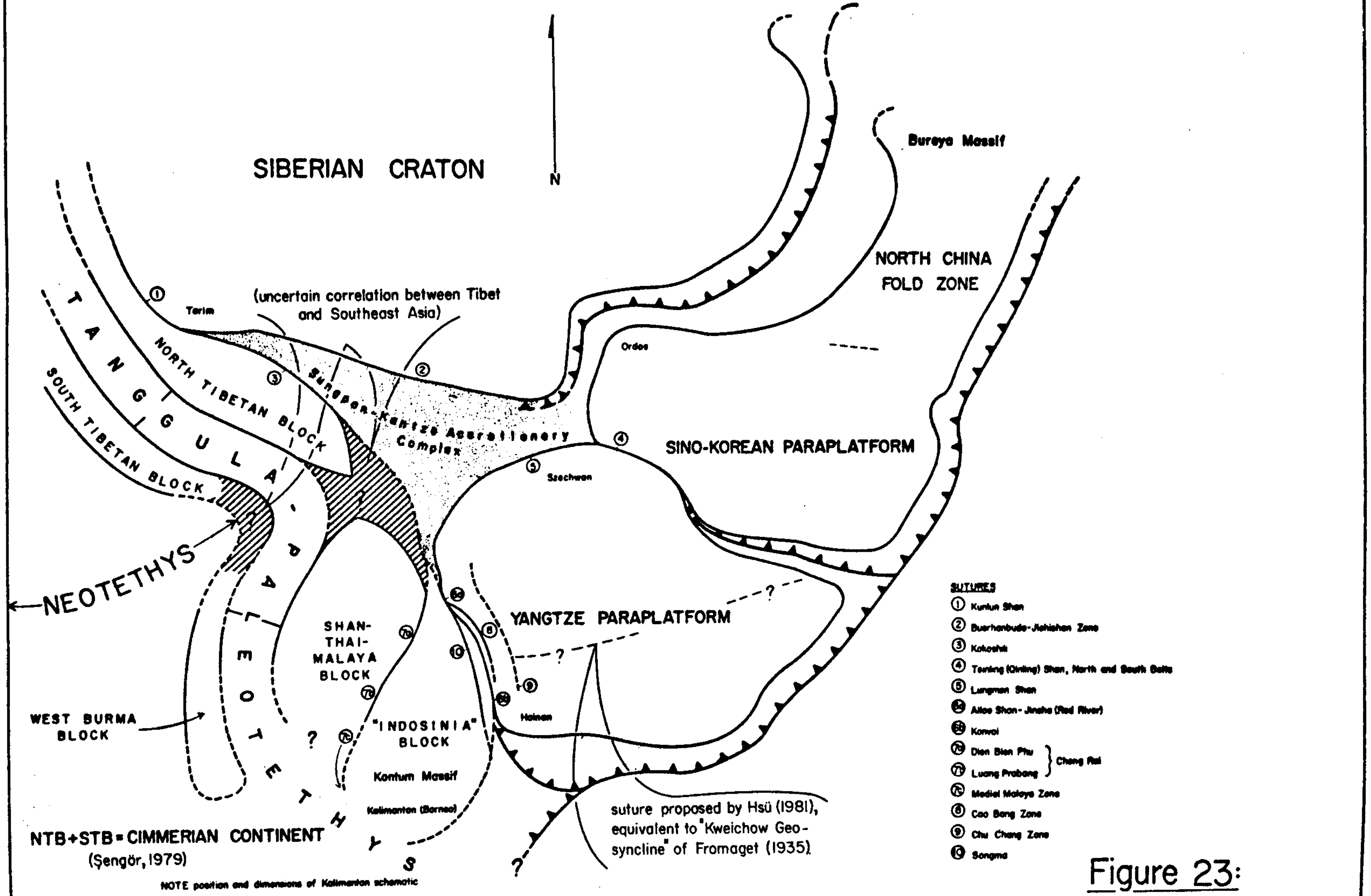



Figure 23:

LATE TRIASSIC-EARLY JURASSIC ("INDOSINIAN") (195 MY)

(Bhot, 1981) and Sikkim Traps.

## 11.2 Late Triassic-Early Jurassic (Indosinian)

The late Triassic to early Jurassic can be generally characterized as a time of accretion, during which the structural edifice of eastern China and Southeast Asia began to acquire a more familiar configuration (Figure 23). True oceanic conditions were terminated throughout most of the region except in certain restricted localities and in belts bordering the Tethys and Kula/Pacific Oceans. Although no reliable paleomagnetic data exists for this region for the Triassic-Jurassic boundary, there is sufficient geologic evidence which allow several statements concerning the relative positions of the major tectonic elements to be confidently made.

Collision of the combined Sino-Korean Paraplatform-North China Fold Zone Block and the Yangtze Paraplatform appears to have commenced at this time but did not reach completion until considerably later. A west to east decrease in ages of the earliest granites and collision-related thrusts along the Qinlingshan-Dabieshan-Huaiyang suture ranging from late Triassic to medial Cretaceous (Tan, 1923; Geologic Map of China, 1975) (Plate 1) appears to imply a diachroneity of convergence at an along-strike rate of approximately one centimeter/year. Evidence of collision is most complete for the late Triassic-early Jurassic of the Qinlingshan where ophiolites, flysch, subduction zone mélange a paired metamorphic belt indicating northward-dipping subduction, granites, granodiorites, calc-alkaline volcanics and fossiliferous marine strata from Carboniferous through late Triassic age have been recognized (Chao and Huang, 1931; Lee, 1938; Jiang, 1964; Zhang _et al._, 1979; Bally _et al._, 1980; Fen _et al._, 1980;Wang, 1980;

Yin, 1980; Li, 1981). A pair of east-west trending ophiolite belts are known from the eastern Qinlingshan and appear to bracket an ancient island arc trapped between the Sino-Korean and Yangtze Paraplatforms (Fen et al., 1980). A marked angular unconformity between strongly deformed Triassic greywackes, cherts, and limestones and overlying gently folded paralic and terrestrial facies Jurassic sequences has been observed within as well as on opposing sides of the belt (Plates II and III).

Suturing of the Indosinia Block to the southwestern margin of the Yangtze Paraplatform during this time is probably the best constrained Mesozoic collisional event in all of southeastern Asia. It is the locality of the Indosinian orogeny which is marked by a regional unconformity between highly deformed Carnian deep water marine deposits and only slightly deformed Norian paralic facies sequences (Plates II and III) (Postel'nikov, 1960; Jen and Chu, 1970). Déprat and Mansuy (1912) first described the structure of the region as comprising a series of Alpinotype southwest-vergent thrust sheets that were transported over significant distances. Fromagét (1939) proposed a structure comprised of sequentially accreted geosynclinal arcs of Gondwana origin that swept over Southeast Asia in a tide-like fashion. Saurin (1953) contended that the principal structures involve a more localized development of large, well exposed imbricate basement folds cut by shallow-dipping thrust faults along the Black and Red Rivers of northern Vietnam. Izokh and Van Tien (1966), Morgunov (1970), Din Kat (1972 a, b; 1975), Staritsky (1975), and T'yong (1980) have described a late Paleozoic to medial Triassic association of deep-water marine sediments and ultramafic rocks from the Red River Fault which is on strike with strongly deformed by continuous exposures of ophiolites, spilites, subduction zone mélange, glaucophane schists, granodiorites, tine-bearing granites (Mitchell, 1977; Narbut, 1981), calc-alkaline volcanics and fossiliferous marine assemblages of the Jinshajiang-Ailaoshan-Tengtiaohe suture zone of Yunnan, China (Fan, 1978; Zhang, 1979a; Bally et al., 1980; Yin, 19801 Zhang et al., 1980; Li, 1980; Duan et al., 1981). Sheared pyroxenites, spilites, serpentinites, pillow lavas, undifferentiated ultramafic rocks and granodiorites have been described by Gregory and Gregory (1925) and Misch (1945, 1947) from the Tali region of northwestern Yunnan. The northern Vietnamese segment of this belt has also been referred to as the Konvoi suture zone (Din Kat,1972a, b; 1975). It has also been argued by Zeiller (1902); Sze (1942), Asama (1965) and Ridd (1971) to coincide with the boundary separating the Permo-Carboniferous Cathaysian (Gigantopteris) and Gondwana (Glossopteris) floral provinces, although the latter contains a few mixed Cathaysian elements as well (Hart, 1974). Although this belt has been considered to comprise the only late Triassic-early Jurassic plate boundary in western China and northern Indochina, its southern end appears to consist of a branching network of belts, especially to the south of Yunnan. The Black River and Cao Bang zones of northern Vietnam and parts of southern Yunnan splay from and trend subparallel to the Ailaoshan-Tengtiaohe-Konvoi zone, and comprise a variety of ultramafic rocks and serpentinites in association with Triassic(?) marine sequences (Din Kat, 1972 a, b; Workman, 1972; Fontaine and Workman, 1978). Hutchison (1975) however, does not consider the Cao Bang serpentinites as ophiolitic in character.

The Dien Bien Phu-Luang Prabang-Phetchabun-Pak Lay zone (Figures 14, 29) appears to be a south-southwest bifurcation and prolongation of the Jinshajian Ailaoshan-Tengtiohe zone, extending from southwesternmost Yunnan through northwestern Vietnam, Laos and eastern Thailand to near Bangkok and the Gulf of Thailand. It comprises a fairly linear belt of ophiolites, granites, granodiorites, subduction zone mélange, calc-alkaline volcanics, deep water marine clastics and cherts strongly deformed at the end of the Triassic and unconformably overlain by gently folded Rhaetian and younger terrestrial facies sediments (Workman, 1972; Bunopas and Vella, 1978; Chantaramee, 1978; Fontaine and Workman, 1978; Thanasuthipitak, 1978). This zone apparently represents the suture between the Shan-Thai-Malaya Block which encompasses most of eastern Burma, western Thailand and perhaps the western segment of the Malay Peninsula, and the Indosinia Block which comprises Vietnam, Kampuchea, most of Laos, the eastern part of Thailand (Khorat Plateau), northwestern Borneo and a small portion of southeastern Yunnan. The early Mesozoic(?) ultramafic rocks and subduction zone melange of the Medial Malaya Zoen (Bentong-Raub Line), exposed just east of the Main Range Batholith of the central Malay Peninsula (Hamilton, 1979) may be the southern equivalent of this zone, although Hutchison (1975) regards this zone as representing a relict early Paleozoic subduction complex that ceased activity by the late Ordovician-early Silurian. Thanasuthipitak (1978) has suggested convergence along a west-dipping zone based on the juxtaposition of an eastern ophiolite belt against a western volcanic arc in the Uttaradit area of northern Thailand. Triassic-Jurassic(?) granites and volcanics east of the ophiolite belt near Loei and southeast of Bangkok (Klompe, 1962; Ridd,1978) (Figure 18) however, suggests a component of east-dipping subduction polarity as well. The post-Norian terrestiral facies Khorat and Indosinias Groups, Terrain Rouge and Grés Superieurs appear to be post-orogenic,molassic basin fills shed from the rising Jinshajiang-Phetchabun-Pak Lay fold-belts following late Triassic-early Jurassic collisions. It is not known with certainty if the northern and southern Tibetan segments of Şengör's (1979) Cimmerian Continent (Figure 23) were at all continuous with any Southeast Asian crustal elements prior to the early Tertiary. The penetration of the Northeast Indian Promontory (Assam Wedge) with southern Tibet and southwestern China in the Eocene (Molnar and Tapponnier, 1975; Tapponnier and Molnar, 1976, 1977) has disrupted earlier structural relationships, obscuring any simple connections between the two regions (Verma et al., 1980) (note question mark and diagonal-ruled areas in Figures 23-27). It can be confidently stated that Tibet and Southeast Asia shared a common Gondwana parentage (Ridd, 1971, 1976, 1980; Mitchell, 1981). They may not have rifted concurrently from it, though Şengör (1979) has asserted a late Permian rifting of the South Tibetan segment of the Cimmerican Continent from northern Gondwanaland based on the age of the syn-rift Panjal (Bhot et al., 1981) and Sikkim Traps and detailed stratigraphic and faunal correlations. A Siluro-Devonian(?) rifting of the Shan-Thai-Malaya Block is suggested by the rift facies deposits of the Phuket Formation of southwestern Thailand which are comprised diamondiferous fluviatile gravels, pebbly mudstones and conglomerates, interbedded with sparsely fossiliferous shales bearing plant remains (Ridd,1976). The provenance of these diamonds has not been determined, but they are intuitively suggestive of a Gondwana source. There is still disagreement regarding the age and origin of the Phuket Formation. Mitchell et al. (1970) regarded them as a Cambrian through Devonian-Carboniferous oceanic deposits whereas Waterhouse (1982) regards them as early Permian shallow water marine pebbly mudstones based on their brachiopod content.

The North Tibetan Block (Bally et al., 1980) became sutured to the southern margin of the Tarim Basin along the western Kunlunshan Foldbelt and Sungpan-Kantze Accretionary Complex (Şengör, 1979) along the Kokoshili- (Kekexili-) shan ophiolite belt (Bally et al., 1980; Yin, 1980). Also known as the Sungpan-Kantze Indosinian Foldbelt (Huang, 1978) it is one of the most conspicuous and puzzling of the tectonic elements of China. It is roughly triangular in outline (Figure 10), bracketed by late Triassic-early Jurassic ophiolites and subduction zone mélange and comprises for the most part a metamorphosed series of medial Triassic and older marine deposits containing a tropical (?) Tethyan fauna. These in turn are overlain by late Triassic to Jurassic redbeds and are intruded by Triassic, Jurassic and early Cretaceous granites (Plate II) (Geologic Map of China, 1975; Yin, 1980). It is confined by the Qaidam-Alashan Block to the north, the Yangtze Paraplatform to the southeast and the North Tibetan Block to the west and southwest, and appears to form a "suture knot" of rather immense proportions but it is not known with certainty to what degree this region may be founded on oceanic crust. Şengör (1981, personal communications) feels that following the medial Triassic, the Sungpan-Kantze was a broad area of relatively low relief, bracketed on all sides by rising mountain belts, that became filled with coarse terrigenous, red bed facies clastics shed from the surrounding highlands comprising the Lungmenshan, Kekexilishan, Qilianshan and Buerhanbuda-Jishishan Ranges (Plate IX).

The northwest-southeast trending Chü Chang zone of southwestern Sichuan and Guizhou provinces is a rather ill-defined zone of pillow lavas, radiolarian cherts and Triassic marine rocks (Huang, 1932) of a presumed late Permian-medial Triassic back-arc basin which closed in the late Triassic-early Jurassic. Hsü (1981) has postulated that the oceanic assemblages of the Chü Chang zone are part of a continuous northeast-southwest trending belt of strongly deformed late Triassic-early Jurassic(?) ophiolites and deep water marine deposits (the "Kweichow Geosyncline" of Fromagét [1935]) that extend across the Yangtze Paraplatform to the Yangtze delta, approximately coincident with the Chang-Nan Geanticline, is a suture joining the Yangtze craton with a strip of continent herein referred to as the Cathaysian Arc.

Although there have been no mention of marine Triassic sediments discovered between the Siberian Craton and the Sino-Korean Paraplat-from-North China Fold Zone Block except for a few exposures in the Dzhirgalantu River basin of northeastern Mongolia (Zonenshain et al., 1971) and in the Mongol-Okhotsk Foldbelt (Krasnyy, 1972, 1973; Kosygin and Parfenov, 1976; Misnick and Shevchuk, 1977, 1980), an ocean basin of indeterminate width located east of the Great Khingan Range is postulted. There do not appear to have been any very active convergent margins along either side of this ocean during this time.

Northwestern Borneo may have occupied a position near the southeastern margin of the Indosinia Block. The late Triassic-early Jurassic terrestrial facies deposits of this region (Hamilton, 1979) are similar to the post-orogenic molasse facies basin fills of Indochina and eastern Thailand and may have had the same provenance.

The initiation of an active, west-dipping subduction zone along the eastern margin of the Yangtze Paraplatform, Sino-Korean Paraplatform and the North China Fold Zone commenced during the late Triassic-early

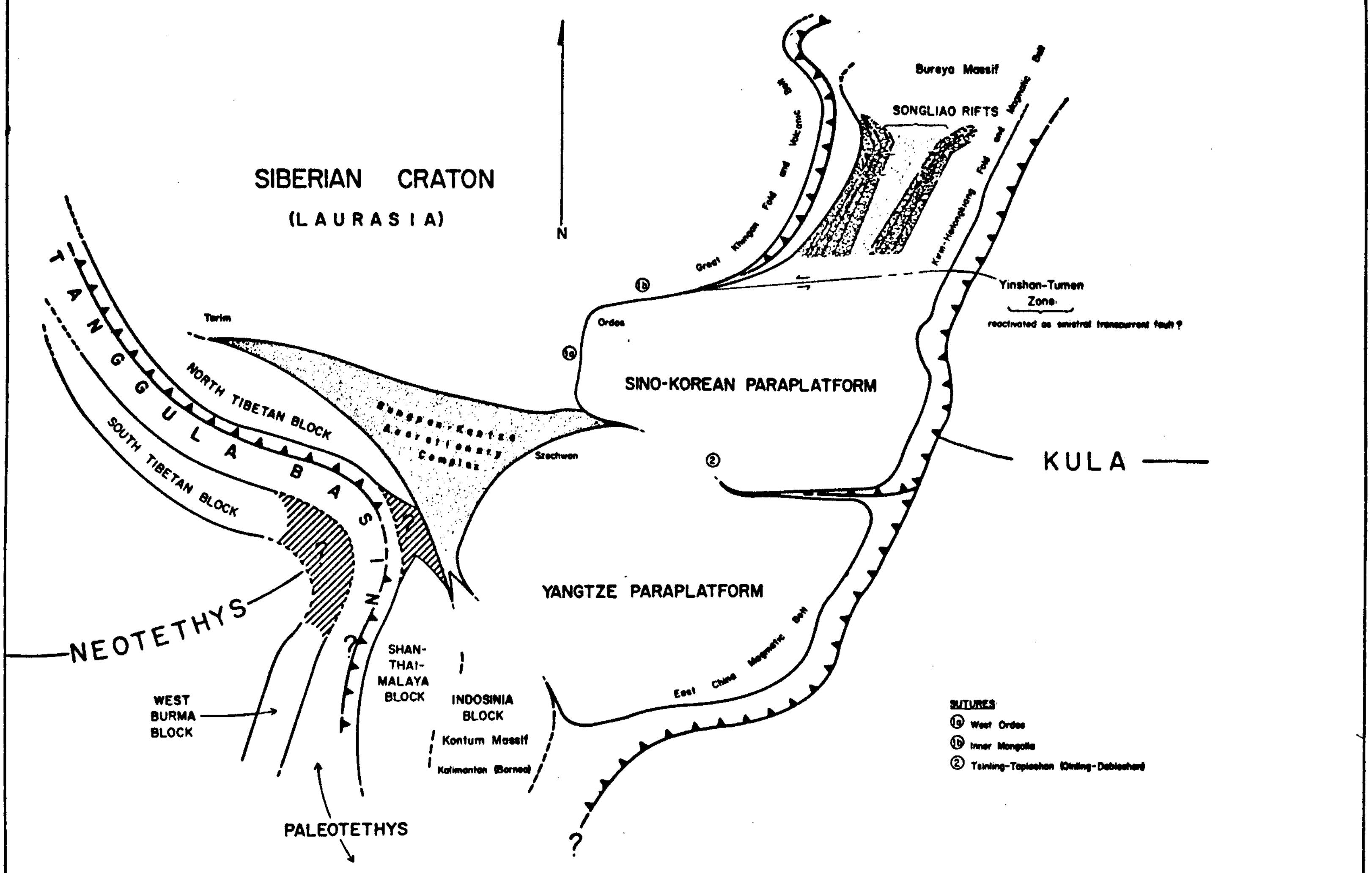



Figure 24:

MEDIAL AND LATE JURASSIC (YENSHANIAN-I) (170 - 140 MY)

Jurassic. This subduction zone appears to have extended along an Andean-type margin for the entire length of the western Kula-Pacific margin. It may perhaps have joined a south-dipping(?) subduction complex in northwestern Borneo, which resided at the southern margin of the Indosinia Block. The far northwestern part of Borneo, comprising Sarawak, and parts of Sabah appear to have been part of Indosinia at this time. Late Triassic volcanics and terrigenous clastics of this region are remarkably similar to the post-orogenic Indosinias-Grés Superieurs-Terrain Rouge-Khorat Group sediments of Indochina and eastern Thailand and may be equivalents.

## 11.3 Medial and Late Jurassic (Yenshanian I)

By medial and late Jurassic times (Figure 24), the structural framework of eastern China and Southeast Asia was nearly complete. An Andean margin was causing widespread igneous activity along the Chinese continental margin, manifest in the extensive granite and granodiorite batholiths and rhyolite and andesite flows comprising the East China and Kirin-Heilongjiang Fold and Magmatic Belts (Jahn, 1974; Geologic Map of China, 1975; Compilation Group of the Geologic Map of China, 1977; Shi, 1979; Wang, 1982, personal communication).

A steadily diminishing tract of ocean remained between the Sino-Korean and Yangtze Paraplatforms, but most had since disappeared beneath the Dabieshan-Tongbaisahn Foldbelt of Henan and Hubei provinces. Strongly deformed early to medial (?) Jurassic ophiolites, subduction zone mélange, flysch, granites, granodiorites, calc-alkaline and tholeiitic island arc volcanics and a paired metamorphic belt suggestive of north-dipping subduction have been described from the northern Dabieshan (Zhang et al., 1981).

The western promontory of the Sino-Korean Paraplatform (Figure 24) had evidently become sutured to the Siberian Craton by the medial Jurassic. A sinuous belt of late Jurassic to early Cretaceous ultramafics, glaucophane schists (Metamorphic Map of Asia, 1978), scattered silicic to intermediate plutonics (Geologic Map of China, 1975), a regional Jurassic-Cretaceous unconformity (Plate II) and west- and north-vergent folds and thrusts extend from the Holanshan at the western margin of the Ordos Basin in central Ningxia Hui province to the Yinshan and Tachingshan of central Innter Mongolia (Teilhard de Chardin, 1924; Wang, 1928; Wong, 1929; Sun, 1934). Ultramafic rocks from the western Yinshan in northern Ningxia Hui (Plate II) comprise the Siaosungsan Series of pyroxenites, perioditites, dunites and mafic volcanics of presumed ophiolitic affinity (Lin, 1962; Roger, 1963).

The sutured Sino-Korean Paraplatform appears to have become essentially "locked" against the Siberian Craton by the medial Jurassic,and a northward-gaping ocean remained between the Craton and the North China Fold Zone.

It is suggested that a combination of sinistral shear accommodated by the Yinshan-Tümen Zone (Figure 24) during the medial Jurassic and early Cretaceous (Huang, 1978) and crustal extension across the North China Fold Zone roughly orthogonal to the convergence direction caused by subduction of the Kula/Pacific ocean floor under the North China Fold Zone contributed to the formation of the Songliao Rifts. A similar hypothesis has been proposed by Castellarin and Rossi (1981) to explain medial Triassic rifts in the Southern Alps on the southern, passive margin side of Paleotethys while that ocean was being consumed in a subduction zone on its northern side bordering central Europe.

The opening of the Songliao Rifts was accompanied by widespread mafic volcanism and became rapidly filled with coarse terrigenous facies clastics, volcaniclastics, and flows of andesite shed from Andean-type margin located to the east (Jilin-Heilongjiang foldbelt) (Plate I and II) (Chin, 1980). Fan (1980) has proposed an alternate model for the Songliao Rifts, whereby the subduction of the Kula/Pacific Ridge beneath northeastern China caused a thermal uplift which resulted in the formation of a three-armed failed rift system. Widespread intermediate to mafic volcanism continued in the Great Khingan Range throughout this time (Figure 28).

A widespread medial to late Jurassic unconformity, a change in sedimentation from carbonate platform to more flyschoid type, and calc-alkaline volcanism, observed in the middle and lower Amur River basins of the southern Soviet Far East suggests the initiation of subduction here as well (Figure 2). Kosygin and Parfenov (1976) compared the Mesozoic stratigraphy of nine "basins" in the Primorye district of the southern Soviet Far East, including the Torom, Uda, Bureya, Upper Amur and Amur-Zeya, and Dzhagdy "basins" (Figure 2) which lie at the junction of the Mongol-Okhotsk and Sikhote Alin foldbelts. Their studies indicated the existence of coeval early to medial Mesozoic "geosynclinal" sequences in each of the basins suggesting that the Amur-Okhotsk segment of the Mongol-Okhotsk Foldbelt and the Sikhote Alin Foldbelt were the sites of two synchronous convergent plate margins. The existence of a medial to late Jurassic unconformity throughout all of these basins between strongly deformed lower marine and gently folded upper terrestiral clastics and volcanics indicates the termination of marine deposition by the closure of an ocean basin, collision, and the deposition of post-collisional molasse. This medial-late Jurassic unconformity is regionally developed and synchronous throughout the entire Primorye district. The persistence of marine deposition into the late Jurassic-early Cretaceous in basins located nearer to the Sikhote-Alin Foldbelt suggests a somewhat later termination of marine conditions than that of the Mongol-Okhotsk Foldbelt. A northeastern prolongation of the Mongol-Okhotsk foldbelt, the Mongol-Chukotka Fault System, extends for approximately 8,000 kilometers from eastern Mongolia and northeastern China along the Amur River to the Sea of Okhotsk and the mouth of the Anadyr River. It consists of a 100 kilometer wide zone of late Jurassic to early Cretaceous north- and west-vergent folds and thrusts involving ultramafic rocks, glaucophane schists, Barrovian zone metamorphics and intermediate to silicic plutonics (Shilo and Umitbaev, 1977), whose geometry is suggestive of a north- and west-dipping subduction complex.

An east-dipping subduction zone appeared to the east of the Shan-Thai-Malaya Block during the latter part of the Jurassic as indicated by the first appearance of coeval, calc-aklaine volcanics and tin-bearing granites (Hutchison, 1972, 1975; Mitchell, 1977, 1981) (Figure 29).

The collision of southern Kalimantan (Borneo) with the south-eastern end of the Indosinia Block appears to have occurred along a north-dipping subduction zone, based on the emplacement of the Jurassic-Cretaceous Lupar Line (Hutchison, 1975) ophioloites and subduction zone mélange comprising the Serabang Formation of western Sarawak (Hamilton, 1979) onto a north-facing Atlantic-type margin (Figure 21) and the intrusion of granites and granodiorites of late Cretaceous age into the mélange.

The closure of the Okcheon "Geosyncline" of central Korea during this time (Ziegler, et al., 1977) is suggested to be due to collision between a combined South Korea-southwest Honshu microcontinent (?) and the eastern Sino-Korean Paraplatform
Sasajima (1981).

11.4 Early Cretaceous

By the beginning of the early Cretaceous, only very narrow tracts of ocean existed between the Sino-Korean and Yangtze Paraplatform as well as between the Siberian Craton on the North China Fold Zone (Figure 25). The Songliao Rifts appear to have been still active, although most active subsidence may have been confined to their northern termination near the Lesser Khingan Range and Bureya Massif. The northeast-trending, 2400 kilometer-long Tancheng-Lujiang Fault Zone appeared during the latest Triassic but became most active during the latest Jurassic and early Cretaceous (Xu, 1980). It is a major sinistral shear that transects the eastern Chinese margin from south of the Dabieshan to the Sea of Okhotsk (Huang, 1978; Yao et al., 1981; Wu et al., 1981; Wu, 1981, personal communication). The eastern "border fault" of the Songliao Rifts appers to have been captured by the Tancheng-Lujiang Fault. An estimate of 740 kilometers of sinistral displacement has been postulated by Xu (1980) from a period spanning the late Triassic to the Cretaceous with an average annual rate of between 1 and 10 centimeters. The relative motion of the Kula/Pacific Plates with respect to the east Asian continental margin was essentially northwards at this time, while the age of oceanic crust consumed beneath eastern Asia was becoming progressively younger due to the westward migration of the Kula/Pacific Ridge (Hilde,

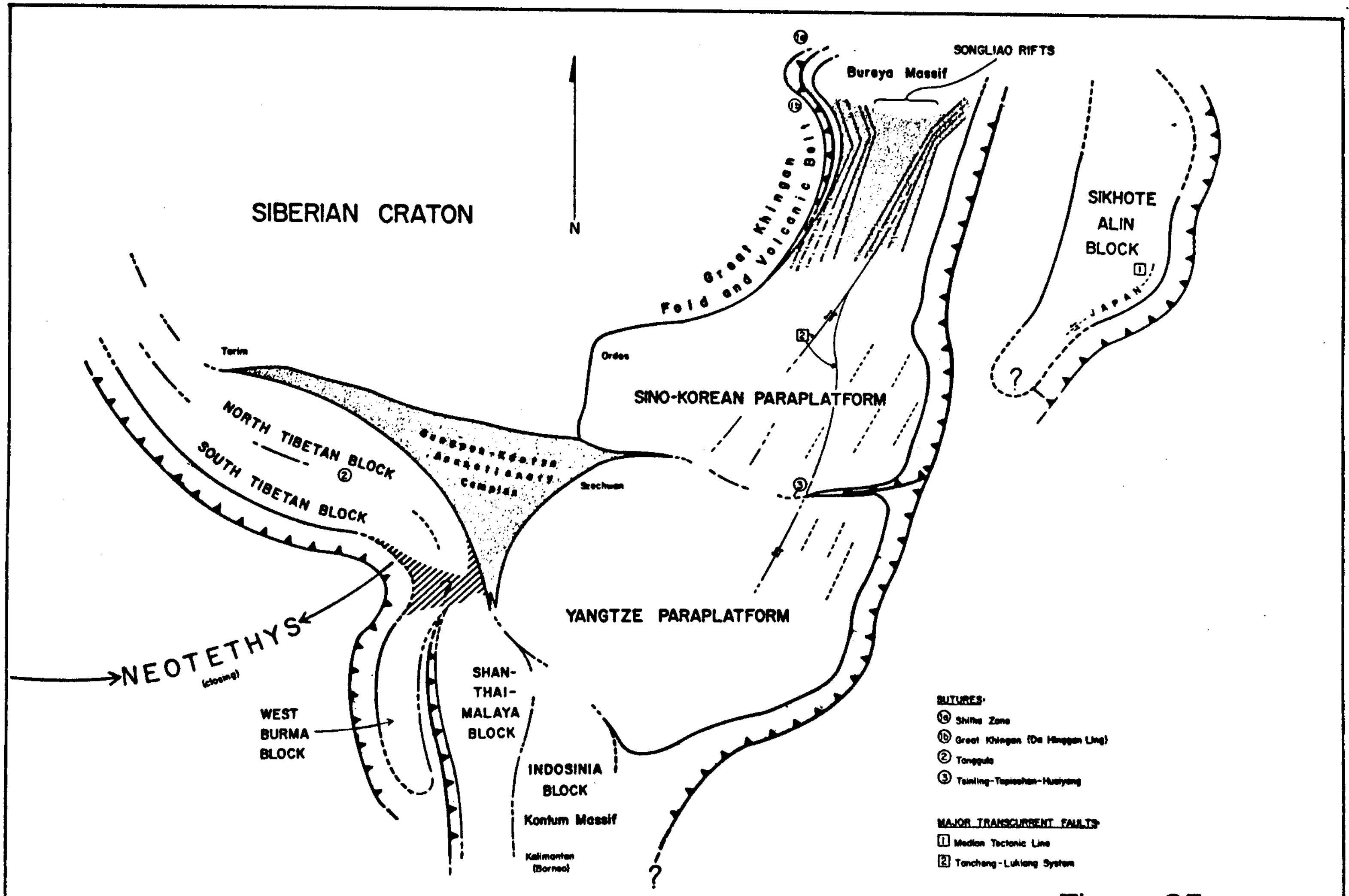



Figure 25:

EARLY CRETACEOUS (YENSHANIAN·I) (120 MY) et al., 1977; Ben-Avraham, 1978). The character of the east Asian convergent margin can be predicted to have been increasingly "compressional" with time due to the subduction of progressively younger oceanic lithosphere (Dewey, 1980). Coupled with the apparent obliquity of convergence and, perhaps, the relatively easily deformed nature of the margin contributed by a long-standing period of continuous magmatism, major intracontinental sinistral shears were initiated. The Tancheng-Lujiang, Taihangshan, Fushun-Mishan faults of northeastern China and the Median Tectonic Line of eastern Japan are the most prominent (Figure 26).

By the end of the early Cretaceous, the intervening ocean between the Siberian Craton and the North China Fold Zone, and its continuation into the Mongol-Okhotsk Foldbelt of northeastern Mongolia and the southern Soviet Far East had disappeared. A belt of highly deformed late Jurassic-early Cretaceous serpentinites, subduction zone mélange and medial Jurassic deep water marine deposits comprise the Shilka Ophiolite Complex (Figure 30) of the eastern Transbaikal segment of the Mongol-Okhotsk Foldbelt (Misnick and Shevchuk, 1977, 1980). Numerous thrust sheets comprised of serpentinite, marbles, calcareous schists, gabbros, gneisses and strongly deformed medial Jurassic marine deposits exposed along the Shilka and Kurenga Rivers in the eastern Transbaikal (Misnick and Shevchuk, 1979, 1980) are interpreted as a dismembered late Mesozoic ophiolite complex (Figure 30). They occur in a narrow belt only 2 kilometers in width and can be traced for 100 kilometers northeast from Sretensk. These rocks are also associated with quartz-mica schists, greenschist facies metamorphics, granites, granodiorites and south-vergent steeply dipping folds and thrusts. The trace of the Shilka Ophiolite Complex is interpreted to mark the suture along which the Great Khingan region of northeastern China and the Eastern Transbaikal Block (Misnick and Shevchuk, 1980) were joined to the southern margin of the Siberian Craton (Aldan-Vitim Shield) following the closure of the Mongol-Okhotsk basin during the late Jurassic and early Cretaceous, accompanied by widespread silicic magmatism (Dudenko and Saltykovskiy, 1978; Seminskii, 1977; Solov'ev et al., 1977; Van-Van-E, 1977). The complex is comprised of the East Aginsk, Ural'ga, Dzhorol, Nikol'sk, Lower Shilka and Byrka ophiolites (Figure 30) which trend in two belts from the eastern Borschchovochnyy Range to the Shilka-Argun-Amur River junction and between northeastern Mongolia and the middle reaches of the Argun River. Deposition of terrestrial facies deposits unconformably on top of the strongly deformed medial to late Jurassic marine deposits and glaucophane schists of the Amur-Okhotsk segment of the Mongol-Okhotsk Foldbelt (Kosygin and Parfenov, 1976; Itsikson, 1980) and in the Amur-Zeya Basin of the southern Soviet Far East (Figure 2), apparently signifies the suturing of the northern part of the North China Fold Zone to the Siberian Craton.

The disappearance of the Tanggula Basin between the North and South Tibetan Blocks was completed by the early Cretaceous. A linear zone of dismembered ophiolites, subduction zone mélange, silicic to intermediate plutonics and strongly deformed Triassic to late Jurassic deep water marine deposits mark the trace of the Tanggula suture, which are in turn unconformably overlain by coarse terrigenous early Cretaceous clastics (Geologic Map of China, 1975; Sun et al., 1979; Bally, et al., 1980; Li et al., 1981).

The east-dipping subduction zone located to the west of the Shan-Thai-Malaya Block apparently persisted into the early Cretaceous as

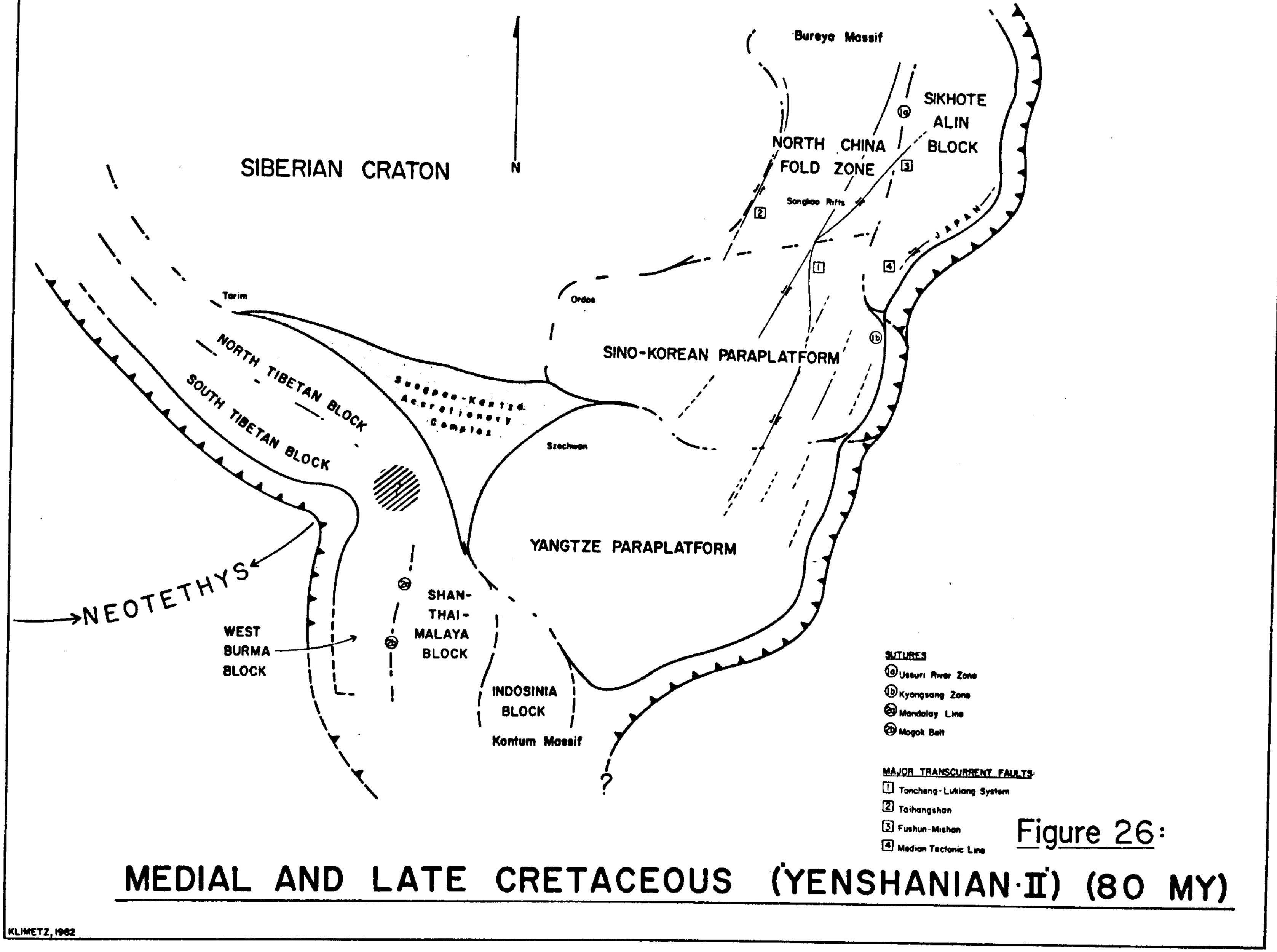



Figure 26:

MEDIAL AND LATE CRETACEOUS (YENSHANIAN·II) (80 MY) suggested by the presence of coeval paired metamorphic belt and synchronous calc-alkaline volcanism along this margin (Hutchison, 1975; Mitchell, 1981).

A west-dipping subduction zone was located along the eastern margin of the northwest-migrating Sikhote Alin (Japan-Sakhalin) Block as indicated by the coeval east-facing paired Sanbagawa and Ryoke-Abukuma metamorphic belts, the latter accompanied by island arc volcanism, granite emplacement and regional metamorphism (Miyashiro, 1972; Uyeda and Miyashiro, 1974; Matsumoto, 1978; Hiroi, 1981). It appears to have been initiated at some time during the Jurassic.

An active Andean-type margin accompanied by widespread silicic to intermediate magmatism persisted along the eastern coast of China throughout this time (Geologic Map of China, 1975; Wang, 1982, personal communication).

## 11.5 Medial and Late Cretaceous

The suturing of the Sikhote Slin (Japan-Sakhalin) Block against northeastern China and the southern Soviet Far East during medial and late Cretaceous times (Figure 26) was accompanied by major ophiolite nappe emplacement, east-vergent folding and thrusting and olistostrome formation along the Ussuri River Zone-Lower Amur Fault and the formation of the Nadanhada Foldbelt (Ablayev et al., 1972; Ivanov, 1961; Beznosov, 1978; Huang, 1978; Bally et al., 1980; Li, 19801 Mel'nikov, 1980; Usenko 1980; Sereda, 1980).

The Lower Amur Fault (Usenko, 1980) comprises a north-south, 350 kilometer long, 1 to 5 kilometer wide dislocation that is clearly traceable to the north of Khabarovsk. At its extreme southern end the fault zone appears as a series of parallel scarps slicing through

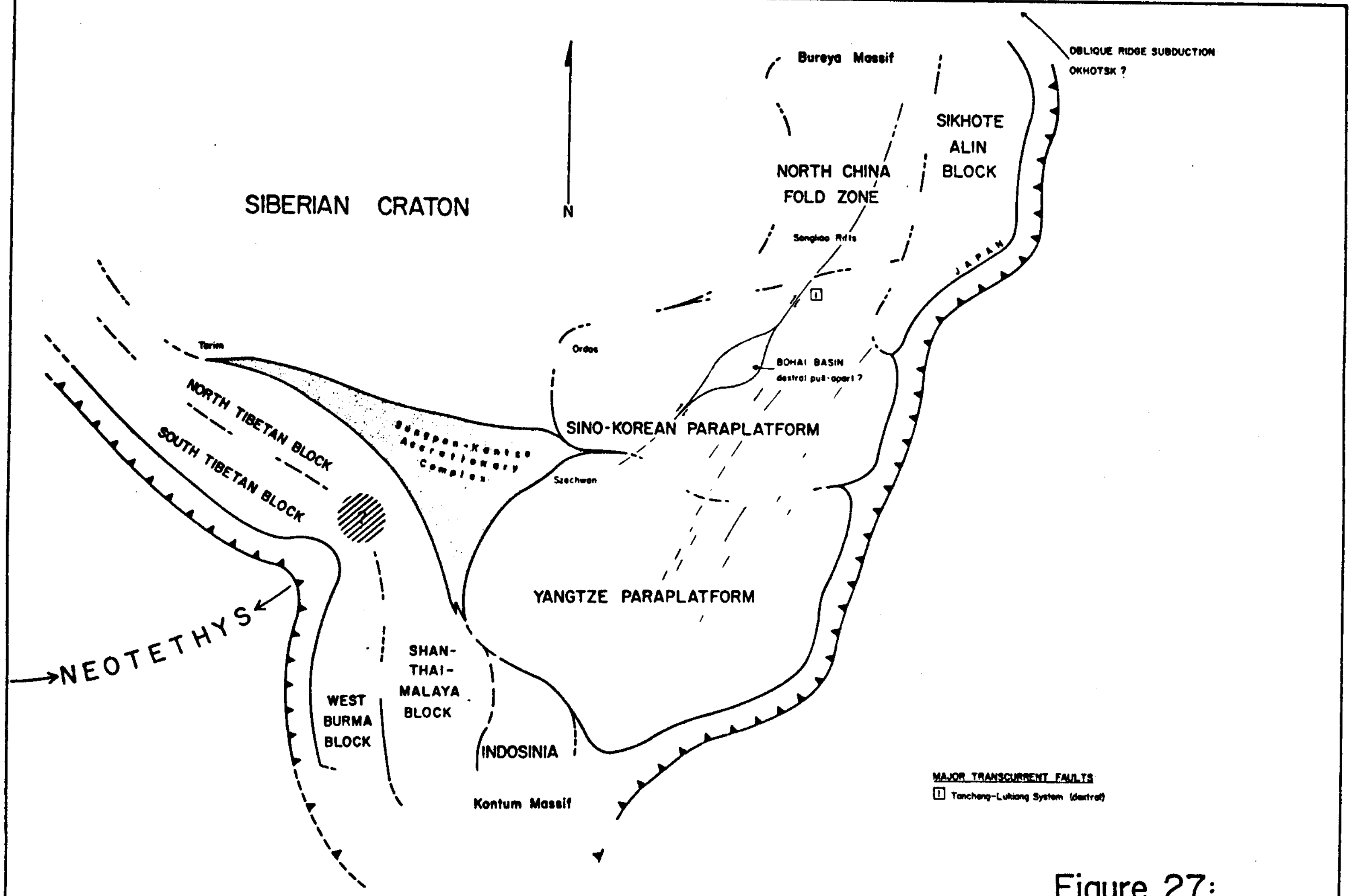



Figure 27:

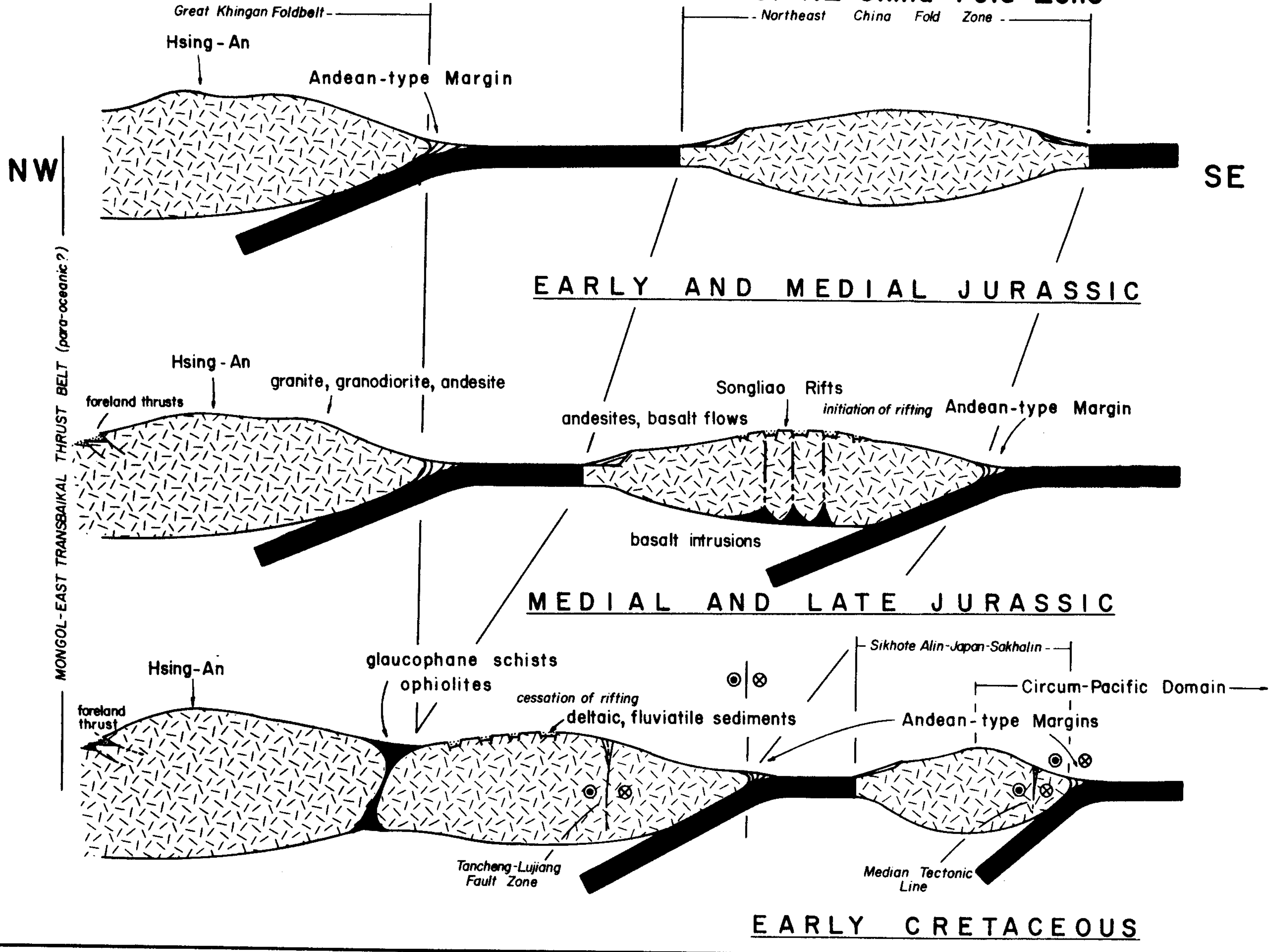
LATE CRETACEOUS-PALEOCENE ("YENSHANIAN-II") (70-55 MY) granites and ultramafics of late Mesozoic age. Further to the north the fault zone appears graben-like, filled with Eocene-Oligocene continental deposits. At its northern termination it is expressed as a wide zone of cataclasis transecting a series of high-grade metamorphic rocks. The Lower Amur Fault is interpreted as the northern continuation of the Sikhote Alin (Ussuri River) suture.

The Kyongsang Zone of southeastern Korea (Sillitoe, 1977; Ki, 1978) may be the southern equivalent of the Ussuri River Zone-Lower Amur Fault. The Sikhote-Slin (Japan-Sakhalin) Block may have comprised part of the hypothetical continent of Pacifica (Nur and Ben-Avraham, 1978) during Permian times and it would be interesting to determine if the South Korea-southwest Honshu microcontinent (Sasajima, 1981) was an integral part of the Sikhote Alin Block throughout the late Paleozoic and Mesozoic or if it comprised a distinct and separate continental fragment. Paleomagnetic results indicate a rapid northward movement from 8° north to 42° north latitude between the late Jurassic and medial Cretaceous for southwestern Honshu (Sasajima, 1981).

The collision of a West Burma Block to the eastern Shan-Thai-Malaya Block was completed by the Cretaceous. The suture zone is interpreted from undifferentiated ultramafic rocks, serpentinites, peridotites, gabbros and actinolite schists complexly interspersed with glaucophane and kyanite schists and gneisses of the Mandalay Line and Mogok Gneiss Belt which have been described from the northern Shan States where they are unconformably overlain by Tertiary clastics (La Touche, 1913; Hutchison, 1975; Thien, 1978) (Figure 29).

Active sinistral slip along the Tancheng-Lujiang Fault Zone appears

FIGURE NO. 28: Mesozoic tectonic evolution of NE China Fold Zone



to have persisted at least up until the medial Cretaceous (Xiu, 1980) at which time movement may have temporarily ceased during the collision of the Sikhote Alin Block in the medial to late Cretaceous. All activity had terminated in the Songliao Rifts by the beginning of the medial Cretaceous with the complete suturing of the North China Fold Zone to the Siberian Craton.

An Andean margin with extensive silicic to intermediate magmatism persisted along the eastern margin of China and Sikhote Alin throughout the medial and late Cretaceous (Jahn, 1974; Geologic Map of China, 1975; Shi, 1979; Wang, 1979; Shui, 1981; Wang, 1982, personal communication) (Figure 28).

The consumption of Neotethyan oceanic crust along a northeast-dipping subduction zone which would be the future sites of the Indus-Yarlungzangbo and Naga Hills-Arakam Yoma suture zones commenced during the early Cretaceous and persisted to the Paleocene/Eocene (Hutchison, 1975; Bally et al., 1980; Bannert and Helmcke, 1981; Brookfield and Reynolds, 1981) (Figure 29).

### 11.6 Late Cretaceous-Paleogene

By late Cretaceous-Paleogene times (Figure 27) a change in displacement sense of the Tancheng-Lujiang Fault from sinistral to dextral (Wu et al., 1981) appears to have initiated a pull-apart rifitng of the Bohai Basin of central northern China. The oblique subduction of the Kula/Pacific Ridge near Okhotsk (?) may have caused the shift in displacement direction, with the Tancheng-Lujiang becoming a dextral analogue to the San Andreas Fault. A large number of smaller pull-apart related structures accompanied by alkalic basalt intrusions are known from subsidiary branches of the Tancheng-Lujiang

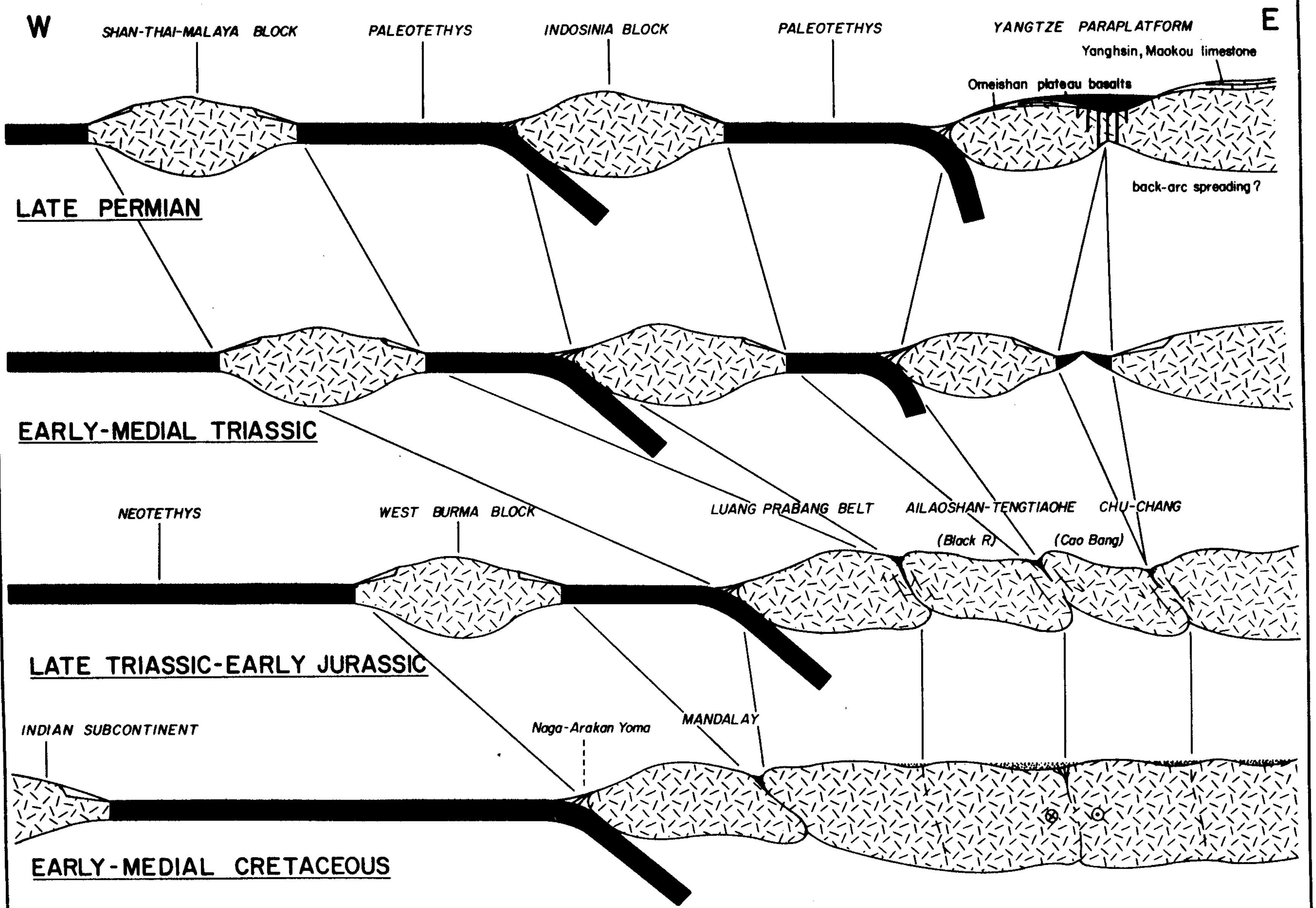
Fault from Shantong to Hubei and in coastal provinces as well (Chao, 1960a, b; Geologic Map of China, 1975; Minero-Petrographic Lab, 1977; Zheng, et al., 1978; Zhou and Chen, 1981). An active convergent margin (with westward subduction) and a dextral transcurrent component of displacement persisted along the entire eastern coast of China and Sikhote Alin (Japan-Sakhalin) (Chai, 1972; Krasnyy, 1972, 1973, 1974; Jahn, 1974; Geologic Map of China, 1976; Juan, 1976; Beznosov, 1978; Ki, 1978; Krasilov, 1978; Matsumoto, 1978). Dextral strike-slip faulting and the intrusion of mafic alkaline basalts appears to have commenced at this time along the Red River and Cao Bang Fault zones of Yunnan and northern Vietnam, initiating the pull-apart style Yunnan graben from Lake Tali to Kunming (Bien, 1940a, b; 1941; Misch, 1945; Geologic Map of China, 1976; Tapponnier and Molnar, 1977) and associated mafic alkalic volcanism (Geologic Map of China, 1976).

### 11.7 Conclusions

It is evident from the foregoing that previous views (Stroganova, 1975; Scotese et al., 1979; Ziegler, et al., 1979; Ziegler, 1981) of a late Paleozoic consolidation of southeastern Asia are no longer tenable. The formation of the structural edifice of eastern China, Southeast Asia and the Soviet Far East, consists of the assembly of new continental and island arc blocks representing no less than three disparate late Paleozoic paleogeographic provinces, and accreted to the Siberian craton solely during the medial and late Mesozoic.

Whether some of these blocks comprised parts of a larger hypothetical continent such as "Pacifica" (Nur and Ben-Avraham, 1978) is unlikely. Nonetheless, such events clearly refute the existence of a "Wegenerian" Permo-Triassic Pangaea in the strict sense and explan the widespread Mesozoic orogenesis of eastern China and Southeast Asia in terms of continental collisions.

FIGURE NO. 29: Mesozoic tectonic evolution of Southeast Asia-Southwest China



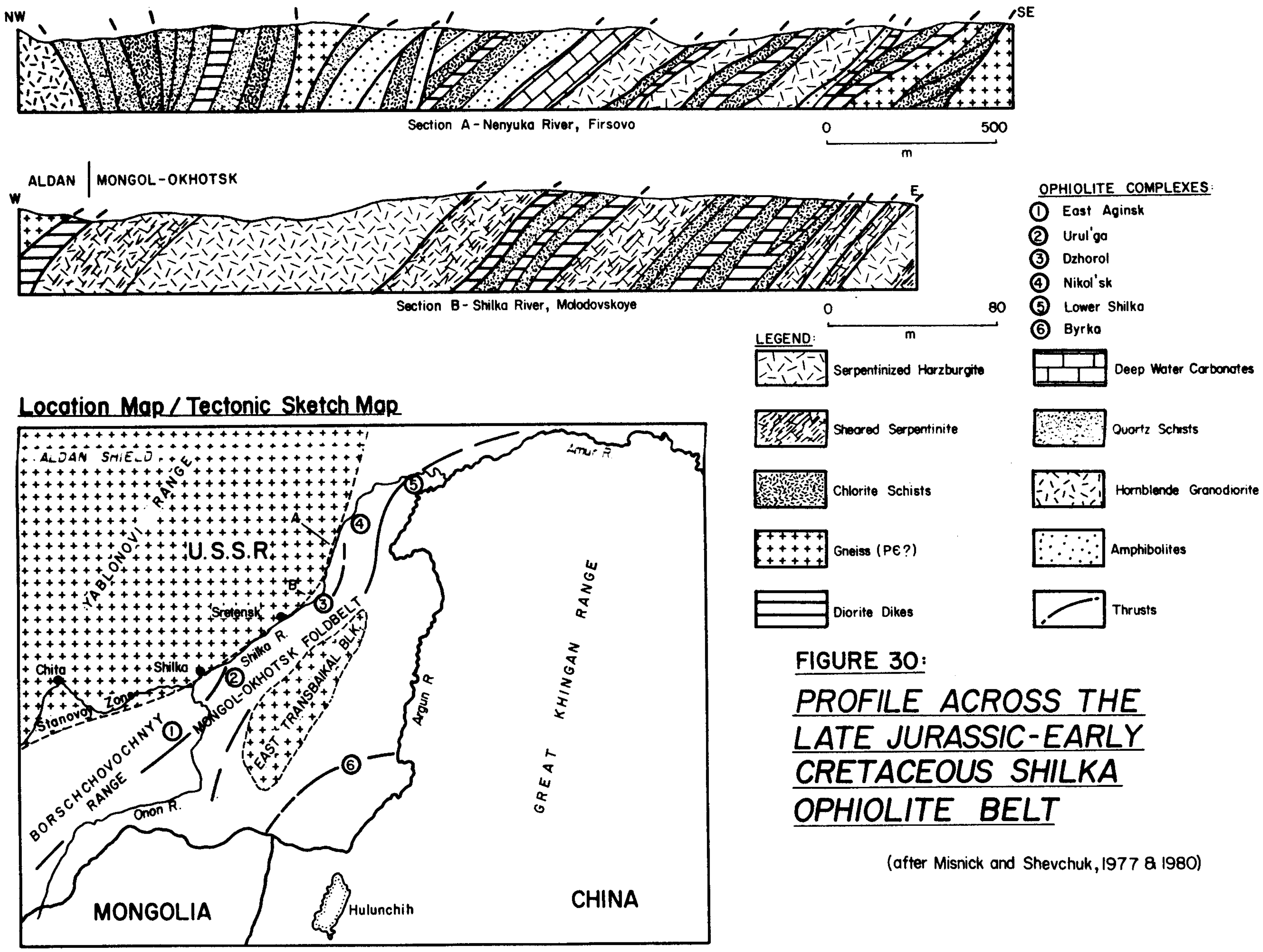



FIGURE 30:

*PROFILE ACROSS THE LATE JURASSIC-EARLY CRETACEOUS SHILKA OPHIOLITE BELT*

(after Misnick and Shevchuk, 1977 & 1980)

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# APPENDIX I:

## Permian-Paleogene Stratigraphic Columns of China

| Prefix | Location | Source |
|---|---|---|
| **Northeast China (Plate II):** | | |
| N1 | SW Central Innter Mongolia and Ningh-sia Hui Autonomous Regions | LX37 * |
| N2 | North Central Innter Mongolia Autonomous Region | LX16 |
| N3 | Ordos Basin | LX37 |
| N4 | Central Innter Mongolian Auto-nomous Region | LX18 |
| N5 | NW Shansi | LX42 |
| N6 | East Central Innter Mongolia Autonomous Region | LX5 |
| N7 | Central Shantung | LX49 |
| N8 | NE Hopeh and SW Liaoning | VI of Lin, 1956 |
| N9 | Shantung Peninsula | LX51 |
| N10 | NE Hopeh and SW Liaoning | LX22 |
| N11 | Liaotung Peninsula | VII of Lin, 1956 |
| N12 | Mid (central ) Liaoning | VII of Lin, 1956 |
| N13 | Korea | Tateiwa, 1960 |
| N14 | Liaotung-Ch'ang Pai Shan | IV of Lin, 1956 |
| N15 | Japan | ESCAP Atlas of Stratigraphy; Kouno, ed., 1980 |
| N16 | N. Liaoning (Yinshan-Tumen) | V of Lin, 1956 |

* (LX = Location number from Lexique Stratigraphique International, 1960, v. III, fasc. 1, Republique Populaire de Chinois, (Asie), compiled by J. Roger)

APPENDIX I: (cont'd)

| Prefix | Location | Source |
|---|---|---|
| N17 | NE Hopeh, NW Liaoning and SSE Inner Mongolia, A.R. | LX20 |
| N18 | Hsing-an | I of Lin, 1956 |
| N19 | Inner Mongolia A.R. (Great Khingan Region) | LX2 |
| N20 | Sungliao | III of Lin, 1956 |
| N21 | Lesser Khingan | II of Lin, 1956 |
| N22 | Heilongkiang Mtns. (nr Ussuri River) | IV of Lin, 1956 |
| N23 | Central and NE Heilunghiang (Lower Sungari River) | LX7 |

Southern China (Plate III):

| Prefix | Location | Source |
|---|---|---|
| S1 | W. Yunnan | LX90 |
| S2 | W. Szechwan and Central Yunnan | LX91 |
| S3 | NE Yunnan and Kweichow | LX92 |
| S4 | Central and South Kweichow | LX95 |
| S5 | SW Kwangsi | LX110 |
| S6 | SW Kwangtung (Chin Hsien and Jung Hsien Region) | LX112 |
| S7 | W. Kwangtung | LX113 |
| S8 | Central Kwangsi | LX111 |
| S9 | E. Kwangsi | LX102 |
| S10 | N. Kwangsi | LX98 |

APPENDIX I: (cont'd)

| Prefix | Location | Source |
|---|---|---|
| S11 | S. Hunan | LX101 |
| S12 | S. Kiangsi | LX105 |
| S13 | W. Fukien | LX106 |
| S14 | E. Fukien | LX107 |
| S15 | W. Szechwan Basin | LX72 |
| S16 | E. Chekiang | LX89 |
| S17 | W. Chekiang | LX88 |
| S18 | SE Anhwei | LX86 |
| S19 | Central Szechwan | LX70 |
| S20 | SE-NW Anhwei | LX63 |
| S21 | S. Kansu | LX54 |
| S22 | S. Kansu | LX56 |
| S23 | N-SE Kansu | LX36 |

# APPENDIX II

| No. | Location | Source |
|---|---|---|
| | **Vietnam, Laos, Kampuchea and Western Yunnan Permian-Paleogene Stratigraphic Columns (Plate IV)** | |
| 1. | Lan-Ping, Ssu Mao Fold Belt | Bally, et al., 1980 |
| 2. | Lan-Ping, Ssu Mao Fold Belt East | Bally, et al., 1980 |
| 3. | Ailao Shan Uplift | Bally, et al., 1980 |
| 4. | Kampuchea West | Fontaine and Workman, 1978 |
| 5. | Kampuchea Southeast | Fontaine and Workman, 1978 |
| 6. | Kampuchea Northeast | Fontaine and Workman, 1978 |
| 7. | Laos South | Fontaine and Workman, 1978 |
| 8. | Laos East and Central (Kammouane) | Fontaine and Workman, 1978 |
| 9. | Laos Central and Sam Neua | Fontaine and Workman, 1978 |
| 10. | Laos North | Fontaine and Workman, 1978 |
| 11. | Southwest Vietnam (Ha Tien) | Fontaine and Workman, 1978 |
| 12. | South Vietnam (Bien Hoa) | Fontaine and Workman, 1978 |
| 13. | Northeast Laos (Sam Neua) | Fontaine and Workman, 1978 |
| 14. | South Central Vietnam (Ban Me Thuot) | Fontaine and Workman, 1978 |
| 15. | South Central Vietnam (Nha Trang) | Fontaine and Workman, 1978 |
| 16. | South Central Vietnam (Nong Son) | Fontaine and Workman, 1978 |

APPENDIX II (cont'd)

| No. | Location | Source |
|---|---|---|
| 17. | North Central Vietnam (Song Quang Tri) | Fontaine and Workman, 1978 |
| 18. | North Central Vietnam (Truong Son) | Fontaine and Workman, 1978 |
| 19. | North Central Vietnam (Song Ca) | Fontaine and Workman, 1978 |
| 20. | North Central Vietnam (Phu Hoat) | Fontaine and Workman, 1978 |
| 21. | North Central Vietnam (Song Ma) | Fontaine and Workman, 1978 |
| 22. | North Central Vietnam (Song Da) | Fontaine and Workman, 1978 |
| 23. | North and Northeast Vietnam (Song Hong) | Fontaine and Workman, 1978 |
| 24. | North and Northeast Vietnam (Song Lo) | Fontaine and Workman, 1978 |
| 25. | North and Northeast Vietnam (Bac Thai) | Fontaine and Workman, 1978 |
| 26. | North and Northeast Vietnam (Ha Lang) | Fontaine and Workman, 1978 |
| 27. | North and Northeast Vietnam (Quang Ninh) | Fontaine and Workman, 1978 |
| 28. | North and Northeast Vietnam (An Chou) | Fontaine and Workman, 1978 |