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An outline of the tectonic characteristics of China

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ABSTRACT

The major tectonic units of China, outlined in several previous articles, are briefly described, with important revisions and supplements. These include four Precambrian platforms and a number of Palaeozoic, Mesozoic and Cenozoic geosynclines. The variation of crustal thicknesses in different parts of China is discussed. Emphasis is laid on the classification of depth fractures (deep faults) and the main characteristics of the principal depth fractures are analyzed. Since the Indosinian Orogeny came into being, a fundamental change in tectonic pattern took place, and since then the tectonic development of China was dominated by three tectonic domains: the Pal-Asiatic Tectonic Domain (mainly Variscan), the Marginal-Pacific Tectonic Domain and the Tethys-Himalayan Tectonic Domain. The Marginal-Pacific is characterized by Indosinian, Himalayan and particularly Yenshanian Orogeny with corresponding magmatism and basin deposition, which might have been the product of the interaction between the Pacific plate and the Asiatic plate. The Tethys-Himalayan is characterized by Indosinian, Yenshanian and particularly Himalayan Orogeny with the formation of geosynclinal foldbelts of corresponding ages. The Himalayan folding is apparently the product of the collision between the Asiatic plate and the Indian craton, but the Mesozoic folds might have come into existence as the result of subduction of a Tethyan oceanic plate of unknown extension. The polycyclic evolution of the tectonics of China is remarkable, and this is particularly revealed in eugeosynclinal regions, where (like the Tienshan and the Nanshan) polycyclic orogeny is closely accompanied by polycyclic sedimentation, polycyclic magmatism, polycyclic metamorphism and polycyclic metallogenesis. Preliminary observations on plate tectonics of China are briefly described. Plate motions also appear to be polycyclic.

RÉSUMÉ

Les unités tectoniques majeures de la Chine, proposées dans plusieurs articles précédents, sont sommairement décrites, avec d'importantes révisions et précisions. Ces éléments comprennent quatre plate-formes précambriennes et un certain nombre de geosynclinaux paléozoïques, mésozoïques et cénozoïques. Les variations de l'épaisseur de la croûte dans différentes parties de la Chine sont discutées. On insiste sur la classification des fractures profondes et on analyse les charactères essentiels des fractures profondes principales. Depuis le début de l'orogénèse Indosinienne, un changement fondamental de la trame tectonique a eu lieu, et depuis ce temps, l'évolution tectonique de la Chine fût caractérisée par trois domaines tectoniques: le domaine tectonique paléo-Asiatique (essentiellement varisque), le domaine tectonique Pacifique-Marginal et le domaine tectonique Téthys-Himalaya. Le Pacifique-Marginal est caractérisé par les orogénèses Indosinienne, Himalayenne et particulièrement Yenshanienne, avec leur magmatisme et leur développement de bassin, qui aura pu être le produit de l'interaction entre la plaque Pacifique et la plaque Asiatique. Le Téthys-Himalaya est caractérisé par les orogénèses Indosinienne, Yenshanienne, et surtout Himalayenne, avec la formation de zones plissées géosynclinales des âges correspondants. Le plissement Himalayen c'est apparemment formé par la collision entre la plaque Asiatique et le crâton de l'Indie péninsulaire, mais les plis mésozoïques auraient pu résulter de la subduction d'une plaque Océanique Téthydienne d'extension inconnue. L'évolution polycyclique des

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tectoniques de la Chine est un fait remarquable, et ceci s'observe particulièrement bien dans des régions eugéosynclinales, comme le Tienshan et le Nanshan, où l'orogénèse polycyclique s'accompagne étroitement par la sédimentation, le magmatisme, le métamorphisme et la métallogénèse polycycliques. Des observations préliminaires sur la tectonique des plaques en Chine sont brièvement décrites. Il apparaît que les mouvements des plaques sont également de nature polycyclique.

1. Introduction

In the early years of the present century, western scholars used to interpret the geology of China from the works of Richthofen, Loczy, Obruchev, Willis, Grabau and others. The Chinese themselves published their geological results in several English-written periodicals[2]). Unfortunately, no comprehensive treatise on the geology of China was available until the "Geology of China" by LEE appeared in 1939. LEE's work stressed the conception of "tectonic systems" which led him later to develop his well-known theory of geomechanics. In his "On Major Tectonic Forms of China" HUANG (1945) assembled and analyzed all available geological data up to 1945, and attempted to systematically elucidate the tectonic characteristics of China.

Since the founding of the People's Republic of China, with the rapid development of organized geological work by the people's government, tectonic research work began to attract attention of the general public, and stimulated by Chairman Mao's policy of "letting a hundred schools of thought contend", proponents of different schools, using different methods and from different standpoints, try to discover the rules of development of tectonic history of China. More recently, adequate attention has also been paid by Chinese geologists to the modern theory of sea-floor spreading and plate tectonics. However, most of the Chinese works are published in Chinese and are not easily accessible to foreign readers. The present paper intends to give a "bird's eye view" of the tectonic characteristics of China, and geologists who want to know more are advised to read the articles cited in the bibliography and to consult the voluminous publications in Chinese.

2. Tectonic units of China

The tectonic units of China were classified and discussed in several previous articles (HUANG CHI-CHING et al. 1965; HUANG CHI-CHING et al. 1974; HUANG T.K. 1945; HUANG T.K. 1960). This classification was accepted by many foreign geologists. Based upon abundant recent geological and geophysical data, the author tries in the present paper to describe very briefly the various tectonic units (Fig. 1).

a) The Sino-Korean Paraplatform

This paraplatform covers the whole territory of North China, the southern part of North-East China, the Gulf of Pohai, the northern part of the Yellow Sea and the northern part of Korea. This paraplatform is the oldest in China, with its basement

[2]) Such as Bulletin of the Geological Society of China, Memoirs of the Geological Survey of China, Memoirs of the Geological Institute, Academia Sinica, etc.

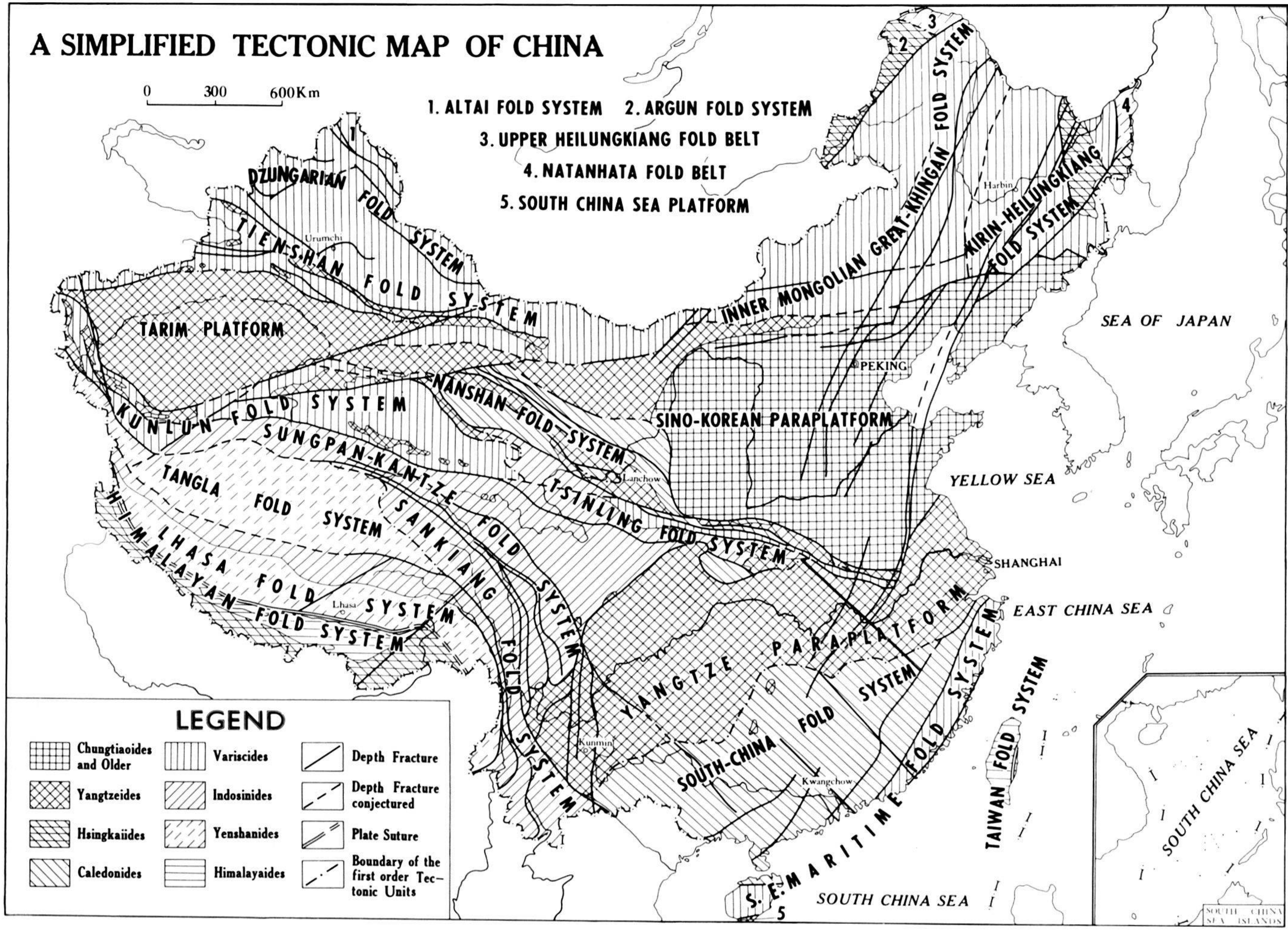

Fig. 1. A simplified tectonic map of China.

(The national boundary of China on this map is adopted from the "Map of the People's Republic of China", 6th ed., 1971.)

essentially taking shape about 1,700 my BP through the Chungtiao Orogeny[3]) (Table 4). The marginal parts of the paraplatform, such as the Alashan region, were consolidated by the end of the Proterozoic through the Yangtze Cycle. Geologists have now come to an agreement that the main portion of the paraplatform developed through three stages as revealed by three major unconformities (CHENG YU-CHI et al. 1973), i.e. 1. the unconformity between the Archaean Fuping Group and the Lower Proterozoic Wutai Group, representing the Fuping Orogeny about 2,350-2,550 my BP[4]), 2. the unconformity between the Wutai Group and the upper part of the Lower Proterozoic, or the Huto Group, representing the Wutai Orogeny about 2,000 my BP, and 3. the unconformity between the Huto Group or its equivalents and the Upper Proterozoic Sinian Suberathem[5]), representing the Chungtiao Orogeny. The blanket of the platform consists of Sinian and Cambro-Orodovician neritic sediments (largely carbonate rocks), Permo-Carboniferous terrestrial sediments (with marine intercalations) as well as purely terrestrial Meso-Cenozoic sediments. The Sinian s.s. is present in a few regions, while Silurian, Devonian and Lower Carboniferous are entirely absent. A great amount of Mesozoic continental volcanics and granitoid intrusions occurs in the eastern part of the paraplatform, especially in the Yenliao Depression, in Shangtung and other regions. Cenozoic basalts are widespread. Tectonic disturbances of the Indosinian Cycle were limited in Inner Mongolia, Liaotung and the Yenliao Depression.

b) The Yangtze Paraplatform

This paraplatform, second in importance in China, comprises the greater part of the Yangtze Basin from eastern Yunnan to Kiangsu, including also the southern part of the Yellow Sea. Previously, the consolidation of the Yangtze Paraplatform was considered contemporaneous with that of the Sino-Korean Paraplatform, i.e. about 1,700 my BP. Recent investigations on stromatolites, micro-paleoflora and isotopic geochronology of the basement rocks indicate that its consolidation is about 700 my BP (Yangtze Orogeny). The blanket of the paraplatform consists chiefly of carbonate and clastic deposits ranging in age from Sinian s.s. to Triassic, with Devonian and Carboniferous mostly wanting in Szechwan and north of Kweichow, while terrestrial Jurassic, Cretaceous and younger deposits occur in Szechwan, Central Yunnan, Hupeh, Kiangsu and other regions. Tectonism was strong chiefly in the Yenshanian Cycle with the formation of well-developed blanket folds. The

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[3]) Since in the Lüliang area the Cambrian directly lies upon the Lower Proterozoic, the Upper Proterozoic being absent, the term "Lüliang Orogeny" is here replaced by Chungtiao Orogeny, with the type locality of Chungtiaoshan where the Upper Proterozoic is well-developed and lies unconformably upon the Lower Proterozoic.

[4]) The oldest rocks of the basement are dated 3,200-3,400 my BP according to the latest isotopic analysis.

[5]) In this paper the author accepts the classification of the Sinian as given in the new Geological Map of China (1:4000000). The term "Sinian System", with its standard section in the Yangtze Gorges, comprises sediments ranging in age from ± 600 my to ± 800 my BP. The term "Sinian Suberathem" with its standard section in Chihsien near Peking, comprises sediments ranging in age from ± 600 my to ± 1,700 my BP. The terms "Sinian" and "Sinian s.s." in this paper correspond respectively to Sinian Suberathem and Sinian System.

Kam-Yunnan Axis, the Lower Yangtze and the like, however suffered polycyclic tectonism and magmatism; the former belongs essentially to the Variscan Cycle while the latter belongs to the Yenshanian and Indosinian Cycle. Formerly the Huaiyang Massif (old name "Huaiyang Shield") was considered a portion of the Sino-Korean Paraplatform; recent data show that it belongs to the Yangtze Paraplatform.

c) The Tarim Platform

The Tarim Platform is bordered by the Tienshan in the north and by the Kunlun in the south and is largely covered by Cenozoic deposits. Its basement, together with its Palaeozoic blanket, crops out mainly along the northern border as seen in Kelpin and Kuruk Tagh. In the latter region, late Proterozoic (Sinian) tillites and stromatolites are found, showing that the Tarim Platform took shape near the end of the Proterozoic just as the Yangtze Paraplatform did.

d) The Tienshan-Khingan Geosynclinal Fold System and the Argun Fold System

These two systems are components of the great Central Asiatic-Mongolian Arcuate Fold Region which extends between the Siberian Platform, on the north, and the Sino-Korean Paraplatform and the Tarim Platform, on the south. This fold region is separated into two halves by the Derbugan Depth Fracture (eastern extension of the Mid-Mongolian Depth Fracture); the southern half is the Tienshan-Khingan Geosynclinal Fold System while the northern half includes the Argun Fold System. The latter is Hsingkaiian (see below) and the former consists, within the Chinese territory, of the Altai (Caledonides and Variscides), the Dzungarian (Variscides), the Tienshan (Variscides), the Inner-Mongolian - Great Khingan (Variscides) and the Kirin-Heilungkiang (Variscides) Fold System. All of them, except the southern Tienshan, are eugeosynclinal in nature. During the Caledonian Cycle, volcanic activities chiefly submarine, were widespread in Ordovician and Silurian. Radiolaritic cherts were found closely associated with spilites and ultrabasic intrusives forming ophiolitic suites, such as in western Dzungaria. During the Variscan Cycle, the Devonian and Carboniferous were characterized by calc-alkaline volcanics (mainly andesites). From Carboniferous to the end of Permian[6]) the geosynclinal formations accompanied by granitoid intrusives were brought into intense and complicated folds, thus converting the geosynclines into a craton. During the Yenshanian Cycle, a general tendency of increasing intensity of tectonism from east to west can be recognized, especially in the Kirin-Heilungkiang and Great Khingan region, where strong rhegmagenesis and magmatism took place. During the Himalayan Cycle, the general tendency of increasing intensity of tectonism was inverted. Faulting and uplifting along the general strike of the Tienshan were strong and widespread, forming lofty mountain ranges with deeply sunken northern and southern foredeeps as well as intermontane depressions such as the famous Turfan Basin.

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[6]) This is Variscan Orogeny. Caledonian orogenic movements are also present but are very limited in distribution.

e) The Kunlun-Nanshan-Tsinling Geosynclinal Fold System and the Tibet-Yunnan Geosynclinal System

These two tectonic units, separated from each other by the Chinshakiang-Red River Depth Fracture, occupy the vast territory south of the Tarim Platform and Sino-Korean Paraplatform, west of the Yangtze Paraplatform and north of the Tsangpo Depth Fracture (see below).

The Kunlun-Nanshan-Tsinling Geosynclinal Fold System is a typical polycyclic geosynclinal fold system embracing three orogenic cycles. During the Caledonian Cycle, a eugeosyncline came into action mainly in the Nanshan, with well-developed ophiolitic suites and glaucophane schist belts. During the Variscan Cycle, a large portion of the system was miogeosynclinal, while eugeosynclines were maintained only in Burkhanbuddha, Amnemachin and along the Chinshakiang. During the Indosinian Cycle, miogeosynclinal development continued in the Sungpan-Kantze, Tsinling and South Kokonor Range, while the area along the Chinshakiang remained eugeosynclinal. Different parts of the system differ in age of folding. The Nanshan is Caledonian, the Kunlun is Variscan, while the Sungpan-Kantze and Tsinling are basically Indosinian. The Yenshanian and Himalayan cycles are characterized by rhegmagenesis accompanied by a certain extent of magmatism. The facts that Cambrian volcanics were overthrust upon Late Tertiary red beds in the Lachishan of Chinghai and Jurassic sandstones were overthrust upon Quaternary gravels at the Hungliu Gorge near Yümen of Kansu demonstrate that intensive horizontal compression was at work even in the youngest geological time.

The Tibet-Yunnan Geosynclinal Fold System, situated to the south and west of the Chinshakiang-Red River Depth Fracture, is a Mesozoic arcuate fold system, consisting of the Sankiang[7]) or Three-River (Indosinides), the Tangla (Yenshanides) and the Lhasa (Yenshanides) fold systems. The existence of the so-called Precambrian Tibetan Massif, as formerly cherished by many geologists (TERMAN 1973; Geol. Inst. Akad. Sci. USSR 1966) is negated by recent observations. The Sankiang Fold System has been investigated in some detail. It includes western Yunnan and the Changtu district of Tibet, and is characterized by geosynclinal folds strictly controlled by depth fractures among which the Chinshakiang-Red River Depth Fracture, the Lantsangkiang Depth Fracture and the Nukiang Depth Fracture are of prime importance. Along these depth fractures, eugeosynclines developed, with polycyclic tectonism accompanied by intensive polycyclic magmatism. Not only the Palaeozoic and Mesozoic but also, in some localities, the Tertiary formations underwent tectonism and metamorphism in various grades and, as a result, several tectono-magmato-metamorphic belts, among which the Ailaoshan, the Lantsangkiang and the Kaolikungshan Metamorphic Belt are most prominent, came into existence.

f) The Himalayan Geosynclinal Fold System

This tectonic unit, situated to the south of the Tsangpo and Indus River, consists of the Sulaiman (in Pakistan), the Himalayas and the Arakan Yoma (in Burma). It

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[7]) So named because it embraces the Chinshakiang, the Lantsangkiang and the Nukiang drainage system.

must be pointed out that true geosynclinal deposits are absent in the Himalayas proper but appear immediately to the south of the Tsangpo, where a more or less continuous belt of ophiolitic suite is well-exposed: The lofty ranges of the main Himalayas form in fact the northern border of the Indian craton and associated Hsingkaiides, whose metamorphic and sedimentary rocks were deeply involved in the stupendous Himalayan folding when the Indian craton collided with Tibet (CHANG et al. 1973; GANSSER 1964, 1966; MOLNAR et al. 1975).

g) The South China Geosynclinal Fold System

This tectonic unit is located to the south of the Yangtze Paraplatform. In the light of recent investigations, the author is of the opinion that this unit is not entirely Caledonian as previously regarded, but consists of two parts of different character. The major part, still called the South China Fold Belt, is truly Caledonian but the subordinate part, including coastal regions of Chekiang, Fukien and Kwangtung and the neighbouring continental shelves as well as a greater part of the Hainan Island, belongs to Variscides, to be named the Southeastern Maritime Fold System. Owing to the fact that this latter was strongly transformed by Mesozoic tectonism and widely covered with Jurassic and Cretaceous continental volcanics, its tectonic character has long been misjudged.

h) The Natanhata Eugeosynclinal Fold Belt and the Upper Heilungkiang Miogeosynclinal Fold Belt

They are components of the Mesozoic geosynclinal fold systems located to the east of the Siberian Platform. The Natanhata belongs to the Sikhote-Alin Fold System while the Upper Heilungkiang belongs to the Mongolo-Okhotsk Fold System. Both are Yenshanides.

i) The Taiwan Fold System

It constitutes one of the links of the island arc system of the western Pacific.

3. Deep-seated structures and depth fractures in China

a) Outline of the deep-seated structures in China

From a comprehensive examination of geophysical and seismic data available, it is preliminarily revealed that the lithosphere within the Chinese territory can be subdivided into several layers of heterogenous constitution, the same as elsewhere in the world. This layering character is demonstrated by recent investigations (TENG CHI-WEN et al. 1974*a*/*b*, 1975) of seismic sounding along a profile from Yüanshih to Tsinan in the North China Plain, and another profile across the eastern section of the Tsaidam Basin. In these regions the earth's crust possesses layers of high-velocity gradients in addition to low-velocity zones. A broad view of the depth variation of the Mohorovičić discontinuity in the mainland of China is shown in the following Table.

Table 1: *Depth variation of the Mohorovičić discontinuity of China.*
(Compiled from data by the State Bureau of Seismology and the Institute of Geophysics, Academia Sinica.)

WESTERN CHINA		EASTERN CHINA		
NW China: 40 - 50 km locally > 50 km	Yinchuan Liupanshan	more than 40 km	Great Khingan- Taihangshan	NE and N China: less than 36 km
West Kunlun-Altyn- North Nanshan Gravity Gradient Belt		North Tsinling		North Huaiyang Gravity Gradient Belt
Tibet-Chinghai Plateau: 50 - 70 km	Lungmenshan Kam-Yunnan Gravity Gradient Belt	more than 40 km (excl. Szechwan Basin, less than 40 km)	Wulingshan Gravity Grandient Belt	S China: less than 38 km

A clear block-like pattern of the Chinese mainland, especially its eastern part, manifests itself from the above table. Each block is confined generally by depth fractures of long-continued development. For instance, the Yinchuan-Liupanshan-Kam-Yunnan Gravity Gradient Belt (Kunming-Yinchuan Depth Fracture System) separated eastern China from western China in the ancient geological past. The Great Khingan - Taihangshan - Wulingshan[8]) Gravity Gradient Belt, to be a dividing line between the eastern and western belts of the Marginal-Pacific Tectonic Domain (see below), came into existence at least since late Mesozoic time. The northern section of the above-mentioned gravity gradient belt, i.e., the section from the Great Khingan to Taihangshan, obviously coincides with a depth fracture zone. The North Tsinling - North Huaiyang Depth Fracture Zone is a geological dividing line between North and South China. The gravity gradient belt of West Kunlun - Altyn - North Nanshan essentially coincides with the depth fracture zones between the Tarim Platform and Alashan Massif on the north and the geosynclinal fold belts on the south.

Moreover, the present geomorphic features of China form the mirror image of the Mohorovičić discontinuity as shown in Figures 3–4; mountains and plateaus correspond to the "downwarps" of the Moho, while plains and basins agree with its "uplifts". This appears to be the result of a combining effect of the Pacific plate and the Indian plate acting against the continental block of China since the Indosinian, particularly since the Himalayan Cycle. In these movements not only the crust but also the upper mantle were involved.

b) Depth fractures of China

The author is inclined to classify depth fractures into three classes according to depth (Table 2).

Translithospheric fractures are the first class depth fractures of greatest magnitude, usually separating continental crust from oceanic crust. Generally, they are accompanied by well-developed ophiolitic suites, mélanges and high P/T and low

[8]) No N-S directed depth fracture is present along the Wulingshan.

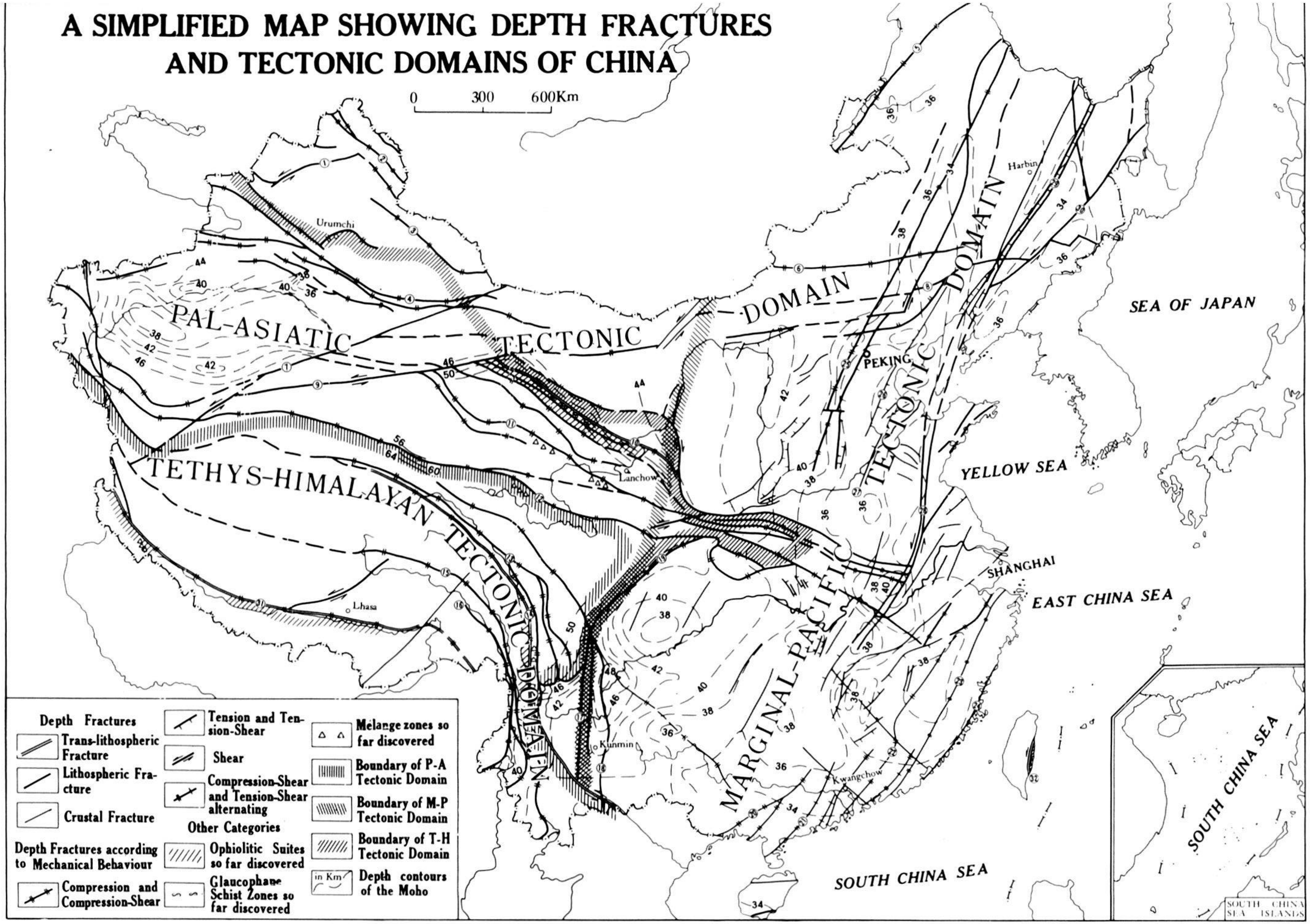

Fig. 2. A simplified map showing depth fractures and tectonic domains of China.
(The national boundary of China on this map is adopted from the "Map of the People's Republic of China", 6th ed., 1971.)

Table 2: *Classification of depth fractures according to depth.*

NAME	DEPTH	EXAMPLES	
		the world	China
Crustal Fracture			
-Sialic Fracture	dissecting the sial but not clearly extending into sima	many	Heyuan Depth Fracture
-Simatic Fracture	dissecting the whole crust but not clearly extending into the upper mantle	many	East Tsangchow Depth Fracture
Lithospheric Fracture *)	dissecting the lithosphere but not clearly extending into the astenosphere	rift valleys of East Africa	Tancheng-Lukiang Depth Fracture
Translithospheric Fracture	dissecting the lithosphere and extending deep into the astenosphere	Benioff zones along island arcs of the western Pacific	Tsangpo Depth Fracture

*) Lithospheric Fracture and Translithospheric Fracture may be called Transcrustal Fractures.

P/T paired metamorphic belts. Translithospheric fractures either came into action during a definite geological period or continued in motion till today as marked by a series of deep focus earthquakes (Benioff zones). *Lithospheric fractures* are generally characterized by basic and ultrabasic complexes but without well-developed ophiolitic suites. *Crustal fractures* are of much smaller magnitude and are usually accompanied by acid and/or intermediate magmatites (sialic fractures), or by basalts (simatic fractures).

Depth fractures can also be divided into three classes[9]) according to their mechanical behaviour i.e., tension depth fracture, compression depth fracture and shear depth fracture. Fractures along the mid-oceanic ridges and along the great rift valleys are tension depth fractures. Fractures along the island arcs of the western Pacific (marked by the deep sea trenches) are models of compression or compression-shear depth fractures. The San Andreas Fault of North America, the Altyn Depth Fracture and the Tancheng-Lukiang Depth Fracture of China (see below) are examples of shear depth fractures. Without a shadow of doubt, depth fractures are not unchangeable. On the contrary, their formation, development, transformation and extinguishment came one after another in succession during the long history of the evolution of the earth. Numerous facts explain that different sections

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[9]) In fact, there are transitional types, such as compression-shear and tension-shear depth fractures, which are attributable respectively to compression, tension and shear depth fractures according to their dominant mechanical behaviour.

of the same depth fracture zone might have come into being in different geological ages, belong to different types and possess different characters.

Based upon preliminary analyses of geological and geophysical data available, the main depth fractures of China are listed in Table 3, and a brief description of some representatives of them is given as follows.

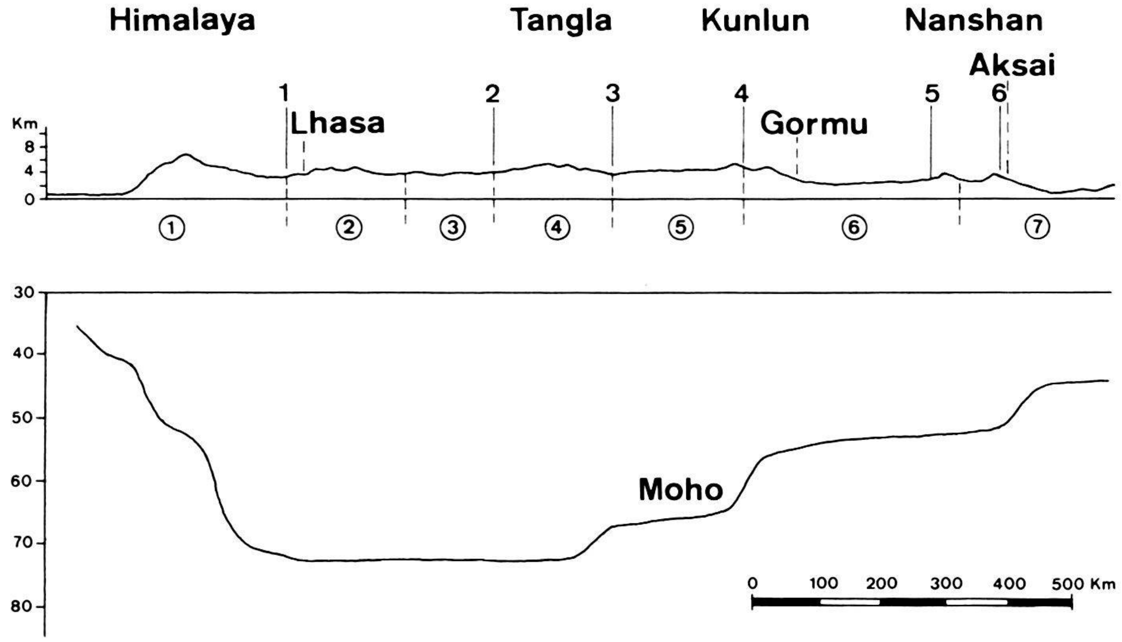

Fig. 3. Cross section of the Moho from Himalaya to Nanshan.

1 = Tsangpo Depth Fracture
2 = Lantsangkiang Depth Fracture
3 = Chinshakiang Depth Fracture
4 = East Kunlun Depth Fracture
5 = Depth Fracture along northern margin of Tsaidam
6 = Altyn Depth Fracture
7 = Depth Fracture Zone of North Nanshan
8 = Depth Fracture of western margin of Ordos
9 = Depth Fracture Zone of Taihangshan
10 = Tancheng-Lukiang Depth Fracture Zone

① = Himalaya Fold System
② = Lhasa Fold System
③ = Sankiang Fold System
④ = Tangla Fold System
⑤ = Sungpan-Kantze Fold System
⑥ = Kunlun Fold System
⑦ = Nanshan Fold System
⑧ = Nanshan Fold System
⑨ = Sino-Korean Paraplatform

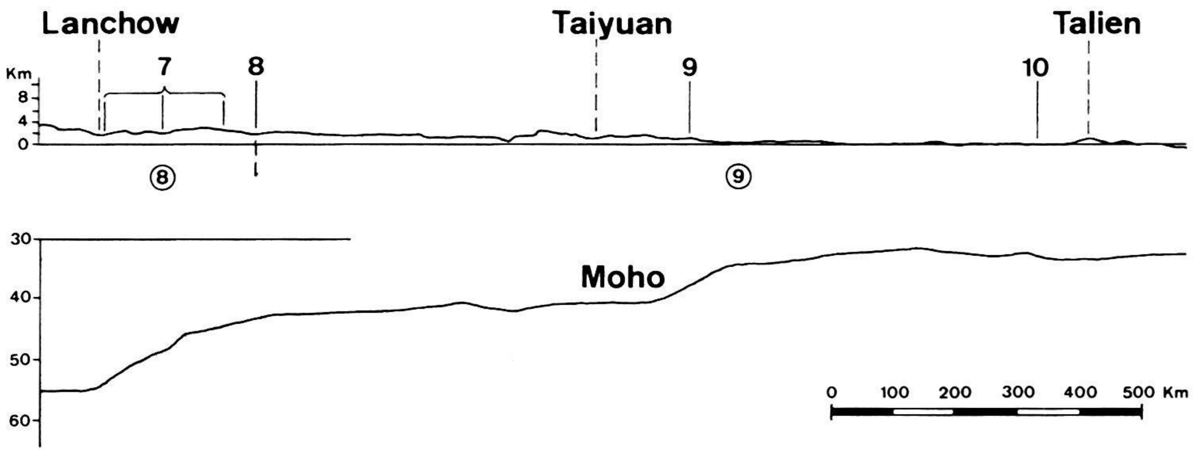

Fig. 4. Cross section of the Moho from Lanchow to Talien (same legend as Fig. 3).

Table 3: *List of the principal depth fractures in China*

Number *)	Name of depth fracture zone	Depth	Character	Age of activity	Magmatism & metamorphism
1	Darbut	L	s	Pz	OS
2	Irtish	L	c-s	Pz	Σ
3	Karameili	L	c-s	Pz	Σ
4	North Margin of Central Tienshan	L	c-s	Pt?, Pz	Σ
5	Derbugan	L	c-s	Pz	
6	Silamulun	L	c-s	Pz	Σ, gs
7	Cherchen	L	s/s	Pz	
8	Northern Margin of Inner Mongolian Axis	L	c-s	Pt?, Pz	Σ
9	Altyn	L	s/s	Pz	Σ
10	North Nanshan-Northern Margin of North Tsinling-North Huaiyang	L	c-s	Pt, Pz	OS, gs
11	Northern Margin of Tsaidam-Southern Margin of North Tsinling-North Huaiyang	L	c-s	Pz	Σ, m
12	East Kunlun	L	c-s	Pz	Σ, m
13	Kantze-Litang	L	c-s	Pz	Σ
14	Chinshakiang-Red River	L	c-s	Pz	Σ, m
15	Lantsangkiang	L	c-s	Pz	Σ
16	Nukiang	L	c-s	Pz	Σ
17	Anningho	L	c-s	Pz	Σ
18	Hsiaokiang	C	c-s	Pz	β
19	Lungmenshan	L	c-s	Pz	Σ
20	Lingshan	C	c-s	Pz	γ
21	Wuchuan-Szehwei	C	a	Pz	γ
22	Heyuan	C	a	Mz	γ
23	Lishui-Haifeng	C	c-s	Pz	γ
24	Changle-Amoy	C	c-s	Mz	γ
25	Taihangshan	C	c-s	Mz	γ
26	East Tsangchow	C	t-s	Mz	β
27	Liaocheng-Lankao	C	t-s	Mz	β
28	Tancheng-Lukiang	L	s/s	Pt?, Mz?	Σ
29	Yilan-Yitung	C	t-s	Mz	β
30	Fushun-Mishan	L	s/s	Pz	β
31	Tsangpo-Indus	T	c-s	Mz	OS, m
32	Longitudinal Valley of Taiwan	T	s/s	Mz	OS, m, gs

*) Numbering here corresponds to numbers in Figure 2 showing thus ③, ⑥, etc.

Explanation:

T = Translithospheric fracture zone
L = Lithospheric fracture zone
C = Crustal fracture zone
c-s = Compression and compression-shear
t-s = Tension and tension-shear
s = Shear (s/s sinistral; s/d dextral)
a = Compression-shear and tension-shear alterating

Pt = Polycyclically active since Proterozoic
Pz = Polycyclically active since Palaeozoic
Mz = Polycyclically active since Mesozoic
OS = Ophiolitic suites
Σ = Basic and ultrabasic complexes
γ = Granitoid plutons
β = Basalts
m = Mélanges
gs = Glaucophane schists

— The *Tsangpo Depth Fracture Zone:* This depth fracture zone was discovered in 1960 (HUANG 1960). It extends westwards following the Indus River valley, hence it was termed the Indus Suture (FITCH 1972). It is now considered as the suture line between the Indian Plate and the Eurasian Plate and is marked by well-developed ophiolitic suites extending about 2,000 km within the defines of China (CHANG et al. 1973; GANSSER 1964).

— The *Longitudinal Depth Fracture Zone of Taiwan:* It forms only a small section of the long depth fractures (Benioff zones) along the island arcs of the western Pacific. Its presence is marked by ophiolitic suites, glaucophane schists and mélanges, and especially by frequent deep-focus earthquakes.

Available data indicate that the North Nanshan Depth Fracture, the Chinshakiang - Red River Depth Fracture, the Hsilamulun Depth Fracture and the Derbugan (Mid-Mongolian) Depth Fracture are translithospheric depth fractures or ancient plate sutures (see below).

In China a great majority of depth fractures in geosynclinal regions and a part of those in platforms belong to lithospheric fractures. Among them the most important ones are:

— The *Tancheng-Lukiang Depth Fracture System:* It is perhaps the most important depth fracture system of eastern Asia and is composed of the Tancheng-Lukiang, the Fushun-Mishan and the Yilan-Yitung depth fractures with a total length of about 2,400 km. From south to north, it cuts through the South China Fold System, the Yangtze Paraplatform, the Sino-Korean Paraplatform and the Kirin-Heilungkiang Fold System, and appears to be an important volcanic, metallogenetic and seismic zone, especially during Meso-Cenozoic times. Sinistral shear happened in the geological past but dextral shear has been detected by analyses of modern earthquake mechanism. Some geologists consider that this fracture system was already in existence in Pre-Sinian times, while others suggest that it was formed in the Indosinian cycle. It continued northwards into the Far East of the USSR.

— The *Kunlun-Tsinling Depth Fracture System:* It includes the North Nanshan - North Tsinling - North Huaiyang Fracture Zone, the Northern Margin of Tsaidam - South Kokonor Range - North Tsinling - North Huaiyang Fracture Zone and the east Kunlun-Tsinling Fracture Zone.
These complicated fracture zones controlled the origination and development of the Kunlun-Tsinling Geosynclinal Fold System and constituted a geological dividing line between northern and southern China. This dividing line shifted southwards from the line of North Nanshan - North Tsinling - North Huaiyang during the Caledonian Cycle, to the line of the Northern Margin of Tsaidam - South Kokonor Range - North Tsinling - North Huaiyang during the early Variscan Cycle, and finally to the line of East Kunlun - North Tsinling - North Huaiyang since the late Variscan Cycle. It is important to note that these fracture zones deepened from east to west. Widespread submarine volcanic rocks occur along the western section, where eugeosynclinal conditions prevailed, and especially in North Nanshan, where remarkable zones of ophiolitic suites 700 km

long and zones of glaucophane schist more than 100 km long were recently discovered, indicating the existence of an ancient plate suture (see below). On the contrary, the eastern sections of these fractures, being characterized by flysch formations and scanty ultrabasic rocks, appear to be miogeosynclinal. This is perhaps the reason why the Tsinling Geosyncline became appendix-like toward the east between the Sino-Korean and the Yangtze Paraplatform.

Crustal fractures are numerous in China. Good representatives of them are the depth fractures along the southeastern coast. These are characterized by: large-scale acid-intermediate plutons with extensive volcanics of the "Pacific" type, lack of ultrabasic rocks, and zones of strong compression followed by strong tension along the same zones, thus giving rise to a series of Cretaceous-Tertiary basins filled with red beds along growth faults[10]) of depth fracture nature. Afterwards, in late Tertiary and Quaternary, they were subjected to compression again. In this respect the Heyuan Depth Fracture is one of the fairly good examples.

Another type of crustal fractures in eastern China is represented by numerous tension fractures along which there originated and developed Mesozoic and/or Tertiary fault basins, filled with terrestrial clastic deposits. Among them the East Tsangchow Depth Fracture, the Liaocheng-Lankao Depth Fracture and the Weiho-Fenho Graben[11]) are the most important. Unlike the Heyuan Depth Fracture, they originated as tension fractures in Cretaceous or Early Tertiary time and are buried by Late Tertiary and Quaternary deposits. Thus, they are typical growth faults, forming with the afore-said clastic deposits, the so-called "dustpan-like basins" accompanied by basalt flows. Geophysical data show that these depth fractures dissect the entire earth's crust but do not extend deep into the upper mantle and therefore should belong to simatic fractures.

4. The tectonic development of China

Two major stages of tectonic development of China before Palaeozoic time can be distinguished. The first is the stage from Archaean to Early Proterozoic or the Pre-Sinian stage, through which the Sino-Korean Paraplatform came into being about 1,700 my BP. The second is the Late Proterozoic or Sinian stage, through which the Yangtze Paraplatform and the Tarim Platform came into being about 700-800 my BP. The great importance of the Yangtze orogenic cycle should be emphasized here. Available data show that platform areas formed through the Yangtze Orogeny were more extensive than the present Yangtze Paraplatform and Tarim Platform. Platform-type formations correlatable with the Sinian System, lying unconformably upon metamorphosed Sinian Suberathem, are met with in East Kunlun, Tsinling, Altyn and along the northern border of the Tsaidam Basin. Moreover, phosphatic sediments of Early to Middle Cambrian age, characteristic of the Yangtze Paraplatform, have been discovered also in the Tienshan and Peishan. These facts suggest that a gigantic craton, to which the name of Chinese Proto-platform is provisionally given, might have been created by and maintained through

[10]) Also termed synsedimentary faults.
[11]) The Fenho Graben was formed in Late Tertiary.

the Yangtze Orogeny with a time span of about 200 my (Sinian s.s. to Lower Cambrian).

The tectonic development of China since Palaeozoic time could be divided into two stages: the Palaeozoic stage and the Meso-Cenozoic stage. In spatial distribution, three major units, hereafter to be called tectonic domains, were developed during this long period of time. They are the Pal-Asiatic Tectonic Domain (abbreviated to P-A), the Marginal-Pacific Tectonic Domain (abbreviated to M-P) and the Tethys–Himalayan Tectonic Domain (abbreviated to T-H). The Pal-Asiatic Tectonic Domain took shape and developed through the Hsingkaiian, the Caledonian and the Variscan orogenies. The process was roughly as follows: As soon as the Sayan - North Mongolian - Argun Geosynclinal System was folded and uplifted at the end of the Early Cambrian (Hsingkaiian), the Chinese Protoplatform was disintegrated and partially transformed to form the Tienshan, the Nanshan, the Tsinling and other geosynclines, all of which were again folded, transformed and consolidated at the end of the Variscan Cycle. As a result these newly consolidated geosynclinal folds joined and "cemented together" the pre-existing four platforms: the Siberian Platform, the Tarim Platform, the Sino-Korean Paraplatform and the Yangtze Paraplatform, to form a gigantic craton, to be called Pal-Asia. During the Meso-Cenozoic stage, the tectonic development of China was under the control of the Marginal-Pacific Tectonic Domain and the Tethys-Himalayan Tectonic Domain. The former may be subdivided into an inner or Cenozoic tectonic belt and an outer or Mesozoic tectonic belt. The Taiwan Fold System is the only representative of the inner belt within the Chinese territory. The outer belt of great importance was superimposed upon older tectonic units of various ages. In addition to the Southeastern Maritime Variscides and the Mesozoic Northeast Asiatic Geosynclinal Fold System, they are, from north to south, the Inner Mongolian - Great Khingan Variscides, the Kirin–Heilungkiang Variscides, the Sino-Korean Paraplatform, the Yangtze Paraplatform and the South China Fold system (Caledonides). The belt is characterized by large swells and depressions trending NE or NNE, with Mesozoic blanket folds and faults, extensive "Pacific type" volcanics and large-scale granitoid intrusives.

5. On the problem of the polycyclic evolution of the tectonics of China

In several articles H. Stille put forward his conception of tectono-magmatic cycle in geosynclinal development, whose essentials are as follows:

1. Geosynclinal period with initial magmatism, mainly basic and ultrabasic rocks.
2. Orogenic phase with synorogenic magmatism, mainly granitoid intrusions.
3. Quasicratonic phase with subsequent magmatism, mainly porphyries and andesites.
4. Full cratonic period with final magmatism, mainly basalts.

Since then, many well-known tectonic and economic geologists accepted Stille's conception, which we shall call the "monocyclic conception", especially in Soviet Union and in western Europe, such as Bilibin (1955), Smirnov (1974), Beloussov (1962), Rittmann (1960), de Sitter (1964), Aubouin (1965) and many others. Even

Table 4: *Subdivision of orogenic cycles and important events of tectonic development of China*

	Geological chronology	Isotopic age (my)	Subdivision of orogenic cycles and important events of tectonic development of China		Orogenic cycles of Europe
Cenozoic	Quaternary	15	Himalayan	Formation and development of M-P and T-H	Alpine
	Tertiary	67	Yenshanian		Cimmerian
Mesozoic	Cretaceous	137			
	Jurassic	190	Indosinian	Destruction and disintegration of parts of P-A; intensive activity of M-P and T-H	
	Triassic	230	Variscan	Consolidation of Central Asiatic-Mongolian ... geosynclines; cementation of Siberian Platform with Sino-Korean and Tarim Platforms; formation of P-A	Variscan
Palaeozoic	Permian	280			
	Carboniferous	350		Formation and development of P-A	
	Devonian	405	Caledonian	Formation of South China Platform	Caledonian
	Silurian	440			
	Ordovician	550			
	Cambrian	570	Hsingkaiian	Disintegration of Chinese Protoplatform; formation of Kunlun, Tsinling, Peishan, Tienshan (central and southern parts) and other geosynclines	
Late Proterozoic (Sinian Subera)	Eocambrian	700	Yangtzeian	Formation of Yangtze and Tarim Platforms; combination of these platforms with Sino-Korean Paraplatform to form the Chinese Protoplatform	Assyntian
	Sinian s.s.				
	Chingpaikou	1000	?		Dalslandian
	Chihsien	1400			
	Changcheng	1700*)	Chungtiaoian	Formation of Sino-Korean Paraplatform	Svecofennian
Early Proterozoic	Huto	2000	Wutaiian		Karelian
	Wutai	2500	Fupingian		Belomorian
Archaean	Fuping				

*) According to the latest report by the Institute of Geochemistry, Academia Sinica, the lower limit of the Sinian Subera is fixed at 1,950 ± 50 my BP (June 17, 1976).

as late as 1975, AUBOUIN et al. subdivide geosynclinal development into magmatic stages as follows:

- Ante-geosynclinal volcanism, spilites or porphyrites.
- Geosynclinal volcanism, basalts with radiolarites and ophiolitic massifs.
- Synorogenic geosynclinal plutonism, granites (syntectonic, late tectonic and post-tectonic).
- Post-geosynclinal volcanism, basalts.

It can thus be seen that Stille's monocyclic conception held sway for more than 30 years in geological literature. It is also to be recalled however, that Satpaev accepted the polycyclic conception for mineral deposits already in the fifties, and VAN BEMMELEN (1949) advocated a similar conception for the development of the Indonesian geosynclines.

In his explorations of many key regions of the geology of China, the author first conceived the idea in 1945, that geosynclines developed polycyclically both in orogeny and in magmatism, and published several articles (1945, 1960, 1962, 1965, 1974) on that subject. Recent geological mapping in the Tienshan and Nanshan again confirms his view of polycyclic development of geosynclinal foldbelt, which is briefly summed up as follows:

1. The Tienshan Fold System[12]), especially the North Tienshan, consists of eugeosynclinal Variscides. The Nanshan Fold System, especially the North Nanshan, consists of eugeosynclinal Caledonides. Both exhibit unquestionable polycyclic orogenies: seven orogenies, of which three are the most important, are found in the former, while four orogenies, of which the last is the most important, are found in the latter. Roughly coinciding with the orogenies, intrusion of granitoid plutons took place, five times in the Tienshan and four times in the Nanshan. Besides, important magmatism generally corresponds to important orogeny.
2. Submarine volcanic eruptions are also polycyclic. In the Tienshan intermediate volcanics (andesites) prevail and are found in four cycles corresponding to four important orogenic cycles. In the Nanshan volcanics, generally basic in nature (tholeiites and spilites), can also be divided into four cycles corresponding to four important orogenic cycles.
3. Basic and ultrabasic rock complexes are likewise polycyclic. In the Nanshan they are best developed and are divisible into five cycles, each corresponding to an orogenic cycle, of which the second cycle ($€_2$–O_1) is the most important. Basic and ultrabasic rocks together with radiolarites form three typical ophiolitic suites of three different ages (Z, $€_2$, O_1). On the contrary, ultrabasic rocks are poorly developed in the Tienshan, where ophiolitic suites are wanting.
4. Marine flyschoid sediments are well-developed in both regions, and together with submarine volcanics they form polycyclic volcano-flyschoid formations. However, they are andesito-flyschoid in the Tienshan and basalto-flyschoid in

[12]) Most of the data for the Tienshan given in the following pages are furnished by the Sinkiang Bureau of Geology to whom the author tenders his cordial thanks.

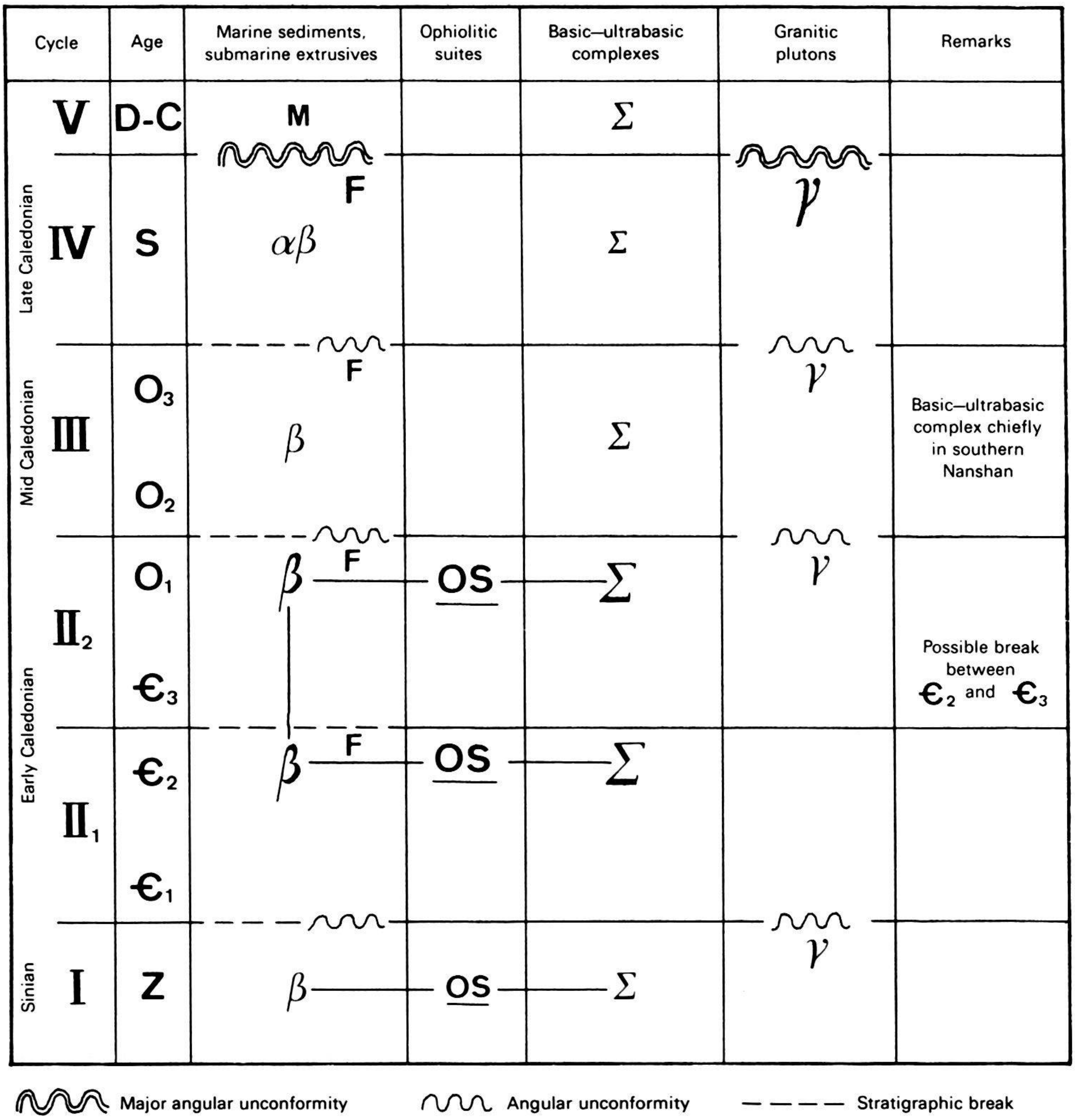

Fig. 5. Diagram showing the polycyclic development of the Nanshan Eugeosyncline.

β = Basic submarine extrusives, mainly tholeiites and spilites
a = Andesite; a_a = Andesite having an acidic tendency;
a_b = Andesite having a basic tendency
ρ = Rhyolite
F = Flyschoid deposits, often alternating with *β* and *a*
M = Molasse, divided into two stages $D_{1\text{-}2}$ and D_3, in Nanshan
Σ = Basic and ultrabasic rocks, generally serpentinized
OS = Ophiolitic suites, formed of serpentinites, basic extrusives (with pillow structures) and radiolarites
G = Basic intrusives
γ = Granitic plutons

Z = Sinian
€ = Cambrian
O = Ordovician
S = Silurian
D-C = Devon-Carboniferous
D = Devonian
C = Carboniferous
P = Permian
T = Triassic

The size of the letters representing the different rocks corresponds to the degree of their importance.

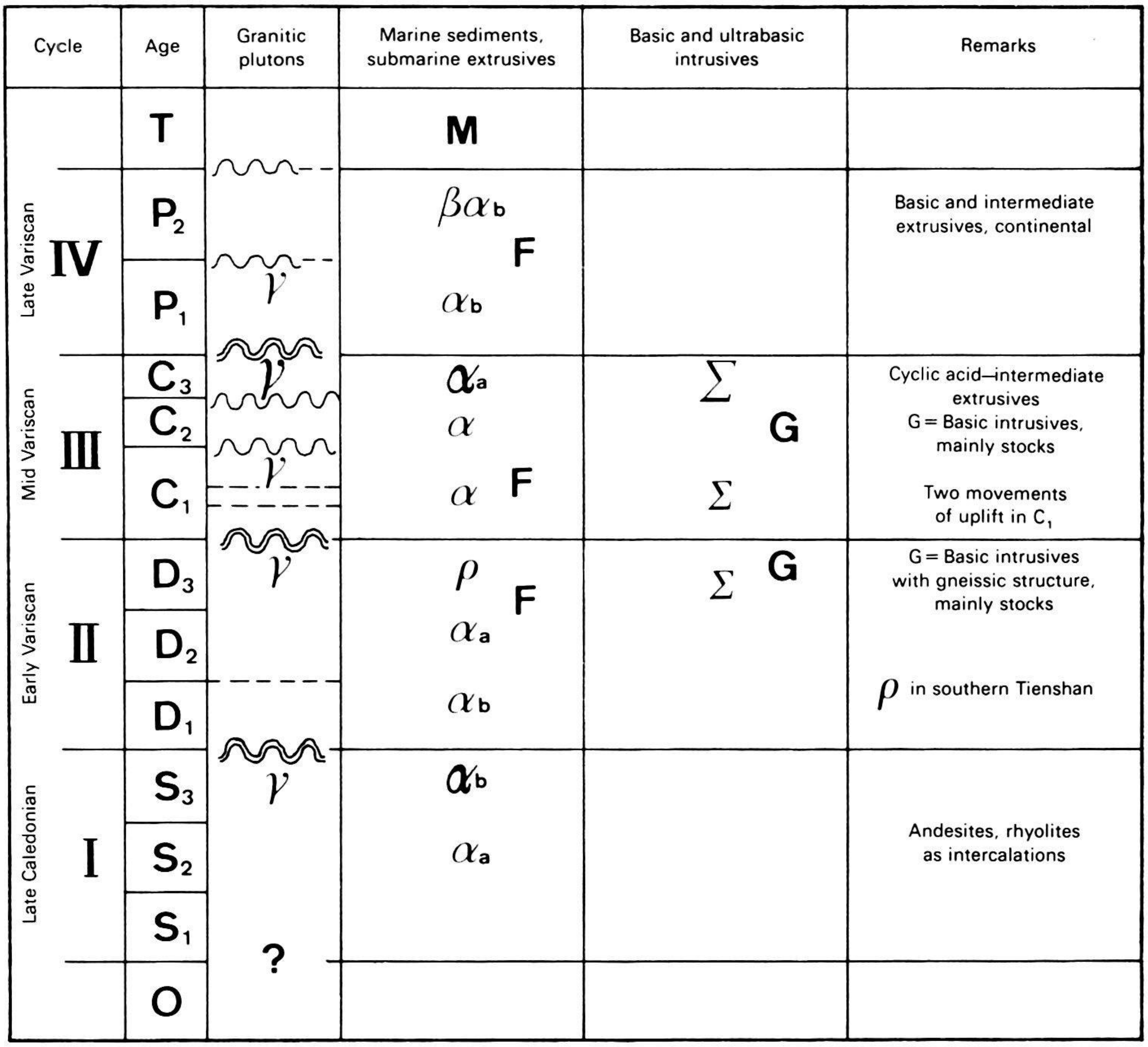

Fig. 6. Diagram showing the polycyclic development of the Tienshan Eugeosyncline (same legend as Fig. 5).

the Nanshan. Continental molasses are developed in both regions at the close of geosynclinal evolution. The Devonian molasses of the Nanshan are the most typical.

It is of importance to emphasize that the above-mentioned polycyclicity of geosynclinal development must not be considered as simple repetitions of geological processes as some writers understood them to be, but rather they are processes of vectorial spiral-like evolution with a regular arrangement. In the Nanshan Geosyncline, for instance, ophiolitic suites began to develop in Cycle I, reaching their acme of development in Cycle II, especially in Subcycle II_2 [13]). In Cycle III, though basic and ultrabasic rocks are present, no ophiolitic suites were formed. In Cycle IV, they dwindled away. On the contrary, flyschoid sedimentation, poorly developed in Cycle I and Subcycle II_1, obviously strengthened itself in Subcycle II_2 and Cycle III

[13]) The author divides an orogenic cycle, for example the Caledonian Cycle, into subcycles, and for the simplicity of writing subcycles are also considered cycles in this paper (see also Fig. 5-6).

and reached its acme of development in Cycle IV. Folding, faulting and granitoid intrusion all played an important part in each cycle, but it is obvious that they possessed a tendency of increasing activity from Cycle II to Cycle III and reached their acme of development in Cycle IV. Cycle V indicates the close of geosynclinal sedimentation, when extensive molasses came into existence.

The polycyclic evolution toward a definite direction of the Tienshan Geosyncline is even more prominent. There, granitoid magmatism was not important in Cycles I and II, but was greatly strengthened in Cycle III, and became best developed in the later part of Cycle III, i.e., in Late Carboniferous time. Granitoid magmatism rapidly decreased in Cycle IV. Moreover, granitoid plutons of Cycles I and II show gneissic structure, which is wanting in those of Cycles III and IV. It must be pointed out that each of the five granitoid magmatisms is closely connected with orogeny while the occurrence of large-scale granite batholiths is generally contemporaneous with principal orogenies. From petrochemical points of view, it is preliminarily ascertained that granitoid intrusives of early Variscan abound in plagioclase granites and albite granites, those of middle Variscan are generally normal granites, while those of late Variscan are characterized by potassium granites and alaskites, and even syenites appear. In other words, the petrochemical characteristics of granitoid intrusives change from acid-intermediate to acid, then to acid-alkaline and finally to alkaline.

From the above discussion, the author arrives at the preliminary conclusion that the Nanshan Geosyncline is characterized by polycyclic basic extrusives (tholeiites and spilites) which, together with ultrabasic rocks, form polycyclic ophiolitic suites. The Tienshan Geosyncline on the other hand is characterized by polycyclic intermediate extrusives (andesites) without ophiolitic suites. Thus the two types of geosynclines are quite different from each other in character.

Polycyclic geosynclinal development is also distinctly revealed in other geosynclines of China among which the Tsinling Geosyncline and the East Kunlun-Tangla Geosyncline are typical. This is described in another article (HUANG CHI-CHING et al. 1974) to which the reader is referred.

It must be pointed out also that many of the famous geosynclinal systems in the world such as the Appalachian, the Cordilleran, the Uralian and the Tasman Geosynclines are characterized also by polycyclic development. And consequently polycyclic development of geosynclines is, without doubt, to be considered as the general rule.

For the sake of easy understanding, the author proposes here a preliminary model for the development of geosynclinal foldbelts as shown in Figure 7. It can be seen that the development of geosynclinal foldbelts includes:

1. Early geosynclinal cycles including Cycle I, Cycle II (and possibly Cycle III).
2. Principal geosynclinal cycles, including Cycle III and Cycle IV.
3. Post-geosynclinal cycles including Cycle I and Cycle II.

It is to be noted that each geosynclinal cycle may include: "initial magmatism" (ophiolitic suites), "synorogenic magmatism" (granites) and "subsequent magmatism" (porphyries and andesites), but usually without "final magmatism" (plateau basalts). Moreover, flysch and molasse formations are also polycyclic, while the

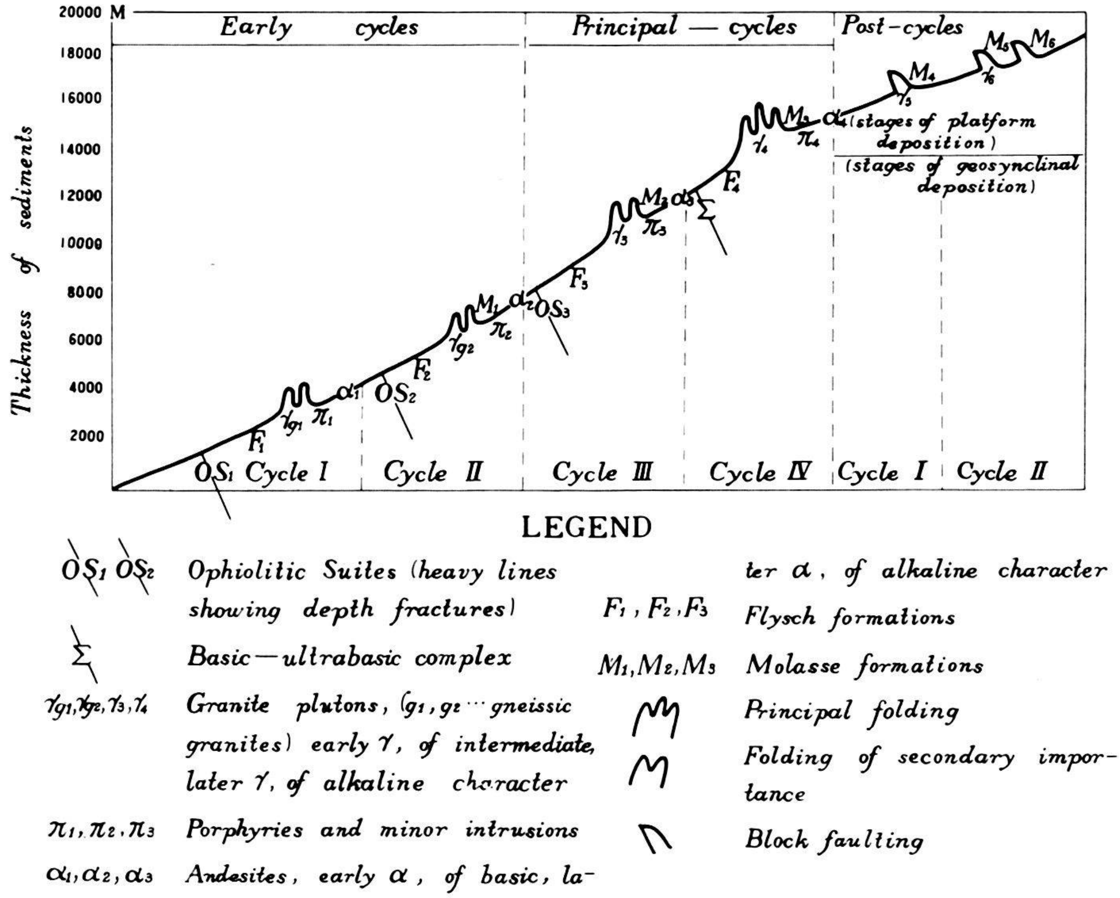

Fig. 7. Diagram showing polycyclic development of geosynclinal foldbelts.

post-geosynclinal cycles are characterized by block-faulting accompanied by folding, again with polycyclic granites and polycyclic molasses (such as in eastern China).

If we accept the theory of plate tectonics to interpret the origin and development of geosynclines, as quite a number of geoscientists are doing, we shall unavoidably come to the conclusion that plate motions are likewise polycyclic in nature. This is particularly manifested in the case of the Tasman Geosyncline. SCHEIBNER (1972) pictured the development of that geosyncline as a series of successively eastward-accreting continental blocks, subducted by a series of successively eastward-retreating oceanic crust. From his palinspastic maps, it appears clear that the Tasman foldbelt was formed by polycyclic plate motions.

6. Preliminary observations on plate tectonics in China

Recent field observations indicate the existence of plate tectonics in several regions of China.

a) Plate tectonics of the Tsangpo Depth Fracture Zone

Geological and geophysical data showing the existence of plate tectonics along the Tibetan part of the Himalayan Geosyncline were collected and analysed by

Chinese geologists (HUANG CHI-CHING et al. 1974; CHANG et al. 1973, 1977). Recent observations in the Tsangpo Valley reveal the occurrence of abundant ophiolitic suites, and to the east of Shigatze typical mélanges with exotic blocks of limestone containing Triassic and Jurassic fossils are found. It is thus probable that the Tsangpo Depth Fracture Zone is a subduction zone with the southern oceanic plate underthrusting the northern Asiatic plate. Such subducting activities might be polycyclic in nature.

b) Plate tectonics of the Nanshan - Tsinling region

The eugeosynclinal character of the northern Nanshan was described in previous articles (WANG QUAN et al. 1976; HUANG CHI-CHING et al. 1965, 1974), while its polycyclic development has already been stressed (see above).

It is to be added here that the glaucophane schist zone chiefly consists of quartz-muscovite glaucophane schist and garnet-epidote glaucophane schist, and the majority of the tholeiites of the ophiolitic suites are characterized by very low contents of K_2O (usually less than 0.3%). It is interesting to note that all these features are similar to those of other paleo-eugeosynclines in the world. Since the ophiolitic suites are polycyclic (see above), it is evident that the subduction of the oceanic plate is also polycyclic, the successive motions being from the south to the north (WANG QUAN et al. 1976).

The northern Tsinling Geosyncline is the continuation of the northern Nanshan. Recent observations show that the Caledonides of the Tsinling extend from south of Paochi to Nanyang Basin, probably including ophiolitic patches. LEE CHUN-YÜ (1975) advocates that the Tsinling is characterized by plate tectonics. It is possible that the eastern Tsinling Fold Belt was formed by the mutual approach between the Sino-Korean and the Yangtze paraplatforms.

c) Plate tectonics of the Chinshakiang - Red River Depth Fracture Zone[14])

Recent mapping in the Chinshakiang - Red River region discloses evidences of paleo-plate motions. South of Batang, in the western side of the upper Chinshakiang Fracture Zone, there occur typical ophiolitic mélanges characterized by serpentinites, spilites with pillow structure and various kinds of basic-ultrabasic rocks intercalated with radiolarites, while many exotic blocks of omphacite-eclogite, diallage-cinnamon stones and particularly of limestones with Devonian, Carboniferous and Permian fossils are found in the matrix. In the eastern side of the same zone, Wildflysch-like deposits characterized by a matrix of argillaceous and arenaceous rocks are found with various exotic blocks yielding many fossils ranging in age from Silurian to Permian, which are, without exception, older than those in the matrix. Judging from all the facts observed so far, it is probable that a western oceanic plate approached and collided, from Permian to late Triassic time, with the eastern suboceanic plate (this belongs to the Indosinian Orogeny). Along the Red River valley, the existence of ophiolitic mélanges and glaucophane schists is also

[14]) This section is contributed by Chang Chih-meng.

probable. Apparently, the Chinshakiang Zone and the Red River Zone belong to the same system of convergent plates.

Since in western Yunnan and northern Burma, there occur a series of lithospheric fractures, i.e., Chinshakiang-Red River, Lantsangkiang, Nukiang and Naga-Arakan Yoma, and since the principal ages of these fracture zones seem respectively to be Indosinian, early Yenshanian, late Yenshanian and Himalayan, the hypothesis is suggested that polycyclic plate subductions happened from east to west in successive retreating manner.

Postscript

The present contribution is the collective work of T.K. Huang, Jen Chi-shun, Jiang Chun-fa, Chang Chih-meng and Xu Zhi-qin. Jen wrote the main part of the original Chinese text, and Chang is responsible for much of the English translation. The main part of section V is written by Hsiao Hsü-chang. Several members of the Group of Tectonics, Institute of Geology and Mineral Resources, also took part in the work.

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