静岡大学地球科学研究報告 22 (1995年7月) 1頁～10頁
Geosci. Repts. Shizuoka Univ., 22 (July, 1995) 1-10

The geology of Vietnam: A brief summary and problems

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Abstract: The territory of Vietnam is divided into five structural blocks: Northeast (NE), Northwest (NW), Truongson, Kontum and Nambo. The NE block is a part of the South China plate, in which strata and igneous rocks have been found dating from the Early Paleozoic to the Quaternary. The NW and Truongson blocks are regarded as NW-SE trending Paleozoic folded systems filled with thick (>12000 m) Paleozoic formations. Precambrian strata are widespread in the Red River fault zone and Fansipan range in the NW block, and in the Kontum block. Archean rocks are found only in the Kontum block, which is regarded as a stable massif without Paleozoic sedimentary rocks. The Nambo block is covered with a very thick (>6000 m) sequence of Cenozoic formations deposited in a continental rift. During the Mesozoic many such graben structures were formed and become basins for sedimentation. Igneous activity in Vietnam is divided into five episodes from the Archean to Quaternary. The most important impediments to the description and interpretation of geology in Vietnam are lack of reliable radiometric and structural data, and scarcity of good outcrops.

Key words: Vietnam, Kontum massif, Truongson, Red River fault zone, Precambrian strata.

INTRODUCTION

Vietnam is a country of area 331,689 square kilometers situated on the Indochina peninsula (Fig. 1). Because of many important geological features reflecting regional geological evolution, Vietnam has attracted the special attention of numerous geologists from various countries (e.g., FROMAGET 1941; SAURIN 1956; DOVJICOV *et al.* 1965; KUDRIAVTSEV *et al.* 1969; RANGIN *et al.* 1993). Recent English publications concerning the geology of Vietnam have been limited mostly to plate reconstruction models for the whole East Asian region and the South China Sea (DEWEY *et al.* 1989; HUCHON *et al.* 1994; LEE & LAWVER 1994; PELTZER & TAPPONNIER 1988; TAPPONNIER *et al.* 1986), and in general publications in English describing and discussing any aspects of the geology of Vietnam are very scarce. The aim of this paper is to give a general picture of the geological characteristics of this country based on the results of research by an array of local and international researchers and to summarize the most important obstacles to future progress.

TECTONIC OUTLINE

The territory of Vietnam is a part of the South China Plate and Indochina Plate. The plate boundary is the Red River fault zone that strikes NW - SE and extends over a length of > 1000 km between the Gulf of Tonkin and Tibet (TAPPONNIER *et al.* 1990) (Fig. 1). The Red River fault zone corresponds to two distinct structures: the Ailao Shan - Red River shear zone referring to the narrow metamorphic cores of the fault zone and the active Red River fault system (LELOUP *et al.* 1994). According to the model of TAPPONNIER *et al.* (1986), the whole of Indochina has extruded

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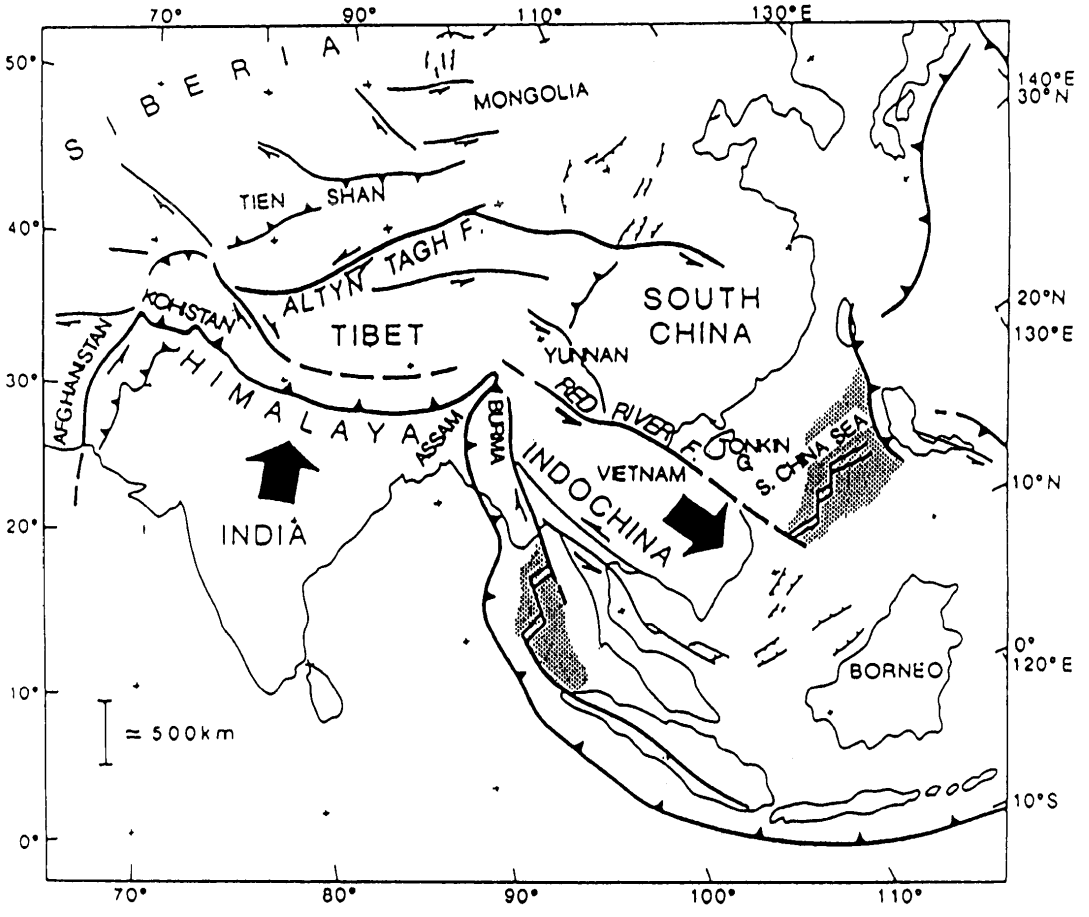

Fig. 1. Schematic map of the major Cenozoic fault zone in eastern Asia. Oligo-Miocene sea floor is shaded. (After SHÄRER *et al.* 1990.)

to the SE during the collision of India with Asia. The relative movement between Indochina and South China along the Red River fault zone has been estimated to be from 330 km (LACASSIN *et al.* 1993) to 500 - 740 km (TAPPONNIER *et al.* 1986, 1990) of left - lateral motion during the Tertiary. The South China Sea to the East of Vietnam is, therefore, suggested to have originated as a pull - apart basin at the termination of the Red River fault zone.

Figure 2 shows the tectonic divisions of the territory of Vietnam. The territory of Vietnam can be divided into five units as structural blocks. They are the Northeast (NE), Northwest (NW), Truongson, Kontum and Nambo blocks. The NE block is recognized as part of the former Chinese continent. The stratigraphy and igneous rocks there range from the Late Proterozoic to Quaternary. The NW and Truongson blocks, with the thickest Paleozoic strata in Vietnam, are recognized as NW - SE trending Paleozoic folded systems, but there are some differences in tectonic development between them, especially in the Late Paleozoic. The Kontum block is an uplifted massif. The oldest stratigraphy of the Archean is found there, but Paleozoic rocks are mostly absent. The Nambo block is a part of the Malaysia - Miami "geosynclinal system" and is recognized as a continental rift filled with thick (6 km) Cenozoic deposits (DE *et al.* 1986).

STRATIGRAPHY OF VIETNAM

The rocks of Vietnam range from Precambrian to Quaternary. The strata of each of the blocks (NE, NW, Truongson, Kontum and Nambo) is different (Fig. 3).

PRECAMBRIAN STRATIGRAPHY

The Precambrian formations in Vietnam are found along the axis of the Fansipan range, in the Red River valley (NW block), and in the Kontum massif (Fig. 3).

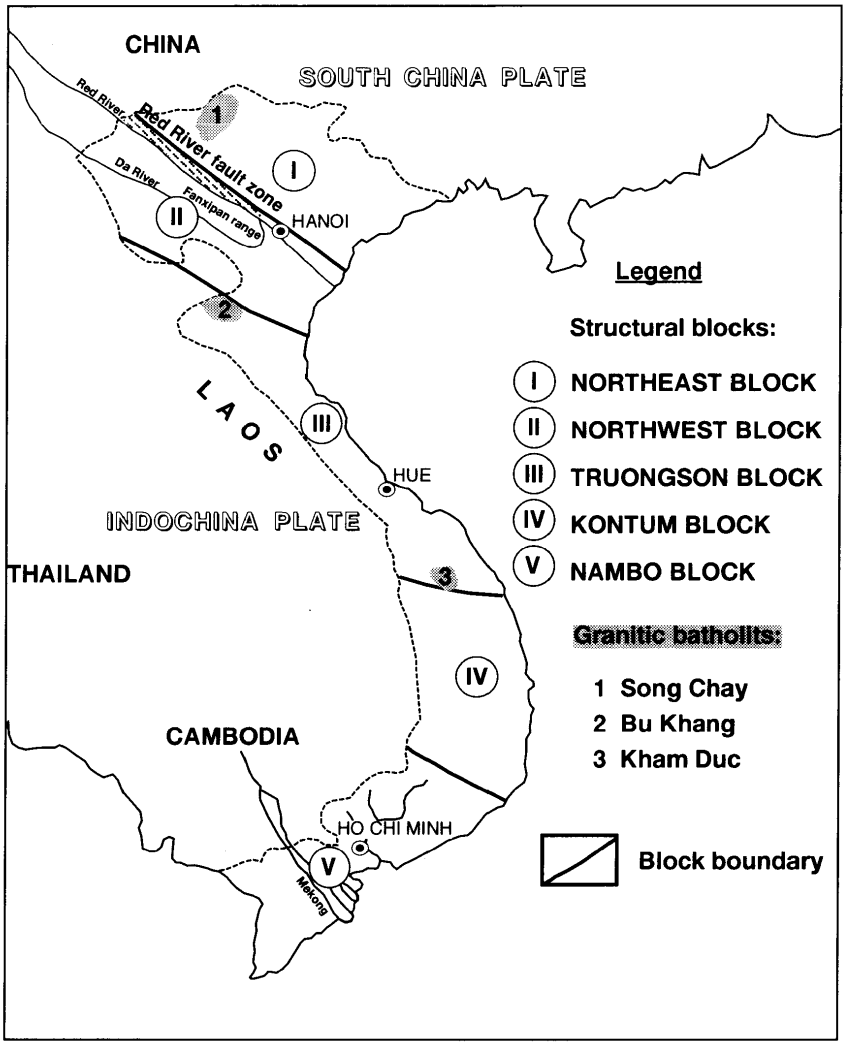

Fig. 2. Tectonic divisions of the territory of Vietnam.

Archean metamorphic rocks

In the Kontum massif the Archean granulites, grouped into the Cannak complex, which is the oldest stratigraphic unit in Vietnam, are found in close connection with autochthonous plutons of alkali - charnokites (orthopyroxene - bearing granites). The thickness of the complex has been estimated to be > 4000 m. The complex consists mainly of two - pyroxene and hypersthene - garnet - bearing granulites, and sillimanite - garnet - cordierite - bearing khondalites. Several calciphyre and marble intercalations are found among the khondalites. The representative mineral associations of the complex are typical of the cordierite - hypersthene - orthoclase subfacies, the highest temperature part of intermediate - pressure granulite facies, corresponding to P - T conditions of 800 - 850 ℃ and 7 - 8 kbars. The Archean age of the complex is proposed on the basis of petrological correlation with classic Archean granulites in other parts of the world (HAI 1986; THI 1985).

Lower Proterozoic metamorphic rocks

Lower Proterozoic rocks are found in the Kontum massif and in the cores of the Fansipan range and Red River fault zone (see Fig. 2 for locality). They are placed into different complexes under local names. The general thickness of the complexes has been estimated to be 2500 - 3000 m. The lowest part of the complexes is mainly composed of amphibolite - biotite gneisses, hornblend - biotite plagiomigmatite and intercalations of amphibolites. The principal constituents

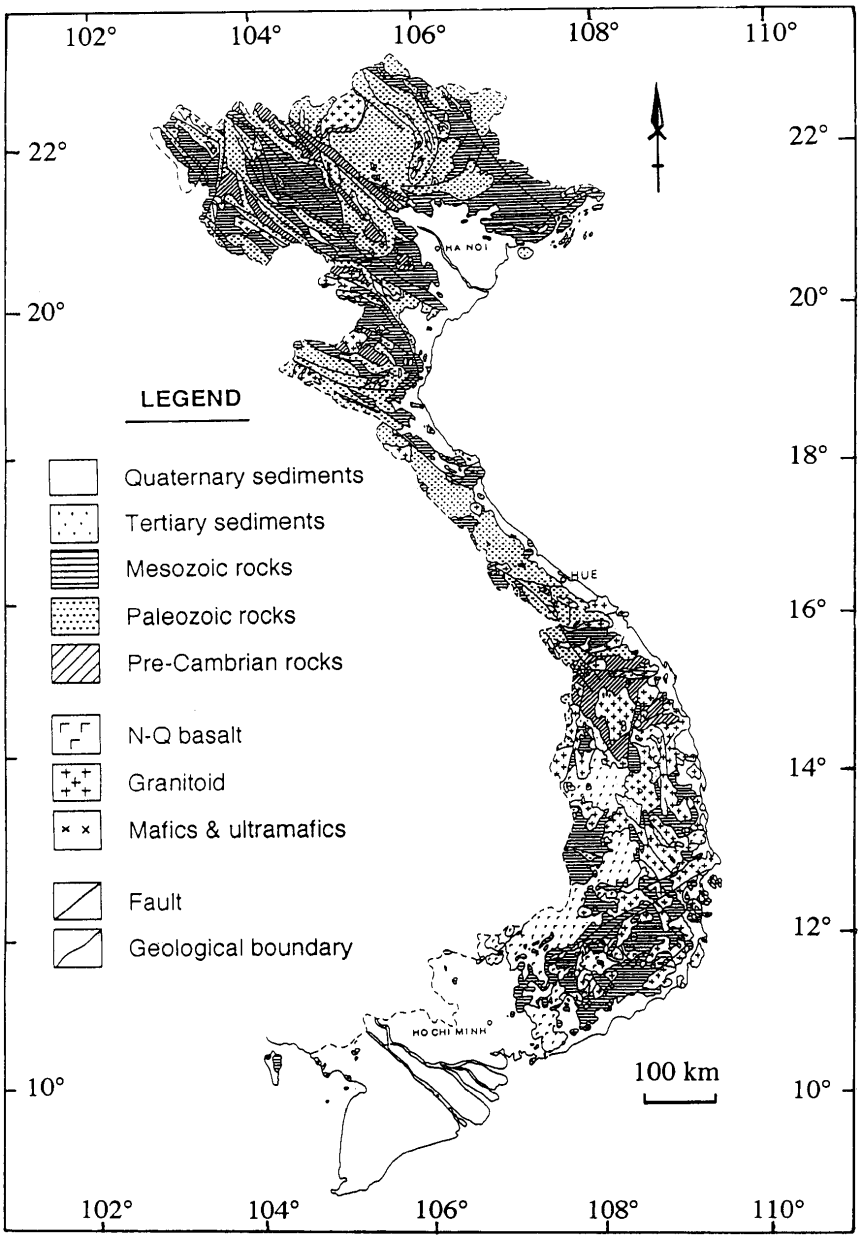

Fig. 3. Geological map of Vietnam. (After TRAN & NGUYEN 1986.)

of the upper part are sillimanite - biotite - garnet gneisses and schists. There are also graphite - bearing schists and intercalations of quartzite, lenses of marbles and calciphyres in this part. The metamorphic conditions have been estimated to be intermediate - pressure amphibolite facies, corresponding to P - T conditions of 650 - 700 °C and 7 - 7.5 kbars. The oldest K - Ar ages registered from these complexes vary from 2070 to 2300 Ma (TRI *et al.* 1977, THI 1985).

Upper Proterozoic metamorphic rocks

Upper Proterozoic metamorphic rocks, with a strata thickness of 1000 - 1200 m, are widespread and form a large (50 - 60 km wide) belt bordering the Kontum massif. They are composed of amphibolite with garnet and cummingtonite, with intercalations of garnet - cummingtonite amphi-

bolite, marble and plagioclase - diopside schists in the lower part. The upper part is built up of two - mica schist, gneiss, quartzite, amphibolite and marble.

In the NW block, the Upper Proterozoic rocks consist mainly of two - mica schists and sericitic schists intercalated with quartzite and marble. The strata thickness has been estimated to be 900 - 1000 m (HAI 1986).

The metamorphic conditions of the Upper Proterozoic rocks have been estimated to be close to 400 - 500 ℃ and 2 - 3.5 kbars, representing the highest - temperature part of greenschist facies (THI 1985).

PALEOZOIC STRATIGRAPHY

Paleozoic strata in Vietnam are widespread in the NE, NW and Truongson blocks, but are absent in the Kontum and Nambo blocks (Fig. 3).

Lower Paleozoic strata

The 1300 - 2000 m thick Middle Cambrian - Lower Ordovician strata that consist mainly of limestone, mudstone and sandstone have been divided into two types, namely the Changpung and Thansa types. The latter is distributed in the NE block, whereas the former is in the NW and Truongson blocks. The fauna of the Thansa type is closely related to that of Southeastern China and Tienshan, whereas that of the Changpung type has been regarded as a member of the Eastern Asia - Australia paleobiogeographical province (NGAN *et al.* 1986).

The 400 - 1000 m thick Middle and Upper Ordovician strata that crop out in the NE block are composed of terrigenous brown coarse - grained clastic rocks with the remains of species of brachiopods (e.g., *Vietnamia douvillei* (MANS) and *Lonchodomas yohi* SUN) and other taxa (NGAN *et al.* 1986).

The 3000 - 3500 m thick Upper Ordovician - Lower Silurian formations are largely distributed in the NE and Truongson blocks and partly in the low course of the Da River in the NW block. Except for the sedimentary rocks along the Da River, which contain coral fossils, the others are terrigenous flysch in character and contain graptolite assemblages.

The 2000 - 3500 m thick Upper Silurian formations conformably overly the above mentioned formations. Many fossil taxa have been discovered in the Upper Silurian formations, such as graptolites, brachiopods, trilobites, and acritarchs. The Upper Silurian formations cover large areas in the Truongson and NE blocks and the low course of the Da River of the NW block (NGAN *et al.* 1986).

Upper Paleozoic stratigraphy

In the NE and NW blocks the lowest Devonian strata, with a thickness of 600 - 700 m, are continental formations containing fresh - water fish fossils, unconformably overlying the Lower Paleozoic formations; in the lower course of the Da River (NW block) there are carbonate - terrigenous formations conformably resting on Silurian formations and containing fossil assemblages of brachiopods. The Middle Devonian strata are mainly composed of 500 m thick carbonate formations containing abundant remains of corals. The Upper Devonian strata, with a thickness of 200 m, crop out in limited areas. The strata contain are bedded siliceous limestone, shale, and siliceous rocks, containing Frasnian and Famennian conodont assemblages (THANH *et al.* 1986; TRI 1977).

In the Truongson block, the Lower Devonian strata are characterized by a 2000 m thick formation of shale and sandstone, containing *Nowakia*, *Monograptus*, *Erbenoceras*, etc. In the Hue area, southern part of the Truongson block, the Lower Devonian strata are continental red - colored beds of conglomerate, sandstone and mudstone. The Middle Devonian strata are characterized by a 1200 m thick terrigenous formation in the lower part and a 500 m thick carbonate formation in the upper part, the latter containing abundant assemblages of coelenterates and brachiopods. The thin Upper Devonian strata are composed of two facies: the carbonate facies contains Frasnian - Famennian stromatoporoids and conodonts distributed in the north part of the block, whereas the clastic facies of the tidal - littoral zone is only Frasnian in the south part (THANH *et al.* 1986; TRI 1977).

The Carboniferous - Permian formations are widely distributed in the NE, NW and Truongson blocks. In the NE block these formations are characterized by Carboniferous - Permian limestone containing numerous foraminifers and Upper Permian siliceous shale, bauxite and limestone. In the NW block these formations are composed of limestone, shale, siliceous shale, and porphyrite basalt, whereas in the Truongson block they are composed of Lower Carboniferous shale, sandstone, conglomerate, limestone and Carboniferous - Permian limestone containing

abundant assemblages of foraminifers. The total thickness of the Carboniferous - Permian strata has been estimated to be 1800 - 2200 m (HUNG & TIEN 1986).

MESOZOIC STRATIGRAPHY

In Vietnam the Mesozoic strata consists of Triassic and Jurassic marine sedimentary and volcano - sedimentary rocks, and Cretaceous red continental formations. They are distributed in Mesozoic grabens. In the NE block the grabens trend from NE - SW to sub W - E, whereas in the other bocks they mostly trend NW - SE.

The Triassic formations mainly consist of terrigenous deposits, volcanics, and limestone containing abundant assemblages of pelecypods. The Norian - Rhaetian consists of coal - bearing deposits containing the famous Hongai flora (KHUC & THU 1986).

Cretaceous red continental formations mainly consist of sandstone, siltstone, light violet to red brown shales and conglomerates. In some places, there are salt - bearing formations (THU & TIEN 1986).

TERTIARY FORMATIONS

Tertiary (mainly Neogene, in some areas with Upper Paleogene) deposits are of limited quantity and belong to three types: lacustrine with the intercalation of volcanic rocks, lagoonal or deltaic, and marine. The lacustrine deposits are characterized by their gray color, rhythmically interbedded with conglomerates and coarse sandstone, and coal - bearing units. They are distributed in narrow (a few hundred meters wide) depressions and often developed along the main faults under the lakes or grabens. Fossil remains of vegetation, spores and pollen, mollusks and diatoms have been collected in these deposits in South Vietnam. Basalts are also found in the same deposits. Very thick (3500 - 6000 m) lagoonal or deltaic formations are distributed in the Hanoi and Mekong basins. Marine formations are deposited only on the continental shelf of Vietnam (DZANH 1986).

QUATERNARY SEDIMENTS

Quaternary formations in Vietnam consist of two series: deltaic sediments distributed in the Hanoi & Mekong basins and coastal plains, and basalts that are widely distributed in the highland of the Kontum massif.

IGNEOUS ACTIVITY

The magmatic evolution in Vietnam is divided into five episodes: Archean, Early Proterozoic, Early - Middle Paleozoic, Late Paleozoic - Early Mesozoic and Late Mesozoic - Cenozoic. Some episodes are subdivided into cycles (QUYEN 1986).

INTRUSIVE BODIES

Intrusive bodies during the Archean episode have been found only on the Kontum massif with compositions varying from ultramafic to granitic.

Early Proterozoic intrusive bodies are mainly plagiogranite and migmatite, and are distributed in the Kontum massif and in the Fansipan range of the NW block.

The Early - Middle Paleozoic episode is subdivided into four stages: Middle Cambrian, Ordovician - Silurian, Early Devonian, and Carboniferous. The intrusive bodies of this episode are widely distributed over Vietnam and vary from ultramafic to granitic in composition.

The Late Paleozoic - Early Mesozoic episode is subdivided into two stages: Permian - Triassic and Middle Triassic - Norian. Intrusive bodies of this episode are commonly granodiorite, granite, with some mafics and ultramafics.

The Late Mesozoic - Cenozoic episode is subdivided into three stages: Late Jurassic - Early Cretaceous, Late Cretaceous - Paleogene and Late Paleogene. Intrusive bodies of this episode are high - alumina granitoid, alkaline granite and alkaline syenite.

The ages of the intrusive bodies have been estimated based in part on radiometric data, but mostly on comparison with relative ages of associated volcanic formations.

VOLCANIC FORMATIONS

Volcanic formations are found in Vietnam throughout geological time. Thin pre - Mesozoic volcanic formations are found in a wide variety of geological structures. They are intercalated with polymineral - terrigenous, graywacke, siliceous and carbonate rocks of Archean, Protero-

zoic, Early Cambrian - Early Ordovician, Late Ordovician - Early Silurian, Late Silurian - Early Devonian, Late Carboniferous - Early Permian and Permian ages (QUOC 1986). Thick (> 800 m) sequences of Mesozoic (Middle Triassic and Jurassic) volcanic formations are found in many Mesozoic volcanic grabens in Vietnam. Paleogene and Neogene - Quaternary volcanic formations cover the modern relief of some areas.

GEOLOGICAL HISTORY

The geological history of the territory of Vietnam (Fig. 4) stretches back to over 2300 million years ago, when the Archean rocks were formed. The first granitization process took place in the Kontum massif, making it the earliest continental part of the territory of Vietnam. The second granitization probably took place during the Early Proterozoic in the Kontum and NW blocks, where granite and migmatite of the Early Proterozoic are found.

The Kontum massif has been stable since the Later Proterozoic, with only thin platform cover formations and no Paleozoic formations. In contrast, intensive granitization took place in the Truongson, NW and NE blocks during the Early Paleozoic to form large granitic dome - like structures (e.g., granitic batholiths of Song Chay, Bu Khang and Kham Duc; see Fig. 2).

During the Paleozoic, the Truongson and NW blocks were "geosynclinal basins" situated between the Indochina micro - continent to the south and the Chinese continent to the north. The basins gradually uplifted and became a continental region by the Late Paleozoic. Evidence for this is based on the temporo - spatial distribution of sedimentary facies. Devonian red - colored sediments of conglomerate, sandstone and mudstone are found in the Hue area, and cross - bedded sandstone containing fresh - water fish fossils is found in the NE block, whereas there are marine sequences of the same age in the center of the basin.

Carboniferous - Permian nonclastic limestone containing abundant assemblages of foraminifers found in several regions is interpreted as a platform cover, except for in the Da River region (in the NW block), where limestone is intercalated with basalt that is regarded to be a rift formation.

In the Triassic - Early Jurassic several grabens were formed. They became basins for the deposition of sedimentary and volcanic rocks.

Cretaceous red continental sedimentary successions are recognized as orogenic formations.

During the Neogene - Quaternary there are only two main basins, the Hanoi and Mekong, for sedimentation. Basalt effusion took place in the high land of the Kontum massif, and other parts of the territory of Vietnam have undergone weathering and erosion.

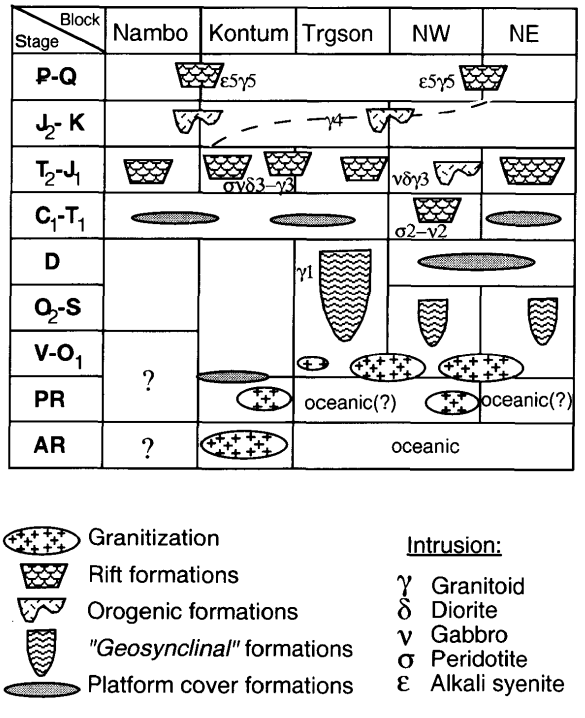

Fig. 4. Geological history of the territory of Vietnam.

THREE MAJOR PROBLEMS FACING GEOLOGISTS IN VIETNAM

(1) A large problem for interpretation of the geological history of Vietnam is a lack of reliable radiometric age data. Precambrian stratigraphy and the relative ages of igneous rocks are still debated. The oldest stratigraphic unit in Vietnam, the Archean Cannak complex in the Kontum massif, is proposed to be Archean only on the basis of petrological correlation, while 1119 - 1216 Ma Rb - Sr and 1200 - 1800 Ma K - Ar ages from the complex (suggesting a Proterozoic age) are thought to be ages of superimposed metamorphism (THI 1985). The high - grade metamorphic core of the Red River fault zone in Vietnam has been placed in the Proterozoic based on the 2,070 - 2300 Ma K - Ar ages from hornblend -

biotite plagiomigmatite (TRI *et al.* 1977). In contrast, the cores of the Red River fault zone in China that are made of the same rocks have been thought to have resulted from the deformation and metamorphism of Paleozoic and Mesozoic sediments during the Tertiary (TAPPONNIER *et al.* 1990; SCHÄRER *et al.* 1990; LELOUP & KIENAST 1993). These are only two examples of many illustrating problems due to the lack of reliable chronological data for formations in Vietnam.

(2) Large faults in Vietnam are commonly proposed on the basis of geophysical data; however, their geological aspects have not been studied sufficiently, even for the large boundaries between structural units such as the Red River fault zone. Because of the lack of geological structural data, there are many differing tectonic maps and interpretations of the geological evolution of the territory of Vietnam.

(3) The soil cover in Vietnam is very thick. The moist tropical climate promotes intense chemical weathering, dense vegetation, and soil formation, thus good outcrops are very scarce. This lack of outcrops is perhaps the largest barrier to geological research in Vietnam.

ACKNOWLEDGMENTS

The author is grateful to Professors K. KANO and N. NIITSUMA for constructive comments on this manuscript. The author would like to thank Dr. T. MASUDA for joining in field work in Vietnam and valuable discussion about the geology of Vietnam. The author also wishes to thank Dr. R. M. ROSS for editing this manuscript.

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