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OVERVIEW OF MAGMATISM IN NORTHWESTERN VIETNAM

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Abstract: Amalgamation of tectonic plates of Southeast Asia occurred in northwestern Vietnam. Six groups of magmatic rocks are related to the tectonic events. The first group corresponds to the major episodes of crustal formation in the South China block, or is linked with the formation of Gondwana. The second group includes granitoids in connection with the collision and formation of the Caledonian–Hercynian folding event. The third group contains Upper Permian ophiolites, as well as the Permian extrusives, formed in intraplate setting, related to back-arcs spreading. The fourth group is related to Triassic Indosinian orogeny, the fifth group comprises Jurassic–Cretaceous intraplate granitoids. Finally, during Cenozoic times, magmatic rocks were represented by alkaline granitoids – the effect of strike-slip faulting related to the collision of India and Eurasia plates.

Key words: Vietnam, plate tectonics, magmatism, Palaeozoic, Mesozoic, Cenozoic.

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INTRODUCTION

In Northwestern Vietnam (NWVN), magmatic intrusions and effusions have mainly acid and minor mafic to ultramafic compositions (Fig. 1). They have been subdivided into 21 complexes and 5 formations through Proterozoic to Cretaceous times. The scientific research on the magmatic rocks of NWVN area applying new technology led to new results and different interpretation of the origins of geological events. Therefore, carrying out a synthetic review of the magmatic rocks is necessary in order to provide a comprehensive overview of the regional geology. This paper presents the overview of petrographic, geochemical and geochronological studies on different magmatic rock types from the NWVN area. It also attempts to explain mechanism responsible for magmatic processes and help to understand the magmatic characteristics and the tectonic implications. The author's research is combined with results obtained by the Department of Geology and Minerals of Vietnam (DGMV). The geochemical, mineralogical and geochronological data were given mainly by Tran Trong Hoa (1996, Tran Trong Hoa *et al.*, 1999). Some newest data were published by Pham Trung Hieu *et al.* (2008, 2009). The magmatism history of northwestern Vietnam is also supported by 1:50,000–1:200,000 geologic maps and other recent geological studies (Bui Cong Hoa, ed., 2004, Bui Phu My, ed. *et al.*, 1977, Dinh Minh Mong ed., 1977 and references therein). The paper's interpretation is focused on: 1. the relationships between the NWVN area (including Song Hong-Phan Si Pan, Tu Le, Song Da, Song Ma and Sam Nua areas) and adjacent areas; 2. the magmatic evolution of the NWVN as a whole.

The complexes of granitoids are closely related to tectonic setting; therefore one can successfully use the mineralogy, chemistry and trace element discrimination diagrams for the tectonic interpretation of granitoids (Pearce *et al.*, 1977; Condie, 1997). Various discrimination plots are presented which sequentially discriminate the different tectonic environments. These plots used the GeoPlot software and some elements in the CorelDraw software. GeoPlot is a free VBA macro program used in Excel for plotting geochemical data. It has the following major plotting functions: X-Y plot and triangular plot, normalized spidergram, discrimination diagram, and the related functions, such as calculating formulas and CIPW norm. GeoPlot also contains many normalization values used for spidergram and many discrimination diagrams. Users can also add new normalization values for spider diagrams and the specification data for a new discrimination diagram into GeoPlot. GeoPlot has the advantage over the existing stand-alone plotting programs because it allows data to be plotted and visualized easily in the Excel environment, which geochemists use to organize and evaluate the data. A menu and a toolbar in Excel allow easy management of data and functions. In summary, GeoPlot is

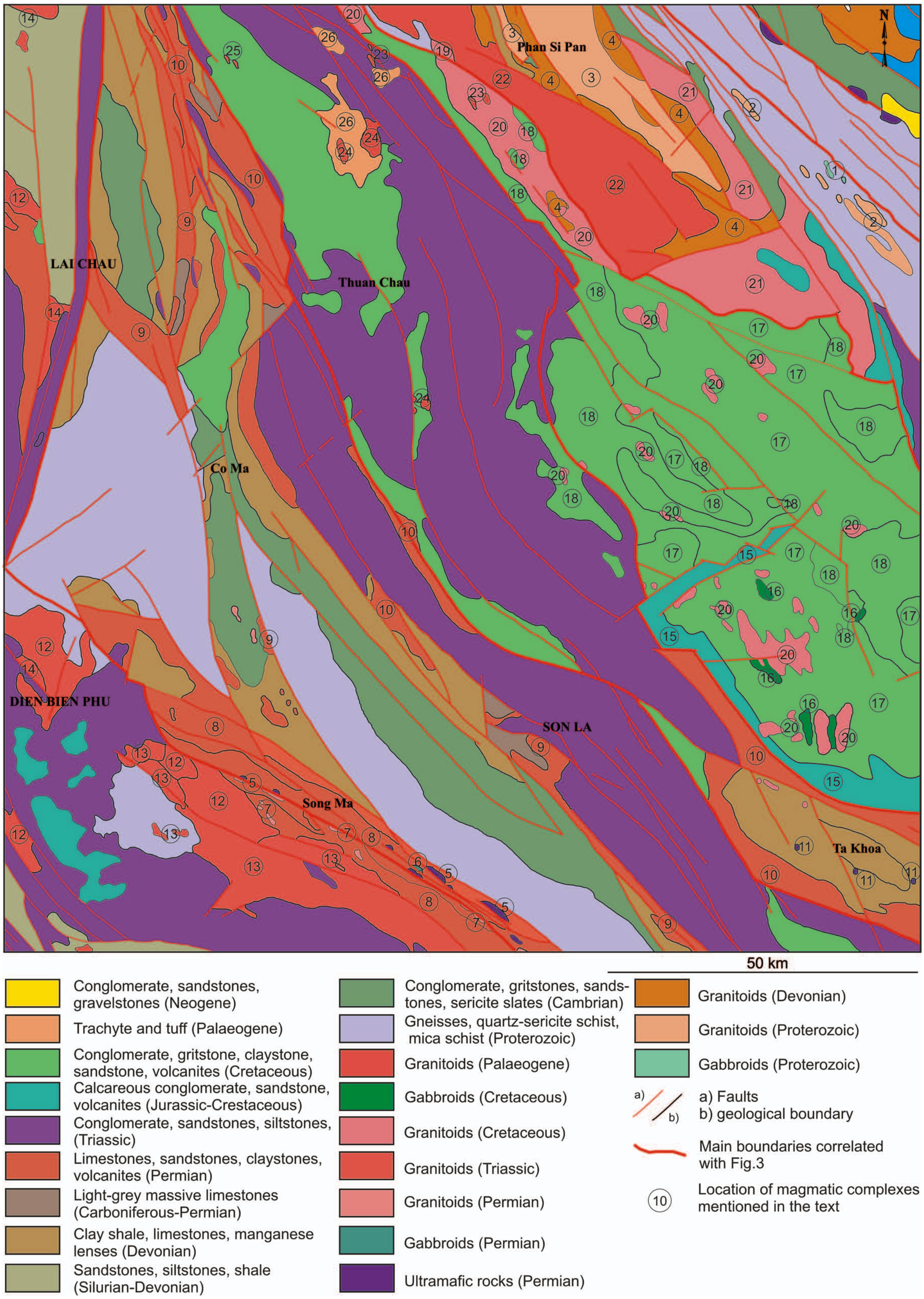

Fig. 1. Geological map of the Northwestern Vietnam (compiled from geological maps of the northern Vietnam at 1:200,000 scale). 1 – Bao Ha complex, 2 – Xom Giau complex, 3 – Po Sen complex, 4 – Song Chay complex, 5 – Nui Nua complex, 6 – Bo Xinh complex, 7 – Chieng Khuong complex, 8 – Huoi Hao Formation, 9 – Cam Thuy Formation, 10 – Vien Nam Formation, 11 – Ban Xang complex, 12 – Dien Bien Phu complex, 13 – Song Ma complex, 14 – Phia Bioc complex, 15 – Suoi Be Formation, 16 – Nam Chien complex, 17 – Tu Le volcanic subcomplex, 18 – Ngoi Thia volcanic subcomplex, 19 – Muong Hum complex, 20 – Phu Sa Phin complex, 21 – East Ye Yen Sun complex, 22 – West Ye Yen Sun complex, 23 – Nam Xe-Tam Duong complex, 24 – Pu Sam Cap complex, 25 – Coc Pia complex, 26 – Pu-Tra Formation

practical and enables geochemists to plot data professionally. The source codes are accessible to all users and can be modified for special use. The software is developed by Jibin Zhou from Guangzhou Institute of Geochemistry Chinese Academy of Sciences.

GEOLOGICAL BACKGROUND

Sedimentary rocks

More than fourty lithostratigraphic formations have been identified in the NWVN. They are divided into 8 complexes.

1. Neoproterozoic complex includes Xuan Dai group, Nam Su Lu and Nam Co formations, Bo Xinh group and Sa Pa group.
2. Cambrian complex contains Cam Duong, Ben Khe, and Ham Rong formations.
3. Ordovician–Silurian complex contains Dong Son, Sinh Vinh and Bo Hieng formations.
4. Silurian–Devonian complex contains Ban Pap, Nam Pia, Tay Trang, Nam Cuoi, Ban Nguon, Nam Sap, and Ban Cai formations.
5. Carboniferous–Permian complex includes Da Nieng, Bac Son, Ban Diet, Yen Duyet, Si Phay, Na Vang formations.
6. Triassic complex includes, Tan Lac, Hoang Mai, Dong Giao, Nam Tham, Muong Trai, Lai Chau, Nam Mu, Pac Ma, Suoi Bang formations.
7. Jurassic–Cretaceous complex contains Nam Thep, Nam Po, Nam Ma, Yen Chau formations.
8. Neogene–Quaternary sediments form the last complex.

Mesozoic terrigenous, terrigeno-effusive and acidic effusive formations occupy the large central part of the NWVN, while Proterozoic, Palaeozoic flyschoid and carbonaceous sedimentary formations cover smaller area in the northeast and the southwest parts of NWVN. The Cenozoic formations are distributed mainly along the river catchment's area. The Palaeozoic and Mesozoic sedimentary rocks have been intruded by Mesozoic granites and small Cenozoic intrusive bodies (Fig. 1).

Magmatic units

Magmatic rocks consist of intrusive and extrusive rocks, occupying large part of the NWVN (Fig. 1) and forming bodies of various sizes (Tran Van Tri, ed., 1979; Tran Duc Luong & Nguyen Xuan Bao, eds., 1995). Main magmatic activities took place during the Late Palaeozoic, Mesozoic and Cenozoic, resulting in various types of granites, gabbros and acidic volcanic rocks, namely: Nui Nua and Ban Xang ultramafics, gabbroic Bo Xinh, Chieng Khuong granitoid complexes, Huoi Hao basalt Formation; Cam Thuy, Vien Nam mafic effusive formations, complex; Dien Bien Phu, Song Ma, Phia Bioc granitoid complexes; basalts of Suoi Be Formation, gabbroic Nam Chien, Tu Le-Ngoi Thia volcanic, Muong Hum, Phu Sa Phin, Ye Yen Sun granitoid complexes; Nam Xe-Tam Duong, Pu Sam Cap, Coc Pia subalkaline to alkaline syenite complexes, and Pu Tra Volcanogenic Formation. The Proterozoic gabbroic Bao Ha and granite of Xom Giau complexes are distributed along the Red River fault zone and in NE area, while Palaeozoic mafic-ultramafic Nui Nua, gabbroic Bo Xinh, granitoid Chieng Khuong, Song Chay complexes are distributed in both NE and SW parts of NWVN, along Song Ma and Song Hong fault zones. The Cenozoic igneous rocks, comprising Ye Yen Sun, Nam Xe-Tam Duong, Pu Sam Cap, Coc Pia granitoid complexes, are distributed in the central part of the NWVN area.

Plate tectonics

East and Southeast Asia comprise different terranes and blocks, which were derived from the northern margin of Gondwanaland (Leloup *et al.*, 1995, 2001; Findlay, 1997, Findlay. & Phan Trong Trinh, 1997; Tran Ngoc Nam, 1998; Fan, 2000; Carter *et al.*, 2001; Golonka *et al.*, 2006a). Successive rifting and breakup formed several continental blocks during Palaeozoic and Mesozoic times. The northward movement of these blocks resulted in the amalgamation of present-day Southeast Asia. The closing of the Palaeotethys between the blocks led to the formation of several sutures like Song Ma, Song Da, Nan-Uttaradit and so on (Metcalfe, 1996a, b, 1999, 2006; Golonka *et al.*, 2006a).

Metcalfe (1998, 2002) and Golonka *et al.* (2006a,c) distinguished a number of plates and terranes within Vietnam and adjacent areas (Fig. 2). The northwestern Vietnam belongs to Indochina (ICB) and South China (SCB) blocks. The SCB includes the southern part of China and northeastern fragment of Vietnam. It is separated from North China by the Quingling-Dabie suture, from Indochina by the Song Ma suture, from the Sibumasu Plate by the Ailaoshan suture, from the Songpan-Ganzi accretionary complex by the Longmenshan suture. The southeastern margin of South China is a passive margin connected to South China Sea by extended continental crust. To the East SCB is bordered by the Taiwan foldbelt and the Okinawa trough passive margin. The SCB block was finally formed during Precambrian times.

The Indochina block (ICB) comprises the countries of Vietnam, Laos, Cambodia and western Thailand, perhaps also southeastern part of Malayan Peninsula, a fragment of Sumatra and the westernmost fragment of Borneo belong to ICB. To the West ICB is separated from the Sibumasu plate (from south to north) by Raub-Bentong, Phra Kaeo and Nan-Uttaradit sutures; to the northeast it is separated from the SCB by the Song Ma suture. The eastern margin of Indochina is a passive margin connected to South China Sea by extended continental crust.

The tectonic structure of Northwestern Vietnam results from three major collisional events that took place during the Palaeozoic, Permo-Triassic and Cenozoic (Khuong The Hung & Golonka, 2008). The large scale (~600 km) sinistral displacement along the Ailao Shan-Red River (ASRR) shear zone occurred during ~27±22 Ma (Chung *et al.*, 1997) event. The suture between Indochina and South China is located along the Song Ma belt. The Song Ma belt is characterized by the occurrence of mafic and ultramafic

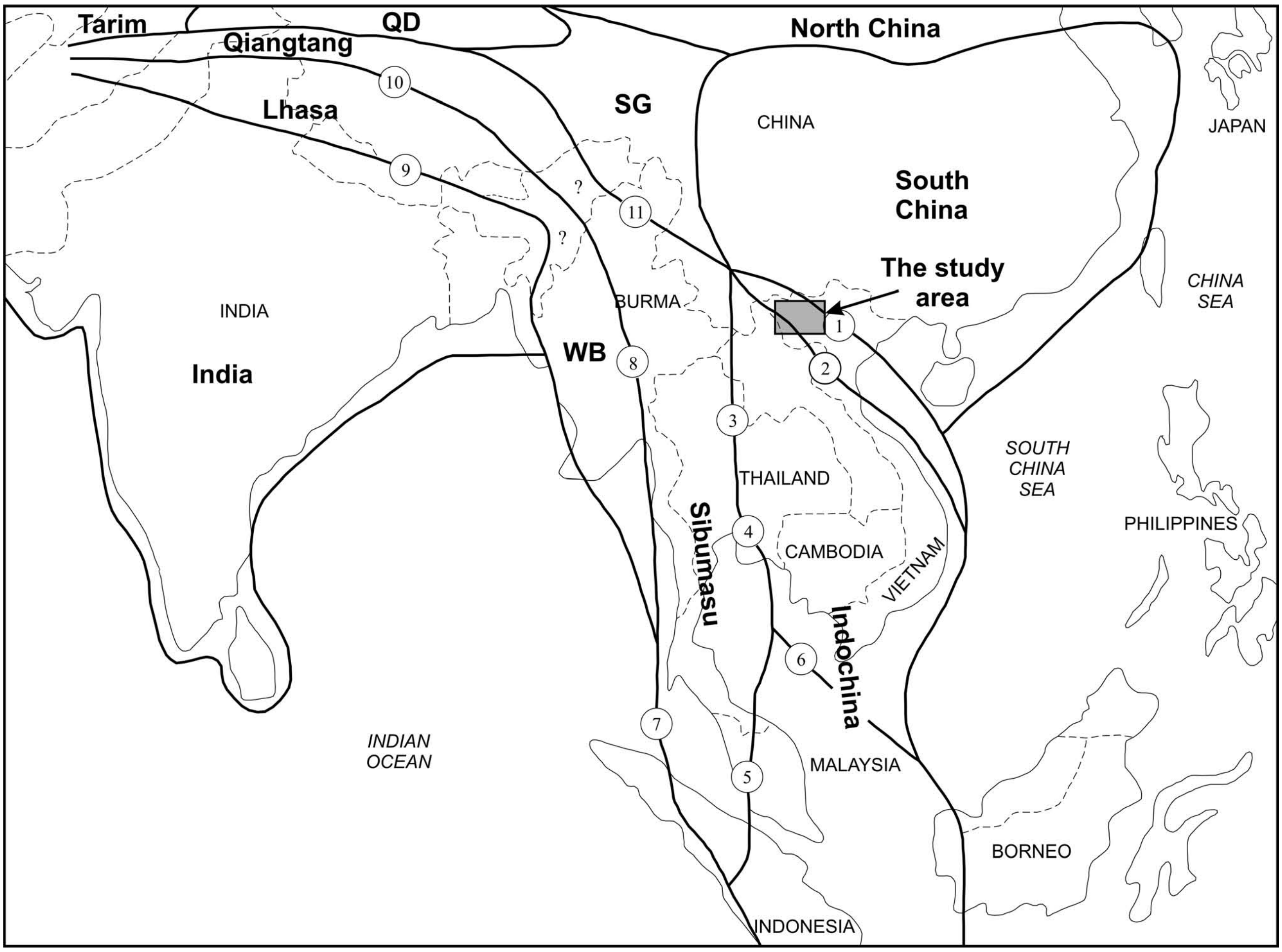

Fig. 2. Main plates and terranes of Southeast Asia. Partially from Mecalfe (1998), Golonka *et al.*, 2006a. WB – West Burma, SG – Songpan Ganzi accretionary complex, QD – Qaidam terrane. Sutures and major strike-slip faults: 1 – Red River zone, 2 – Song Ma, 3 – Nan-Uttaradit, 4 – Phra Kaeo, 5 – Raub Bentong, 6 – Three Pagodas, 7 – Woyla, 8 – Shan boundary, 9 – Indus Yarlung Zangbo, 10 – Banggong, 11 – Ailaoshan

masses originated in oceanic domain and metamorphosed into Lower Palaeozoic greenschists. They are unconformably covered in many localities by Devonian redbeds (Hutchison, 1989). These mafic-ultramafic rocks have been widely interpreted as ophiolitic fragments, derived from the Paleo-Tethys and obducted during the collision of Indochina with South China (*e.g.*, Golonka *et al.*, 2006a and references therein). Moreover, the Song Ma ophiolite can be correlated with the Shuanggou ophiolite cropping out in the south of the Ailao Shan range (Zhang *et al.*, 1994; Graciano *et al.*, 2008). These ophiolitic belts delineate the boundary between Indochina and South China. The collision time had previously been thought to be Silurian based on a greenschist metamorphic age of ~455 Ma obtained by the K±Ar method (Tran Van Tri, ed. 1979). Recent data about metamorphic terranes in Vietnam recorded that the Indosinian metamorphism occurred ~250 Ma ago overprinting older events (Lepvrier *et al.*, 1997, 2004, 2008, Lepvrier & Maluski, 2008, Lan *et al.*, 2000; Tran Ngoc Nam, 1998). This implies that the final suturing between Indochina and South China took place in the earliest Triassic, during the early phase of the Indosinian orogeny that resulted in regional metamorphism and magmatism (Hutchison, 1989). However, the tectonic model that fully explains Indosinian orogeny still requires further detailed geochemical and geochronological investigations on the constituent rocks.

Tectonic subdivision of Northwestern Vietnam

Fromaget (1937, 1941) first distinguished structural units in NWVN and gave those names such as Phu Hoat and Song Ma arcs, Song Da depression, Song Ca and Sam Nua synclines. He called structural units in north Laos and Dien Bien – Lai Chau fault zone the “Upper Laos element”, distinguishing Burmese element in the western Upper Laos. Dovjikov (ed.) *et al.* (1965) defined the entire North Vietnam as the geosynclinal’s domain turned into folded Mesozoic, distinguishing Sam Nua depression as a structural unit within the Truong Son folded region. Since 1965, Vietnamese geologists have followed these ideas researching geology of Vietnam. Tran Van Tri *et al.* (1977) conducted detailed geological studies and described the NWNV area as the West Bac Bo Fold System, which extends between the Song Ma Suture and the Chay River Fault. A deformed Upper Proterozoic and Lower Palaeozoic metamorphic belt occurs north of the Song Ma suture forming broad antiform

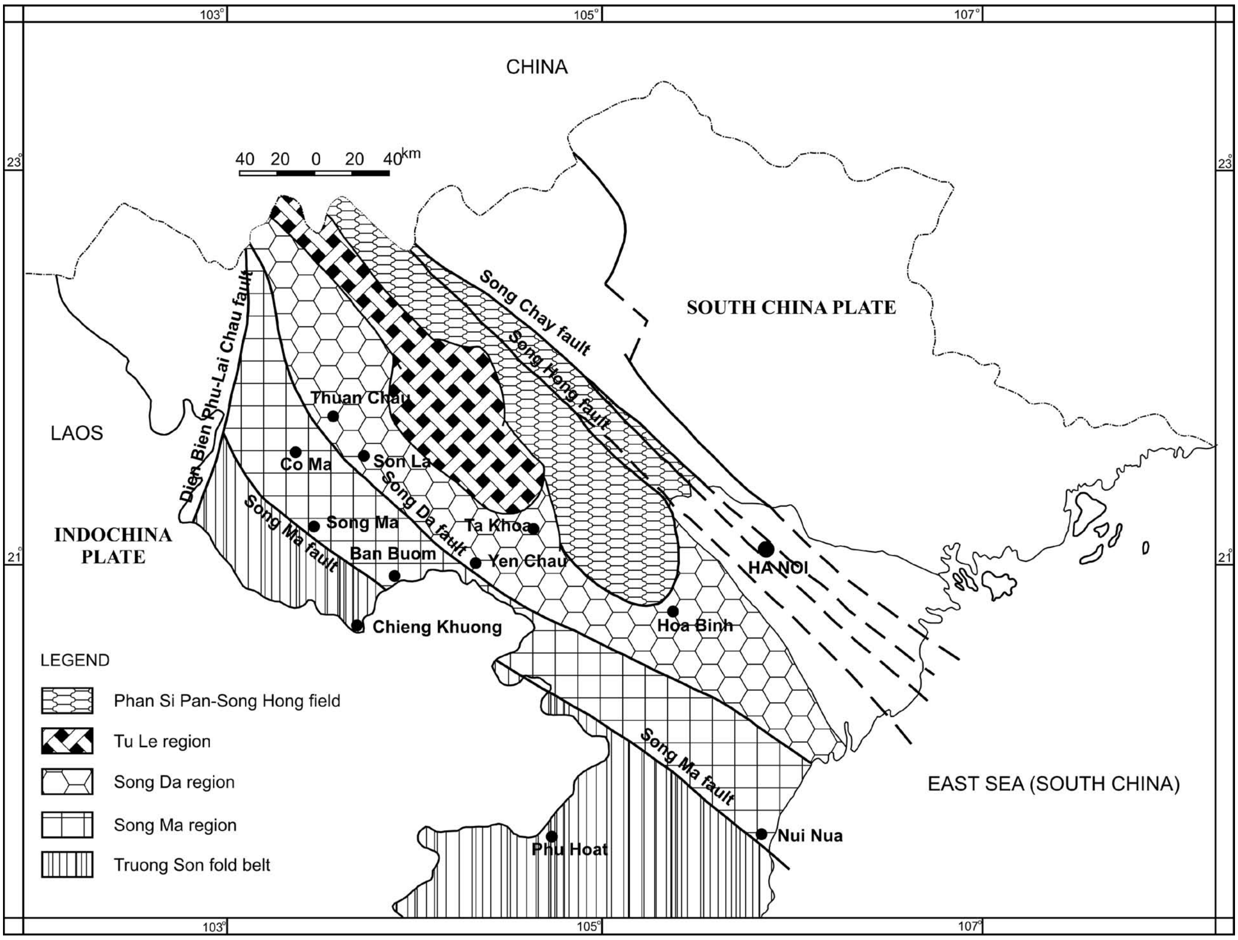

Fig. 3. Geological terrane map of the Northwest Vietnam (After Tran Van Tri ed., 1979)

unit, called the Song Ma Anticlinorium. Farther north, mafic and ultramafic rocks, intercalating Permian–Early Triassic terrigeneous-carbonate sedimentary succession, form the strongly folded Song Da zone, which is unconformably overlain by Cretaceous red beds.

Based on present-day knowledge of plate tectonics, distinctive morphotectonic features, structure and lithostratigraphy, the general geology of northwestern Vietnam, depicted in Fig. 3, shows five geological entities, from the north to the south: Phan Si Pan-Song Hong, Tu Le, Song Da, Song Ma and Sam Nua regions.

The Phan Si Pan-Song Hong (Red River) region, which lies between the Song Chay and the Phong Tho faults and is dominated by a linear belt of highly strained high-grade schists assigned to the Proterozoic in Vietnamese geological maps. This region was referred to as the Phan Si Pan structural zone in Dovjikov (ed.) *et al.* (1965) or the Hoang Lien Son continental belt which belongs to the Tonkin – Yangtze – Cathaysia zone in Nguyen Xuan Tung and Tran Van Tri (1992). The northwestern part of this zone is occupied by the Phan Si Pan massif where the geology is dominated by migmatitic and granitic complexes offset sinistrally by major fault. Slivers of Cambrian to Devonian sedimentary sequences also occur in this zone and trend more or less northwest.

The Tu Le region was referred to as the Tu Le zone in Dovjikov (ed.) *et al.* (1965) or the Tu Le rift depression in Tran Van Tri (ed., 1977). It is located between the Song Da and the Phan Si Pan-Song Hong structures, and dominated by Jurassic to Cretaceous calc-alkaline volcanic units and continental sedimentary rocks.

The Song Da region is a part of the SCB; it is bordered to the northeast by the Van Yen-Nam Xe-Phong Tho fault and to the southeast by the Song Da fault. It was referred to as the Song Da rift depression in Tran Van Tri (ed., 1977) or the Song Da arc in Fromaget (1937, 1941). The Song Da terrane consists of Cambrian to Cretaceous sedimentary rocks ranging from marine carbonates to continental red beds, and includes a widespread series of Permian basalts and Permo-Triassic sedimentary series.

The Song Ma region is located between the Truong Son fold belt and the Song Da region. It is an arched northwest trending structure often referred to as the Song Ma Anticlinorium (*e.g.*, Tran Van Tri, ed., 1979). It is dominated by low to high-grade unfossiliferous schists intruded by Devonian and Triassic granitoids, metagreywackes, greenschists, amphibolites, and marbles. The southern part of the structure contains serpentinised ultramafic bodies referred to as ophiolites by Vietnamese geologists (*e.g.*, Tran Van Tri, ed., 1979; Phan Cu Tien, ed., 1989 and references therein), and a gneissic plagiogranite called the Chieng Khuong complex. The Song Ma region also contains nonschistose fossiliferous middle Cambrian limestones at Dien Lu and perhaps Permian Nui Nua ultramafic massif west of Thanh Hoa. The suture zone between the IDB and the SCB is located within the Song Ma region.

The Sam Nua region (Truong Son fold belt) is a part of the IDB within northwestern Vietnam; it is bordered to the northeast by Song Ma fault and limited westward by the border between Laos and Vietnam. This is a complex, faulted region with imbricated thrust fold and fault structures, dominated by Ordovician to Cretaceous sedimentary and subsidiary volcanic beds and contains possibly Cambrian but undated low to high-grade metamorphic rocks at Phu Hoat (Tran Van Tri, ed., 1977; Phan Cu Tien, ed., 1989). The Triassic to Cretaceous units in northern part of the fold belt could be correlated with those in the Song Da zone (Tran Van Tri, ed., 1977; Phan Cu Tien, ed., 1989).

THE CHARACTERISTICS OF MAGMATISM IN NORTHWESTERN VIETNAM

The petrographic, geochemistrical and geochronological characteristics of magmatic complexes of the NWVN are described in this chapter. Based on the present geochemical and geochronological data, six groups of magmatic rocks developed in different tectonic setting are recognized. These groups and complexes are organized according to their age, from oldest to youngest.

Petrography and geochronology

The first group – Proterozoic

The Bao Ha complex was established by Izokh (in Dovjikov, ed. *et al.*, 1965). It comprises small massifs (1–2 km^2) in the eastern part of NWVN area, found mainly within the distribution area of metamorphic rocks of the Sinh Quyen Formation, in the Phan Si Pan-Red River structural zone. These massifs are composed mainly of gabbros of ophitic texture, amphibolized and albitized gabbrodiabase and diabase, locally, melanocratic olivine gabbros near to lherzolite. These rocks were metamorphosed to epidote-amphibolite facies. Cu and Au mineralization of gabbros of the Dong An massif is related to the hydrothermal alteration. The isotopic dating of gabbros indicated Proterozoic times, reaching 1777 Ma obtained by Rb-Sr method (Nguyen Van The, ed., 1999), and 1036 Ma by Ar-Ar method (Tran Trong Hoa *et al.*, 2000).

The Xom Giau complex was described by Phan Viet Ky (1977) (in Phan Cu Tien, ed. *et al.*, 1977). It is distributed in the Suoi Chieng, Sinh Quyen formations and belongs to the Phan Si Pan-Song Hong zone. Petrographic composition of this complex is fairly simple, consisting mainly of leucocratic microcline-rich aranite (biotite <5%) or biotite monzogranite (?10%); locally pegmatitoid granite. Almost all rocks display regular-grained or weakly porphyritic texture and massive or striped gneissoid structure. The Xom Giau complex intrusives penetrate metamorphic rocks of the Suoi Chieng and Sinh Quyen formations. The fragments of these metamorphic rocks are also present as xenoliths. The position of the Xom Giau complex indicates Neoproterozoic age. Similar magmatic intrusives situated in the Ha Noi area gave isotopic ages from 1350 to 1386 Ma (Phan Cu Tien, ed. *et al.*, 1977).

The Po Sen complex was described by Tran Quoc Hai (1967). It includes granitoid massifs, distributed mainly in the middle of the Phan Si Pan-Song Hong structural zone, with a composition changing from diorite to granodiorite and biotite-amphibole granite. The greatest Po Sen massif with an area of 250 km^2 and other small massifs are scattered in the northwestern Phan Si Pan-Song Hong zone. The majority of granitoids of the Po Sen complex belongs to quartz diorite (tonalite) and granodiorite. According to Wang *et al.* (1999), the TIMS U-Pb age of zircon from Po Sen gneiss is 760±25Ma. The SHRIMP U-Pb age of zircon is 751±7Ma, (Tran Ngoc Nam, 2003). According to Pham Trung Hieu *et al.* (2009), the LA-ICP-MS Lu-Hf ages of zircons from Po Sen complex are 723±14 Ma and 760±12 Ma, also Neoproterozoic.

The second group – Devonian

The Song Chay complex composed of the Song Chay, Nui Lang and Nui Bao massifs, was established by Izokh (in Dovjikov, ed. *et al.*, 1965). The Song Chay massif is distributed mainly in the Phan Si Pan-Song Hong structural zone with an area of 200 km^2. It includes two mica, felsic and ultrametamorphic granites.

The Song Chay and Ha Giang formations cover conformably the Song Chay structural massifs. As was mentioned above, the Song Chay Formation was dated as Early Devonian (Tran Van Tri, ed., 1977), while biotite sample from the Nui Lang massif provided isotope age of 350 Ma. Remarkably, the Song Chay granite is similar to the Dai Loc complex, which is distributed in the southern Vietnam, where intrusive granitoids penetrate the Cambrian–Ordovician formation and underlies the Devonian Tan Lap Formation.

The third group – Permian

The Nui Nua complex was established by Le Dinh Huu (in Phan Cu Tien, ed. *et al.*, 1977). This complex is composed of 4–5 km long and 300–400 m wide lentiform ultramafic bodies. They are distributed in the Song Ma structural zone, along the Song Ma Fault. The Nui Nua complex is composed of harzburgite, dunite and pyroxenite; almost completely serpentinized or transformed into talc, chlorite and talc-carbonate rocks. Secondary minerals are represented by actinolite and widespread accessory minerals: magnetite, ilmenite and rutile. Rocks of the Nui Nua complex lie conformably with metabasalt of the Huoi Hao Formation and are metamorphosed to the greenschist facies. The isotopic dating ($^{206}Pb/^{238}U$) of metabasalt indicates 254±12 Ma age (Pham Trung Hieu *et al.*, 2008), the LA-ICP-MS method indicates Late Permian times. These Permian rocks belong to the lower part of the ophiolite section, composed of ultramafic rocks (Nui Nua complex), metabasalt (Huoi Hao Formation) and gabbrodiabase (Bo Xinh complex).

The Bo Xinh complex was described by Dao Dinh Thuc (1976). It is composed of small bodies of gabbro, gabbro-diabase, gabbroic amphibole diabase, closely related in space and time to metamorphosed mafic effusives of the Huoi Hao Formation. Many dykes of gabbrodiabase penetrate greenschist (metabasite) of the Huoi Hao Formation along the Song Ma zone. This setting is similar to the area where the described below Chieng Khuong plagiogranite penetrates and causes the alteration to the metabasalt and metagabbro.

The Bo Xinh complex comprises amphibole gabbro, gabbrodiabase, gabbrodiorite and diabase. Amphibole gabbro is light to dark green, small- to medium-grained, displaying compressed gneissoid structure. Along the Song Ma fault, it is strongly metamorphosed and transformed into gabbro-amphibolite. Gabbrodiabase is rather widespread and forms intrusive bodies of great size. It is usually schistose, greenish in colour, rarely of massive structure. Gabbro-diorite is small- to medium-grained, greenish-grey in colour, of granular texture, rather rich in plagioclase (80%), with prismatic, regularly arranged amphiboles. Diabase is small- to medium-grained, of residual diabasic texture and schistose, mostly actinolitized and transformed into greenschist, difficult to distinguish from metabasalt. Gabbroids of the Bo Xinh complex are closely related to Late Permian metabasalt of the Huoi Hao Formation (Pham Trung Hieu *et al.*, 2008). Thus, this complex has been assumed a Late Permian age.

The Chieng Khuong complex was described by Dao Dinh Thuc (1976). Plagiogranite of this complex is largely distributed in the Song Ma structural zone. It forms usually lentiform intrusive bodies stretching in the NE–SW direction, in coincidence with the structural trend of surrounding Neoproterozoic–Lower Cambrian rocks. This complex includes the Chieng Khuong and Ban Phung massifs and some small bodies located within the terrigeno-volcanic beds of the Bo Xinh group. They crop out along right side of the road from Ha Noi to the Song Ma province, and in the middle of Ma River.

These rocks are greenish-grey, small- to medium- grained, weakly compressed. Mineral composition is as follows: 76–86% of plagioclase, 5–7% of hornblende, some biotite separated from hornblende, 5–8% of calcifeldspath; quartz from 5% in diorite to 20–30% in granodiorite. The rocks have residual granulo-hypidiomorphic texture, and directive structure. Plagiogranite forms the major part of massifs.

As was mentioned above, the rocks of the Chieng Khuong complex penetrate volcano-terrigenous, terrigeno-cherty and terrigeno-carbonate beds of the Bo Xinh Group causing their hornfelsification. The pebbles of plagiogranite from the basalt conglomerates of the Middle Cambrian Song Ma Formation of the Nam Co Anticline have petrochemical characteristics similar to rocks of the Chieng Khuong complex. They yield the isotopic (Rb-Sr) age of 254 ± 14 Ma. Pham Trung Hieu *et al.*, (2008) supported the isotopic ($^{206}Pb/^{238}U$) 262±8Ma age of Chieng Khuong plagiogranite using the LA-ICP-MS method. Based on these results, the Chieng Khuong complex can be Middle-Late Permian in age.

The Huoi Hao Formation was established by Pham Dinh Tuong (ed., 1999). It is an equivalent of the former "Lower Bo Xinh subsuite" (Phan Son, ed. *et al.*, 1978) and belongs to the Song Ma zone. The Bo Xinh metabasalt section along the Huoi Hao stream was chosen as type section for the new Huoi Hao Formation (Pham Dinh Tuong, ed., 1999; Nguyen Van Thuat, ed., 1999).

The lower part of this formation is composed mainly of greenschists (metabasalt, metadiabase) and beds of altered tuffs. Three members were recognized in the section extending along Ma River from Nam Ma to Bo Xinh. The first member is represented by greenschist interbeded with quartz-sericite schist, second member by schistose greenschist, unclearly striped, locally massive greenschist, and the last one by greenschist interbedded with cherty schist and quartz-sericite schist. The lower boundary of the formation is unknown, while its upper part underlies conformably the Nam Ty Formation.

The LA-ICP method (Pham Trung Hieu *et al.*, 2008) follows results of $^{206}Pb/^{238}U$ dating, giving the of 254±12 Ma age of metabasalt samples from the Song Ma belt. The Late Permian age was established for Huoihao Formation according to these results.

The Ban Xang complex distributed in the Ta Khoa area belonging to the Song Da structural zone, was established by Dovjikow (ed.) *et al.* (1965). According to his description, the Ban Xang complex is located near the axis of the Ta Khoa anticline, and penetrates micaschist, biotite-muscovite hornfels, and actinolite-muscovite hornfels of the Nam Sap Formation. Intrusive massifs lay conformably with country rocks. Copper-nickel mineralization in the compact or disseminated form occurs often in the contact zone.

The petrology of the Ban Xang complex suggests ophiolitic, obducted origin. The massifs are composed mainly of strongly serpentinized dunite containing forsterite. Accessory minerals are represented by magnetite and chrome-spinel. The rock has panidiomorphic, medium- to coarse-grained texture. It is serpentinized, compact, near black in colour, of netted texture. Abundant olivine consists of nuclei surrounded by antigorite, forming lamellar, acicular assemblage; less numerous chrysotile forms micro-veins and transversal fibres. In some places, chrysotile is replaced by carbonate and some ore minerals.

The Late Permian age of the Ban Xang complex was assumed based on penetration of the sedimentary beds, which have yielded an age range from Devonian to Early Permian. The ophiolitic character contradicts this penetration. The relationship to the other ophiolites from this area suggests similar, Permian age.

The Cam Thuy Formation exposed west of the Son La Town and belonging to the Song Da structural zone was described by Dinh Minh Mong (ed., 1977). A section cutting through the Son La Pass comprises two members: the 350 m thick member one is composed mainly of basalt, amygdaloidal basalt, porphyritic basalt with beds of basaltic tuffs and lavas (2–3 m thick); – 300 m thick member two contains mainly chocolate tuffaceous siltstone with beds of tuffs lavas and basalt. The studied rocks are exposed in the road to Dien Bien area.

Krobicki and Golonka (2008) argued that basalts of the Cam Thuy Formation are loaf-shaped pillow lavas formed during submarine eruptions, due to rapid cooling of lava at the contact with seawater. Both the continental basalts and the pillow lavas indicating marine affinities were perhaps associated with back-arc spreading. Moreover, Tran Van Tri (ed., 1977) and Tran Trong Hoa *et al.* (1998) considered them as products of Song Da rift.

The Cam Thuy Formation covers the eroded surface of limestone containing *Neoschwagerina craticulifera* of the Carboniferous–Permian Bac Son Formation and underlies terrigenic-carbonate beds containing Late Permian brachiopods of the Yen Duyet Formation. The isotopic dating of five basalt samples from Cam Thuy Formation yield age 283 ± 21 Ma (Nguyen Hoang *et al.*, 2004), corresponding to Early-Middle Permian.

The Vien Nam Formation was described by Phan Cu Tien, ed. *et al.* (1977). This formation is distributed in the Song Da and Song Ma zones forming long bands of NW–SE direction. Well studied sections are exposed along the Trat Stream, and along the road from Phu Yen to Muong Lang (Son La province). The formation in these sections is composed in the lower part of porphyritic basalt, aphyric basalt, high-magnesium basalt; in the upper part of porphyritic diabase, basaltic tuff, andesitobasalt, trachybasalt, andesitodacite, dacitic tuff, trachytic tuff, porphyritic trachite, rhyotrachyte, rhyolite, tuffaceous sandstone and tuffaceous siltstone. Tran Trong Hoa *et al.* (1995) and To Van Thu, ed. (1996) consider the Vien Nam Formation as basaltoids.

The Vien Nam Formation overlies unconformably the Bac Son Formation and unconformably underlies the Tan Lac Formation. Tran Xuyen *et al*. (1983) and Nguyen Hoang (2004) showed that volcanites of the Vien Nam Formation in its stratotype area penetrate the Upper Permian Yen Duyet Formation. The Late Permian–Early Triassic age of the Vien Nam Formation can be established using these results.

The fourth group – latest Permian–Triassic

The Dien Bien Phu complex distributed mainly in the Sam Nua zone was described by Izokh (in Dovjikov, ed. *et al.*, 1965). A well exposed block of this formation is located in the Da River near the road from Muong Lay to Muong Te. The complex is composed mainly of gabbro-diorite, diorite, quartz diorite and biotite-hornblende granite. According to the time of the forming process, the complex has been subdivided into three intrusive phases as follows: Phase 1 – gabbro-diorite and diorite; Phase 2 – quartz diorite and granodiorite; Phase 3 – variegated biotite-hornblende granite, rich in K-feldspath granite. The rocks of phase 2 are most widespread. Granitoid massif of the Dien Bien Phu complex penetrates the Nam Co, Ben Khe, Nam Pia, and Song Da formations forming hornfels bearing andalusite and amphibole in the contact aureole. These granitoids are covered by coal-bearing Suoi Bang Formation and penetrated by biotite granite of the Phia Bioc complex. Pb-Zn polymetal mineralization related to the Dien Bien Phu granitoids is expressed by placer dispersal aureoles, bearing pyromorphite, galenite and anglesite.

Fromaget (1937) considered the Dien Bien Phu granitoids as Hercynian granite. In the geological work on North Vietnam, Izokh (in Dovjikov, ed. *et al.*, 1965) dated them as post-Permian. Tran Van Tri and Nguyen Xuan Tung (1977) postulated three stages of their development Late Permian–Carnian times. Some isotopic values received from granitoids of the complex yield ages 252–266 Ma (Tran Trong Hoa *et al.*, 2008a). These results and geological position indicate Late Permian–Early Triassic age.

The Song Ma complex was established by Dao Dinh Thuc *et al.* (1995). Subvolcanic massifs, developed mainly in the Sam Nua structural zone and related to Anisian felsic effusives, belong to the Song Ma complex. The Song Ma massif is the greatest intrusion of the area, having a clearly prolonged form in W–NW direction with a length of 80 km, a width of 5–10 km and an area of about 418 km^2. It spreads mainly on the left side of the Ma River, along the great fault, which separates the Song Ma and Sam Nua structural zones (Song Ma fault zone). In the east, the massif has tectonic contact with greenschist (metabasite) and quartz-sericite schist of the Upper Permian Bo Xinh Group and granodiorite of the Dien Bien Phu complex. In the southwest, it is closely related to Middle Triassic felsic-intermediate effusives of the Dong Trau Formation. Beside the intrusive massif, small satellite intrusions developed in the distributive area of effusives of the Dong Trau Formation. The Song Ma complex is composed mainly of biotite granite and biotite tonalite. In the northeast of the massif, biotite granite has the small-grained poikilitic texture and gradually transforms into porphyritic granite of effusive appearance. Two sides of the massif are bounded by faults, and, between them, large pieces of basal conglomerate of the Norian–Rhaetian Suoi Bang Formation occur, covering unconformably the intrusive massif.

On the geological, petrological and geochemical sides, the Song Ma complex is closely related in space and in origin to the Middle Triassic felsic-intermediate effusive of the Dong Trau Formation. Its rocks are covered unconformably by coal-bearing beds of the Suoi Bang Formation, the basal conglomerate of which contains pebbles from granitoids of the Song Ma complex. The Rb-Sr whole rock isochron age yields 232 ± 11 Ma age (Nguyen Minh Trung, 2007). The subvolcanic Song Ma complex can therefore be dated as Middle Triassic.

The Phia Bioc complex was described by Izokh (in Dovjikov, ed. *et al.*, 1965). In the studied area, the Phia Bioc complex is bounded in the west by faults. In the east, granite of the massif penetrates shales of the Lai Chau Formation causing its hornfelsification (the hornfels zone is 200–300 m in width). It is covered by Upper Triassic coal-bearing beds of the Suoi Bang Formation in the south. The geological position of granitoids of the Phia Bioc indicates that this complex is younger than Middle-Upper Triassic rocks and older than Norian–Rhaetian coal-bearing formation.

The fifth group – Jurassic–Cretaceous

The Suoi Be Formation was described by Nguyen Xuan Bao (ed., 1970). This formation is distributed in the southeast margin of the Tu Le structural zone, forming NW–SE oriented band which includes two parts. The lower part is represented by purple-chocolate to green tuffaceous conglomerates and gritstones, sandstones, silty sandstones, tuffs and lenses of aphyric basalt. The upper part contains different kinds of basalts, such as the plagiobasalt, andesitobasalt, and trachybasalt. These basalts form irregular flows, interbeds or lenses, interbeded with basalt tuff, lenses of agglomerate tuff, and crumpled black-green tuffaceous shale. Both parts are penetrated by small diabase bodies.

Post-effusive alterations are represented mainly by propylitization with high temperature facies (actinolite-epidote). In addition, medium temperature association (albite-epidote-chlorite) and low temperature association (calcite-albite-chlorite) occur. Au and Ag mineralization occurs within the formation.

The isotopic age of three basalt samples yield ages around 117.3 ± 0.6 ÷ 176.3 ± 0.8 Ma (Tran Tuan Anh *et al.*, 2004). Based on these results and Jurassic–Cretaceous flora fossils collected in the adjacent Thuan Chau area, the formation can be dated as Jurassic–Cretaceous.

The Nam Chien complex in the Tu Le structural zone was established by Phan Viet Ky (1977) (in Phan Cu Tien, ed. *et al.*, 1977). This complex is composed of amphibole gabbro and gabbrodiabase. Their mineral composition is rather simple with Cpx (amphibolized) + Plagioclase + Ilmenite + Apatite.

Their composition and origin are similar to those of subalkaline basalts of the Suoi Be Formation. Because of this similarity the age of gabbroids of the Nam Chien complex have been preliminarily assigned to Cretaceous.

The Tu Le volcanic subcomplex was established by Vu Khuc & Bui Phu My (eds., 1989). In the study area, the complex includes felsic-intermediate, subalkaline and alkaline effusives. It occurs in the Tu Le volcanic depression zone. Rocks of the effusive facies play a predominant role in the composition of the subcomplex. They are accompanied by tuffaceous sandstones of eruptive facies and agglomerate tuffs of neck facies.

From the petrographic point of view, the subcomplex consists of rhyodacite, rhyolite, and trachyrhyolite with a porphyritic trachyte. They usually display transitional relations with subvolcanites of the same composition. Almost all the rocks were show results of compression, having banded structure and porphyritic texture. The phenocrystalss consist mainly of kalifeldspath, a little plagioclase and quartz. Besides these, the compressed felsite and microfelsite also occur. Chromatic minerals in rhyodacite and rhyolite usually are biotite of titanium-high content and relatively iron-high content. In trachyte and trachyrhyolite, there is alkaline amphibole apart from biotite.

According to Lan (2000); the isotopic dating of 3 rhyolite samples is around 58.603 ± 0.2 – 79.30 ± 0.3 Ma. Based on these results, the subcomplex can be dated as Cretaceous.

The Ngoi Thia volcanic subcomplex, distributed in the Tu Le volcanic depression zone was first distinguished by Nguyen Vinh (ed.) *et al.* (1977). Bui Cong Hoa (ed., 2004) described the subcomplex as mainly the subvolcanic facies with porphyritic rhyolite and comendite. Porphyritic rhyolite is light-grey in colour, massive, its texture is porphyritic with microgranular groundmass. Comendite contains alkaline chromatic mineral (riebeckite); it is grey, massive, porphyritic, with microgranular texture. The porphyritic rhyolite display micropoikilitic groundmass, massive structure, porphyritic texture with quartz surrounded by micropoikilitic groundmass. The Ngoi Thia subcomplex overlies unconformably the Suoi Bang and Suoi Be formations, and occupies the uppermost position within the Tu Le structural zone. The Late Cretaceous age was assumed for this subcomplex

The Muong Hum complex was described by Izokh (in Dovjikov, ed. *et al.*, 1965). Alkaline granitoid massif of this complex occurs in the Phan Si Pan mountain range and belongs to the Phan Si Pan-Song Hong structural zone. The main composition of the Muong Hum granitoid complex corresponds to granosyenite and granite. Main mineral composition includes quartz, feldspar K, plagioclase, amphibole, and biotite; alkaline pyroxene (aegyrine) and alkaline amphibole (arfvedsonite). Accessory minerals are represented by apatite, sphene, sometimes garnet.

Due to the Muong Hum granitoids appearance on the Phan Si Pan zone, the complex has been preliminarily dated as early Palaeozoic. The result of isotope dating of Nguyen Trung Chi (1999) shown that the Muong Hum granitoid complex reaches 75 Ma with TDM =0.6–0.8 Ga, and it can be dated as Cretaceous.

The Phu Sa Phin complex was described by Izokh (in Dovjikov, ed., *et al.*, 1965). This complex is composed of hypahyssal intrusive and subvolcanic bodies with kalifeldspath granite, granosyenite and syenite closely related in space, time and origin to Cretaceous rhyolite and comendite formations in the Tu Le zone. In the Phu Sa Phin mountainous area, these subvolcanic-intrusive bodies form the basement of the effusive cover. In some places within the Tu Le zone, these intrusive massifs are associated with effusive along the Phong Tho-Nam Pia fault zone.

The main rocks of the complex consist of alkaline feldspar granite, quartz porphyritic syenite, porphyritic granosyenite and granophyric granite. Average mineral composition of granite is as follows: kalium-natrium feldspar = 50–70%; plagioclase = 0–10%; quartz = 30–35%; biotite = 3–5%; amphibole and pyroxene = 1–5%. Accessory minerals are represented by fluorite, sphene, apatite, zircon and magnetite.

According to the field materials, petrochemical and geochemical characteristics, the co-magmatic relationship between Phu Sa Phin granitoids and Cretaceous Tu Le-Ngoi Thia effusives has been proved. Thus, the age of granitoids can be considered close to that of effusives. The rocks of the Phu Sa Phin complex were penetrated by biotite granite of the Ye Yen Sun complex and intrusions of the Pu Sam Cap complex. In addition, Ar-Ar age data yield the value 89–144 Ma to Phu Sa Phin granite (Tran Tuan Anh *et al.*, 2003), corresponding to Cretaceous. Therefore, the Cretaceous age of Phu Sa Phin complex is established.

The sixth group – Palaeogene

The Ye Yen Sun complex was established by Izokh (in Dovjikov, ed. *et al.*, 1965). The Ye Yen Sun batholith stretches over thousands square kilometres from the Vietnam–Chinese border in the northwest to southeast through the Phan Si Pan range. Bui Phu My (ed.) *et al.* (1977) and Nguyen Trung Chi (1999) described the northwestern and southeastern parts of this massif. They distinguished granodiorite and biotite-amphibole granite, which belong to rather typical calc-alkaline series according to their petrographic characteristics.

Tran Tuan Anh (2003, 2004) has distinguished within the Ye Yen Sun complex, distributed around the O Quy Ho Pass, two different types: leucocratic granite, with high-K calc-alkaline character of I-granite type in the west, and subalkaline biotite granite of A-granite type in the east. According to Zhang and Schärer (1999), the U-Pb age data gives the Ye Yen Sun granite an age of 35 Ma (the west Ye Yen Sun type) corresponding to Palaeogene.

The Pu Tra Formation was established by Tran Duc Luong & Nguyen Xuan Bao (1988). This formation occurs in the Song Da structural zone with a small distributive area (0.5–1 km^2). It is composed of volcanogenic rocks of eruptive facies with the clay shale, trachytic tuff, porphyritic trachyte fragments. The formation can be subdivided into two members: member 1 – conglomerate interbeded with medium-grained sandstone, chocolate claystone, 15–20 m thick; member 2 – alkaline effusives, tuffs, agglomerate tuff, trachytic tuff, about 300 m thick. Agglomerate tuff contains many clasts of trachyte, porphyritic trachyte and porphyritic syenite. Their size ranges from few millimeters to 80 cm. The Pu Tra Formation lay unconformably upon the Upper Cretaceous Yen Chau Formation. In addition, a value of isotopic dating of 45±3 Ma confirms the Palaeo- gene age of the Pu Tra Formation.

The Nam Xe-Tam Duong complex was established by Izokh (in Dovjikov, ed. *et al.*, 1965). This complex includes small bodies distributed along the fault zone between the Song Da structural zone in the west and the Phan Si Pan zone in the east.

The massifs are composed mainly of subalkaline to alkaline syenite and granosyenite. Characteristic paragenetic minerals include quartz, K-feldspar, plagioclase, pyroxene, amphibole, and biotite. The studied rocks have regular-grained structure. Pyroxenes are represented mainly by diopside, sometimes rich in aegirine-augite, amphiboles by high-alkaline hornblende or arfvedsonite. The rocks often contain sphene and titanium-high garnet (melanite); the content of garnet sometimes reaches 5–10% in melanocratic syenite.

The Palaeogene age of the Nam Xe-Tam Duong complex is derived from its geological setting. The Nam Xe-Tam Duong intruded volcanic trachytes of the Pu Tra Formation, the syenite bodies of the complex also penetrate granitoids of the Phu Sa Phin and Ye Yen Sun complexes. The Nam Xe deposit of radioactive ores and RRE and mineralization of lead-zinc, barite and fluorite are related to the Nam Xe syenite.

The Pu Sam Cap complex was described by Izokh (in Dovjikov, ed. *et al.*, 1965). This complex includes sub-volcanic intrusions scattered in the Song Da structural zone. They are closely related to felsic-intermediate-alkaline volcanites (trachyte, trachyrhyolite) of the Pu Tra Formation, and together with them they form a very typical volcano-plutonic association.

The massifs of the studied rocks have a rather simple structure, almost entirely composed of leucocratic syenite and granosyenite. The melanocratic varieties, which have the composition corresponding to monzogabbro and shoshonite, or melanocratic syenite having clearly monzonitic texture occur in some massifs (Khuon Ha, Khao Cum). The isotopic dating (Ar-Ar method) yield two values of 31.5 ±0.2 and 35.4 ±0.2 Ma (Tran Trong Hoa *et al.*, 1999) indicating the Palaeogene age.

The Coc Pia complex includes mafic-potassic alkaline and potassic ultra-alkaline formations, composed of volcanites, neck intrusives and dykes largely developed in southeast of Tam Duong and Phong Tho areas in the Song Da zone. These rocks are best exposed southeast of Tam Duong (Coc Pia, Sin Cao) in the distribution area of intermediate-felsic-alkaline volcanites and subvolcanites of the Pu Tra, Pu Sam Cap type described above, as well as of Triassic terrigeno-carbonate formations. They form rather typical volcano-plutonic associations with three manifestation forms: eruptive, intrusive neck form, dykes and veins (Tran Trong Hoa *et al.*, 1999).

The mafic-akaline tuffaceous breccia can be usually observed in volcanic structure of pipe type, together with the trachytic tuff. It often corresponds in composition with alkaline andesitobasalt (absarokite-according to Lacroix, 1933), or lamproite tuff (cocite tuff). Absarokite tuff contains usually fragments of trachyte and trachyrhyolite. Sometimes, leucitite and similar variety as wyomingite have been observed.

The isotopic dating by Rb-Sr method of lamproite from the Dong Pao has yield the 42±7 Ma age (Tran Trong Hoa *et al.*, 1995), by Ar-Ar method of lamproite and absarokite from the Coc Pia and Sin Cao 29–34 Ma age (Tran Trong Hoa *et al.*, 1999). Based on these results, the complex has been dated as Palaeogene.

Geochemistry

Representative chemical and trace element composition of different magmatic rock types from the NWVN are listed in Table 1 to Table 19 (see Appendix). The nomenclatures of the plutonic rocks from the NWVN are deciphered on the TAS diagram of Cox *et al.* (1997) (Fig. 4) and on the AS diagram of Dmitriev *et al.* (1972) (Fig. 6).

The Bao Ha, Bo Xinh, Nam Chien mafic rocks are classified as gabbros. The Xom Giau, Po Sen, Song Chay, Chieng Khuong, Song Ma, Phia Bioc, Muong Hum, Ye Yen Sun, Nam Xe-Tam Duong and Phu Sa Phin rocks represent granites, sometimes granodiorites. The rocks from Pu Sam Cap are classified as syenite and nepheline syenite, Coc Pia as syenodiorite and gabbro, and the Dien Bien Phu magmatic represent rocks changing from granite, gabbrodiorite to diorite, gabbro (Fig. 4).

On the AFM diagram of Irvine and Baragar (1971), gabbroic rocks belong to the tholeiitic series (TH), while the granites and dacites and others are calc-alkaline rocks, except the Dien Bien Phu magmatic rocks ranging from tholeiitic to calc-alkaline rocks (Fig. 7). The Nui Nua ultramafic rocks are classified as harzburgites sometimes lherzolites, while the Ban Xang ranges from clinopyroxenite, verlite and lherzolites (Fig. 6). On the AFM diagram of Irvine and Baragar (1971) (Fig. 8), ultramafic rocks belong to tholeiitic series (TH).

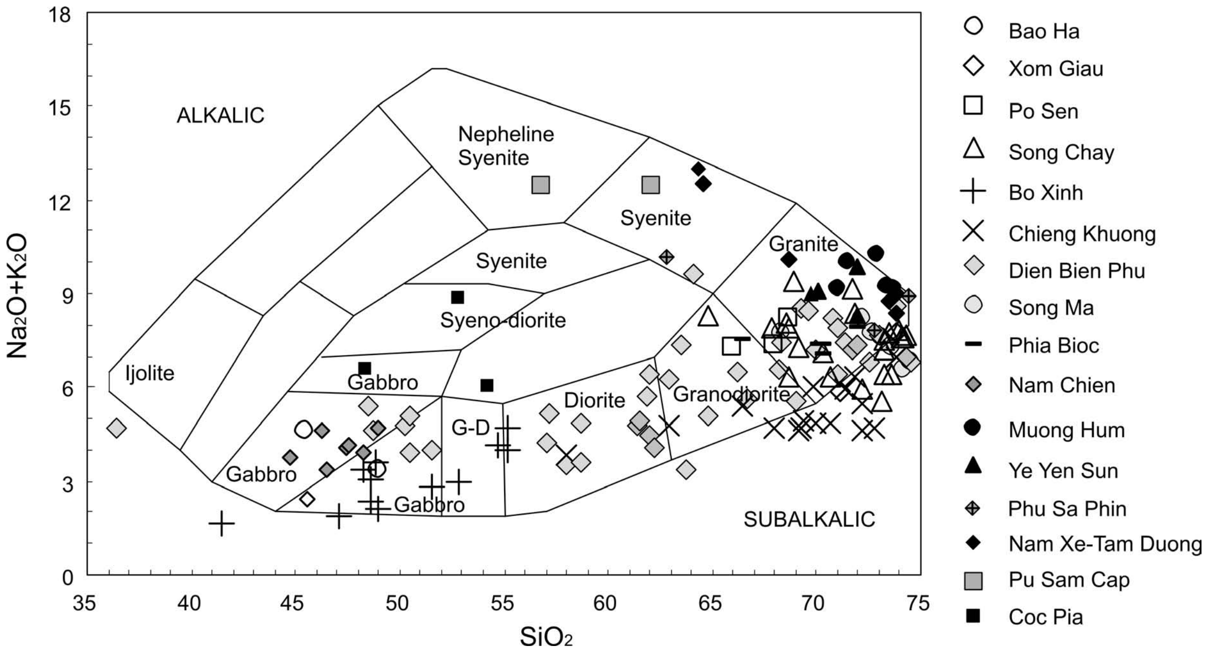

Fig. 4. Classification diagram for the NWVN plutonic rocks (applied method of Cox *et al.*, 1979)

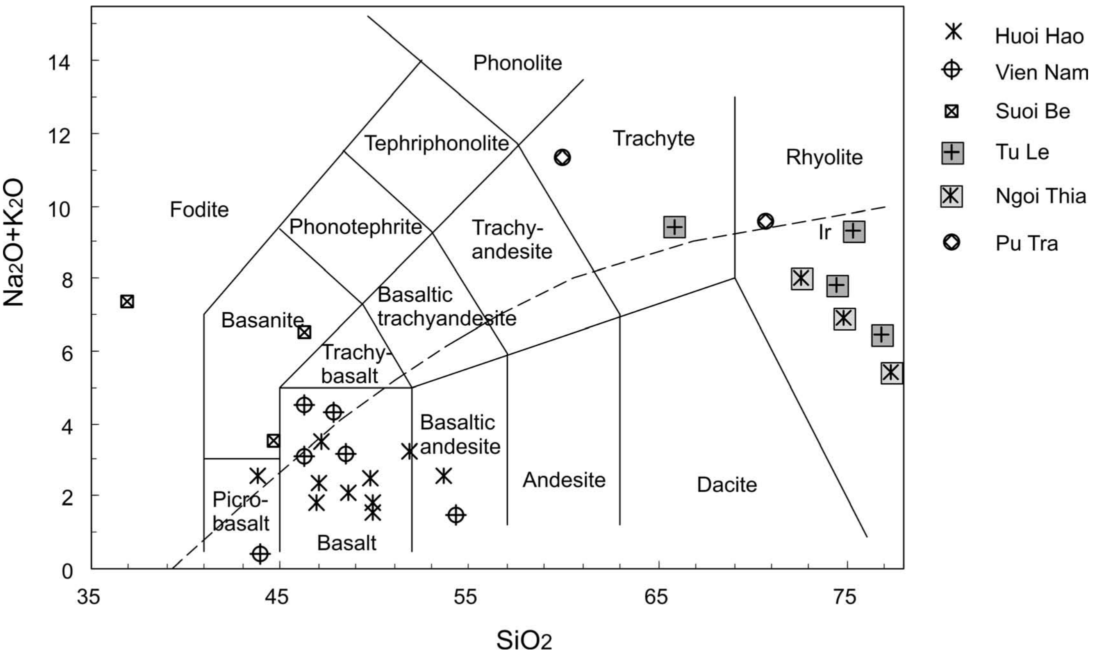

Fig. 5. Classification diagram for the NWVN volcanic rocks (applied method of Le Maitre, 1989)

The nomenclatures of the volcanic rocks from the NWVN are shown on the TAS diagram of LeMaitre *et al.* (1989) (Fig. 5). It shows that the Huoi Hao, Vien Nam are classified as basalt; the Suoi Be is plotted in basanite sometimes fodite field; while the Tu Le, Ngoi Thia represent rhyolite, and the Pu Tra, rhyolite sometimes trachyte. On the AFM diagram of Irvine and Baragar (1971) (Fig. 8), rhyolite and trachyte belong to calc-alkaline series (CA), while basalt and basanite belongs to tholeiitic series (TH).

The serpentinized harzburgite of the Nui Nua complex are poor in silica (SiO_2 = 36.08–46.36%), alkali (Na_2O+ K_2O < 2%), and in aluminum (Al_2O_3 = 0.21–2.12%), but rich in magnesium (MgO = 34.39–38.8%); with the MgO/FeO ratio: 7–29 (Table 5). The Mg/Fe ratios: 8.9–12.8 (Nguyen Van Chien, 1964) indicate that this complex was crystallized from peridotite magmatic source. The serpentinized dunite of the Ban Xang complex are poor in silica (SiO_2 =34.3–45.82%), very rich in calcium (CaO =0.24–10.6%), with sodium > potassium (Table 10). On the FeOt-MgO-Al_2O_3 diagram of Pearce *et al.* (1977) (Fig. 14), most of all the ultramafic rocks corresponding to the ocean ridge-floor (ORF). According to the DGMV (unpublished

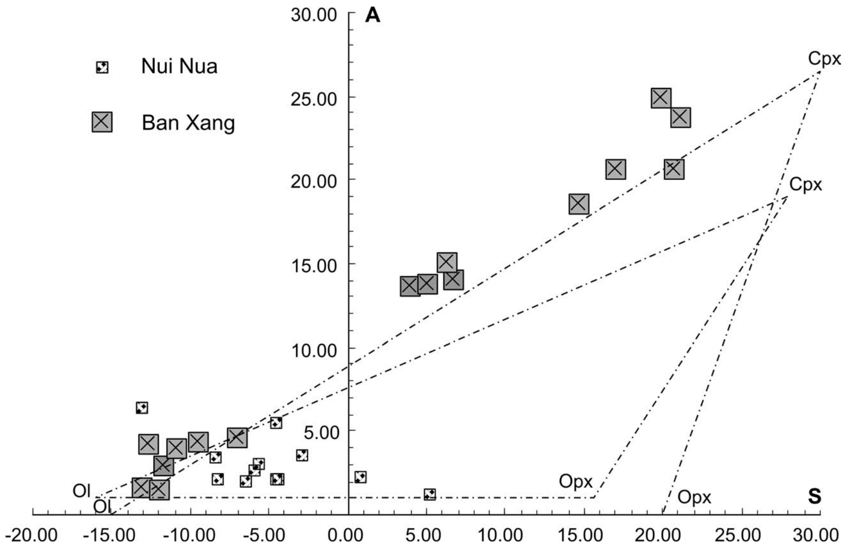

Fig. 6. Classification diagram for ultramafic rocks (applied method of Dmitriev *et al.*, 1972), A = $Na_2O+K_2O+Al_2O_3+CaO$; S = $SiO_2-(TiO_2+Fe_2O_3+FeO+MnO+MgO)$

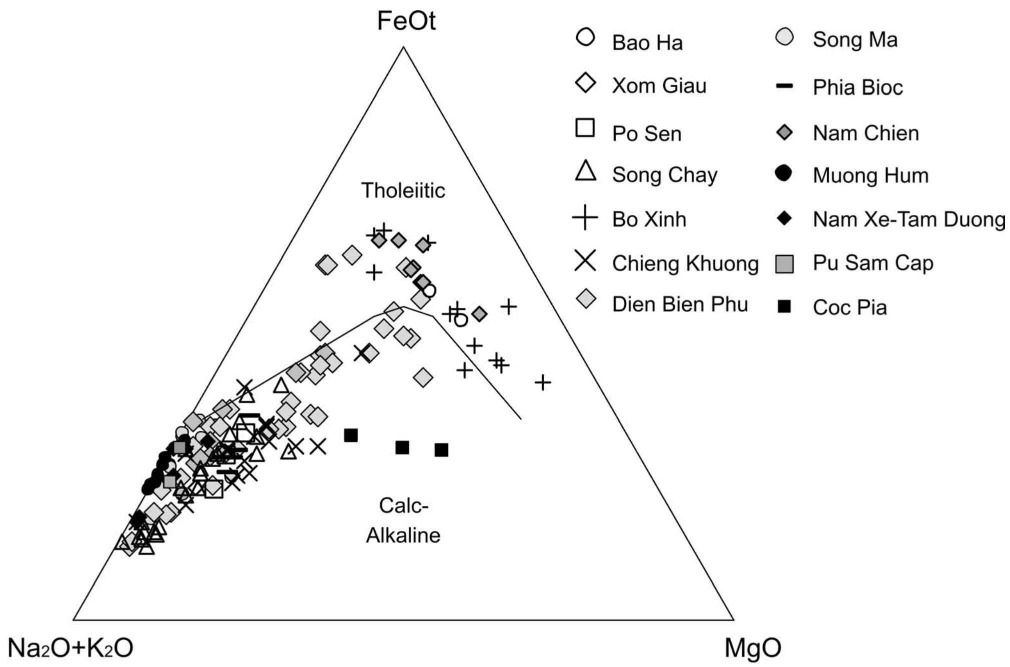

Fig. 7. A subdivision diagram showing the boundary between the calc-alkaline field and tholeiitic field of NWVN plutonic rocks (applied method of Irvine & Baragar, 1971)

data), the content of Ba, Rb, Sr, Y, Yb, Th, Ce, Zn, and Zr is 1–14 times higher than Clarke; specifically the ore forming elements Cu, V and Pt are 3–8 times higher than Clarke. On the Na_2O-K_2O-CaO diagram of Green & Poldervaart (1958) (Fig. 10), the Nui Nua and Ban Xang complexes belong to sodic rock types. On the FeOt-MgO-Al_2O_3 diagram of Pearce *et al.* (1977), they also belong to ocean ridge-floor (ORF) magmatic rock types.

Geochemically, all studied plutonic rock samples from the NWVN, except for serpentinized harzburgite and dunite of the Nui Nua and Ban Xang complexes, are fairly subdivided into three series. The first series contains the mafic plutonics of the Bao Ha, Bo Xinh, and Nam Chien gabbroic samples, which are silica undersaturated rocks (SiO_2 = 41.4– 55.14%) with low alkalinity (total Na_2O+K_2O =2.49–4.77%). Na_2O content is higher than K_2O content. On the Na_2O-K_2O-CaO diagram of Green and Poldervaart (1958) (Fig. 9), they belong to sodic types. On the Nb*2 - Zr/4-Y ternary diagram of Meschede (1986) (Fig. 13), the Bao Ha complex belongs to intraplate alkaline and tholeiite gabbros, while the Nam Chien complex plot in intraplate alkaline field. On the other hand, on the FeOt-MgO-Al_2O_3 diagram of Pearce *et al.* (1977) (Fig. 14), the Bao Ha belong to island ocean field (IO), while the Nam Chien fall into continental ocean types (CO). The Bo Xinh complex displays a wide range of mafic rock types, but mainly island ocean

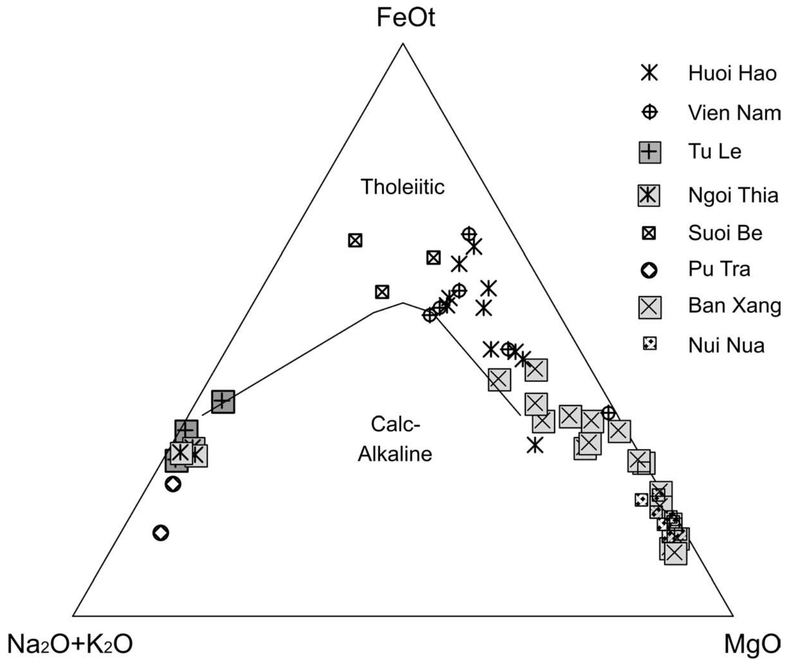

Fig. 8. A subdivision diagram showing the boundary between the calc-alkaline field and tholeiitic field of NWVN volcanic rocks (applied method of Irvine & Baragar, 1971)

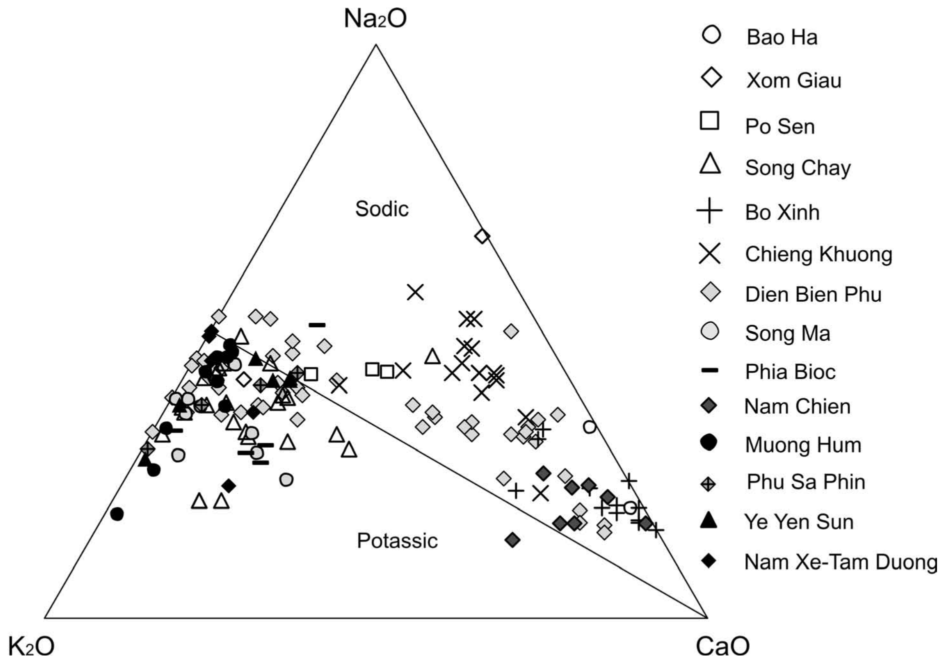

Fig. 9. Na_2O-K_2O-CaO diagram for the NWVN plutonic rocks (applied method of Green & Poldervaart, 1958)

(IO) and ocean ridge-floor (ORF). Particularly, the chemical composition of the Bao Ha complex characterizes the rock type relatively high in titanium (TiO_2 =1.32–2.66%), medium in magnesium (MgO =6.73–7.32%), and relatively low in aluminum (Al_2O_3 =13.11–14.59%) (Table 1). These rocks are rather poor in Cu (55–73 ppm), Cr (146–271 ppm), and relatively rich in V (316–402 ppm). Their content of Rb is relatively poor (2.1–4.3 ppm), however Nb, Zr and Y are rather stable in high level in comparison with the low-alkali tholeiite type. They are rich in rare earth elements (REE), especially the light rare earth elements (LREE) (Fig. 15-1). The distributive characteristics of Rb, Sr, Nb and REE show that gabbroids of the Bao Ha complex belong to within-plate (intraplate) type (Fig. 21). The origin of this complex was related to the spreading process of the continental margin. The described rocks of the Bo Xinh complex are low in TiO_2 = 0.8–2.1%, their chemical composition displaying a mantle origin (oceanic crust of the IO or ORF

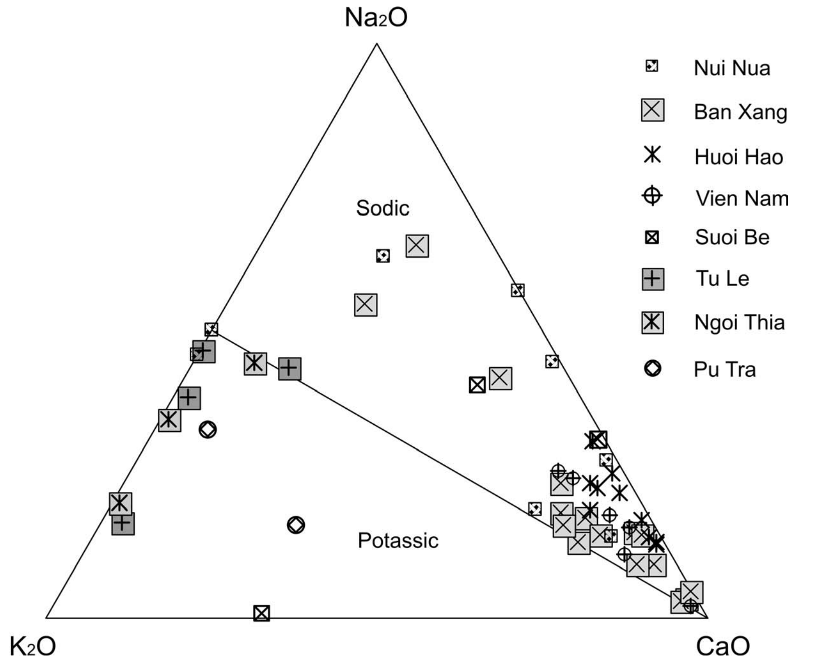

Fig. 10. Na_2O-K_2O-CaO diagram for the NWVN ultramafic and volcanic rocks (applied method of Green & Poldervaart, 1958)

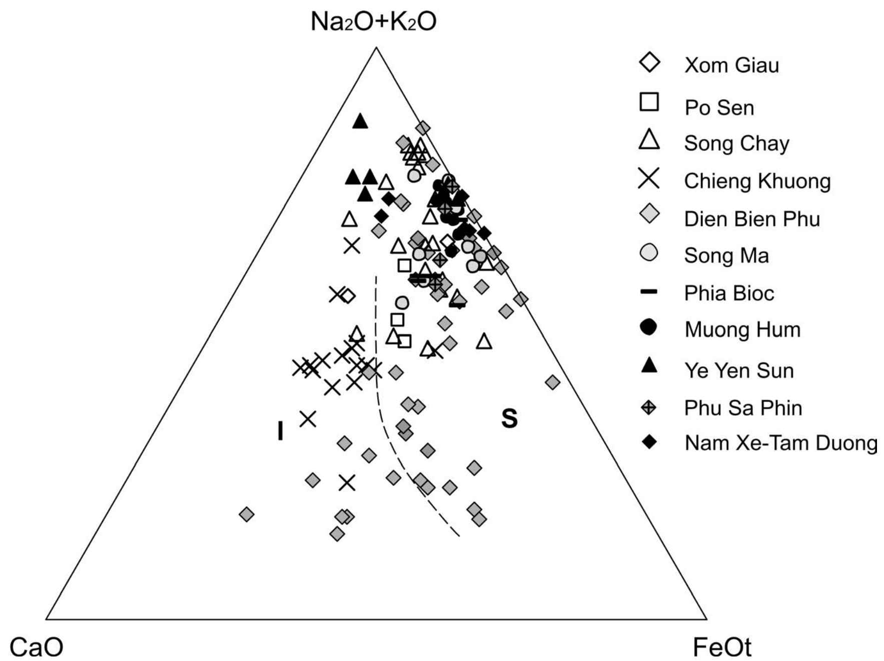

Fig. 11. Na_2O+K_2O-FeOt-CaO diagram classifying for the NWVN granitoid types (I, S) (applied method of Chappell *et al.*, 1974)

type). The Cu, Ni, Cr, Ti and V elements are higher than Clarke (Table 6). Chemical composition of the Nam Chien complex has following characteristics: high in titanium (TiO_2 =2.02–3.63%); relatively high in calcium (CaO = 7.47–11.22%) (Table 14). The rocks are all rich in Rb, Ba, Th, LREE, belonging to tholeiite within-plate (intraplate) series of the mid-ocean ridges (Figs 13, 21).

The second series contains the felsic plutonics from the Xom Giau, Po Sen, Song Chay, Chieng Khuong, Dien Bien Phu, Song Ma, Phia Bioc, and Muong Hum, Ye Yen Sun, Nam Xe-Tam Duong, and Phu Sa Phin complexes. These plutonics are granites, sometimes granodiorites. They show a wide range of SiO_2 (57.94–78.15), and are rich in the alkalis (Na_2O+ K_2O =3.89–13.0). On the Na_2O-K_2O-CaO diagram of Green and Poldervaart (1958) (Fig. 9), most of them belong to potassic types, except the Xom Giau, Po Sen, and Chieng Khuong complexes, which belong to sodic types. On the Na_2O+K_2O-FeOt-CaO diagram classifying granite types (I, S) of Chappell *et al.* (1974) (Fig. 11), granitoids of the Xom Giau, Po Sen, Song Ma, Phia Bioc,

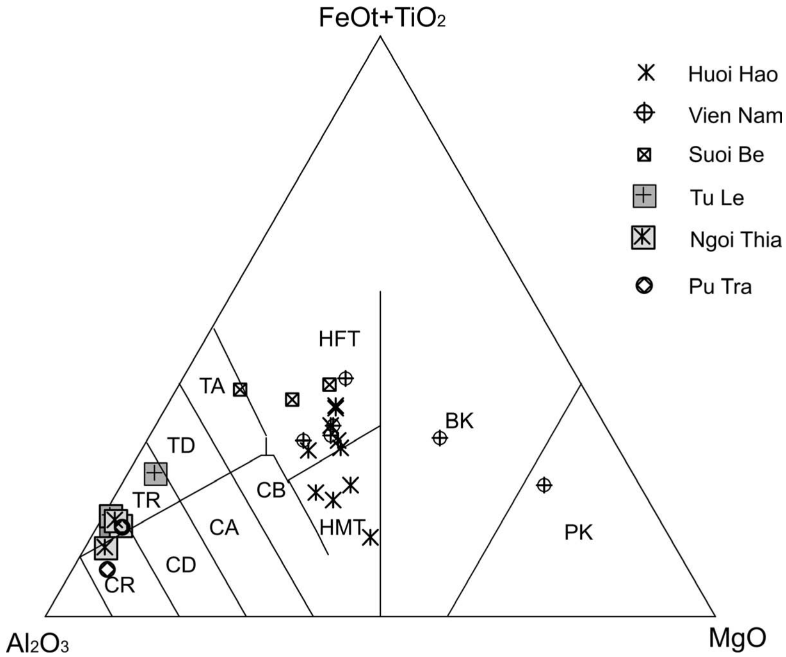

Fig. 12. Discrimination diagram for the NWVN volcanic rocks (applied method of Jensen & Rickwood, 1989). BK – Komatiitic basalt; PK – Komatiite; HFT – High iron tholeiite; HMT – High magnesium tholeiite; TA – Andesitic tholeiite; TD – Dacitic tholeiite; TR – Rhyolitic tholeiite; CB – Basaltic calc-alkaline; CA – Andesitic calc-alkaline; CD – Dacitic calc-alkaline; CR – Rhyolitic calc-alkaline

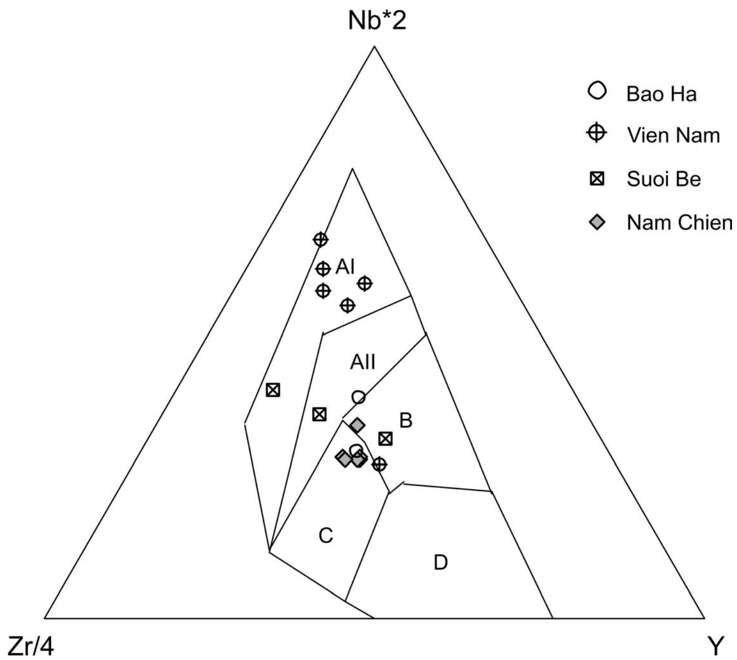

Fig. 13. Nb*2 - Zr/4-Y ternary diagram for the NWVN mafic rocks (applied method of Meschede, 1986), AI – Intraplate alkali basalts; AII – Intraplate alkaline and tholeiite basalts; B – MORB-E type – Enriched tholeiites of mid-ocean ridges and tholeiites of intraplate structures; C – Intraplate alkaline; D – MORB-N type – Depleted tholeiites of mid-ocean ridges

Muong Hum, Phu Sa Phin, and Nam Xe-Tam Duong complexes belong to S-granite types, while the Chieng Khuong complex belongs to I-granite type. The Song Chay, Dien Bien Phu, and Ye Yen Sun complexes represent the I-granite changing to the S-granite, respectively. Chemical composition of biotite from the Xom Giau complex places it in the type low in titanium (TiO_2 =1.3%), relatively high in aluminum (Al_2O_3 =15.7%) and high in iron (FeO =19.5%). It displays intermediate characteristics between biotite from S-granite and A-granite (Nguyen Van The, ed., 1999). The studied rocks characterize the type rich in Rb (170 ppm), Zr (476 ppm), Th (55 ppm), U (9 ppm), but rather poor in Nb (8.5 ppm), Ta (1.65 ppm) (Table 2). They are very rich in REE, especially LREE, with La =102–240 ppm, Ce =132–140 ppm, Nb =43.3–102 ppm. Based on the distribution of Rb, Sr, Zr, Nb, Ta Th, and REE (Fig. 15-2), granitoids of

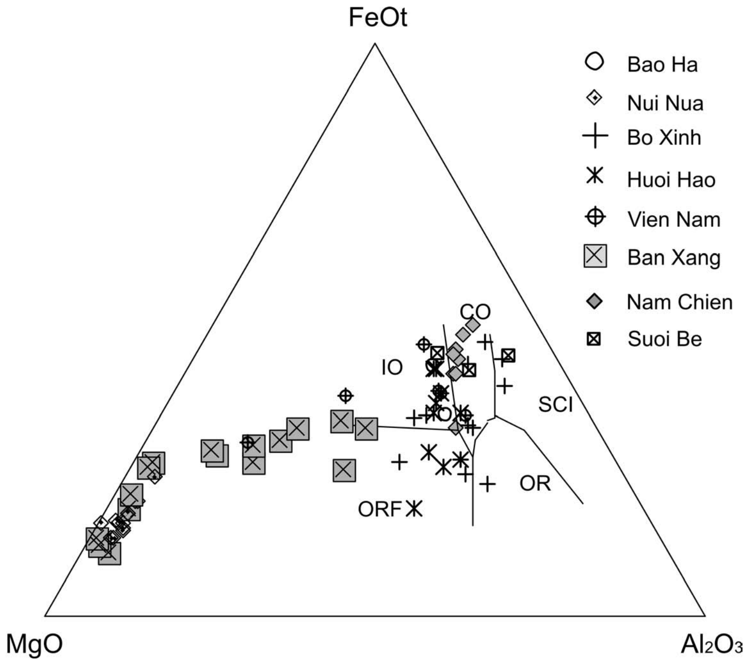

Fig. 14. FeOt-MgO-Al_2O_3 diagram subdividing the NWVN ultramafic and mafic rocks (applied method of Pearce *et al.*, 1977), IO – Island ocean, CO – Continental ocean, SCI – Spreading center-island, OR – Orogenic ridge, ORF – Ocean ridge-floor

the Xom Giau complex bear the intermediate characteristics between S-granite and A-granite. The shortage of Nb, Ta and other elements as well as its close spatial (possibly even time) relationship with calc-alkaline granitoids of Ca Vinh type indicate that origin of Xom Giau granitoids is related to subduction. The chemical composition of the Po Sen complex (Table 3) is rather rich in Rb (67–84 ppm), Sr (429–548 ppm) and LREE; expressing a weak Eu min. The distribution of REE is typical for calc-alkaline series (I-granite). The rocks are all relatively poor in Nb, Ta, Hf, Zr, Sm, Y and Yb in comparison with a granite of chrondrite and ocean island (Figs 15-3, 15-4). Based on these characteristics and the Rb vs Y+Nb correlation, the Po Sen granitoids correspond to volcanic arc granites (Fig. 20), and were perhaps formed in the active continental margin tectonic setting. Lan (2000) argues that the granitic rocks originated by melting of older crustal sources, but with a significant input of mantle component during magma genesis. Pham Trung Hieu *et al.* (2009) using the Hf isotopic ratios lHf(t) = –16.1 to +3.4 and wide range of isotopic ages TDM1(Hf) = 1186 to 1945Ma demonstrated participation of both mantle materials and newly-formed components of continental crust in this complex. The mixing crust-mantle model best explains the origin of the Po Sen Complex. Basically, the Sn, Pb, Sb, Zr, Y bearing rocks are prevailing in the Song Chay complex. Zr is 10 times and Y 9–10 higher than Clark index. The Song Chay granitoid complex is depicted as S-type post orogenic granite in tectonic classification diagram (Figs 17-4, 17-5). Rocks of the Chieng Khuong complex have high aluminum content ($A1_2O_3$ = 13.8–16.35%). In comparison with Clarke, the rock making micro-elements (Sr, Mn, Ti, V, Cr) are higher from 1.2 to 5 times. Cu is 8.9 times higher than Clarke, Pb-1.5; Zn-1.8 and As-10 times higher than Clarke. The ratios Ba/Sr =2.7; La/Ba =1.03; Nd/Sm =3.97; La/Sr = 0.08; $^{87}Sr/^{86}Sr$ =0.669 (after DGMV, 1999).

The granitic rocks of the Song Ma and Phia Bioc complexes are similar to the granites generated in volcanic arc-related tectonic setting (Figs 19, 20), while the rocks of the Dien Bien Phu complex are mainly of the I-granite (early phases) changing to the S-granite (late phase) (Fig. 11). Their magmatic mixed nature originated during their forming process related to the subduction zone (Tran Trong Hoa, 1999).They can be correlated to syn-collision granite type. Particularly, the Song Ma complex represents volcanic assemblage formed during the magmatic Triassic in a dynamic environment of post-collision, bearing characteristics of volcanic arc granite type (VAG). Based on the geochemical characteristics of trace element group (Fig. 16-1), the described rocks of the Phia Bioc complex have clearly higher content of light rare earth elements (LREE), comparing with heavy rare earth elements (HREE), without the negative Eu anomaly. Besides, they have high content of lithophilous element group (Rb, Ba, Th, K, etc.) and low content of elements having stable field (Ta, Nb, Zr, Th). More specifically, they have an extreme low content of Ti, Y and Yb, very characteristic for magmatic association forming in the convergent margin – post collisional tectonic setting (Fig. 17-6).

The Muong Hum granitoids are relatively rich in Ba (285–3854 ppm), Rb (110–210 ppm), and rich in Nb (83–252 ppm), Ta (5.88–21.28 ppm), Zr (668–1384 ppm), Y (50.95–346.8 ppm), Hf (16.01–41.14 ppm), and very poor in Sr (19.06–180 ppm); except for the H-906 sample. The K/Rb ratio is relatively low (1653.2–451.9), Rb/Sr (0.09–9.70), and Rb/Ba (0.07–0.67). They are rich in REE, especially the LREE, their content is 200 to 1000 times higher than that of chondrite (Sun & McDonough, 1989) (Fig. 16-3). The $(La/Sm)_N$ ratio is (6.18–44.00) and based on the REE characteristics, the Muonghum granitoids correspond to the A-granite and quite express the peaks of Eu

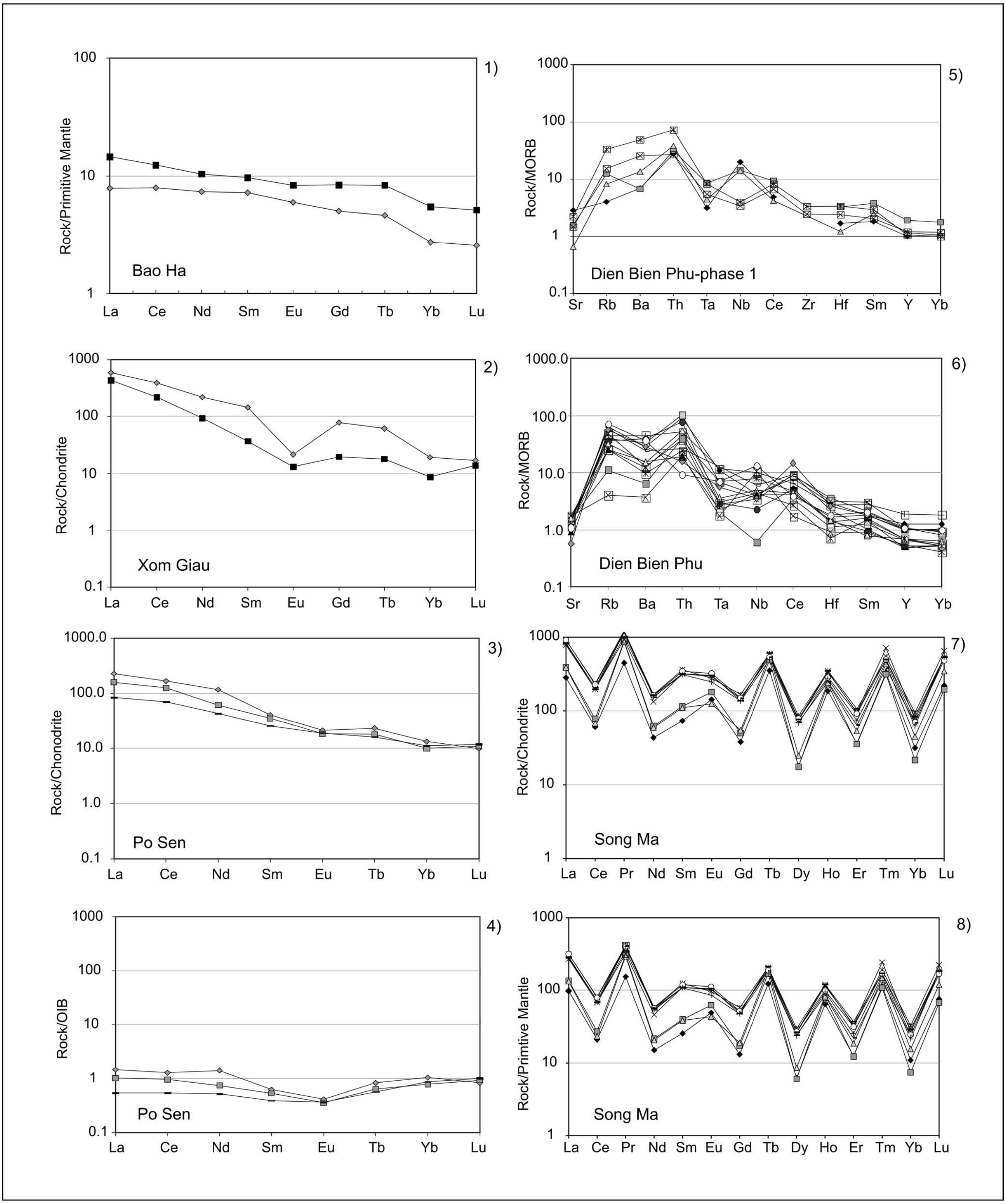

Fig. 15. Primitive mantle, chondrite-normalized, ocean island-normalized, and mid-ocean ridge basalt (applied method of Sun & McDonough, 1989) REE distribution patterns for the NWVN igneous rocks

anomalies (Eu/Eu* =0.14–0.39) (Table 16). Based on characteristics of high in alkali (potassic alkali type), rich in Rb, Zr, Nb and rare elements, Tran Trong Hoa (1995) inferred that the Muong Hum granitoids correspond to the A-granite representing the formation and evolution of the Tu Le Depression (144–73 Ma). Perhaps, it is a product of within-plate (intraplate) magmatic activity, related to the collision between the Izanagi Plate (proto-Pacific Ocean) and South China blocks during Jurassic–Cretaceous times. The development of the Red River strike-slip influenced the Muong

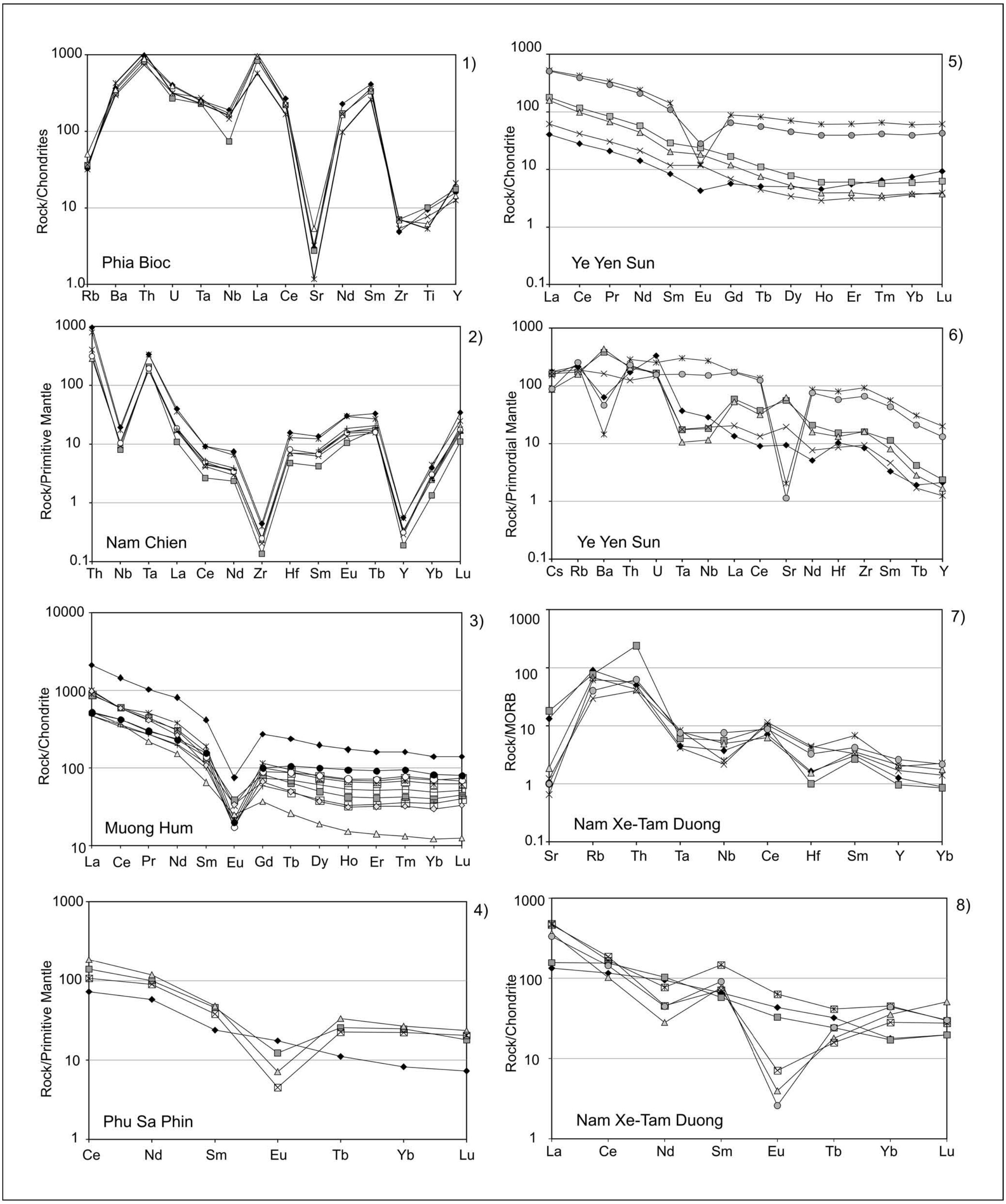

Fig. 16. Primitive mantle, chondrite-normalized, ocean island-normalized, and mid-ocean ridge basalt (applied method of Sun & McDonough, 1989) REE distribution patterns for the NWVN igneous rocks

Hum granitoids, producing "fish-tectonics", and metamorphism manifested in the granite gneisses widespread in the southeastern Phan Si Pan-Song Hong zone. For the Phu Sa Phin complex, based on the $(K_2O+Na_2O)/CaO$-$(Zr+Nb+Ce+Y)$ and Fe^*/MgO-$(Zr+Nb+Ce+Y)$ correlations, they correspond to the A-granite type. They represent within-plate (intraplate) magmatism related to intracontinental spreading (Table 16, Fig. 21).

The subalkaline biotite granite of the Ye Yen Sun complex in the east, based on the following characters: rich in

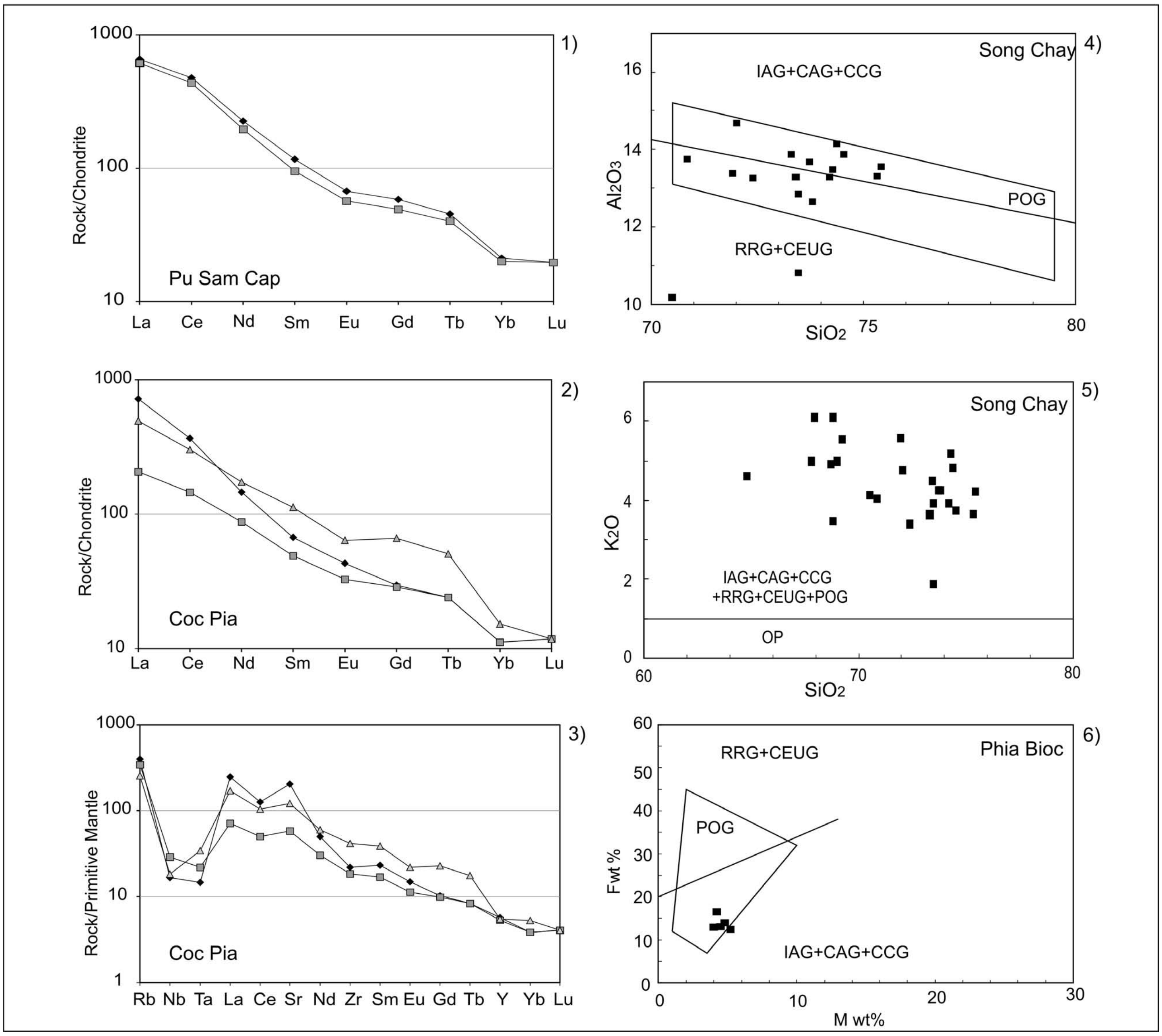

Fig. 17. Primitive mantle, chondrite-normalized (applied method of Sun & McDonough, 1989) REE distribution patterns (1-3); the correlated diagrams between SiO_2 and Al_2O_3; SiO_2 and K_2O (4, 5); and discrimination diagram of granitoids (applied method of Maniar & Piccoli, 1989). IAG – Island arc granitoids; CAG – Continental arc granitoids; CCG – Continental collision granitoids, POG – Post-orogenic granitoids; RRG – Rift related granitoids; CEUG – Continental epeirogenic uplift granitoids, OP – Oceanic plagiogranites

potassium, in Rb, Zr, Nb, Ta and rare earth Th, U elements, poor in Sr, Ba, is completely close to the subalkaline granite of the Phu Sa Phin complex, and bears the characteristics of within-plate (intraplate) magmatic activity (Table 17, Fig. 21). The leucocratic granite in the west of the pass is characterized by its relatively high alkalinity of the potassium-sodium type; it is rich in Rb, Sr, Ba and relatively poor in Nb, Ta, Hf, and Zr, bearing complex characteristics of magmatic activities of continental arc or post-collisional, related to the compressional movement caused by the Eurasia-India collision. The Ye Yen Sun complex needs further detailed studies on isotopes in association with isotopic dating for clarifying the problem of its exact setting.

The content and distributive characteristics of REE are different in the studied granites (Table 17, Figs 16-5, 16-6). In the east, granite is very rich in REE, especially LREE with the ratio (La/Yb) N = 8.65–12.88. The western granite is relatively poorer in REE with strongly changing ratio (La/Yb) N = 5.38–41.46. The eastern granite is characterized by strong negative Eu anomaly (Eu/Eu* = 0.11–0.30), while the western granite has positive Eu anomaly or weak negative Eu anomaly (Eu/Eu* = 0.62–1.30). The absence of negative Eu anomaly and the relative richness in HREE is a particular feature of the western granite that needs further studies.

The studied rocks of the Nam Xe-Tam Duong complex are rich in Rb (59.4–180 ppm), very rich in Ba (35.3–796 ppm), Sr (78.5–2169 ppm), and Y (29–78.4 ppm), but relatively poor in Zr (73–92 ppm), Nb (7.61–19.3 ppm), and Ta (0.8–1.48 ppm). The content of REE in Nam Xe-Tam Duong granite is rather high, but not reaching the characteristics of calc-alkaline granitoid series. The characteristics of distribution of REE and the shortage of Nb, Ta, Zr and Hf (Table 19, Figs 16-7, 16-8) correspond to granitoids related

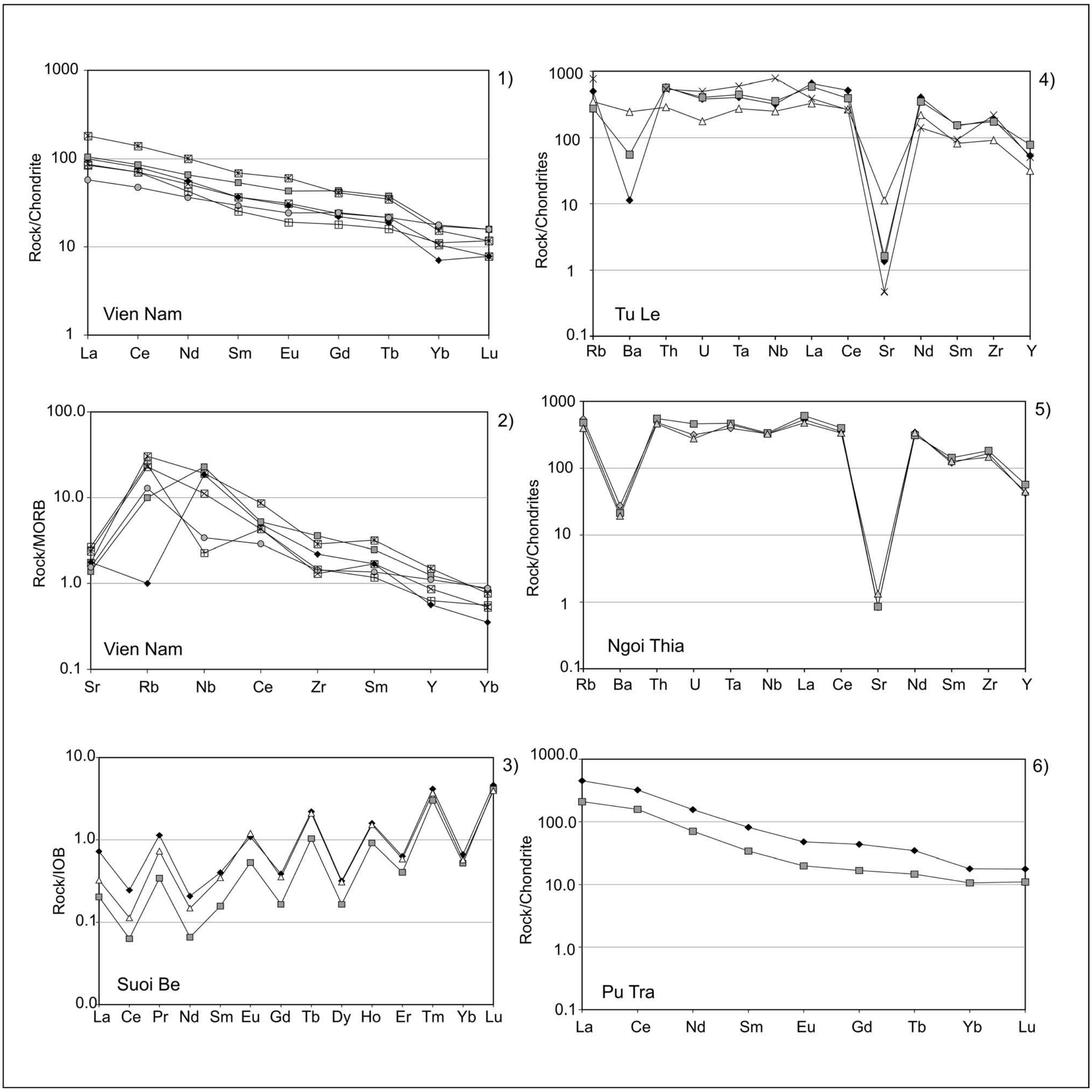

Fig. 18. Chondrite-normalized, ocean island-normalized, and mid-ocean ridge basalt (applied method of Sun & McDonough, 1989) REE distribution patterns for the NWVN volcanic rocks

to the post-collision tectonic setting, belonging to the within-plate (intraplate) granite (Figs 19, 20).

Other series includes syenite and nepheline syenite of the Pu Sam Cap complex, and syeno-diorite and gabbro of the Coc Pia complex. Rocks of the Pu Sam Cap complex are characterized by high and very high alkalinity (Na_2O+K_2O =12.46–12.47%), and belong to the potassic and ultra-potassic series (K_2O/Na_2O>2–4.4). They are rich in Rb (241.6–265.7 ppm), Sr (2535–3989 ppm), Zr (521.8–559.1 ppm), Y (43.52–47.1 ppm), but rather poor in Nb (32.2–32.8 ppm), and Ta (1.5 ppm). They are also rich in LREE, as well as Th and U (Table 19), and the curve of their distribution has an unclear Eu min. In general, the characteristics of distribution of rare elements represent oceanic ridge granite and are similar to granitoids of the Nam Xe-Tam Duong complex with well manifested shortage of Nb and Ta (Fig. 17-1). As mentioned above, the characteristics of the Nb-Zr, Nb-Y and so on, indicate that alkaline granitoids of the Pu Sam Cap complex (A-granite) were formed in the within-plate (intraplate) (Figs 19, 20) extension environment which perhaps related to the strike-slip Ailao Shan-Red river fault zone during the Palaeogene. In addition, the rocks of the Coc Pia complex (including all volcanites, intrusives, dykes and veins) correspond mainly to mafic group (SiO_2 = 48.32– 54.26%). They are also rich in Rb (163–253 ppm), Sr (1226– 4318 ppm), Zr (206–469 ppm) and REE, but relatively poor in Nb (12–20 ppm), Ta (0.6–1.4 ppm), and TiO_2 (0.5–0.8 ppm) (Table 19). The characteristics of distribution

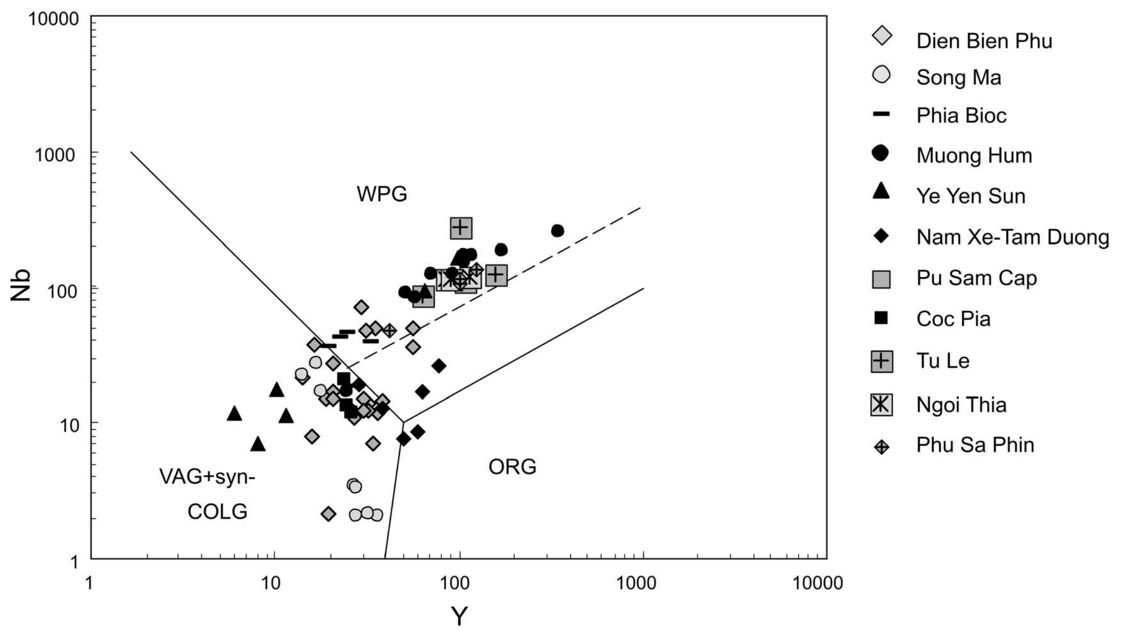

Fig. 19. Nb vs Y binary diagram for the NWVN granitoids (applied method of Pearce *et al.*, 1984). ORG – Ocean ridge granitoids; Syn-COLG – Syn-collision granitoids; VAG – Volcanic arc granitoids; WPG – Within-plate (intraplate) granitoids

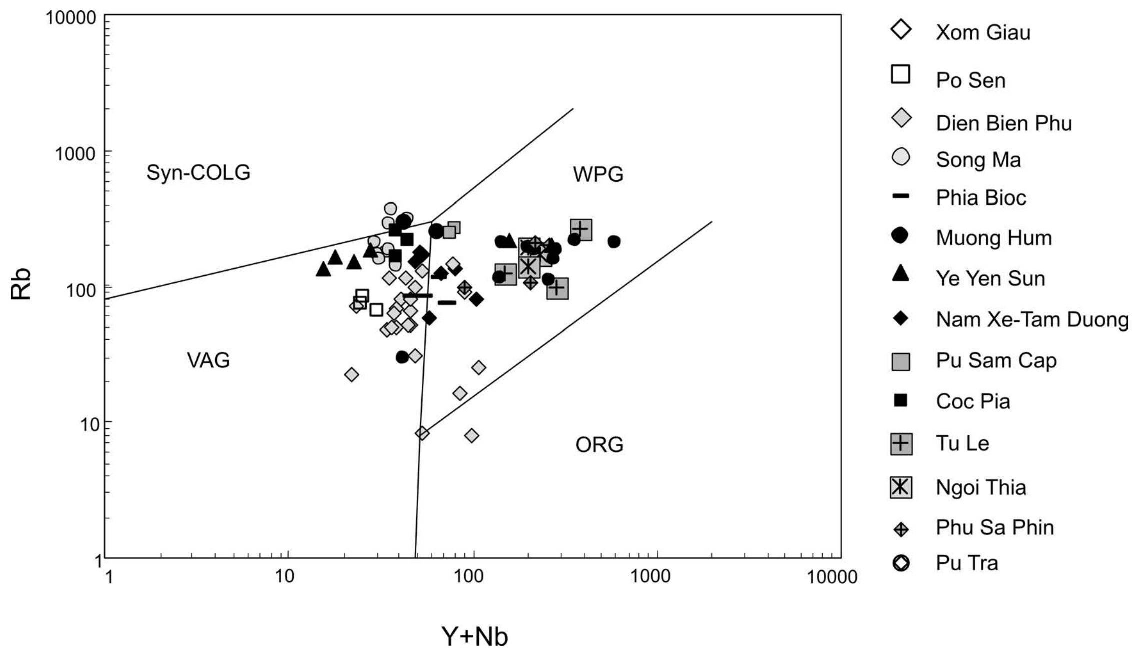

Fig. 20. Rb *vs.* Y+Nb binary diagram for the NWVN granitoids (applied method of Pearce *et al.*, 1984). ORG – Ocean ridge granitoids; Syn-COLG – Syn-collision granitoids; VAG – Volcanic arc granitoids; WPG – Within-plate (intraplate) granitoids

of rare elements and REE of lamproite and absarokite show similarities of rocks within the Coc Pia complex (Figs 17-2, 17-3). The geochemical characteristics indicate that the magmatic fluid originated from materials of mantle basement that are enriched by lithophilous matters and other incompatible elements by later metasomatism. However, the exhausted manifestations of Nb, Ta, and Ti show properties of a subduction zone during the forming process of potassic alkaline and potassic ultra-alkaline rocks of the Coc Pia complex. In general, the mafic-potassic alkaline and potassic ultra-alkaline rocks of the Coc Pia complex are products of within-plate (intraplate) extension (Figs 19, 20) related to the strike-slip process of the Ailao Shan-Red River fault zone, which was caused by the collision between the Indian and Eurasian blocks (Chung *et al.*, 1997; and references therein).

The geochemical volcanic rocks from the NWVN area are also distinguished into mafic and felsic series (Figs 5, 8). Volcanic mafic series comprise mainly of basalts of the Huoi Hao, Vien Nam formations, basanite and fodite of the

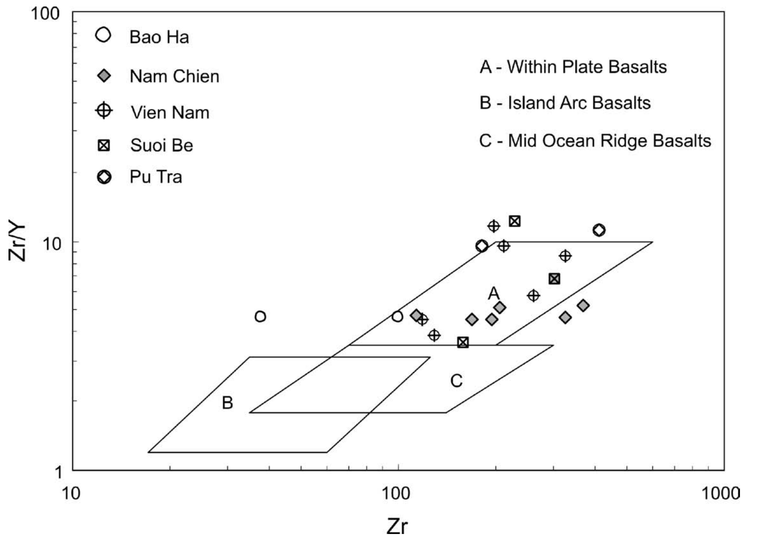

Fig. 21. The Zr/Y *vs.* Zr correlation for the NWVN magmatic rocks (applied method of Pearce & Norry, 1979)

Suoi Be Formation, which are characterized by silica under-saturation (SiO_2 =36.82–54.29%), low alkalinity (Na_2O+ K_2O =0.38–7.29%), K_2O/Na_2O ratio is often lower than 1, except the T931344 sample of the Suoi Be formation, and high in titanium (TiO_2 =0.4–3.26%). On the Na_2O-K_2O-CaO diagram of Green and Poldervaart (1958) (Fig. 10), they belong to the sodic rock type, except a sample of the Suoi Be Formation, which is plotted in the potassic field. On the discrimination diagram of Jensen and Rickwood (1989) (Fig. 12), the rocks of Suoi Be Formation are mainly high iron tholeiite (HFT), while the Huoi Hao Formation is plotted in high iron tholeiite (HFT) and high magnesium tholeiite (HMT). The Vien Nam basalts also display a wide range of komatite (PK), komatitic basalt (BK) to high iron tholeiite (HFT). Moreover, on the FeOt-MgO-Al_2O_3 diagram of Pearce *et al.* (1977) (Fig. 14), the Huoi Hao basalts fall into island ocean (IO) and ocean ridge-floor (ORF) type, the Vien Nam Formation are mainly island ocean (IO), while the Suoi Be basalts belong to continental ocean (CO).

Particularly, rocks of the Vien Nam Formation are all relatively poor in Cu, Ni and Co, but rather rich in V, lithofile elements (Rb, Sr, Zr, Nb) and LREE (Table 9, Figs 18-1, 18-2). Based on the characteristics of distribution of REE and the Zr *vs.*Y-Zr, the mafic-ultramafic volcanites of the Then Sin-Phong Tho band can be considered as subalkaline association of within-plate (intraplate) magmatism (Fig. 21). Moreover, the described rocks of the Suoi Be Formation have the content of Ti, Mn, Pb-Zn, Au, V and Co is higher than Clarke (Table 13). The rocks correspond to within-plate (intra-plate) magma- tism (Fig. 21).

Finally, the third series, which comprise the Tu Le, Ngoi Thia, and Pu Tra formations, is represented mainly by rhyolites and some trachytes. They are characterized by high contents of SiO_2 (59.55–77.56%), and total Na_2O+ K_2O (5.27–11.4%) with potassium prevailing sodium (K_2O/Na_2O = 0.96–4.84). On the Na_2O-K_2O-CaO diagram of Green and Poldervaart (1958) (Fig. 10), they belong to the potassic rock type. On the discrimination diagram of Jensen and Rickwood (1989) (Fig. 12), the Tu Le, Ngoi Thia, and Pu Tra volcanic rocks belong to the rhyolitic tholeiite type (TR). Both of the Tu Le and Ngoi Thia formations also displaying the characteristics of distribution of rare elements in rhyolite from the Binh Lu area are completely similar to those from the Tu Le, and Tram Tau areas and to granite (A-granite) of the Phu Sa Phin complex (Figs 16-4; 18-4, 18-5). They indicate the products of within-plate (in-traplate) magmatism (Table 15, Figs 19–21) and have isotopic characteristics: $^{143}Nd/^{144}Nd$ =0.512562; lNd(0) = –1.48 (original ratio lNd(T) = 0.6) (Lan, 2000 and references therein). In addition, the Pu Tra volcanic rocks are rich in Rb, Ba, Sr, Zr and LREE (Table 18, Fig. 18-6). Due to the limited data of analysed samples, we cannot identify certain tectonic setting for the Pu Tra Formation, but both characteristics of the Nb *vs.* Y+Nb, and Zr *vs.* Zr-Y suggest that the Pu Tra Formation may be related to the within-plate (intraplate) setting (Fig. 21).

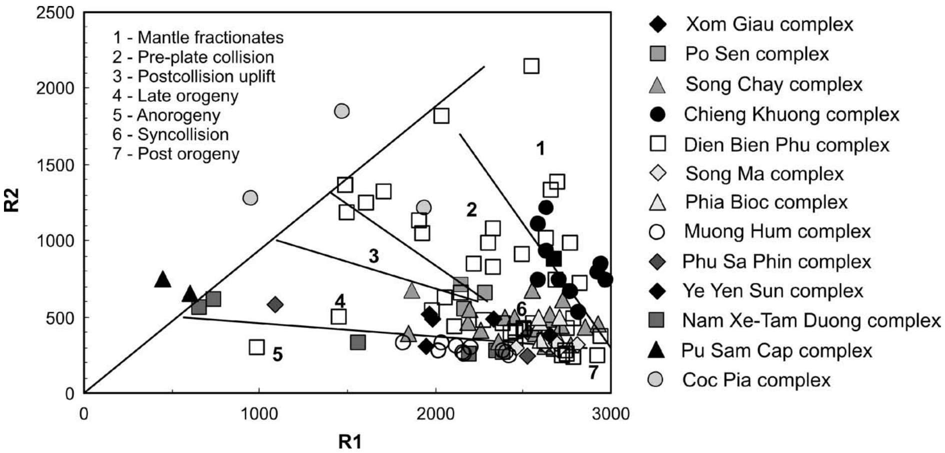

Fig. 22. The R1–R2 discrimination diagram for granitoids (applied method of Batchelor & Bowden, 1985). R1 = 4Si-11(Na+K)-(Fe+Ti); R2 = 6Ca+Al

DISCUSSION

The detailed magmatic units and their relationship to tectonics are presented in Fig. 23.

The mafic and acid rocks of the first group were formed in strong active continental margin of the South China block during Proterozoic time, corresponding to the major episodes of crustal formation in the South China block (Li *et al.*, 1999). The Jinning episode may represent the collision between Yangtze and Cathaysia plates (Tran Ngoc Nam, 2003), the other events may be related to the early effects of the mantle plume that initiated the breakup of Rodinia (Li *et al.*, 1999) or to the earliest collisions leading to formation of Gondwana (Metcalfe, 2006). The core of South China block, recorded by the Bao Ha, Xom Giau and Po Sen complexes in NWVN, was formed during the Proterozoic times. The micro-continental plates, perhaps derived from Gondwanaland, existed during Palaeozoic times (Metcalfe, 1996, 2000; Golonka *et al.*, 2006a,b,c).

Based on the global plate tectonics and palaeogeographic studies of Southeast Asia, Krobicki and Golonka (2006) showed that South China and Indochina were separated by deep-water basin with thinned continental or may be oceanic crust in Ordovician times. The presences of Ordovician–Silurian sediments and the uplift and volcanic rocks support this possibility. According to Shouxin and Yongyi (1991), the southern part of the SCB is covered by deep water synorogenic clastic deposits – more than 4000m of weakly metamorphosed flysch, sandstones and graptolitic shales. Similar rocks formed on the margins of Indochina block. They are known as Pa Ham Formation in the Northern Vietnam. The deep water Ordovician and Silurian synorogenic deposits were replaced by continental Early Devonian red beds (Tran Van Tri, ed., 1979). The lower Palaeozoic greenschists of deep sea origin are also unconformably covered in many localities by Devonian redbeds. This redbeds were follow, particularly in Song Ma zone, by Lower Devonian Nam Pia Formation composed mainly of terrigenous sediments and Lower-Middle Devonian Huoi Nhi Formation composed of marl, medium-bedded to massive fine-grained limestone. These formations represent shallow water sediments (Phan Son, ed. *et al.*, 1978). Perhaps the Late Silurian–Early Devonian was time of the first accretion of IDB to SCB in the collisional process. The granitoids of Song Chay complex are linked to this event. Plate tectonic reconstructions (Metcalfe *et al.*, 1996) indicate the possibility of connection between the Early Devonian deformation and uplift and the rifting of the South China block from Gondwanaland. This event is perhaps also related to the global Caledonian orogenic process. The

Erathem Era	System Period	Lithological complexes	Symbol	Magmatic rocks		Probable tectonic setting
				Intrusive	Effusive	
Cenozoic	Palaeogene	Pu Tra	26		x	intraplate extension
		Coc Pia	25	x		intraplate extension
		Pu Sam Cap	24	x		intraplate extension
		Nam Xe-Tam Duong	23	x		intraplate extension
		West Ye Yen Sun	22	x		intraplate extension
Mesozoic	Cretaceous	East Ye Yen Sun	21	x		intraplate magmatism
		Phu Sa Phin	20	x		intraplate magmatism
		Muong Hum	19	x		intraplate magmatism
		Ngoi Thia	18		x	intraplate magmatism
		Tu Le	17		x	intraplate magmatism
		Nam Chien	16	x		intraplate magmatism
		Suoi Be	15		x	intraplate magmatism
	Permian–Triassic	Phia Bioc	14	x		post-orogenies
		Song Ma	13	x		post-orogenies
		Dien Bien Phu	12	x		syn-collision related to the subduction zone
Palaeozoic		Ban Xang	11		x	oceanic island basalt (OIB)
		Vien Nam	10		x	intraplate extension
		Cam Thuy	9		x	intraplate extension
		Huoi Hao	8		x	ophiolite belt
		Chieng Khuong	7	x		ophiolite belt
		Bo Xinh	6	x		ophiolite belt
		Nui Nua	5	x		ophiolite belt
		Song Chay	4	x		post-orogenic granite
Proterozoic		Po Sen	3	x		volcanic arc granite to subduction
		Xom Giau	2	x		volcanic arc granite to subduction
		Bao Ha	1	x		active continental margin

Fig. 23. The magmatic rocks and their relationship to the tectonic setting of NWVN area

Devonian shallow-water sedimentary rocks were followed by Carboniferous–Permian sequences, represented by the limestone of Carboniferous–Permian Bac Son, clay shale of Lower-Middle Permian Si Phay, and the limestone of Middle Permian Na Vang formations (Phan Son, ed. *et al.*, 1978). The new oceanic basin opened between ICB and SCP plates during Late Permian times, recorded by ophiolite belt, which consists of the Nui Nua, Bo Xinh, Chieng Khuong complexes, Huoi Hao Formation and perhaps ultramafic Ban Xang complex. Its origin is related to the closure of the Palaeo-tethys Ocean between Sibumasu and ICB by subduction below Indochina (Golonka *et al.*, 2006a).

The discovery of the Hon Vang serpentinite body within the ICB and SCB (located outside the investigated area) provided additional information about ophiolite belt in this area (Nguyen Minh Trung *et al.*, 2006, 2007). The ages of these ophiolites are still somewhat uncertain. Probably, their crystallization and accretion process was completed by Late Permian times.

The widespread volcanic eruption took place in the Song Da zone during Permian times. This event is related to the origin of the Cam Thuy and Vien Nam formations. The cause of this event is still subject of hot debate. Some geologists argued that Cam Thuy and Vien Nam formations were perhaps related to the plate reorganization and mantle plume activity, known in China and Indochina as Emeishan plumes and related to Siberian basaltic traps (Hanski *et al.*, 2004; Tran Trong Hoa *et al.*, 2008b; Krobicki & Golonka, 2008 and references therein). They were formed in withinplate (intraplate) setting, related to back-arcs spreading (Lepvrier *et al.*, 1997, 2004; Golonka *et al.*, 2006a,c) or Songda rift of Tran Van Tri (ed., 1979). The preferred geodynamic reconstruction assumes that this magmatism was formed during the convergence of the Sibumasu and the newly formed Indochina-South China block. The oceanic crust was subducted southward under ICB (Tran Trong Hoa *et al.*, 2008a). This subduction led to the origin of Late Permian–Triassic magmatic events and Song Da volcanism.

Remnants of oceanic lithosphere were accreted into the northern edge of the IDB and appeared in the Song Ma fault zone and Sam Nua zone (Golonka *et al.*, 2006a; Nguyen Minh Trung *et al.*, 2007 and references therein). The Indosinian orogeny of Fromaget (1937, 1941) represents the final stage of this closure. The orogeny was recorded by magmatic, metamorphic and deformation events in Truong Son, Sam Nua, Nam Co, and Song Ma structural zones (Hutchison, 1989; Tran Ngoc Nam ,1998; Lepvrier *et al.*, 1997, 2004, 2008; Lan *et al.*, 2000). The folded Triassic and older rocks were uncoformably covered by Upper Triassic coal bearing molasse beds of the Suoi Bang Formation. The granitoids of the Dien Bien Phu, Song Ma and Phia Bioc complexes are related to Indosinian orogeny. The granitoids of Dien Bien Phu complex were formed in syn-collisional, while the granitoids of the Song Ma and Phia Bioc complexes in post-collisional tectonic setting.

During the Jurassic times, the strong volcano-plutonic activities, known as an Yanshanian tectonic cycle, related to the collision between the Izanagi Plate (proto-Pacific Ocean) and South China blocks, appeared in the southeastern China (Metcalfe, 1996a.b; Golonka, 2007). This event was not restricted to the southeastern China but was also recorded in many areas of Vietnam including the NWVN. The Jurassic–Cretaceous intraplate magmatism, which includes basalt of the Suoi Be Formation, gabbro from Nam Chien, rhyolitic Tu Le, Ngoi Thia subcomplexes and granosyenite and granite of the Muong Hum, Phu Sa Phin, East Ye Yen Sun complexes provides evidence of the Yanshanian tectonic cycle activity in the NWVN. However, based on the similarity of lack of depletion in the high field strength elements (Nb, Ta and Ti), it is possible to speculate that the Late Permian–Early Triassic Song Da basalts may serve as the source material for Jurassic to Cretaceous A-type granitic rocks of the Phu Sa Phin complex as well as rhyolites of Tu Le and Ngoi Thia subcomplexes.

During Palaeogene times, the extrusion, transpression, transtension and extension related processes, which resulted from the India-Asia collision (Himalayan tectonic cycle), produced high-potassic rocks in the northwestern Yunnan and northern Vietnam (Leloup, 1995; Lan *et al.*, 1999, 2001; Golonka *et al.*, 2006a). The related tectonic activity formed the leucocratic granite, rhyolite and calc-alkaline intraplate rocks of the West Ye Yen Sun complex, Pu Tra Formation, Nam Xe-Tam Duong, Pu Sam Cap, and Coc Pia complexes. Following the Himalayan cycle activity, the transtension tectonics accompanying the mantle plumes moved from the South China Sea southwestward to ICB continent (Nguyen Hoang & Martin, 1996). This movement led to the formation of intraplate volcanism of the "pull-apart" type, with the assemblage of basaltic effusives in Vietnam's territory including the Late Neogene basalt in Dien Bien Phu basin of the NWVN (Koszowska *et al.*, 2004).

CONCLUSIONS

The suggested model for the tectonic evolution of the NWVN is shown in Fig. 24. Six groups of magmatic rocks are related to the tectonic events. The first, Proterozoic group corresponds to the major episodes of crustal formation in the South China block, or is linked with the formation of Gondwana. The tectonic environment of the Northwestern Vietnam changed from a subduction-related magmatism (orogenic) to a matured continental intraplate magmatism (anorogenic) in the time span between the Palaeozoic–Early Triassic and Cretaceous.

The second group comprises the Devonian Song Chay granitoids, coeval with the Palaeozoic orogenic event. The third group contains Permian magmatic rocks – ophiolites of the Nui Nua, Bo Xinh, and Chieng Khuong complexes, ultramafic Ban Xang complex and Huoi Hao Formation as well as extrusives of Cam Thuy, and Vien Nam formations formed in intraplate setting, related to back-arc spreading.

The fourth group is related to the the Triassic Indosinian orogeny and includes granitoids of the Dien Bien Phu, Song Ma and Phia Bioc complexes. The granitoids of Dien Bien Phu complex were formed in syn-collisional, while the granitoids of the Song Ma and Phia Bioc complexes in post-collisional tectonic setting.

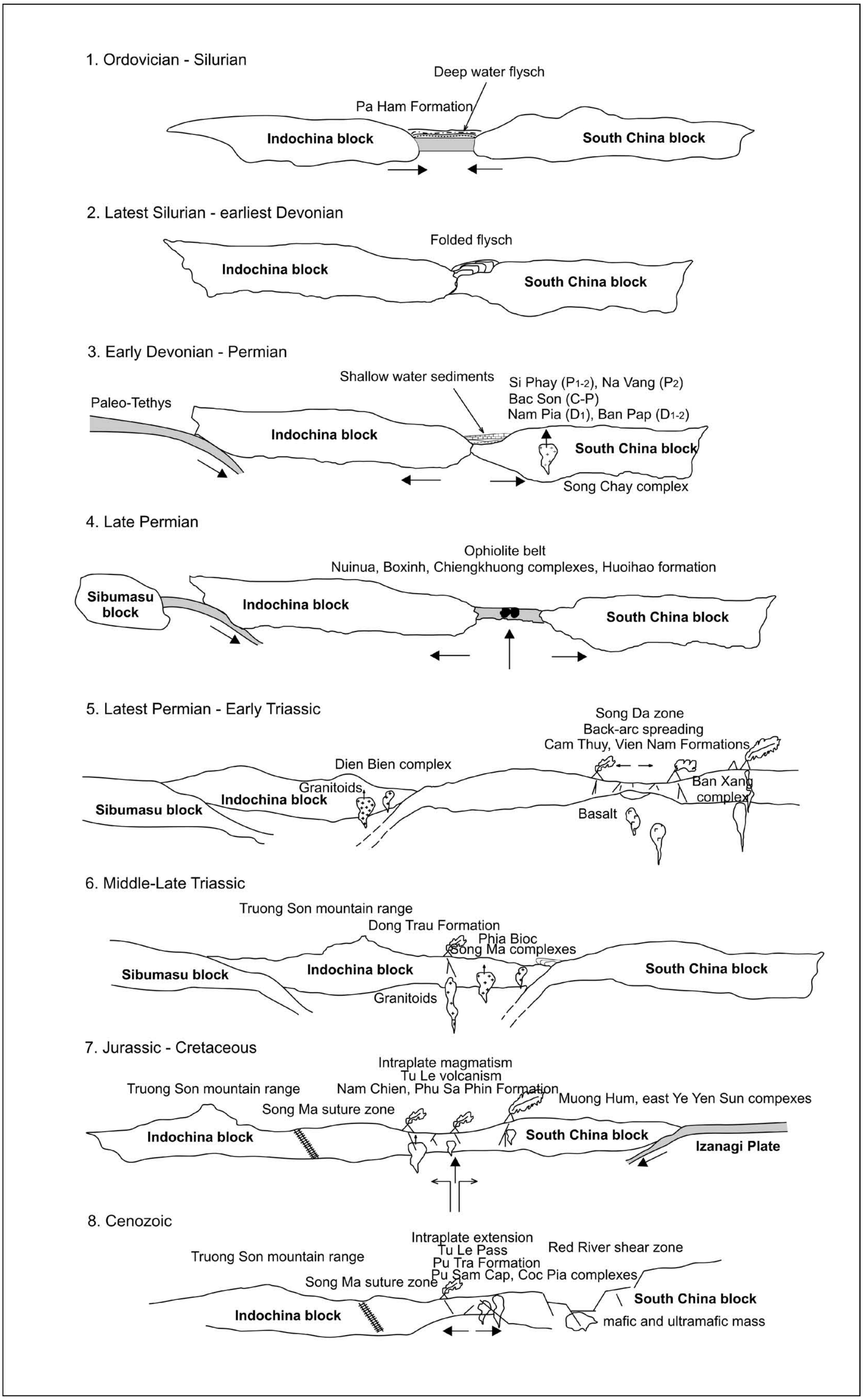

Fig. 24. Plate tectonic evolution of the NWVN area

The fifth group comprises the mafic effusives of Suoi Be Formation, gabbroic Nam Chien complex, acidic volcanics from the Tu Le and Ngoi Thia complexes, granosyenite and granite from Phu Sa Phin and Muong Hum complexes, and biotitic granite of the East Ye Yen Sun complex. They were formed during Jurassic–Cretaceous plate magmatism, linked to the Yanshanian tectonic cycle, related to the collision between Izanagi Plate (proto-Pacific Ocean) and South China.

The last group comprises the West Ye Yen Sun leucocratic granite, subalkaline to alkaline Nam Xe-Tam Duong granites, syenite and granosyenite from Pu Sam Cap, mafic-potassic alkaline Coc Pia complexes and rhyolite from the Pu Tra Formation. These rocks were formed during Cenozoic times, as an effect of strike-slip faulting related to the collision of India and Eurasia plates.

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Appendix

Table 1

Representative chemical and trace element composition of gabbroids of the Bao Ha complex (data from Nguyen Van The, ed., 1999, Tran Trong Hoa *et al.*, 1999)

Sample	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	
LY.835	48.98	1.32	14.59	11.72	0.17	7.32	12.3	3.06	0.30	0.12	
LY.10523	45.46	2.66	13.11	15.31	0.18	6.73	8.53	4.47	0.11	0.23	
	Cu	**Ni**	**Co**	**Cr**	**V**	**Rb**	**Sr**	**Zr**	**Nb**	**Y**	**Ta**
LY.835	73	76	32	271	316	4.3	140	37.7	3.6	8.2	0.5
LY.10523	5	115	50	146	402	2.1	51.2	100	14.6	21.5	0.5
	Th	**Hf**	**La**	**Ce**	**Nd**	**Sm**	**Eu**	**Gd**	**Tb**	**Yb**	**Lu**
LY.835	0.6	1.5	5.4	14	10	3.2	1	3	0.5	1.35	0.19
LY.10523	0.9	3.1	10	22	14	4.3	1.4	5	0.9	2.7	0.38

Table 2

Representative chemical and trace element composition of microcline-rich biotite granite of the Xom Giau complex (data from Nguyen Van The, ed., 1999, Tran Trong Hoa *et al.*, 1999)

Sample	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5
LY.3916	73.76	0.32	12.83	3.35	0.03	0.27	0.72	3.47	4.16	0.03
LY.5414	71.06	0.10	14.01	1.9	0.04	0.56	2.80	5.71	0.05	-
	Rb	**Sr**	**Zr**	**Nb**	**Y**	**Th**	**U**	**Ta**	**Hf**	
LY.3916	170	105	476	8.5	44	55	9	1.65	14	
LY.5414	-	-	-	-	-	-	-	-	-	
	La	**Ce**	**Nd**	**Sm**	**Eu**	**Gd**	**Tb**	**Yb**	**Lu**	
LY.3916	140	240	102	22	1.25	16	2.30	3.30	0.43	
LY.5414	102	132.7	43.3	5.6	0.76	4.03	0.67	1.47	0.35	

Table 3

Representative chemical and trace element composition of granitoids of the Po Sen complex (data from Lan *et al.*, 2000)

Sample	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5
RR28A	66.08	0.54	15.88	4.13	0.06	1.25	3.09	4.35	2.71	0.18
RR28B	60.05	0.49	15.44	3.43	0.05	1.05	2.81	4.28	2.87	0.14
RR29	68.73	0.48	14.94	2.79	0.03	1.18	1.88	4.17	3.77	0.14

Table 3 continued

Sample	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5
	Rb	**Sr**	**Nb**	**Zr**	**Y**	**Th**	**U**	**Ta**	**Hf**	
RR28A	67	548	11.1	196	19	5.7	1.3	0.77	6.6	
RR28B	75	433	9.4	163	15	6.7	1.7	0.76	5.8	
RR29	84	429	9.8	169	16	6.0	2.4	0.70	6.0	
	La	**Ce**	**Nd**	**Sm**	**Eu**	**Tb**	**Yb**	**Lu**		
RR28A	54.1	102.2	54.3	6.20	1.23	0.87	2.26	0.25		
RR28B	37.8	76.4	28.6	5.36	1.07	0.67	1.70	0.28		
RR29	36.5	73.2	47.3	5.00	1.08	0.68	0.70	0.28		

Table 4

Representative chemical composition of granitoids of the Song Chay complex
(data from Tran Duc Luong & Nguyen Xuan Bao, 1995)

Sample	NT38	71/3	NTCB37	TH71/1	2674A	71/4	73/50	10552
SiO_2	64.76	67.78	67.92	68.68	68.8	68.8	68.98	69.19
TiO_2	0.43	0.39	0.39	0.25	0.35	0.4	0.14	0.41
Al_2O_3	14.45	16.43	16.94	16.47	16.94	15.68	16.65	16.67
Fe_2O_3	1.91	1.08	0.8	1.14	0.8	1.32	0.78	0.17
FeO	4.09	2.12	2.2	1.29	2.2	2.2	0.96	3.05
FeOt	6	3.2	3	2.43	3	3.52	1.74	3.22
MnO	0.13	0.07	0.11	0.06	0.11	0.06	0.05	0.04
MgO	1.01	0.71	0.75	0.68	0.75	0.78	0.36	0.8
CaO	3.23	1.04	1.2	0.5	1.2	1.29	0.45	1.45
Na_2O	3.7	3.15	1.89	3.185	1.89	3.04	4.37	1.81
K_2O	4.61	5	6.11	4.91	6.11	3.48	5	5.55
P_2O_5	0.15	0.31	0.06	0.22	0.06	0.18	0.33	0.02
	NT2265	**72/3**	**H4658/2**	**H4341**	**H4662/3**	**41M**	**H4337/5**	**2268**
SiO_2	70.49	70.84	71.92	72.02	72.38	73.3	73.4	73.45
TiO_2	0.25	0.57	0.02	0.21	0.04	0.46	0.29	0.25
Al_2O_3	10.19	13.77	13.39	14.68	13.28	13.89	13.3	10.83
Fe_2O_3	2.41	1	0.63	0.54	4.83	1.22	1.13	2.4
FeO	1.66	2.9	0.79	1.05	0.44	1.71	1.36	0.5
FeOt	4.07	3.9	1.42	1.59	5.27	2.93	2.49	2.9
MnO	0.18	0.07	0.29	0.03	0.14	0.16	0.05	0.05
MgO	2.42	0.89	0.5	0.46	1.37	1.33	0.81	0.2
CaO	3.32	1.09	2.48	0.28	1.19	1.01	0.71	3.64
Na_2O	3.1	2.46	3.58	3.65	2.76	2.16	3.13	4.65
K_2O	4.15	4.06	5.58	4.78	3.4	3.64	4.49	1.9
P_2O_5	0.39	0.21	-	0.17	-	-	0.2	0.28
	NT2150	**H4339/1**	**H4345**	**NT.HG4**	**H4347**	**73/4a**	**73/5**	**H4663**
SiO_2	73.47	73.72	73.8	74.19	74.26	74.37	74.54	75.32
TiO_2	0.01	0.12	0.37	0.08	-	0.16	0.06	0.02
Al_2O_3	12.86	13.7	12.66	13.3	13.49	14.14	13.88	13.32
Fe_2O_3	2.24	0.55	1.46	1.23	0.53	0.89	0.79	2.86
FeO	0.07	0.69	1.55	0.12	0.88	0.69	0.83	0.46
FeOt	2.31	1.24	3.01	1.35	1.41	1.58	1.62	3.32
MnO	0.01	-	0.05	0.09	0.03	0.05	0.03	0.11
MgO	0.5	0.05	0.77	0.29	0.51	0.46	0.18	1.23
CaO	1.54	0.35	-	1.05	0.14	0.2	0.4	0.2
Na_2O	3.4	3.57	2.33	4	2.5	2.89	4	2.15
K_2O	3.92	4.26	4.26	3.93	5.2	4.82	3.75	3.67
P_2O_5	0.54	0.22	0.19	0.3	0.13	0.17	0.27	-

Table 5

Representative chemical composition of the ultramafic Nui Nua complex
(data from Phan Son *et al.,* 2005-in the Son La sheet group at 1:200,000 scale)

Sample	S.7270/1	S.7268/1	S.5071	SL.6052	SL.5069/1	S.9101	SL.5124/3	SL.5203	SL.74/2	S.2511/2	SL.4007/3	SL.1806/5
SiO_2	36.080	38.230	38.360	39.080	39.140	39.740	39.820	39.960	40.260	40.680	42.960	46.360
TiO_2	0.070	0.040	0.000	0.000	0.000	0.110	0.000	0.000	0.000	0.060	0.000	0.000
Al_2O_3	2.020	1.270	1.630	2.040	1.430	1.570	1.630	1.850	1.730	2.120	0.930	0.210
Fe_2O_3	10.180	5.980	6.980	5.280	5.580	6.780	4.960	5.590	4.380	7.290	4.100	3.230
FeO	0.000	0.000	2.730	1.720	1.870	1.570	1.290	1.220	3.020	5.180	3.020	3.380
MnO	0.000	0.000	0.110	0.120	0.150	0.090	0.110	0.130	0.050	0.070	0.110	0.090
MgO	38.800	36.660	36.740	37.830	37.920	36.780	37.920	35.820	37.210	36.350	34.890	34.390
CaO	2.240	2.860	0.000	0.000	0.000	0.000	0.000	0.280	0.140	0.630	0.840	0.280
Na_2O	1.830	1.100	0.110	0.130	0.130	0.990	0.130	0.900	0.000	0.180	0.150	0.370
K_2O	0.050	0.050	0.130	0.130	0.130	0.160	0.130	0.250	0.000	0.160	0.080	0.000
P_2O_5	0.110	0.060	0.040	0.030	0.050	0.120	0.050	0.160	0.080	0.040	0.130	0.040
MKN	8.400	13.200	12.280	12.520	12.440	11.470	12.730	13.150	12.260	5.120	11.443	9.730

Table 6

Representative chemical composition of the gabbroic Bo Xinh complex
(data from Phan Son *et al.,* 2005-in the Son La sheet group at 1:200,000 scale)

Sample	SL.4009	SL.4009/4	SL.5340	SL.4010/6	S.1305	SL.4007/6	SL.4008/5	SL.1802	SL.4012/1	S.1632/1	S.8515/1	S.7214
SiO_2	41.4	47.08	48.18	48.6	48.6	48.78	48.94	51.48	52.72	54.68	55.06	55.14
TiO_2	2.1	1.2	0.9	1.1	1.72	1.6	0.8	1.1	1	1.1	1.68	1.9
Al_2O_3	16.69	14.88	14.36	16.81	14.7	12.57	17.92	15.16	15.22	13.98	14.48	12.84
Fe_2O_3t	3.7	3.3	2.06	2.94	15.36	2.45	3.18	2.45	2.34	2.49	2.62	2.43
FeO	10.96	6.75	5.82	5.23	0	8.8	4.28	8.23	7.9	10.85	9.14	12.03
MnO	0.24	0.2	0.15	0.15	0	0.2	0.15	0.21	0.2	0.29	0.11	0.17
MgO	10.33	12.23	6.78	7.82	4.8	8.62	6.82	6.12	5.82	2.41	2.94	2.78
CaO	7.67	8.37	11.1	9.49	10.22	8.93	12	9.77	8.93	5.95	6.73	6.14
Na_2O	1.56	1.77	3.44	2.29	2.6	2.84	2.19	2.31	2.31	3.16	3.74	2.27
K_2O	0.17	0.17	0	0.09	0.52	0.8	0	0.58	0.75	1	0.97	1.8
P_2O_5	0.27	0.13	0.27	0.11	0.27	0.2	0.13	0.27	0.17	0.83	0.16	0.35
MKN	0.48	2.72	2.69	2.69	0.43	3.74	2.24	1.55	1.64	1.52	1.02	0

Table 7

Representative chemical composition of plagiogranite of the Chieng Khuong complex
(data from Phan Son *et al.,* 2005-in the Son La sheet group at 1:200,000 scale)

Sample	SL24	SL6121	SL1805/4	SL1805	SL6122	SL2511/2	SL2511/1	SL6106/1	S540/5
SiO_2	57.94	62.82	66.4	67.88	69	69.12	69.12	69.28	69.76
TiO_2	0.6	0.1	0.1	0.1	0.1	0.4	0.4	0.2	0.58
Al_2O_3	17.77	18.78	18.37	17.03	16.52	16.35	16.35	16.14	15.57
Fe_2O_3	0.49	0.5	0.14	0.75	0.25	1.11	0.11	0.42	0.68
FeO	4.96	2.55	1.87	1.9	1.62	1.9	1.9	1.9	2.18
MnO	0.12	0.02	0.05	0.05	0.05	0.02	0.02	0.04	0.03
MgO	2.39	2.21	1	1.2	0.9	1.1	1.1	1	0.85
CaO	6.94	5.86	4.88	4.19	4.03	3.77	3.77	3.47	3.63
Na_2O	2.36	3.75	4.25	3.75	3.44	3.64	3.64	3.75	5.06
K_2O	1.53	1.06	1.15	0.96	1.25	1.13	1.13	1.25	0.98
P_2O_5	0.29	0.2	0.17	0.16	0.16	0	0	0.17	0
MKN	2.65	0.49	0.42	0.5	0.73	0.1	0.07	0.41	0.11

Table 7 continued

Sample	S7251	S3321	S540	SL1806c	SL1806A	S4219	S1481/1	SL1806B
SiO_2	69.9	70.58	71.22	71.7	72.06	72.12	72.62	73.66
TiO_2	0.32	0.35	0.31	0.1	0.1	0.27	0.09	0
Al_2O_3	15.7	15.21	15.18	15.59	14.36	13.8	14.59	14.62
Fe_2O_3	0.77	0.67	0.74	0.4	0.39	2.3	0.69	0.16
FeO	2.31	2.08	2.12	1.36	2.37	0	2.88	1.29
MnO	0.03	0.07	0.02	0.05	0.07	0	0.06	0.01
MgO	1.1	1	0.8	0.6	1.7	0.2	0.49	0.1
CaO	3.2	3.4	3.77	3.07	3.11	4.76	1.77	2.23
Na_2O	3.82	3.89	5.06	4.09	3.33	4.37	3.68	3.75
K_2O	1.05	1	0.91	2.29	1.34	1.1	1.02	3.23
P_2O_5	0	0	0	0.08	0.08	0	0	0.04
MKN	0.46	1.23	0.07	0.29	0.4	1.07	0.5	0.13

Table 8

Representative chemical composition of metabasalts of the Huoi Hao Formation
(data from Phan Son *et al.,* 2005-in the Son La sheet group at 1:200,000 scale)

Sample	SL.4007/4	SL.90KT	SL.88KT/2	SL.1585	SL.5194	SL.6058	SL.94KT	SL.88KT/3	SL.6062/1	SL.4007/1
SiO_2	43.86	46.94	47.03	47.24	48.64	49.76	49.88	49.94	51.84	53.72
TiO_2	1	1.8	1.7	2.6	1.4	2.1	2.2	0.9	1.3	0.4
Al_2O_3	16.45	13.89	13.34	13.23	14.97	12.32	12.3	16.52	14.06	12.72
Fe_2O_3	0.94	5.12	3.3	3.51	3.87	1.98	4.18	2.13	2.67	0.43
FeO	8.15	7.62	8.24	9.23	5.9	12.29	10	6.91	8.3	4.63
MnO	0.2	0.21	0.18	0.18	0.18	0.29	0.21	0.13	0.25	0.12
MgO	7.82	7.58	7.58	6.72	9.38	6.42	6.29	9.18	5.93	9.43
CaO	6.14	11.1	10.55	9.07	11.38	7.83	9.58	5	8.79	5.3
Na_2O	2.05	1.72	2.19	2.84	1.88	2.25	1.41	1.72	2.25	2.41
K_2O	0.5	0.13	0.19	0.67	0.23	0.25	0.13	0.13	1	0.17
P_2O_5	0.27	0.27	0.27	0.17	0.2	0.24	0.36	0.29	0.11	0.24
MKN	11	2.08	2.87	2.81	0.48	2.43	0.92	5.31	1.56	8.97

Table 9

Representative chemical composition of picrite (P.18), picrobasalt (H.639), basalt (H.615); andesitobasalt (T1500), basaltolivine (T1648) of the Cam Thuy and Vien Nam formations. (H – Sample from the Institute of Geosciences (ASTVN); P, T – Sample from the Phong Tho sheet group at 1:50,000 scale)

Sample	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5
P.18	43.89	2.14	6.55	12.76	0.19	22.91	10.22	0.21	0.17	0.27
P.181/89	47.85	2.64	15.03	11.4	0.16	6.04	8.96	3.25	1.07	0.37
H639	46.27	2.31	9.04	13.23	0.22	12.16	12.78	2.49	0.63	0.25
H615	46.27	2.35	14.02	13.87	0.24	7.32	8.24	3.29	1.25	0.2
T1500	54.29	3.26	10.33	14.41	0.18	5.77	6.79	0.9	0.57	0.39
T1648	48.47	1.58	14.64	13.93	0.23	7.4	10.31	2.39	0.79	0.18
	Ni	Co	Cu	Cr	V	Rb	Sr	Nb	Zr	Y
P.18	-	-	-	-	-	2	212	65	197	17
P.181/89	79	30		390	390	20	166	80	324	37.5
H639	297	67	87	848	227	62	689	59	209	22
H615	95	59	163	125	285	46	287	39	118	26
T1500	91	41	118	263	249	61	210	67	260	45
T1648	320	54	30	240	240	25.8	186	11.9	128.4	33.3

Table 9 continued

Sample	La	Ce	Nd	Sm	Eu	Gd	Th	Yb	Lu
P.18	23.6	49	26	5.6	1.7	4.5	0.7	1.2	0.2
P.181/89	24.8	52.3	30.6	8.2	2.5	8.9	1.4	2.9	0.4
H639	33	68	36	7.4	2.2	5.4	0.8	1.7	0.2
H615	20.4	43	24	5.6	1.8	4.9	0.8	1.8	0.2
T1500	43	86	47	10.5	3.5	8.4	1.3	2.6	0.3
T1648	13.6	29	17	4.5	1.4	5	0.8	3	0.4

Table 10

Representative chemical composition of the ultramafic Ban Xang complex
(data from Nguyen Xuan Bao *et al.,* 2005-in the Van Yen sheet group at 1:200,000 scale)

Sample	844	920/78	P.191	844/78	862/78	861/78	886/78	VY6522
SiO_2	34.3	34.45	35.2	35.44	36.4	37.4	38.05	40.62
TiO_2	0.08	0.05	0.04	0.14	0.14	0.13	0.08	0.6
Al_2O_3	1	0.95	0.5	1.43	1.2	1.3	1.9	4.79
Fe_2O_3	8.86	3.06	4.04	3.48	3.72	3.52	2.33	4.16
FeO	1.48	2.68	2.4	5.45	9.34	9.34	2.77	7.26
MnO	0.12	0.01	0.08	0.01	0.16	0.15	0.01	0.18
MgO	36.85	40.4	40.7	37.35	35.75	33.77	39.9	24.47
CaO	0.62	0.43	0.24	1.89	2.94	2.67	1.33	5.86
Na_2O	0.02	1.12	0.67	0.45	0.09	0.28	1.17	2.08
K_2O	0.01	0.5	0.12	0.25	0.08	0.1	0.3	0.94
P_2O_5	0.01	0.01	0.03	0	0.1	0.09	0	0.2
	VY9536/2	**VY968/1**	**VY9505/1**	**VY4156/2**	**VY4156/d**	**VY9515/1**	**VY904**	**VY4154**
SiO_2	41.82	41.82	42.18	43.98	44.02	44.36	45.38	45.82
TiO_2	0.7	0.8	1.1	1.7	1.9	1.1	1.4	0.6
Al_2O_3	4.2	7.46	6.75	6.99	6.86	8.61	11.32	11.42
Fe_2O_3	2.72	2.51	2.17	3.05	2.33	3.16	2.31	2.98
FeO	8.98	8.69	10.2	7.54	8.19	7.44	9.3	6.04
MnO	0.21	0.16	0.17	0.17	0.17	0.17	0.23	0.15
MgO	24.27	22.95	22.26	16.85	14.44	11.85	12.27	14.94
CaO	7.11	6.38	6.84	8.05	10.6	10.04	9.58	10.46
Na_2O	1.25	0.31	1.25	2.13	2	1.75	2.19	1.15
K_2O	1.26	0	0.31	1.5	1.23	0.31	1.88	0.75
P_2O_5	0.24	0.17	0.24	0.33	0.36	0.2	0.24	0.13

Table 11a

Representative chemical composition of granitoids of the Dien Bien Phu complex
(data from Tran Dang Tuyet *et al.*, 2005- in the Khi Su-Muong Te sheet group at 1:200,000 scale)

Sample	M.301	M.63/4	M.8005	M.64/2	M.302	M.1532	M.5017	M.1039/3	M.1500	M.67/1	M.1506	M.6128
SiO_2	48.54	48.74	50.3	50.58	50.58	51.64	57.08	57.26	58.03	58.74	58.82	61.5
TiO_2	2.1	0.2	1.3	1.9	1.08	1.33	0.6	1.4	0.76	0.7	0.97	0.4
Al_2O_3	14.75	14.77	14.87	15.59	15.04	17.09	16.47	16.69	17.5	16.4	16.68	17.43
Fe_2O_3	2.29	3.95	1.92	7.62	3.55	3.65	3.31	2.48	3.45	2.87	3.66	1.71
FeO	8.66	9.27	6.03	3.5	9.38	6.2	4.49	7.61	3.65	4.35	3.6	3.88
MnO	0.24	0.27	0.15	0.25	0.24	0.13	0.16	0.13	0.1	0.17	0.1	0.12
MgO	5.91	5.84	5.95	4.43	4.11	1.56	3.33	5.11	0.82	3.33	0.89	1.7
CaO	7.25	6.17	6.87	6.17	5.86	13.14	5.47	4.32	8.84	4.63	9.43	16
Na_2O	3.06	3.75	3.57	3.59	3.47	2.75	3.21	4.75	2.3	3.04	2.16	3.06
K_2O	2.34	0.87	1.25	1.53	0.47	1.26	1	0.42	1.2	1.87	1.43	1.71
P_2O_5	0.4	0.55	0.31	0.58	0.4	0.26	0.29	0.31	0.24	0.29	0.2	0.16

Table 11a continued

Sample	M.6142	M.6135/1	M.6121	M.6117	M.5	M.6129	M.6158	M.6144/1	TD.68	M.6138	M.68	M.1038
SiO_2	61.58	61.98	62.02	62.02	63.02	62.26	63.54	63.82	64.14	64.86	66.34	66.78
TiO_2	0.4	0.4	0.3	0.3	0	0.2	0.4	0.2	0.5	0.3	1.3	0.4
Al_2O_3	16.33	15.51	16.6	16.55	14.8	16.96	15.51	15.42	15.46	15.62	13.31	15.34
Fe_2O_3	2.03	2.35	1.71	1.32	2.23	1.3	2.02	1.32	1.93	1.72	2.16	1.01
FeO	3.73	3.44	2.66	3.66	3.8	3.66	2.87	2.66	1.94	3.95	3.06	3.09
MnO	0.13	0.13	0.15	0.18	0.15	0.17	0.16	0.12	0.07	0.12	0.09	0.08
MgO	2.19	2.1	1.3	2.51	1.68	1.6	2.19	1.5	0.69	1.91	1.91	1.6
CaO	4.44	3.89	5.83	1.95	4.42	5.27	1.94	6.66	1.52	4.46	0.42	3.35
Na_2O	3.21	3.21	3.25	3.5	3.75	3.06	3.21	2.5	4.14	3.19	2.81	3.33
K_2O	1.72	2.5	1.25	2.97	2.5	1.05	4.17	0.91	5.5	1.93	3.75	2.32
P_2O_5	0.16	0.16	0.16	0.16	0.17	0.2	0.11	0.11	0.16	0.16	0.45	0.17

Table 11b

Representative trace element composition of granitoids of the Dien Bien Phu complex
(data from Tran Dang Tuyet *et al.*, 2005 – in the Khi Su-Muong Te sheet group at 1:200,000 scale)

Sample	N.7113/1	MT.7085	N.7109	MT.27/1	MT.303	MT.53/1	MT.47	MT.46	MT.32/2	MT.50	MT.49	MT.305
	Dien Bien 1					Dien Bien 2				Dien Bien 3		
La	18	39.9	44.8	26	34.8	12	8.6	17.9	45.8	37	47.5	18.5
Ce	48.9	93.4	41.9	66.7	82.7	33	22	32	88.4	78.6	89.6	42.7
Nd	19.5	25.5	18.3	33.9	46.5	17.9	14	22.6	29	8.48	46.5	22.6
Sm	6.04	12.6	8.2	6.7	9.7	4	3.5	6	5.01	6	6.9	5.9
Eu	1.66	1.3	1.02	1.8	1.8	1.1	1	1.1	1.2	1.03	0.94	1
Gd	-	-	-	8.2	8.2	4.6	4.4	6.4	5.9	6.99	7.7	5.2
Tb	0.94	1.43	0.47	1.2	1.1	0.7	0.76	0.97	2.8	1	0.95	0.8
Dy	-	-	-	8	6.8	4.6	5	6.66	5.2	7.4	6.5	5.6
Ho	-	-	-	1.08	1.2	0.94	1	1.4	1.1	1.54	1.4	1.2
Er	-	-	-	5	3.6	2.7	2.9	4.21	3.19	4.64	4.2	3.6
Tm	-	-	-	-	-	-	-	-	-	-	-	-
Yb	3.49	6	3.6	4	3.4	2.2	2.5	3.9	2.9	4.2	2.74	3.5
Lu	0.15	0.22	0.16	0.5	0.58	0.37	0.33	0.51	0.3	0.45	0.47	0.5
Y	29.9	57.1	34.9	36	32	19	25.9	33.7	27	38	32	30.2
Nb	70	50.3	49.3	12	14	14.9	12.5	7	11	14.7	14	15
Ga	-	-	-	26.9	14.8	7	7.8	12.9	13.7	26	15	7.6
Zr	-	-	-	221	300	98	200	135	223	289	320	176
Sr	343	188	78.1	177	267	76.7	157	121	231	165	167	111
Th	5.53	6.34	7.58	5.4	14.5	2.1	2	1.9	16	18.2	20.7	3.9
Cr	18.6	65.7	53	64.5	16.4	328	35	325	66.9	4.8	656	226
U	0.44	0.75	1.5	0.4	4.4	0.2	0.5	0.3	2.2	3.9	3.6	0.2
Rb	8.02	24.9	16.4	30.8	66.6	48	49.3	80	68.7	129	80	51.8
Ba	139	135	271	511	984	121	520	353	1347	563	667	312
Hf	4.06	7.82	2.91	5.8	8.1	2.2	4.8	3	5.6	7.1	8.6	4
Zn	190	102	71.2	728	306	86	88.5	137	166	430.1	149	80
Ta	0.57	1.54	0.8	0.99	1.5	0.3	0.5	0.1	0.3	2	1.2	0.4
Sb	2.14	1.36	0.24	3.1	1	0.1	0.7	0.4	1.5	92.6	0.8	1.2

Table 11b continued

Sample	MT.7085/1	N.7112	MT.304/1	N.7111	MT.7122	MT.7109/1	MT.7109/2	MT.7082/3	N.7119/2	N.7119/1	MT.7082/2	N.7075
	Dien Bien 3											
La	104	30.3	29.8	45.8	31.6	44.17	54.8	41.5	14.8	20.1	37.2	26.9
Ce	92.9	46.7	51.2	64.3	92.3	53	146.8	34.7	44.2	17.3	27.5	38.3
Nd	16.2	11.7	19.1	13.3	18.1	22.38	22.9	7.49	4.52	4.82	9.96	7.7
Sm	9.93	5.18	3.1	9.17	3.43	4.88	6.05	4.12	2.61	2.86	4.83	6.79
Eu	0.63	0.55	0.5	1.93	1.45	0.51	1.22	0.5	0.96	0.43	0.34	1.21
Gd	-	-	2.8	-	-	3.95	-	-	-	-	-	-
Tb	0.55	0.26	0.5	0.94	0.35	0.64	0.77	0.31	0.35	0.23	0.24	0.98
Dy	-	-	3.5	-	-	3.56	-	-	-	-	-	-
Ho	-	-	0.75	-	-	0.63	-	-	-	-	-	-
Er	-	-	2.08	-	-	2.47	-	-	-	-	-	-
Tm	-	-	-	-	-	0.43	-	-	-	-	-	-
Yb	3.12	1.94	1.8	6.23	1.8	1.84	3.31	1.77	2.14	1.4	1.8	3.4
Lu	0.39	0.57	0.28	0.75	0.51	0.29	0.49	0.32	0.08	0.27	0.59	0.37
Y	32.4	21	15.7	55.7	14.2	14.17	30.7	19.7	20.5	16.3	20.9	31.6
Nb	12.1	27.5	7.9	35.5	21.3	-	12.3	2.12	17.2	37.2	15.2	46.9
Ga	-	-	6	-	-	-	-	-	-	-	-	-
Zr	-	-	135	-	-	-	-	-	-	-	-	-
Sr	207	142	176	139	168	-	69	176	189	209	150	131
Th	8.76	7.65	15.6	10.3	5.22	-	3.14	7.88	10.9	4.01	4.86	1.89
Cr	9.99	13.1	3.8	15.2	26.5	-	11.8	5.94	9.94	3.33	4.8	14
U	1.97	1.15	3.3	1.63	1.2	-	0.66	1.73	2.36	0.63	1.34	0.74
Rb	51	96.5	72.2	90.4	116	-	113	22.4	64.2	8.15	50.6	144
Ba	249	254	800	892	500	-	579	128	307	73.5	193	738
Hf	7.63	3.3	3.4	6.39	5.22	-	6.13	2.73	3.56	2.21	1.7	4.37
Zn	29.9	20.1	58.5	44	58	-	48.6	23.5	83.1	11.4	13.5	62
Ta	0.5	1.27	0.53	2.15	2.35	-	0.99	0.37	0.65	0.32	0.54	1.27
Sb	0.58	1.02	0.4	0.98	1.56	-	0.91	0.02	1.37	0.3	1.08	0.63

Table 12

Representative chemical and trace element composition of granitoids of the Song Ma complex (data from RIGMR & DGMV, 2007)

Sample	26	27	28	29	30	31	32	33	34
SiO_2	68.34	72.16	72.66	73.12	73.54	74.2	74.58	75.18	76.29
TiO_2	0.8	0.23	0.45	0.4	0.3	0.3	0.33	0.8	0.35
Al_2O_3	14.45	13.27	14.12	12.33	12.68	12.2	12.5	12.65	12.78
Fe_2O_3	0.05	1.39	1.13	1.24	0.99	0.89	1.2	1.28	0.6
FeO	2.95	1.62	1.17	2.87	2.59	2.25	2.08	0.57	2.73
MnO	0.09	0.22	0.16	0.12	0	0.03	0.06	0.08	0
MgO	1.4	0.15	0.63	0.22	0.44	0.04	0.05	0.3	0.48
CaO	1.4	0.22	0.07	0.29	0.39	1.45	2.25	0.56	0.44
Na_2O	2.9	3.19	2.98	2.82	2.84	2.3	2.16	2.5	2.86
K_2O	4.82	5	4.77	4.81	4.48	4.32	4.66	5.88	3.18
P_2O_5	0.27	0.02	0.03	0.02	0.04	0.3	0	0.17	0
La	67.15	92.7	91.67	184.85	215.76	216.67	187.27	196.67	195.45
Ce	37.13	47.92	41.44	120.45	143.18	139.77	120.45	127.27	120.45
Pr	42.32	84.02	81.43	88.13	115.18	110.71	109.82	114.29	96.43
Nd	20.2	29.07	27.88	62.33	77.83	76.17	73	71.83	76.17
Sm	11.27	17.62	16.96	48.78	55.25	52.87	47.73	48.56	48.4
Eu	8.26	10.43	7.25	17.39	16.09	18.7	14.35	17.1	17.54
Gd	7.79	10.24	11.2	29.96	34.38	30.84	28.11	30.36	28.43
Tb	13.19	18.3	20.64	21.49	22.13	20.21	18.51	20	22.77
Dy	4.55	4.43	6.3	19.07	21.72	20.03	17.43	17.81	19.5
Ho	10.57	13	13.57	18.86	19.57	16.14	15.43	14	19.71
Er	5.95	5.85	8.85	16.05	15.55	15.15	12.15	10.55	17.7
Tm	8.33	8	11	18	14	12.67	11.67	9.67	12.67
Yb	5.35	3.65	7.65	13.25	16	12	10.55	11.65	14.25
Lu	5.59	5	8.82	13.53	16.47	12.35	13.53	13.82	13.53
Sr	155	163	129.7	111	63.2	143	93.9	86.2	192
Rb	310.5	361.8	284.4	180.1	141	208.8	172	156	187
Ba	1063	755.5	711.8	672	643	924	846	850	909
U	2.43	2.65	2.86	3.11	2.79	4.33	3.56	4.12	4.17
Th	24	24.85	18.98	25.8	38.3	29.6	26.6	24	22.6
Ta	2.7	2.11	1.53	0.17	0.16	0.16	0.12	0.08	0.1
Nb	27.55	22.18	16.96	2.11	2.05	2.01	3.51	3.32	2.11
Zr	333.06	174.59	230.85	15.55	37.57	16.96	21.5	12.28	12.87
Hf	7.12	5.23	5.41	0.52	0.55	0.51	0.46	0.47	0.52
Y	16.64	14.28	17.75	32.12	35.84	27.51	26.73	27.78	32.67
Ti	3838.7	4307.5	3233.8	2990.8	2243.1	2422.5	2894.8	5735.5	2989.4
V	59	93.5	55.6	252.2	122.3	118.6	254.8	475.2	297.6
Cr	61	44.7	75.4	171.6	176.5	139	166.1	329.1	171.5
Co	12.4	10.8	9	26.5	27.6	33.2	37.4	18.8	21.6

Table 13

Representative chemical and trace element composition of granitoids of the Phia Bioc complex and Suoi Be Formation (data from RIGMR & DGMV, 2007)

Sample	35	36	37	38	39	T931331	T931344	T931352
	Phia Bioc					Suoi Be		
SiO_2	66.4	70.08	70.34	70.36	71.96	46.5	36.82	44.79
TiO_2	0.62	0.61	0.44	0.53	0.38	3.13	2.75	3.15
Al_2O_3	15.22	13.18	13.61	13.34	12.79	15.05	20.76	12.37
Fe_2O_3	1.48	1.07	1.2	0.8	0.91	8.97	15.27	8.58
FeO	3.27	2.48	2.08	2.44	2.23	5.93	4.39	6.82
MnO	0.09	0.05	0.07	0	0.01	0.31	0.29	0.34
MgO	1.21	1.21	1.01	1.11	1.31	4.97	3.12	5.85
CaO	1.4	1.4	1.68	1.68	0.28	5.27	3.45	7.16
Na_2O	4.53	2.5	2.71	2.36	2.64	4.78	0.05	3.3
K_2O	2.97	4.88	4.69	4.72	5.25	1.7	7.24	0.08
P_2O_5	0.2	0.24	0.27	0.18	0.24	0.7	0.52	1.31
LOI	-	-	-	-	-	2.76	5.4	6.69
Total	97.39	97.7	98.1	97.52	98	100.07	100.06	100.44
Sc	-	-	-	-	-	25	32	28
V	-	-	-	-	-	395	353	236
Cr	121.1	111.7	76.2	95.4	64.7	34	139	84
Co	-	-	-	-	-	49	43	43
Ni	-	-	-	-	-	19	121	34
Cu	-	-	-	-	-	9	72	13
Zn	-	-	-	-	-	201	343	167
Ga	-	-	-	-	-	24.3	35.8	19
Rb	75	83.9	116	85.1	74.1	45.4	358	2.1
Sr	21.9	20	38.9	23.5	8.5	250	18	97
Y	24.9	27.8	22.6	19.8	33.3	45	19	44
Zr	18.7	27.5	26.7	20.9	27.3	304	230	159
Nb	46.66	18.16	42.21	35.58	39.74	33	25.4	18.8
Ba	878.7	756.7	843.8	711.1	1022.5	858	654	37
La	242.73	196.97	224.85	223.33	135.45	66.53	18.69	30.05
Ce	163.64	135.23	142.05	135.23	101.59	147.57	37.77	67.88
Pr	129.46	112.5	110.05	118.75	76.43	14.45	4.41	9.29
Nd	106.5	79.5	76.33	76.83	45.67	58.3	18.54	41.59
Sm	62.98	50.83	55.8	55.14	39.78	10.58	4.13	9.18
Eu	24.49	13.33	14.93	15.36	9.42	3.32	1.62	3.66
Gd	44.58	35.26	38.23	35.26	28.39	10.89	4.63	9.95
Tb	30.21	20.43	25.53	28.3	22.13	1.55	0.73	1.47
Dy	28.78	22.3	22.89	22.39	19.77	8.13	4.22	7.89
Ho	25.43	21.14	19.43	20.29	19.14	1.69	0.98	1.63
Er	23.9	18.9	19.9	19.95	18.9	4.92	3.16	4.57
Tm	17.67	20.67	16	17	16.67	0.66	0.48	0.59
Yb	21.05	17.05	17.97	18.35	18.75	4.38	3.43	3.77
Lu	20	15.88	18.24	17.06	16.76	0.63	0.56	0.54
Hf	3.84	4.57	3.61	5.06	4.97	6.67	4.81	3.28
Ta	3.56	3.18	3.46	3.83	3.22	2.02	1.59	1.17
Pb	-	-	-	-	-	11	15	8
Th	27.6	23.3	25.6	21.3	30.7	8.5	5.3	2.8
U	3.22	2.15	3.12	2.54	2.51	0.5	2.4	0.7
Ti	4207.9	4522.1	2767.9	3442.1	2378.9	-	-	-

Table 14

Representative chemical and trace element composition of gabbros of the Nam Chien complex (data from Nguyen Xuan Bao *et al.,* 2005-in the Van Yen sheet group at 1:200,000 scale)

Sample	H154	H155	H156	H158	H161	H167	H168	H170
SiO_2	48.98	45.56	46.58	47.45	48.27	44.78	46.35	47.58
TiO_2	3.47	2.02	3.3	2.66	3.63	2.78	3.29	2.65
Al_2O_3	11.86	15.65	12.85	13.36	11.78	12.1	13.22	13.62
Fe_2O_3	4.72	2.77	4.61	4.34	4.72	2.42	15.64	14.19
FeO	10.59	8.42	10.76	9.38	10.28	10.93	-	-
MnO	0.24	0.18	0.22	0.19	0.21	0.2	0.23	0.21
MgO	2.98	7.28	4.76	5.34	3.66	4.44	5.2	5.58
CaO	7.98	11.22	9.47	9.47	8.62	9.22	7.47	8.77
Na_2O	1.77	2.33	2.8	3.26	2.16	2.24	3.17	3.02
K_2O	3	0.16	0.59	0.88	1.8	1.57	1.51	1.2
P_2O_5	1.47	0.36	0.69	0.45	1.48	0.55	0.62	0.52
LOI	2.77	3.79	3.2	2.81	2.88	8.9	-	-
Total	99.83	99.74	99.83	99.59	99.49	100.13	96.7	97.34
Sc	25	29	34	38	29	43	-	-
V	204	264	433	436	258	347	-	-
Cr	11	155	44	106	13	73	-	-
Co	27	60	43	43	45	39	-	-
Ni	7	146	23	35	9	27	-	-
Cu	17	108	19	36	68	45	-	-
Zn	149	112	151	129	138	162	-	-
Ga	22.6	15.7	20.1	19	23.2	17.9	-	-
Rb	152	3.4	21.1	22	79	96	-	-
Sr	408	276	299	401	387	169	-	-
Y	71	24	43	37	70	40	-	-
Zr	370	113	194	169	325	206	-	-
Nb	32.1	13.4	17.5	15.5	28.9	17.4	-	-
Ba	1884	78	228	369	1015	240	-	-
La	68.67	18.81	30.45	28.67	61.32	32.08	31	28
Ce	122.27	35.34	59.07	55.5	121.52	66.16	70	61
Nd	74.73	23.33	34.86	29.62	64.59	33.75	39	36
Sm	15.92	4.91	8.03	7.26	14.43	7.94	9.3	8.6
Eu	5.17	1.82	2.8	2.3	5.09	2.65	3.15	2.76
Gd	-	-	-	-	-	-	9.8	8.5
Tb	2.38	1.26	1.25	1.14	1.95	1.16	1.5	1.36
Yb	5.89	2	3.71	4.28	6.77	4.61	3.9	3.6
Lu	1.16	0.37	0.67	0.6	0.84	0.59	0.56	0.52
Hf	9.98	3.04	4.45	4.51	8.11	5.15	-	-
Ta	1.81	1.11	0.97	1.07	1.81	1.04	-	-
Pb	7	6	5	6	10	7	-	-
Th	9.8	<0.5	2.9	4.1	8.1	3.2	-	-
U	1.2	<0.5	<0.5	0.6	<0.5	0.6	-	-

Table 15

Representative chemical and trace element composition of rhyolite of the Tu Le and Ngoi Thia subvolcanic complex (data from Tran Tuan Anh *et al.,* 2004)

Sample	T929	T985	RR30	LY.918	H152	H187	H198
	Tu Le				Ngoi Thia		
SiO_2	77.06	74.68	65.64	75.5	75.07	77.56	72.69
TiO_2	0.25	0.23	0.79	0.26	0.24	0.22	0.31
Al_2O_3	11.21	12.33	14.03	11.27	11.9	12.26	12.25
Fe_2O_3	0.79	1.09	3.64	3.12	0.79	1.07	1.16
FeO	2.3	1.96	2.46		2.19	1.14	2.11
MnO	0.12	0.05	0.21	0.05	0.11	0.04	0.11
MgO	0.08	0.2	0.59	0.1	0.36	0.34	0.23
CaO	0.21	0.17	1.65	0.01	0.07	0.07	0.8
Na_2O	1.1	3.07	4.85	4.38	1.39	1.84	3.91
K_2O	5.32	4.78	4.67	4.97	5.43	3.43	4.05
P_2O_5	0.01	0	0.14	0.03	0.01	0.01	0.02
LOI	2.14	0.81	1.16	-	2.04	1.81	1.88
Sc	0	0	-	-	1	<1	2
V	<2	3	24	-	5	<1	<2
Cr	23	11	4	-	7	4	6
Co	2	<1	2	-	<1	3.6	<1
Ni	3	6	4	-	4	3	2
Cu	3	1	5	-	2	<1	1
Zn	180	170	175	-	58	74	40
Ga	23.1	30.5	29.5	-	28.8	31.2	32.8
Rb	176	97	123	270	190	168	139
Sr	15	18	123	5.2	9.2	9.4	14.6
Y	107	156	63	101	84	114	89
Zr	1038	975	514	1221	929	1023	818
Nb	112.1	125.4	87.8	275	114.7	117.3	113.5
Ba	43	211	936		105	81	73
La	207.6	185.7	104.4	123	167.13	191.63	149.66
Ce	419.8	321.8	218.4	215	287.33	326.48	272.73
Nd	243.3	209.4	131.3	84	204.24	185.65	202.62
Sm	28.8	29.7	15.7	17.9	23	27.55	24.26
Eu	0.72	1.67	3.21	0.62	0.82	1.23	1.39
Tb	3.17	3.76	1.84	2.9	2.37	2.99	2.78
Yb	12	9.29	6.54	10	10.65	15.14	10.18
Lu	1.43	1.43	1.06	1.5	1.4	1.59	1.42
Hf	25.6	23.9	18.4	26	25.67	29.43	24.04
Ta	8.13	8.99	5.46	12	7.89	9.35	8.99
Pb	-	-	-	-	2	6	3
Th	29	28.4	14.4	27	24	27.7	23.1
U	5	5.3	2.3	6.5	4.1	6	3.6

Table 16

Representative chemical and trace element composition of granitoids of the Muong Hum and Phu Sa Phin complexes (data from Tran Trong Hoa *et al.*, 2004)

Sample	H-902	H-903	H-906	H10/92	H12/92	H17/92	SH-1317	SH-1318	SH-1319	SH-1320	H178	H182	V188	T962
	Muong Hum										Phu Sa Phin			
Analysis by XRF method														
SiO_2	71.52	71.07	73.37	75.21	76.14	73.67	71.51	75.54	75.35	72.91	62.87	72.9	74.5	77.23
TiO_2	0.33	0.3	0.27	0.29	0.39	0.26	0.35	0.25	0.24	0.28	1	0.33	0.34	0.22
Al_2O_3	11.66	11.06	12.3	10.74	12.35	10.72	13.65	11.97	11.96	12.46	16.06	12.77	11.88	11.02
Fe_2O_3	3.15	4.18	2.85	3.4	4.04	3.05	3.64	3.39	2.56	3.09	2.36	1.19	0.97	1.22
FeO	-	-	-	-	-	-	-	-	-	-	2.82	2.32	1.78	1.07
MnO	0.05	0.05	0.08	0.03	0.13	0.07	0.12	0.07	0.03	0.05	0.19	0.08	0.12	0.05
MgO	0.06	0.19	0.18	0.15	0.04	0.05	0	0	0	0	0.93	0.45	0.13	0.24
CaO	0.38	0.91	0.5	0.18	0.52	0.36	0.59	0.39	0.29	0.22	2.03	1.11	0.07	0.36
Na_2O	2.65	3.67	4.39	3.05	4.59	4.29	4.3	4.29	3.89	1.85	5.21	3.65	2.63	2.63
K_2O	7.34	5.45	4.83	6.01	4.81	4.84	5.63	4.38	4.95	8.37	4.97	4.21	6.27	4.12
P_2O_5	0.03	0.02	0.01	0.02	0.03	0.02	0.03	0.01	0.01	0.03	0.27	0.02	0.01	0
LOI	-	-	-	0.13	0.07	0.34	-	-	-	-	1.13	1.58	1.66	1.24
Total	97.14	96.88	98.79	99.21	103.11	97.67	99.82	100.29	99.27	99.27	99.84	100.61	100.36	99.4
Analysis by ICP-MS method														
Ba	1880	3854	450.9	285.6	1325	420.4	409.4	327.2	1127	1940	1245	277	91	69
Rb	205.1	194.4	29.32	110.4	158.6	187.5	115.4	220.1	184.8	210.4	98	108	202	209
Sr	171	180	309.5	76.97	85.3	70.34	22.34	25.33	19.06	121.9	196	26	7	13
Cs	1.29	0.63	1.16	0.51	0.36	1.09	0.49	0.73	0.74	0.65	-	-	-	-
Ta	21.28	9.78	0.86	12.08	14.96	14.14	5.58	15.64	9.13	9.37	2.93	7.58	12.1	10.5
Nb	252.6	125.8	17.08	154.2	169.6	168.3	83.44	185.3	124.9	91.41	47.3	106.2	133.6	116.9
Hf	41.16	22.91	5.49	29.87	30.16	30.24	16.01	35.93	19.96	20.69	8.42	24.9	31.5	27.8
Zr	1384	874.3	187.3	1008	911.4	890.5	668.9	1167	759	734.3	320	877	1187	1002
Y	346.8	72.18	24.42	108.9	108.4	117.6	58.15	172	93.14	50.95	42	100	124	101
Th	60.57	24.6	18.73	30.35	29.19	32.02	17.61	31.49	27.57	13.81	7	24.6	38.3	23.4
U	10.8	6.91	11.41	5.74	8.98	6.83	3.05	7.71	5.95	3.26	2.8	4.3	7.7	5.8
Cr	0.87	1.68	6.26	2.18	4.18	1.2	-	1.65	-	1.1	7	23	4	8
Ni	0.76		4.26	0.59	0.27	-	-	1.08	-	-	3	4	4	4
Co	1.99	2.06	6.84	1.46	3.19	2.1	-	0.24	-	0.51	5	<1	1	4
Sc	14.49	4.91	12.7	22.36	7.62	12.55	11.89	20.46	10.33	20.64	8	0	0	3.41
V	9.11		11.38	3.05	8.82	9.03	-	2.24		10.86	33	<2	6	5
Cu	15.65	10.61	365	4.91	4.65	6	0.88	7.93	4.97	14.86	5	2	16	1
Pb	38.32	22.95	4.01	6.54	5.73	19.76	6.33	20.08	25.73	39.76	9	-	-	
Zn	267.5	218.4	18.15	195	47.32	152.6	112.4	250.9	188.6	89.1	164	54	295	42
La	503.6	205.1	127.6	239.9	212.3	126.3	113.6	121.7	111.4	234.2	62.4	120.7	166.7	88.7
Ce	891.9	374.5	226.2	361.4	364.8	262	220.4	258.6	209.5	366.2	128.7	248.9	327.8	190.6
Pr	98.31	42.51	20.83	49.2	40.13	28.85	26.38	28.06	26.42	39.43	-	-	-	-
Nd	379.3	141.8	71.07	178.7	147.1	108	92.07	111.1	94.06	124.1	78.7	134.9	160.6	121.8
Sm	64.03	20.7	10.03	28.83	24.63	21.41	15.26	23.72	17.83	16.51	10.6	20.4	21.4	16.9
Eu	4.35	2.25	1.46	1.27	1.9	1.01	1.18	1.15	1	1.96	2.95	2.07	1.2	0.76
Gd	55.91	16.84	7.64	23.47	20.98	18.4	12.11	20.61	15.08	13.78	-	-	-	-
Tb	8.9	2.39	0.97	3.55	3.27	3.29	1.82	3.99	2.62	1.85	1.2	2.78	3.6	2.44
Dy	50.41	12.6	4.83	20.05	18.63	20.13	9.87	25.73	15.3	9.53	-	-	-	-
Ho	9.82	2.37	0.86	3.93	3.74	4.1	1.88	5.36	2.98	1.78	-	-	-	-
Er	26.54	6.87	2.33	11.34	10.62	11.8	5.57	15.24	8.51	5.28	-	-	-	-
Tm	4.12	1.09	0.34	1.9	1.75	1.98	0.92	2.43	1.36	0.83	-	-	-	-
Yb	23.93	6.81	2.08	12.07	10.57	12.09	5.98	14.13	8.3	5.1	4.06	12.2	13.2	11
Lu	3.58	1.14	0.32	1.89	1.58	1.75	1.02	2.04	1.31	0.84	0.54	1.33	1.74	1.52
Ga	-	-	-	-	-	-	-	-	-	-	26	28.3	21.4	34.1

Table 17

Representative chemical composition of granitoids from the Ye Yen Sun complex (data from Tran Tuan Anh *et al.*, 2002)

Sample	SH.1326	SH.1327	SH.1328	SH.1329	SH.1331	SH.1332
	West O Quy Ho				East O Quy Ho	
SiO_2	75.74	69.75	70.1	71.99	78.15	71.9
TiO_2	0.08	0.22	0.2	0.17	0.27	0.36
Al_2O_3	14.89	16.27	16.56	16.1	11.48	14.25
Fe_2O_3	0.35	1.33	1.19	0.8	2.66	2.92
MnO	0	0.04	0.02	0.02	0.01	0.05
MgO	0	0.13	0	0.07	0	0.22
CaO	0.81	1.75	1.45	1.6	0.11	0.17
Na_2O	4.04	4.44	4.34	4.12	2.16	3.73
K_2O	4.03	4.56	4.72	4.17	5.55	6.13
P_2O_5	0.01	0.07	0.03	0.04	0.02	0.04
Cu	1.826	4.892	7.541	4.064	4.825	4.515
Co	-	0.995	0.321	0.508	-	-
Cr	-	2.717	-	1.041	-	-
Pb	39.39	30.01	32.56	29.31	16.74	11.13
Cs	3.348	3.092	1.642	3.319	2.869	1.681
Rb	187.6	150.4	135.3	163	201.4	219.3
Sr	216.7	1289	1447	448.6	46.7	26.02
Y	10.21	11.58	8.1	6.051	97.52	64.37
Zr	92.89	177.2	178.3	103.6	1013	728.8
Nb	17.9	11.35	7.148	11.91	167.7	94.12
Ba	481.1	2890	3319	1229	109.2	349.3
La	9.57	42.32	37.42	14.62	124.5	121.5
Ce	17.15	71.63	60.06	25.44	259.2	238.4
Pr	1.981	7.945	6.364	2.896	31.92	28.27
Nd	6.61	26.89	20.5	9.875	112.1	97.27
Sm	1.278	4.419	3.117	1.796	21.78	16.7
Eu	0.249	1.38	1.057	0.68	0.707	1.637
Gd	1.163	3.462	2.44	1.412	18.1	13.41
Tb	0.19	0.416	0.282	0.167	3.056	2.08
Dy	1.272	1.98	1.329	0.865	17.84	11.54
Ho	0.257	0.339	0.221	0.163	3.45	2.219
Er	0.916	1	0.651	0.525	10.18	6.511
Tm	0.165	0.146	0.09	0.082	1.659	1.061
Yb	1.259	1.002	0.645	0.62	10.19	6.692
Lu	0.236	0.159	0.095	0.1	1.555	1.083
Hf	3.612	5.382	4.643	3.007	28.06	20.32
Ta	1.594	0.751	0.454	0.762	12.98	6.858
Th	16.61	20.97	19.67	12	27.52	22.1
U	8.978	4.524	4.514	4.036	6.862	4.213
K/Rb	178.33	251.58	289.29	212.52	228.68	232
Rb/Sr	0.87	0.12	0.09	0.36	4.31	8.43
Rb/Ba	0.39	0.05	0.04	0.13	1.84	0.63
Eu/Eu*	0.62	1.04	1.17	1.3	0.11	0.33
(La/Yb)N	5.38	29.99	41.46	16.73	8.65	12.88

Table 18

Content of main components of rare and trace elements of trachyte and trachyrhyolite of the Pu Tra Formation
(T – Sample from the Institute of Geosciences (VAST), P – Sample from the Phong Tho sheet group at 1:50,000 scale)

Sample	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5
T.776	59.55	0.48	15.21	3.58	0.07	0.57	4.77	2.61	8.79	0.25
P.175	70.79	0.20	15.01	1.72	0.03	0.74	0.82	3.44	6.17	0.11
	Rb	**Sr**	**Nb**	**Zr**	**Y**	**La**	**Ce**	**Nd**	**Sm**	
T.776	259.6	1777	25.99	413.7	37.3	106.3	196.2	72.9	12.4	
P.175	296.3	614.7	23.39	180.2	18.9	49.5	96.6	32.9	5.2	
	Eu	Gd	Tb	Yb	Lu	Th	U	Ta	Hf	
T.776	2.77	8.95	1.29	3.02	0.45	25.8	7.33	1.356	9.6	
P.175	1.15	3.46	0.55	1.81	0.28	24.8	11.67	1.77	5.09	

Table 19

Representative chemical and trace element composition of alkaline granite of the Nam Xe-Tam Duong, Pu Sam Cap and Coc Pia complexes (data from Tran Trong Hoa, 1996 & 1999)

Sample	H.43	H.45	MT.7077/4	MT.7076/3	MT.7076/2	N.7107/1	T.770	V-III	P.45	T.1591	T.1737
	Nam Xe-Tam Duong						Pu Sam Cap		Coc Pia		
SiO_2	64.29	64.51	68.62	73.53	73.78	73.86	56.87	62.15	48.32	54.26	52.88
TiO_2	0.3	0.22	0.2	0	0	0	0.54	0.41	0.63	0.54	0.8
Al_2O_3	16.81	17.38	14.32	12.5	12.38	12.12	16.24	15.63	11.03	10.02	15.36
Fe_2O_3	2.84	2.59	3.3	0.22	2.82	3.17	5.35	4.01	6.52	5.14	6.73
FeO	-	-	1.15	3.52	0.32	0.86	-	-	-	-	-
MnO	0.06	0.08	0.07	0.3	0	0	0.09	0.14	0.14	0.11	0.15
MgO	0.17	0.17	0.3	0	0.3	0.6	0.21	0.49	9.25	6.07	5.59
CaO	2.52	1.96	0.28	0.28	0	0	3.93	2.98	10.99	6.73	6.52
Na_2O	3.57	5.23	4.64	4.1	4.5	4.1	2.29	4.2	0.3	1.04	2.61
K_2O	9.4	7.33	5.42	4.64	4.5	4.25	10.17	8.27	6.25	4.98	6.23
P_2O_5	0.08	0.06	0.08	0.05	0.11	0.11	0.18	0.18	0.57	0.3	0.53
Rb	180	154	136	59.4	124	80.6	265.7	241.6	253	218	163
Sr	1606	2169	224	147	78.5	120	3989	2535	4318	1226	2555
Nb	13.01	19.3	17.2	7.61	8.74	26.4	32.89	32.27	11.9	20.6	13.1
Zr	91.8	72.9	-	-	-	-	521.8	559.1	246	206	469
Y	37.9	28.8	63.5	50.4	59.4	78.4	47.11	43.52	26	24.2	25
Th	10.1	48.1	8.51	8.11	11.4	12.5	37.4	38.1	-	-	-
U	70.5	93.9	2.68	1.64	1.58	1.66	1.1	9.3	-	-	-
Ta	0.8	1.1	1.42	0.75	1.48	1.36	1.5	1.5	0.6	0.9	1.4
Hf	3.9	2.4	3.7	10.6	10	7.89	12.5	13.3	-	-	-
La	31.5	37	85.9	110	114	79	156.3	146.1	170	49	117
Ce	70.5	93.9	62.2	114	102.1	87.5	292.8	268.2	224	89	185
Nd	44.1	47.8	13.1	21.2	36	20.8	105.9	91.8	68	41	81
Sm	10	8.8	11.7	10.9	22.3	13.9	17.9	14.6	10.3	7.5	17.2
Eu	2.5	1.9	0.23	0.41	3.65	0.15	3.9	3.3	2.5	1.9	3.7
Gd	3.3	2.9	-	-	-	-	12	10.1	6.1	5.9	13.6
Tb	1.2	0.9	0.67	0.59	1.54	0.91	1.7	1.5	0.9	0.9	1.9
Yb	3	2.9	5.99	4.79	7.64	7.44	3.6	3.4	1.9	1.9	2.6
Lu	0.5	0.5	1.29	0.7	0.75	0.76	0.5	0.5	0.3	0.3	0.3
Sb	-	-	0.58	0.21	1.09	0.3	-	-	-	-	-
Cr	-	-	3.55	6.85	16.5	6.35			863	335	169

Table 19 continued

Sample	H.43	H.45	MT.7077/4	MT.7076/3	MT.7076/2	N.7107/1	T.770	V-III	P.45	T.1591	T.1737
	Nam Xe-Tam Duong						Pu Sam Cap		Coc Pia		
Ba	-	-	94.6	137	796	35.3	-	-	-	-	-
Zn	-	-	20.4	16.9	12	39.4	-	-	-	-	-
Cu	-	-	-	-	-	-	-	-	73	64	61
Ni	-	-	-	-	-	-	-	-	346	149	76
Co	-	-	-	-	-	-	-	-	39	15	28
V	-	-	-	-	-	-	-	-	128	107	118

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