

Modern Approaches in Solid Earth Sciences

Trong-Hoa Tran · Gleb V. Polyakov
Tuan-Anh Tran · Alexander S. Borisenko
Andrey E. Izokh · Pavel A. Balykin
Thi-Phuong Ngo · Thi-Dung Pham

Intraplate Magmatism and Metallogeny of North Vietnam

 Springer

Modern Approaches in Solid Earth Sciences

Volume 11

Series Editors

Yildirim Dilek, Department of Geology and Environmental Earth Sciences,
Miami University, Oxford, OH, U.S.A

Franco Pirajno, Geological Survey of Western Australia, and The University
of Western Australia, Perth, Australia

M.J.R. Wortel, Faculty of Geosciences, Utrecht University, The Netherlands

More information about this series at <http://www.springer.com/series/7377>

Trong-Hoa Tran • Gleb V. Polyakov
Tuan-Anh Tran • Alexander S. Borisenko
Andrey E. Izokh • Pavel A. Balykin
Thi-Phuong Ngo • Thi-Dung Pham

Intraplate Magmatism and Metallogeny of North Vietnam

 Springer

Trong-Hoa Tran
Vietnam Academy of Science
and Technology
Institute of Geological Sciences
Hanoi, Vietnam

Tuan-Anh Tran
Vietnam Academy of Science
and Technology
Institute of Geological Sciences
Hanoi, Vietnam

Andrey E. Izokh
Russian Academy of Science
Institute of Geology and Mineralogy
Novosibirsk, Russia

Thi-Phuong Ngo
Vietnam Academy of Science
and Technology
Institute of Geological Sciences
Hanoi, Vietnam

Gleb V. Polyakov
Russian Academy of Science
Institute of Geology and Mineralogy
Novosibirsk, Russia

Alexander S. Borisenko
Russian Academy of Science
Institute of Geology and Mineralogy
Novosibirsk, Russia

Pavel A. Balykin (deceased)

Thi-Dung Pham
Vietnam Academy of Science
and Technology
Institute of Geological Sciences
Hanoi, Vietnam

Responsible Series Editor: F. Pirajno

This is a revised and updated version of the book in Vietnamese “Intraplate Magmatism and Metallogeny of North Vietnam” by the same authors, published by the Publishing House for Science and Technology for the Vietnam Academy of Science and Technology (VAST) in the series of monographs on Vietnam Natural Resources and Ecology in 2010 (no ISBN is available).

ISSN 1876-1682 ISSN 1876-1690 (electronic)
Modern Approaches in Solid Earth Sciences
ISBN 978-3-319-25233-9 ISBN 978-3-319-25235-3 (eBook)
DOI 10.1007/978-3-319-25235-3

Library of Congress Control Number: 2015953432

Springer Cham Heidelberg New York Dordrecht London
© Springer International Publishing Switzerland 2016

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, express or implied, with respect to the material contained herein or for any errors or omissions that may have been made.

Printed on acid-free paper

Springer International Publishing AG Switzerland is part of Springer Science+Business Media (www.springer.com)

Preface

The study of intraplate magmatism with the aim to reconstruct geodynamic settings and estimate related endogenic mineralization has significant scientific and practical meanings. These allow to consider the role of deep mantle and mantle – lithosphere interaction processes in the formation of large-scaled intraplate rift systems, collision and shear zones, and their associated magma – ore formations having high potentials of gold, gold-copper, precious platinum group metal (PGM), rare earth and radioactive metals (REE–U–Th), and gemstones (ruby, sapphire, etc.).

The clearest expression of intraplate magmatism is mantle plume-induced large igneous provinces (LIP) in Asia during the Permian–Triassic (Dobresov 1997; Nikishin et al. 2002). The mantle plume-related magmatic activities were widely developed in the Asian continent in rift and trap environments forming the Siberian craton and Emeishan LIP, which have been well studied. However, intraplate magmatic activities during the period of Permian–Triassic in Viet Nam have not been detailedly studied with focus on their identification and role in southeastern Asian geodynamic evolution as a whole, as well as their associated mineralization.

This monograph is a combined report of petrological and metallogenic studies of late Paleozoic–early Mesozoic and Cenozoic magmatism in northern Viet Nam in the past several decades by the authors through collaboration between the Institute of Geological Sciences, Vietnam Academy of Science and Technology, and the Institute of Geology and Mineralogy, Siberian Branch of the Russian Academy of Sciences, on magma–metallogeny. Two intraplate magmatic–metallogenic stages in northern Vietnam are being introduced in this monograph; these were associated with two important tectonic events in the evolution of the southeastern Asian continent including Emeishan-type mantle plume during ca. 260–250 Ma and India-Eurasian collision ca. 60–55 Ma.

The Emeishan mantle plume-related impact produced magmas which occurred in wide areas in western and southern margins of the Yangtze craton (China) forming a series of mafic–ultramafic and felsic along with alkaline felsic associations in the craton’s peripheral terrains (e.g., Cathaysian multi-cycle folded belt) including the northeastern terrain of Vietnam. Depending on particular structurally geological

positions within the then-northern Viet Nam regional structure – tectonic framework and the geochemistry according to the lithospheric mantle source – the mantle dynamics and nature of mantle–lithosphere interaction of the Permian–Triassic magmatism formed a number of chemically diversified magmatic–metallogenic associations in northern Viet Nam. Among the ore minerals, clearly high potential associations include Cu–Ni–PGM, Ti–Fe–V, Cu–Au, Sn–Pb–Zn–Ag, Sb–Hg–(Au), and others that occurred in industry-rated ore fields that are being exploited to serve the nation’s needs. Among the Permian–Triassic magmatic formations, this monograph will focus only on volcano–plutonic mafic–ultramafic and felsic magmas in the Song Da–Song Hien rift zone and Song Chay anticlinoria. With the new understanding of mantle plume and its role in generating mantle and lithospheric mantle magmatic melts, the Permian–Triassic volcano–plutonic mafic–ultramafic–felsic and alkaline mafic–felsic associations and accompanying metallogeny in northern Viet Nam may be explained by the impact of the Emeishan mantle plume on the lithospheric mantle under different lithospheric structures in southwestern and southern margins of the Yangtze craton. This is the first time that genetic relation between the magmatism and mineralization has been proven using geochemical and isotopic data.

The India–Eurasian collision in the Cenozoic is considered as the major force that changed the form in the southeast Asian tectonic map, forming intercontinental shear zones such as the Ailao Shan–Red River. Along both sides of the shear zone, there are a series of intraplate extended belts containing typical Mediterranean-type mafic and felsic magmatic associations and their accompanying ore mineralization of Cu–Au, Cu–Mo–Au porphyry, REE–Th–U, and others, starting from Tibet to Vietnam. This is also the first time that the formation of Cenozoic magma–metallogenic associations is associated with the evolution of the shear zone.

The monograph contains nine chapters included in three parts: Part I introduces general regional geological structures in northern Viet Nam; Part II is about Permian–Triassic magmatic–metallogenic associations; and Part III dedicates to Cenozoic (Paleogene) magmatic ore mineralization formations, corresponding to the abovementioned geological events. Each chapter describes geological features, principles of dividing magmatic associations in different structures, and compositional characteristics, including geochemical, mineralogical, isotopic, and chronologic compositions analyzed using the latest analyzing methods in world well-known laboratories. In explaining formation conditions of magmatic ore associations and related geodynamic settings, the authors have employed with selection the concept of plate tectonics and plume-related kinematics from the world’s most recent geological literature. Many of the research results being introduced in this monograph have been reported in international and domestic reputed journals, as well as appeared in a number of master’s and doctorate theses. Besides, the monograph also contains newly achieved results that have not been reported elsewhere.

Materials being introduced in this monograph may be useful for both domestic and international geologists in exploring the history of geological and metallogenic evolution in Vietnam as an important marginal region of the Asian continent. One of the most practical contributions offered by the monograph is providing new criteria on prediction and potential evaluation of magmatic metallogenesis,

directly helping in exploring and finding new and valuable mineral resources for national use. The introduced monograph is useful for science and technology projects and may be used as university teaching materials in the field of petrology and metallogeny.

After the first monograph entitled *Permian–Triassic mafic and ultramafic magmatic formations in Northern Vietnam* published in 1996 in the occasion of the 20th Anniversary of the Institute of Geological Sciences, Vietnam Academy of Science and Technology (1976–1996), this monograph is the second being introduced as a result of a 25-year Vietnam–Russia research collaboration (1984–2009).

During the preparation of the monograph, the authors have constantly received support from the leaders of Vietnam Academy of Science and Technology (VAST), Institute of Geological Sciences (IGS), and Science and Technology Publishing House. Discussions with and suggestions by colleagues helped improve the contents of the monograph. Contributors from the Magma Department (IGS), direct or indirect, include Drs. Hoang Huu Thanh, Vu Van Van, Bui An Nien, Tran Quoc Hung, Phan Luu Anh, and other researchers including Tran Viet Anh, Hoang Viet Hang, and Tran Hong Lam; international colleagues from the Russian Institute of Geology and Mineralogy (Siberian Branch, Russian Academy of Science) include Petrov V.G., Petrova T.I., Ponomarchuc V.A., Gaskov I.V., Shelepaev R., Telesev A.E., and many others. Many of the geochemical and isotopic data being introduced here were analyzed at the National Taiwan University and Institute of Earth Sciences, Academia Sinica (Taiwan) thank to Drs. Chung S-L., Lo C-H., and Lan C.Y.

All are gratefully acknowledged.

This monograph is a result of the International Collaboration Research Protocol entitled “Investigation of origin and formation conditions of magma – metallogenic formations having high potentials of Pt, Au and Ti-V in Vietnam” (2007–2009) and Basic Research project coded 70.87.06 “Geodynamics, origin and formation conditions of magmatic – metallogenic formations of high potentials of Cu-Au, Cu-Mo-Au porphyry in Vietnam” with support from the Viet Nam–Russian research collaboration fund № 08-05-90304Viet_a (2008–2009) and Basic Research Project “Permian – Triassic magmatism and metallogeny of Tu Le and Phan Si Pang structures in relation to mantle plume” of the National Foundation for Science and Technology Development (NAFOSTED) coded 105.06.73.09.

Last, regardless of our best effort, there must be shortcomings in the monograph’s preparation and edition, the authors kindly appeal to readers for suggestions in order to improve the quality of the monograph.

Hanoi, Vietnam

Novosibirsk, Russia

Hanoi, Vietnam

Novosibirsk, Russia

Novosibirsk, Russia

Novosibirsk, Russia

Hanoi, Vietnam

Hanoi, Vietnam

Trong-Hoa Tran

Gleb V. Polyakov

Tuan-Anh Tran

Alexander S. Borisenko

Andrey E. Izokh

Pavel A. Balykin

Thi-Phuong Ngo

Thi-Dung Pham

Contents

Part I Structure: Tectonics and Magmatic Activities in Northern Vietnam

1 An Overview on the Structures, Tectonics and Magmatic Activities in North Vietnam	3
1.1 Vietnam in the Southeast Asian Tectonic Framework.....	3
1.2 Major Structural Factors in Northern Vietnam.....	5
1.3 Magmatic Activities in Northern Vietnam	8
References.....	11

Part II Permian: Triassic Magmatic Activity

2 Permian – Triassic Magmatic Activity in the Song Da Structure	17
2.1 Song Da Permian – Triassic Mafic and Ultramafic Pluton – Volcanic Formations.....	18
2.1.1 Magma Classification.....	18
2.1.2 Komatiite – Basalt Associations in Nam Muoi and Ta Khoa Areas	20
2.1.3 High-Ti Basalt Associations	42
References.....	54
3 Plutonic: Volcanic Associations in the Tu Le Basin and Phan Si Pan Uplift, Northwest Vietnam	59
3.1 Problem of Permian: Triassic Age for Volcanic and Sub-volcanic Magmas in the Tu Le Basin and Alkaline Granites in the Phan Si Pan Uplift	59
3.2 Mafic- Felsic Pluton-Volcanic Associations in the Tu Le Basin	60
3.2.1 Geological Characteristics	62
3.2.2 Petrologic, Mineralogical and Geochemical Characteristics.....	63
3.2.3 Isotopic Characteristics.....	71

3.3	Permian Granitoids in the Phan Si Pan Uplift	74
3.3.1	Geology, Petrology and Mineralogy	74
3.3.2	Elemental and Isotopic Geochemistry	78
3.4	Magmatic Formation and Tectonic Settings	95
	References	100
4	Permian – Triassic Pluton – Volcanic Magmatic Associations in the Song Hien Structure, Northeast Vietnam	103
4.1	Basalt – Rhyolite Associations	105
4.1.1	Geology, Age and Petrologic and Mineralogical Characteristics.....	105
4.1.2	Geochemistry and Isotope.....	109
4.2	Gabbro-Dolerite and Gabbro-norite – Lherzolite Associations.....	122
4.2.1	Gabbrodolerite (and Congadiabase)	122
4.2.2	Gabbro-norite – Lherzolite Intrusions.....	131
4.3	Geodynamics	147
	References	149
5	Gabbro and Syenite Intrusions in the Lo Gam Structure, Northeast Vietnam	153
5.1	Gabbro-Granite Series	154
5.1.1	Layered Gabbro-Peridotite Intrusions.....	154
5.1.2	Phia Bioc-Type High-Al Granites.....	173
5.2	Gabbro-Syenite Intrusive Formations in the Lo Gam Structure.....	180
5.2.1	Geology and Formation Age of the Gabbro and Syenite.....	180
5.2.2	Mineralogy	184
5.2.3	Geochemical and Isotopic Characteristics	198
5.2.4	Formation Condition and Geodynamic Setting	205
	References	206
6	Permian – Triassic Metallogeny.....	209
6.1	PGE-Cu-Ni and V-Ti-Fe Mineralization Complexes	212
6.1.1	Komatiite-Basalt Related PGE-Cu-Ni Mineralization Complex in Song Da Rift.....	212
6.1.2	(PGE)-Cu-Ni Sulfide Ore Mineralization in Song Hien Pl-Peridotite	226
6.1.3	Cu-Ni-PGE and Ti-Fe-V Mineralization Related to Nui Chua- Type Layered Gabbro – Peridotite in Phu Ngu – Lo Gam Structures	233
6.1.4	Fe-Skarn Ore Complexes	236
6.2	Au-Sulfide and Sn-Sulfide Complexes	236
6.2.1	Au-Cu Mineralization	236
6.2.2	Au-As Mineralization Type	237

6.2.3	Antimony – Gold (Sb – Au), Antimony – Mercury (Sb – Hg) and Mercury – Gold (Hg – Au) Ore Types	239
6.2.4	Sn-Sulfide Mineralization	245
6.3	Summary on the Permian – Triassic Mineralization Stage	247
	References	250
 Part III India – Eurasian Collision – Related Cenozoic Magmatic Activities		
7	Paleogene Potassic and Ultra-potassic Volcano-Plutonic Associations in the Song Da Rift	257
7.1	Geological Features	258
7.2	Petrography and Mineralogy	261
7.3	Geochemistry and Isotopes	274
7.4	Magma Origin, P-T Parameters and Geodynamic Settings	284
	References	289
8	Magmatic Activities in the Phan Si Pan Uplift and Red River Zone	291
8.1	Cenozoic Ye Yen Sun Granite Complex in the Phan Si Pan Uplift ...	292
8.1.1	Geological, Petrological and Mineralogical Characteristics ...	292
8.1.2	Geochemical Characteristics	297
8.1.3	Magma Source and Geodynamic Setting	302
8.2	Peridotite – Gabbro Associations in the Red River Shear Zone	305
8.2.1	Summary on the Red River Shear Zone	305
8.2.2	Mafic and Ultramafic Magmatism in the Red River Fault Zone	306
8.2.3	Distribution and Geological Structure Characteristics	307
8.2.4	Petrological and Mineralogical Characteristics	315
8.2.5	Geochemical Characteristics	325
8.2.6	Formation Age and Geodynamic Settings	332
8.3	Granite Formations in the Red River Shear Zone	334
8.3.1	Biotite Granite and Leucogranite Associations	335
8.3.2	Petrologic, Mineralogical and Geochemical Characteristics	335
8.3.3	Isotopic Characteristics	338
8.3.4	Formation Ages	340
8.3.5	Source Origin and Formation Conditions	342
8.4	Summary on Cenozoic Magmatic Activities	343
	References	345
9	Metallogeny in the Cenozoic	349
9.1	TR – F – Ba Ore Complex	350
9.2	Au-Cu Complex	351

9.3 Mo-(Cu-Au) Complex	351
9.3.1 Mo-(Cu-Au) Mineralization of O Quy Ho.....	352
9.3.2 Mineralization at Suoi Lanh (Ban Khoang).....	352
9.3.3 Mineralogical, Geochemical and Isotopic Characteristics	354
9.4 Ruby – Sapphire Mineralization.....	357
References.....	357
Conclusions	359
Index	363

Part I
Structure: Tectonics and Magmatic
Activities in Northern Vietnam

Chapter 1

An Overview on the Structures, Tectonics and Magmatic Activities in North Vietnam

Abstract Reconstruction of paleo-geodynamic framework of Vietnam in the relation to major tectonic events in southeast Asia reveals that Paleozoic structures in Northern Vietnam (from northeastern Song Ma suture zone northward) were developed in the southern and southeastern margins of the Yangtze Block. Northern Vietnam is divided into two major folding systems, based on their positions relative to the Song Hong fault zone.

The most important structural elements in northern Vietnam are Precambrian massifs including the Phan Si Pan uplift, the Late Paleozoic – Early Mesozoic Song Da – Tu Le continental rift. Many of the volcanic basins previously determined as Mesozoic have been added to Paleozoic Song Da rift volcanic groups as newly evidence of Permian – Triassic age from sedimentary, volcanic and subvolcanic formations in the Tu Le Basin coming to light. Meanwhile several major tectonic units are classified in Northeastern Vietnam. These include the Song Chay dome – outcrop of Yangtze massif's basement that was reactivated during the Permian – Triassic, and the surrounding Paleozoic folding structures such as Lo Gam and Phu Ngu. The latter are viewed as various erosion terraces of the Song Chay dome. The Paleozoic structures are surrounded by the Mesozoic Song Hien and An Chau basins, and by the circle-shaped Yen Minh – Phu Luong fault zone.

1.1 Vietnam in the Southeast Asian Tectonic Framework

History of SE Asian geological formation and evolution is related to a number of complex geological events, starting from the Archean to the present time. In the present tectonic framework Vietnam belongs to two major geo-blocks, e.g., the Indochina in the southwest and North Vietnam – South China block in the northeast (Tung and Tri 1992) (Fig. 1.1). The two blocks are divided by the Ailao Shan – Red River Shear Zone (RRSZ) (e.g. Tapponnier et al. 1982).

The RRSZ, originating in Tibet (China) running to the continental shelf of the Vietnam East Sea with more than 1000 km. There are four narrow high-grade metamorphic belts located within the RRSZ. One is the Day Nui Con Voi (DNCV) in Vietnam, the other three including Ailao Shan, Diancang Shan and Xuelong are in Yunnan, China (Leloup et al. 1995; Harrison et al. 1996). The DNCV belt is less

than 10 km wide and more than 250 km long, spreading from Lao Cai to Viet Tri province. To the northwest the belt gradually join the Ailao Shan fault zone, while in the south the DNCV is covered by Red River Neogene – Quaternary sediments. The DNCV fault zone is divided from the other northern Vietnam structures by the Song Hong and Song Chay deep fault systems. Both fault systems show a steep, northeasterly dip angle (ca. 70°), and reach down to depths between 30 and 50 km. Proterozoic is the oldest age determined based on the levels of metamorphism (such as almandine – amphibolite – granulite facies) in the Song Hong fault zone (Geological Map of Northern Vietnam 1967, 1977, 1989). However, recent studies have shown that metamorphic and deformed activities in the Song Hong fault zone occurred in the Paleogene, mostly Oligocene (Tapponnier et al. 1990). The metamorphic complexes include amphibole-bearing gneiss, kyanite-schist, surrounded by various mafic and ultramafic bodies. The RRSZ plays an important role in the history of Southeast Asian tectonics. Recent radiometric age data have shown that cooling time of anatexis melts in the regional metamorphic complexes occurred between 24 and 26 Ma (Schaerer and Tapponnier 1990, 1994), most in agreement with the timing of India – Eurasian collision induced continental extrusion (e.g. Tapponnier et al. 1990). The magnitude of extrusion was estimated between 330±60 km (e.g. Lacassin and Leloup 1993) or 500 and 700 km (after Tapponnier et al. 1990; Leloup et al. 1995).

Another important tectonic structure in the northern Vietnam geology is the Song Ma suture zone, that is named for the presence of Paleozoic ophiolite association (Tran Van Tri 1977; Bach 1986). Many researchers believe that the Indochina and

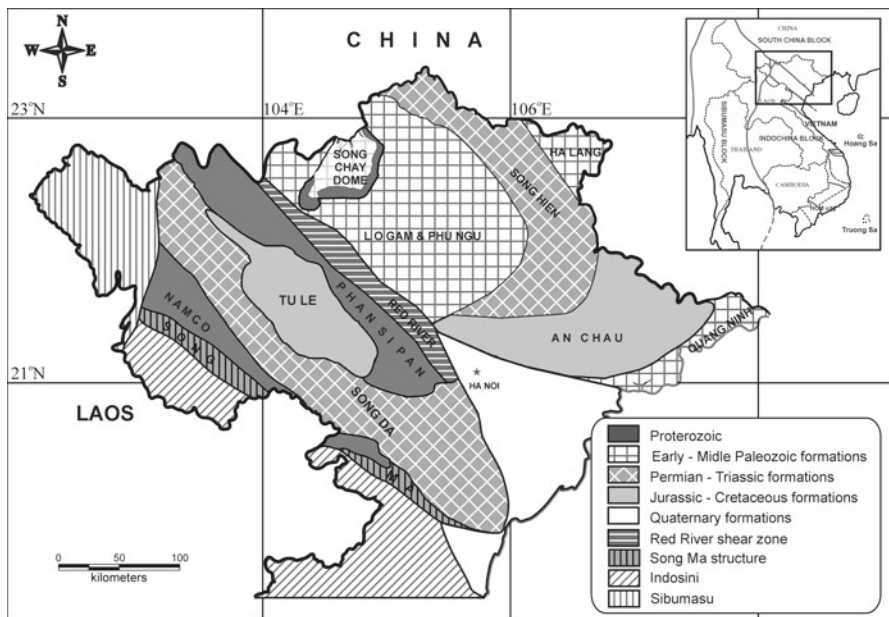


Fig. 1.1 Distribution scheme of major tectonic structures in northern Vietnam

South China (the Yangtze basement and surrounding folded structures) blocks were amalgamated during the late Paleozoic that led to the formation of Truong Son Indosinian orogeny that spans about 1000 km along the margin of Indochina block from the border between China and Vietnam in the north to the Kontum massif in south Central Vietnam (Fig. 1.1). Within this orogeny belt several magmatic types have been identified such as ophiolitic, orogeny, post-orogeny comprising pluton-volcanic magmatic associations; therefore, this structure is termed as Truong Son pluton-volcanic belt (Hoa et al. 2008). To the southeast the orogenic belt is detached by a Mesozoic pluton-volcanic belt that is developed in the northeast direction and termed as Dalat segment (Thi 1995; Hoa et al. 2005). The formation and evolution of the Dalat segment was thought to relate to the subduction of Pacific plate under the Asian continent (Tung and Tri 1992; Bao 2001; Hoa et al. 2005).

1.2 Major Structural Factors in Northern Vietnam

Reconstruction of paleo-geodynamic framework of Vietnam in the relation to major tectonic events in southeast Asia reveals that Paleozoic structures in Northern Vietnam (from northeastern Song Ma suture zone northward) were developed in the southern and southeastern margins of the Yangtze Block. Northern Vietnam is divided into two major folding systems, based on their positions relative to the Song Hong fault zone, being identified as Northwest Northeast. In turn, in each folding system a series of structural units are identified such as facies, zones (Dovjikov 1965; Tri 1977) or terrains (Bach 2001).

The most important structural elements in northern Vietnam are Precambrian massifs including the Phan Si Pan uplift, the Late Paleozoic – Early Mesozoic Song Da – Tu Le continental rift (Fig. 1.1). Many of the volcanic basins previously determined as Mesozoic have been added to Paleozoic Song Da rift volcanic groups as newly evidence of Permian – Triassic age from sedimentary, volcanic and subvolcanic formations in the Tu Le Basin coming to light. This will be described in detail in the subsequent chapters. Meanwhile several major tectonic units are classified in Northeastern Vietnam. These include the Song Chay dome – outcrop of Yangtze massif's basement that was reactivated during the Permian – Triassic, and the surrounding Paleozoic folding structures such as Lo Gam and Phu Ngu. The latter are viewed as various erosion terraces of the Song Chay dome. The Paleozoic structures are surrounded by the Mesozoic Song Hien and An Chau basins, and by the circle-shaped Yen Minh – Phu Luong fault zone.

A brief description of the major structures listed above and embedded intraplate magmatic associations, which are the focus of this monograph, is given below.

The Phan Si Pan Uplift block is an elongated lens-shaped of about 200 km running in the north-southeast direction, from northern tip of Lao Cai province to the northern margin of Song Da structure in Hoa Binh province. To the west the block is separated from the Song Da – Tu Le rift by a system of regional faults, while in the east, is bordered by the RRSZ. The Phan Si Pan is consisted mostly of

Precambrian and Paleozoic metamorphosed sediments and various plutonic associations having diversified compositions and occurrence ages. These include Archean calc-alkaline granitoids such as Ca Vinh type (Lan et al. 2001; Nam 2001), Meso- Proterozoic metagabbro of Bao Ha type (Hoa et al. 1999a), high K-granitoids of Xom Giau type and calc-Neoproterozoic alkaline granitoids of Po Sen type (Nam 2003). Permian alkaline granitoids such as Muong Hum, Phu Sa Phin and Phan Si Pan complexes and Cenozoic Ye Yen Sun granitoids, respectively, are widely spread elsewhere in the block.

Permian – Triassic Song Da – Tu Le continental rift system is a trough-like structure containing terrigenous – volcanic formations. The rift system extends over 300 km long (within Vietnam) and more than 100 km wide. To the west, the Song Da – Tu Le rift is circled by the Nam Co platform system West Bac Bo Paleozoic intracontinental orogenic belt showing outcrops of Precambrian rocks (Tri and Khuc 2011); to the east is bordered by the Phan Si Pan uplift block. There are a number of mafic pluton- volcanic associations of tholeiitic and sub-alkaline types whose geochemistry is closely similar to continental rifting-induced magmas such as East African, Emeishan (China) and Siberian trap basalts. Subalkaline and alkaline felsic pluton – volcanic associations are also widely occurred, especially, in the Tu Le basin. The formation and evolution Song Da – Tu Le continental rift during the Permian – Triassic contemporaneous with the amalgamation of Indochina and Vietnam – South China paleo-continental blocks are viewed as an important geological event. However, the nature of tectonic setting of the Song Da – Tu Le structure remains controversial. Those hypothetical settings include inner-continental rift (Tri 1977; Gatinsky 1986; Hoa 1995, 1998, 2002; Polyakov et al. 1996), ophiolitic belt (Chuong 1996, 2001), and newly formed oceanic crust (Bach and Thang 1995). Discussions and explanations in Chap. 2, Part II of this work may help clarify this matter.

The Song Chay metamorphic dome located in northeastern Vietnam contains Precambrian fragments of Yangtze basement's origin that were involved in early Paleozoic tectonic activities, especially in the Triassic (e.g. 236 Ma) (after Maluski et al. 2001). U – Pb ages determined for gneiss, crystalline schist and migmatite yielded values between 2500 Ma and 1000 Ma (Tri 1977). On the other hand, protolite age of some metamorphic rocks gave a value of 428 ± 5 Ma (Leloup et al. 1999) contemporaneous with the formation age of granite (Ordovician) in the Song Chay block (Ponomareva et al. 1997). U – Pb (SHRIMP) age dating on zircon in lherzolite and gabbrodolerite (266–262 Ma) in the Suoi Cun block (Song Hien belt) showed evidence of 2900 Ma, 1000 Ma and, especially, 480–460 Ma evolution (Hoa et al. 2008). This suggests that the formation and development of geological structures in northeastern Vietnam are closely related to the formation and evolution of marginal terrains of Yangtze basement.

Lo Gam belt, located to the northeast of RRSZ along the southeastern margin of Song Chay dome, is comprised mainly of early- middle Paleozoic sedimentary – metamorphic formations, being penetrated by Ordovician – Silurian high-Al granite of the Song Chay complex (Ponomareva et al. 1997). Magmatic activities in this belt are considered as complicated with the earliest occurrence comprising ophiolite-type mafic and ultramafic associations in the southern margin of Song Chay dome.

The magmatic associations also include strongly- serpentinized dunite and harzburgite of the Nam But, and amphibole gabbro, gabbro-dolerite of the Bach Sa complex (Xuyen 2001). Study of actinolite – epidote – chlorite assemblages in an early Cambrian sedimentary – volcanic formation in Ha Giang complex had led several researchers to believe that they are metabasalt belonged to an ophiolite association (Tri, personal comm.). Besides, according to Lien et al. (2005), meta-andesite outcrops elsewhere along a cross-section toward Hoang Su Phi. Within the Lo Gam belt, to the east of Song Chay dome, observed are Permian – Triassic gabbro – syenite plutons with major compositions being monzogabbro, monzogabbro-dolerite. These magmas show a close temporal, spatial as well as geochemical relationship with the syenite; in turn, the this syenite has genetic relation with the gabbro (Hoa et al. 1999b, 2004b). To the east of Lo Gam belt well-developed are trachy-rhyolite, rhyolite and granosyenite magmas having typical intraplate geochemical characteristics (T.T. Hoa unpublished). Permian age of these rocks were determined by U-Pb, LA-ICP-MS for zircon (Tri, personal comm.). High-Al granite is widely observed in the Phia Bioc complex, having a close spatial connection with the above mentioned gabbro- syenite plutons. This high-Al granite was previously determined as Late Triassic (Dovjikov 1965; Tri 1977; Thuc and Trung 1965); however, latest radiometric age dating of a high-Al granite in the Tam Tao pluton of Phia Bioc complex yielded a value of 250 ± 0.5 Ma (Permian) (Anh and Hang 2005; Hoa et al. 2008), suggesting that the granite may be contemporaneous with the above Permian – Triassic gabbro – syenite pluton.

The Phu Ngu Zone, to the northeast, is bordered by Song Hien Late Paleozoic – Early Mesozoic terrigenous – volcanic depression and An Chau Late Mesozoic superimposed depression. In nature, the Phu Ngu belt is a structure showing deeper erosion as compared to the encircled Song Chay arc-shaped fold zone. Early – Middle Paleozoic (Ordovician, Silurian and Devonian) terrigenous formations as well as mafic and ultramafic blocks, such as Nui Chua formation, are widely spread in the Phu Ngu zone. These plutons are known as potential resources for Ti – Fe, Cu – Ni and accompanying PGE mineralization. Age of the Nui Chua gabbro-norite formation was determined to be 251 ± 4 Ma (Hoa et al. 2008). The Nui Chua magmas show closely spatial and temporal relation to the high-Al granite of the Phia Bioc complex and alkaline pyroxenite, gabbro and syenite in this area. These alkaline gabbroids were previously classified as Nui Chua Late Triassic formation (Dovjikov 1965; Tri 1977; Thuc and Trung 1965); whereas the syenite in Cho Don complex was Paleogene. Recent studies revealed that the gabbroids showed significantly different petrology and geochemistry compared to those of Nui Chua formation, therefore these magmas may be viewed as a separate magmatic association (Hoa et al. 2004c). Among the alkaline magmas, pyroxenite, gabbroids and syenite are known to contain nepheline (jacupirangite); Rb – Sr isotopic age dating of a nepheline-bearing syenite yielded a value of 230 Ma (Chi 2003), suggesting that these magmas are part of the regional Permian – Triassic magmatic activities.

The Song Hien structure, located in the northeast of the Lo Gam – Phu Ngu structure (for this monograph terms Lo Gam or Lo Gam – Phu Ngu are used hereafter to indicate this duo-structure) is a terrigenous – volcanic depression with more than 200 km long, running in the northwest – southeast direction, from Meo Vac

(Ha Giang province to Loc Binh (Lang Son province)). To the northeast the structure is bordered by Ha Lang Paleozoic structure belonged North East Bac Bo orogenic belt (Tri and Khuc 2011), while in the northeast is covered by the An Chau Late Mesozoic sedimentary superimposed depression. The Song Hien depression is filled mostly by Triassic terrigenous sediments, among these organic-rich shale is dominant. Other formations including Devonian terrigenous, Permian – Triassic bimodal basalt – rhyolite as well as mafic (gabbro-dolerite) and felsic (granite – granophyre) sub-volcanic bodies are widely developed. Mafic – ultramafic plutonic (such as) lherzolite, picrite, gabbro-norite, gabbro-dolerite bodies making the Cao Bang complex are outcropped elsewhere in the depression. Whereas, Cretaceous Sn-W –bearing high-Al granite of Pia Oac formation is distributed in the northwest of the Song Hien structure.

The An Chau late- Mesozoic superimposed depression is a terrigenous – volcanic depression closely similar to that of Song Hien. The terrigenous sediments are Early Triassic and Jurassic accompanied by a minor amount of Early-Middle Triassic felsic sub-volcanic rocks such as rhyo-dacite and rhyolite (Geological Map of Vietnam 1989). The products are commonly crisscrossed by porphyric granite sub-volcanic bodies.

The Red River Shear Zone (RRSZ) in Vietnam is a southeastern extension of the Ailao Shan – Red River Shear Zone (ARRSZ), starting from Tibet (China) spanning to Vietnam East Sea. The extension is exposed for more than 250 km in the northwest – southeast direction before being buried under the current Red River Trough. The RRSZ is comprised majorly of paragneiss of biotite – silimanite – almandine – cordierite assemblages, and a subsidiary amount of marble, crystalline shale, paramphibolite and quartzite. Based on the biotite – garnet thermobarometry and the presence of biotite – garnet – cordierite – K-feldspar assemblage the highest metamorphic grade in the Red River zone may be consistent with almandine – amphibole and granulite facies (Thang and Anh 2000).

Within the RRSZ's gneiss strata mantle derived mafic and ultramafic such as lherzolite, pyroxenite and gabbro-amphibole are outcropped elsewhere. Products of re-metamorphosed of gneiss including aplitic and pegmatite granites, and crystalline shale produced by shear motion along the Red River fault zone in the Cenozoic are also well developed. Besides, bright colored magma-origin high-Al and high alkaline granite bodies are commonly occurred. Ages of the mafic and ultramafic bodies vary between 35 and 25 Ma (Izokh et al. 2004), and between 24 and 22 Ma were determined for bright colored granite (Hoa et al. 2000, 2004b).

1.3 Magmatic Activities in Northern Vietnam

Study of the interaction between the lithosphere and mantle, and among the mantle layers has become a new way in geological and mantle geodynamic research (Kuz'min 2003). Given specific tectonic settings different mantle plume with different scales are defined, for example, hotspot (Hawaii, Iceland..), plume and super

plume (Zonenshan and Kuzmin 1983; Flower and Russo 2001; Kuz'min et al. 2001; Yarmolyuk et al. 2000; Dobresov 2003). Melts resulted from the interaction of deep mantle plumes with the crust and lithospheric mantle may form contrast magmas (bimodal) (Yarmolyuk et al. 2000), gabbro – granite series (Litvinovsky et al. 2001) and flood basalt (trap). Large igneous provinces (LIP) comprising pluton-volcanic mafic magmas are believed to intrude into the crust within a short time span by mantle (and lithospheric mantle) melting under the impact of deep-rooted, thermally anomalous mantle plumes. LIPs can be continental (trap) and oceanic: oceanic plateau, seamount groups, passive marginal volcanic activity (Coffin and Eldholm 1994). Many LIPs show temporal relation to some certain continental plate separation events in particular the Gondwana. This period is characterized by thermally anomalous mantle flows expressed by widely spread picrite magmatic activities and high temperature – low pressure metamorphism; strong lithospheric mantle – crust interaction; formation of massive platinum, gold, rare metal and rare earth deposits.

Mantle plume-related magmas appeared in many parts of Asia as continental rift or trap activity (Siberian craton, Emeishan...). The most important LIP occurrence in Asia was in the Permian – Triassic time (Dobresov 2003; Nikishin et al. 2002). For this reason, the monograph will present data of Permian – Triassic mafic –ultramafic and felsic magmas as well as other intraplate magmas occurred in other time periods in northern Vietnam.

Major stages of geological evolution and magmatic activities in northern Vietnam may be listed as follows Precambrian, early – middle Paleozoic, late Paleozoic – early Mesozoic (Indosinian), late Mesozoic (Pacific or Yen Son stage) and Cenozoic (Himalayan stage). The Precambrian formations include granitoidic, metagabbro, gabbrodolerite together with a minor amount of olivine gabbro. Ar-Ar radiometric age dating yielded a value that is no younger than 1700 Ma (Hoa et al. 1999a; Tran Ngoc Nam and Itaya 1998). The Precambrian granitoids being the major component of Phan Si Pan Uplift are divided into the following complexes (1) Archean trondjemite – tonalite – granodiorite (metagranitoids) of Ca Vinh complex (2834–2936 Ma), (2) high-K biotite granite as of Paleoproterozoic Xom Giau complex (2264 Ma), and (3) Neoproterozoic Po Sen calc-alkaline granitoid complex (760 Ma) (Lan et al. 2001; Nam 2001; Nam et al. 2003).

Early-middle Paleozoic magmatic activity are observed in the Song Ma suture zone, northwest Vietnam, and in marginal structures of the Song Chay dome in form of ophiolitic mafic – ultramafic associations (Bach et al. 1982; Hung et al. 1985; Phuong et al. 1999; Nien et al. 2005). Citing from their position among Cambrian and Cambrian – Ordovician sedimentary – metamorphic layers as well as their corresponding radiometric ages the age of the mafic – ultramafic associations may be about 540–460 Ma (Tung and Tri 1992; Thang et al. 1999; Vuong et al. 2006). These formations were extruded to upper lithological strata, in case of the Song Ma ophiolitic associations, for example, during the late Paleozoic. In the Song Chay dome area there was a report on meta-volcanic rocks with andesitic composition in early Paleozoic sedimentary – metamorphic formations (Lien et al. 2005), suggesting the existence of an ancient (early Paleozoic) subduction zone in the region.

By the Ordovician – Silurian period granitoidic magmatic activity (ca. 460 Ma) was recorded in the Song Chay dome. The granitoids show the geochemistry compatible with those of synchronous collision setting (Ponomareva et al. 1997).

In general, there has none representative pre-Indosinian intraplate magmatism been established in any geological structure in entire northern Vietnam.

Magmatic activity in the Permian – Triassic (Indosinian stage) occurred in most of the structures in northern Vietnam. Magmas in northwestern segment of Truong Son orogeny (west wing of the Song Ma suture zone), in the Muong Te – Dien Bien area, are late Paleozoic (Carboniferous – early Permian) calc-alkaline although Permian – Triassic granitoids (diorite – granodiorite of Dien Bien complex) are the major constituent. These granitoids show geochemical signatures that are mostly similar to subduction-related or active marginal magmas (Anh and Hoa 1996; Anh et al. 2005b). High-Al granite (259–265 Ma by Rb-Sr age dating after Thanh et al. 2005; 260 Ma by U-Pb after Tam 2008) and collision-induced pluton-volcanic associations are also observed in this area (Hoa 1995; Hoa et al. 2008). It has been determined that magmatic complexes in the northwest segment within the Truong Son fold zone was related to the Indosinian orogeny (Anh et al. 2005; Hoa et al. 2008).

Meanwhile Permian – Triassic magmatic activity in other tectonic settings in northern Vietnam shows totally different characteristics. The Song Da – Tu Le rift region in the northwest is characterized by contrast intraplate ultramafic – mafic – alkaline felsic; whereas in the Song Hien rift, arc-like mafic – felsic magmas are dominant. The geochemistry of these Permian pluton – volcanic magmas is corresponding to mantle plume melting interacting with different geological blocks having different lithospheric structures (Hoa et al. 2004a; Izokh et al. 2005). In this same period, gabbro – syenite, layered gabbro-peridotite intrusive bodies and subduction-like high-Al granite occurred in marginal structures around the Song Chay dome (Lo Gam and Phu Ngu) (Hoa et al. 2004b). These occurrences are mostly similar to Permian – Triassic representative magmas in the Song Hien zone.

Magmatic activity in Vietnam during the Mesozoic, according to recent investigations, is much less developed. Since the (Mesozoic) subalkaline and alkaline pluton-volcanic rocks in the Tu Le basin were reconsidered to be Permian – Triassic, late Mesozoic (Jurassic – Cretaceous) magmatic activity in northern Vietnam is even more sporadic, most concentrated only in the northeastern region. To the southeastern Lang Son within Song Hien zone among the terrigenous – (rhyolitic) volcanoclastic Tam Lung formations (J_3tl) (Thanh and Khuc 2005) found are Sn – W-bearing two-mica granite classified as late Cretaceous Pia Oac complex (Thuc and Trung 1995). Besides, according to Dovjikov (1965) felsic intrusive and effusive rocks in the Binh Lieu and Mong Cai area, on the border between late Mesozoic An Chau and Paleozoic Quang Ninh, are late Mesozoic. However, Binh Lieu volcanic formations were determined by stratigraphic correlation to be mid-Triassic (Tuyen et al. 1992), and their Anisian age has been kept since. The new isotopic data (U-Pb, LA-ICP-MS, zircon) of rhyolite from Binh Lieu area showed early Triassic age (246 Ma, unpubl. data). Based on latest mineralogical and geochemical studies, Jurassic volcanic rocks in the Tam Lung formation and Cretaceous two-mica granite in the Song Hien basin are produced during the late Mesozoic (Yanshanian) orogeny.

Therefore, according to the most recent studies there is no intraplate magmatic activity in the Mesozoic being observed in northern Vietnam.

Cenozoic magmatic activity in Vietnam may be divided into two sub-stages: Paleogene and Neogene – Quaternary. The first sub-stage is complicated in terms of appearances as well as chemical compositions. They occurred in various structural settings, and their formation is related to the tectonic collision between India and Eurasia; these are pluton – volcanic associations classified as pre-, syn- and post-collision based on the major tectonic activities in the Red River Fault zone during the Paleogene (Hoa 2007). End of the Cenozoic magmatic activity is marked by small-scaled Neogene – Quaternary basaltic eruption in the Phan Si Pan zone (northwestern tip of Lao Cao province) and Muong Te zone (Dien Bien Province). These Neogene – Quaternary magmas are not described in this monograph.

References

- Bui An Nien, Tran Trong Hoa, Ngo Thi Phuong, Hoang Huu Thanh, Tran Tuan Anh, Pham Thi Dung (2005) Mafic and ultramafic magmatic formations in the Ha Giang and north Pho Rang areas. *J Earth Sci* 27(2):103–114 (in Vietnamese with English abstract)
- Coffin MF, Eldholm O (1994) Large igneous provinces – crustal structure, dimensions and external consequences. *Rev Geophys* 32(1):1–36
- Dao Dinh Thuc, Huynh Trung (eds) (1995) *Geology of Viet Nam, P. II: magmatic formations*. Department of Geology and Minerals of Viet Nam Publication, Hanoi
- Dobresov (2003) Mantle plume and their role in formation of the anorogenic granitoids. *Geol Geophys* 44(12):1243–1261 (in Russian)
- Dovjikov (ed) (1965) *Geology of Northern Viet Nam*. Science and Technology Publication, Hanoi, 668 p
- Flower MFJ, Russo RM (2001) Mantle contamination and the Izu-Bonin-Mariana (IBM) ‘high-tide mark’: evidence for mantle extrusion caused by Tethyan closure. *Tectonophysics* 333(1–2):9–34
- Gatinsky YG (1986) Geodynamics of Southeast Asia in relation to the evolution of ocean basins. *Palaeogeogr Palaeoclimatol Palaeoecol* 55:127–144
- Geology of Viet Nam, P. I. Stratigraphy*. Science and Technology publ (1989) Hanoi (in Vietnamese)
- Harrison TM, Leloup PH, Ryerson FJ, Tapponnier P, Lacassin R, Chen Wenji (1996) Diachronous initiation of transtension along the Ailao Shan-Red River Shear Zone. Yunnan and Vietnam, Tectonic evolution of Asia. *World and regional geology series*. Cambridge University Press, New York, pp 208–226
- Izokh AE, Tran Trong Hoa, Polyakov GV, Ngo Thi Phuong, Tran Tuan Anh, Travin AV (2004) Syn-kinematic ultramafic-mafic magmatism in the Red River shear zone. *J Geol B* 23:26–41
- Izokh AE, Polyakov GV, Tran Trong Hoa, Balykin PA, Ngo Thi Phuong (2005) Permian-Triassic ultramafic-mafic magmatism of Northern Vietnam and Southern China as expression of plume magmatism. *Russ Geol Geophys* 46(9):942–951
- Kuz'min MI, Iarmoluk VV, Kovalenko VI, Ivanov VG (2001) Evolution of Central-Asian's ‘Hot’ field in phanerozoic and some problems of plume-related tectonic. *Ir.GTU, Irkutsk*, pp 246–262
- Lacassin R, Leloup PH (1993) Bounds on strain in large Tertiary shear zones of SE Asia from boundinage restoration. *J Struct Geol* 15(6):677–692

- Lan CY, Chung SL, Lo CH, Lee TY, Wang PL, Li H, Dinh Van Toan (2001) First evidence for Archean continental crust in northern Vietnam and its implications for crustal and tectonic evolution in Southeast Asia. *Geology* 29(3):219–222
- Le Duy Bach (1986) Tectonic evolution of Earth crust in the Indochina. *J Geol A* 176–177:29–39 (in Vietnamese)
- Le Duy Bach (2001) Composite terrane: theory and reality. *J Earth Sci* 23(1):1–15 (in Vietnamese with English abstract)
- Le Duy Bach, Ngo Gia Thang (1995) Phanerozoic ophiolites in Indochina. In: Proceedings of the international symposium geology of SEA and adj. areas, *J Geol B* 5–6:212–221
- Le Duy Bach, Vu Minh Quan, Tran Quoc Hùng, Ngo Gia Thang, Hoang Huu Thanh (1982) Song Ma ophiolite. *J Earth Sci* 4:97–106 (in Vietnamese with English abstract)
- Leloup PH, Ricard Y (1999) Shear heating in continental strike-slip shear zones: model and field examples. *Geophys J Int* 136(1):19–40
- Leloup PH, Tapponnier RLP, Scharer U, Zhong Dalai, Liu Xiaohan, Zhang Shan, Ji Shaocheng, Phan Trong Trinh (1995) The Ailao Shan – Red river shear zone (Yunnan, China), Tertiary transform boundary of Indochina. *Tectonophysics* 251:3–84
- Litvinovsky BA, Yarmolyuk VV, Voronov AA, Zhuravlov DZ, Vosokhov VF, Sandimirova GP, Kuz'min DV (2001) Late Triassic stage of formation of the Mongolo-Transbaikalian alkaline granitoid province: data of isotope-geochemical studies. *Russ Geol Geophys* 42(3):445–455
- Maluski H, Lepvrier C, Jolivet L, Carter A, Roques D, Beyssac O, Ta Trong Thang, Nguyen Duc T, Avigad D (2001) Ar-Ar and fission track ages in the Song Chay massif: early Triassic and Cenozoic tectonics in northern Vietnam. *J Asian Earth Sci* 19:233–248
- Ngo Thi Phuong, Tran Trong Hoa, Hoang Huu Thanh, Tran Tuan Anh (1999) Geochemical significances of Paleozoic igneous rocks of Song Ma belt – Northwest Vietnam. *J Sci Earth* 21(1):51–56
- Nguyen Xuan Bao (ed) (2001) Tectonics and metallogeny of south Viet Nam. Final report to the Ministerial project (Ministry of Natural Resources and Environment), Archives of the Center for Geology Information and Literature, Hanoi (in Vietnamese)
- Nguyen Trung Chi (ed) (2003) Petrology and mineralization of alkaline magma formations in northern Viet Nam. Final report of Ministerial Project (Ministry of Natural Resources and Environment), Center for Information and Literature Archives, Dept. Geology and Minerals, Hanoi (in Vietnamese)
- Nguyen Xuan Tung, Tran Van Tri (eds) (1992) Geological and geodynamic formations of Viet Nam. Science and Technology Publication, Hanoi (in Vietnamese)
- Nguyen Duc Thang, Pham Dinh Truong, Bui Cong Ha (1999) Chemical compositions of ophiolite association in the Song Ma belt. *Geol Nat Miner Resour* III:117–141 (in Vietnamese)
- Nguyen Ngoc Lien, Tran Van Tri, Pham Binh, Pham Hoe (2005) Meta-andesite in the Bac Ha area, Lao Cai province. 60-Anniversary of Geology of Viet Nam 122–125 (in Vietnamese)
- Nguyen Van Thanh, Pham Huy Hoc, Le Hung (2005) New results of Rb-Sr age dating of the Pu Si Lung granitoid. In: Proceedings of science symposium on the 60th anniversary of the Vietnamese Geology, pp 221–225 (in Vietnamese)
- Nguyen Van Vuong, Mai Hong Chuong, Ta Trong Thang (2006) Radiometric ages and evolution of thermal tectonics of ophiolites along the Song Ma deformed belt. *J Earth Sci* 28(2):165–173 (in Vietnamese with English abstract)
- Nikishin AM, Zieler PA, Abbott D, Brunet M-F, Cloetingh S (2002) Permo-Triassic intraplate magmatism and rifting in Eurasia: implications for mantle plumes and mantle dynamics. *Tectonophysics* 351:3–39
- Phan Truong Thi (1995) Indosinian block and Indosinian movement in the Indochina and East Sea in Cenozoic. In: Proceedings of 3-rd geological conference of Vietnam: geology, mineral resources and petroleum, Hanoi, pp 137–147
- Phan Luu Anh, Hoang Viet Hang (2005) Crust-origin of the Tam Tao granite block: evidence of late Permian age. *J Earth Sci* 27(2):115–124 (in Vietnamese with English abstract)
- Polyakov GV, Nguyen Trong Yem, Balykin PA, Tran Trong Hoa, Hoang Huu Thanh, Tran Quoc Hung, Ngo Thi Phuong, Petrova TE, Vu Van Van (1996) Permian – Triassic mafic and ultra-

- mafic formations in northern Viet Nam. Science and Technology Publication, Hanoi, 172 p (in Vietnamese)
- Ponomareva AP, Vladimirov AG, Phan Luu Anh, Kruk NN, Rudnev SN, Ponomarchuk VA, Bibikova EV, Juravlov DJ (1997) High-aluminous granites of Song Chay massif (North Vietnam): Ordovician age, petrogenesis, tectonic position. *Geol Geophys* 38(11):1792–1806 (in Russian)
- Schaerer U, Tapponnier P (1990) Intraplate tectonics in Asia: a precise age for large-scale Miocene movement along the Ailao Shan-Red River shear zone. *China Earth Planet Sci Lett* 97:65–77
- Schaerer U, Zhang LS (1994) Duration of strike-slip movements in large shear zones: the Red River belt, China. *Earth Planet Sci Lett* 126:379–397
- BM Tam (2008) Magmatism in Vietnam according to Global Tectonic Theory. Project Report of Research Institute of Geology and Mineral Resources
- Tapponnier P, Peltzer G, Le Dain AY, Armijo R, Cobbold P (1982) Propagating extension tectonics in Asia: new insights from simple experiment with plasticine. *Geology* 7:611–616
- Tapponnier P, Lacassin R, Leloup H, Scharer U, Zhong Dalai, Liu Xiaohan, Shaocheng J, Zhang Lian Shang, Zhong Jiayou (1990) The Ailao Shan – Red River metamorphic belt: left-lateral shear between Indochina and China. *Nature* 343:431–437
- Tong Duy Thanh, Vu Khuc (eds) (2005) Stratigraphic divisions of Viet Nam. National University Publication, Hanoi, 504 p (in Vietnamese)
- Tran Trong Hoa (ed) (1995) Study of Mesozoic – Cenozoic magmatism and its mineralization potential. Final report for National project KT- 01–04 (1992–1995). Archives of the National Center for Science and Technology Information, Hanoi (in Vietnamese)
- Tran Xuyen (ed) (2001) Geology and mineral resources of the Ma Quan – Bac Quang area (geological map, sheet Ma Quan – Bac Quang, scale 1: 200.000)
- Tran Ngoc Nam (2001) SHRIMP U-Pb isotopic age dating on zircons of the Ca Vinh and Xom Giau complexes. *J Geophys Res* 262:1–11 (in Vietnamese with English abstract)
- Tran Trong Hoa (2002) Subdivision and correlation of Permian-Triassic basaltoid associations in the Song Da Structure (NW Vietnam). *J Geol B*, No 19-20/2002, pp 22–30
- Tran Ngoc Nam (2003) 750 Ma U-Pb age of zircon from Po Sen granite and its tectonic significance. *J Geophys Res* 274:1–2 (in Vietnamese with English abstract)
- Tran Trong Hoa (2007) Intraplate magmatism in North Vietnam and related metallogeny. Dissertation of Dr. of Science, Institute of Geology and Mineralogy, Siberian Branch, RAS, Novosibirsk, 382 p
- Tran Ngoc Nam TM, Itaya T (1998) P-T-t paths and post-metamorphic exhumation of the Day Nui Con Voi shear zone in Vietnam. *Tectonophysics* 290:299–318
- Tran Tuan Anh, Tran Trong Hoa (1996) Permian – Triassic calc-alkaline granitoids in the marginal areas of Truong Son micro-continent, vol 2. *Geology and Natural Resources*, Science and Technology Publication, Hanoi, pp 100–108 (in Vietnamese)
- Tran Tat Thang, Tran Tuan Anh (2000) Indications of granulite metamorphic facies in the Red River zone. *J Earth Sci* 22(4):410–419 (in Vietnamese with English abstract)
- Tran Van Tri TKT, Truong Cam Bao (eds) (1977) *Geology of Vietnam, northern part*. Explanation to geological map of Northern Vietnam at the scale 1: 1.000.000. Institute of Geology and Mineral Resources (in Vietnamese), 357 pp
- Tran Van Tri, Vu Khuc (eds) (2011) *Geology and natural resources of Vietnam*. Science and Technology Publication, Hanoi, 645 p
- Tran Quoc Hung, Bui An Nien, Hoang Huu Thanh (1985) Petro-chemical characteristics and genesis of intrusive rocks in the Song Ma Zone. *J Earth Sci* 7(1):6–11 (in Vietnamese)
- Tran Thanh Tuyen, Vu Khuc, Luu Lan (1992) New findings on Song Hien structure in the Binh Lieu area, Tien Yen. *J Geol* A212–213:68–70 (in Vietnamese with English abstract)
- Tran Trong Hoa, Hoang Huu Thanh, Tran Tuan Anh, Ngo Thi Phuong, Hoang Viet Hang (1998) High-Ti basaltoidic formations in the Song Da rift zone: chemical compositions and geodynamic conditions of magma genesis. *J Geophys Res* 244:7–15 (in Vietnamese with English abstract)
- Tran Trong Hoa, Ngo Thi Phuong, Hoang Huu Thanh, Vu Van Van, Bui An Nien, Tran Tuan Anh, Hoang Viet Hang (1999a) Magmatic complexes in the Cao Bang – Dong Khe area. *Geological*

- map of Cao Bang – Dong Khe sheet of 1:50,000. Archives of the Center for Geological Information and Literature, Department of Geology and Minerals of Viet Nam (in Vietnamese)
- Tran Trong Hoa, Ngo Thi Phuong, Tran Tuan Anh, Nguyen Van The, Nguyen Duc Thang (1999b) New findings of Proterozoic ultramafic intrusive magmas in the Phan Si Pang belt. *J Earth Sci* 21(2):159–170 (in Vietnamese with English abstract)
- Tran Trong Hoa, Tran Tuan Anh, Ngo Thi Phuong, Phan Luu Anh, Hoang Huu Thanh (2000) Origin of ultramafic rocks in the Red River zone on the basis of new results of mineralogical, geochemical and isotopic analyses. *J Geol B* 15–16:62–75
- Tran Trong Hoa, Tran Tuan Anh, Ngo Thi Phuong, Pham Thi Dung, Tran Viet Anh (2004a) Permian – Triassic basalt – rhyolite associations in the Song Hien structure, northeast Viet Nam. *J Earth Sci* 26(4):392–405 (in Vietnamese with English abstract)
- Tran Trong Hoa, Tran Tuan Anh, Ngo Thi Phuong, Pham Thi Dung, Tran Viet Anh, Izokh AE (2004b) Mesozoic – Cenozoic magmatic formations in the Phan Si Pang – Red River uplift block, northwest Viet Nam. In: *The Red River fault zone, geodynamics, mineralization and natural hazards*. Science and Technology Publication, Hanoi, pp 297–372 (in Vietnamese)
- Tran Trong Hoa, Tran Tuan Anh, Ngo Thi Phuong, Izokh AE, Polyakov GV, Balykin PA, Ching-Ying Lan, Hoang Huu Thanh, Bui An Nien, Pham Thi Dung (2004c) Gabbro-syenite associations of East Bac Bo structures: evidences of intra- plate magmatism?. *J Geol B* 23:12–25, Hanoi
- Tran Trong Hoa, Hoang Huu Thanh, Ngo Thi Phuong, Vu Van Van, Bui An Nien, Hoang Viet Hang, Tran Tuan Anh, Pham Thi Dung, Tran Hong Lam, Tran Viet Anh, Phan Luu Anh (2005) Survey and evaluation of accompanying minerals in Pb – Zn and Cu mines in Viet Nam. Final report of National project on mineral resources (2002–2004). Archives of the Center for Information and Literature, Viet Nam Academy of Science and Technology (in Vietnamese)
- Tran Tuan Anh, Tran Trong Hoa, Hoang Huu Thanh (2005) Geochemical significances of Carboniferous – Permian intermediate volcanism of South Vietnam. *J Geol B* 26:18–27
- Tran Trong Hoa, Tran Tuan Anh, Ngo Thi Phuong, Pham Thi Dung, Tran Viet Anh, Izokh AE, Borisenko AS, Lan CY, Chung SL, Lo CH (2008) Permo-Triassic intermediate-felsic magmatism of the Truong Son belt, eastern margin of Indochina. *C R Geosci* 340:112–126
- Van Duc Chuong (1996) The ophiolite belts in Viet Nam. *Geogr Nat Resour Viet Nam Monogr* 2:41–52
- Van Duc Chuong, Van Duc Tung, Tran Van Thang (2001) Mafic and ultramafic magmas in ophiolite belts in Viet Nam. *J Earth Sci* 23(3):231–238 (in Vietnamese with English abstract)
- Yarmolyuk VV, Kovalenko VI, Kuzmin MI (2000) North-Asian’s super-plume in the Phanerozoic: magmatism and deep dynamics. *Geotectonica* 5:3–29 (in Russian)
- Zonenshan LP, Kuzmin MI (1983) Intraplate magmatism and their significance for understanding earth mantle processes. *Geotectonica* 1:28–45 (in Russian)

Part II

Permian: Triassic Magmatic Activity

The Permian – Triassic is a special period in the history of geological development in Asian continent and Vietnam, especially. WIDE magmatic activities in a number of tectonic settings at this stage including the Siberian trap, Emeishan large igneous province (LIP), basalt and picrite in northern Vietnam and other LIPs are thought to relate to mantle super-plumes resIDed under the Asian lithosphere (Dobresov 2005). This stage was characterized by anomalous heat flows evIDenced by picritic magmatism, high T-P metamorphism, significant interaction between mantle, mantle lithosphere and crust, and the occurrence of platinoID, gold, rare metal and rare earth deposits elsewhere in the region (Izokh et al. 2005).

Within the Indochina block and composite terrain in northern Vietnam – south China in the Permian – Triassic, as described in Chap. 1, magmas of various origins are wIDely spread. Permian – Triassic orogenic pluton – volcanic associations were recognized in the east and southeast of Indochina Block, while in the southwest of north Vietnam – south China composite terrain intraplate pluton- volcanic and plutonic formations are commonly encountered (Hoa 2005, 2007, 2008). Intraplate magmatic associations are developed in rift-origin structures such as Song Da – Tu Le rift in the northwest and Song Hien in the northeast as well as in other areas in conjunction with rifting domains such as Song Hien – Lo Gam and Phu Ngu. Distribution scheme of the Permian – Triassic magmatic formations are shown in Fig. 1. Petrology, geochemistry and isotope geochemistry of these magmas showed that they are related to different mantle lithosphere sources. Permian – Triassic intraplate magmas described in the following sessions are Song Da, Tu Le, Song Hien and Lo Gam.

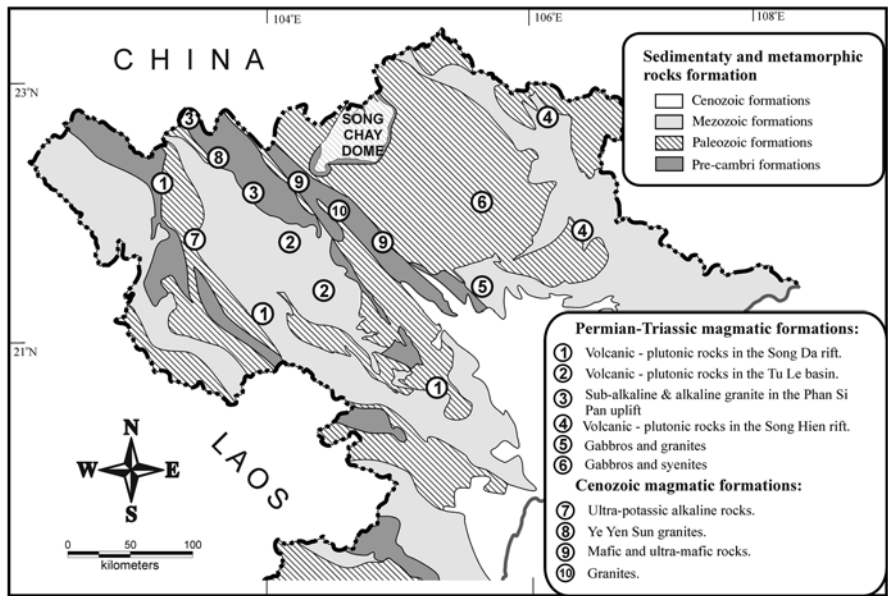


Fig. 1 Distribution scheme of intraplate magmas on a simplified geological background

Chapter 2

Permian – Triassic Magmatic Activity in the Song Da Structure

Abstract Late Permian mafic-ultramafic volcanic and sub-volcanic rocks in the Song Da Rift include four different associations in terms of low-Ti and high-Ti types. Low-Ti, high-Mg volcanic and sub-volcanic rocks are composed of komatiite, komatiitic basalt and basalt and are divided into three groups according to their petrological and geochemical features. Chemical composition of rocks of the komatiite-basalt association is alkali-low (but rather Na-high), very Ti-low, varying from Al-high komatiite to Al-low basalt. They are characterized by high content of Mg, Al, Ni, Co, Cu and Cr, and low of Ti, Fe, Na, K, P, Rb, Ba, Sr, Nb, Ta, Nd, Hf, Zr and REE. In general, based on geochemical and isotopic characteristics the Song Da mafic-ultramafic rocks of the komatiite-basalt association may be products of a melt derived from depleted mantle suffering the impact of mantle plume. Digital modeling showed that the initial melt composition was correspondent to komatiitic basalt. Eruption ages of the magmas are 257 ± 24 Ma (by Rb/Sr age dating), and 270 ± 21 Ma (by Re/Os age dating).

High-Ti basalts (and picrite) and gabbro-dolerites are widely distributed in marginal areas as well as in the center of the Song Da Rift and belong to three associations: andesite-basalt, andesite-picrite-basalt and trachybasalt-trachyandesite-trachydacite. The chemical compositions of high-Ti basalts are characterized by having high Ti content, moderately low Al, medium to low Mg, relatively low alkalinity, but high K, high Rb, Sr, Zr and LREE, but Nb and Ta varies from low- to high. The high-Ti basalts have relatively restricted ranges of $(^{87}\text{Sr}/^{86}\text{Sr})_i$ (0.7048–0.7079) and $\epsilon\text{Nd}(t)$ values (–5.7 to +3.1) indicating weak lithospheric signature that may be related to their trace element-rich nature and this is consistent with abundant earlier studies suggesting that the high-Ti basalts at Song Da or elsewhere in the ELIP formed from low degrees of partial melting.

2.1 Song Da Permian – Triassic Mafic and Ultramafic Pluton – Volcanic Formations

2.1.1 Magma Classification

Intracontinental rifting in northwest – southeast direction was commonly developed in Southeast Asia during the Permian – Triassic (Gatinsky 1986; Khain and Balukhovskiy 1993; Metcalfe 1996). The activity was accompanied by strong ultramafic – mafic magmatism. The Song Da rift is located between the Ailao Shan – Red River shear zone to the northeast and the Song Ma suture zone in the southwest. Although rifting structure features in an intracontinental setting are well described and defined (Gatinsky and Thuc 1982; Toat 1987; Hoa 1995; Polyakov et al. 1996, and references therein) the formation and evolution of this rifting structure is a focus of hotly debate in many geological forums.

The Song Da rift, according to up-to-date geological concerns, includes other structural facies such as Son La, Song Da, Ninh Binh and part of Thanh Hoa zone in the tectonic scheme presented by Dovjikov (1965). There are a number of areas and ultramafic – mafic magmatic associations in this structure such as Cam Thuy, Vien Nam – Ba Vi, Kim Boi – Hoa Binh, Son La Pass, Bac Yen – Van Yen, Deo Chen (Chen Pass), Nam Muoi, Nam So and Sin Ho (Fig. 2.1).

The classification of Permian – Triassic ultramafic – mafic magmatic rocks in northwestern Vietnam have been done in a number of igneous studies; however, up to the present the matter is not conclusive. Based on the petrology, recent studies have shown that the Permian mafic and ultramafic volcanic rocks may be divided into two distinct complexes, e.g., Cam Thuy (P_3) and Vien Nam (P_3). These are described in the monograph ‘Geological stratigraphic divisions of Vietnam’ edited by Tong Dzuy Thanh and Vu Khuc (2005). However, due to lack of radiometric age data the above division may be inappropriate in terms of geochemical compositions of the magmatic associations. The Cam Thuy volcanic rocks comprises mostly homogeneous high – Ti basalt and andesitic basalt (andesite – basalt association); while volcanic (and sub-volcanic) rocks in the Vien Nam complex are geochemically heterogeneous that include both high- and low- Ti mafic and ultramafic types. Among the high- Ti mafic magmas (mostly basalt) of Vien Nam complex there are two distinct magmatic associations picrite – andesite – basalt (Nam So type) and trachybasalt – trachyandesite – trachydacite (Nam Muoi – Suoi Chat type) (Hoa 2002). In general, among the magmas in Vien Nam complex aside from ultramafic – mafic rock types termed as komatiite – basalt association volcanic and sub-volcanic subalkaline felsic rocks are also common (Polyakov et al. 1991, 1996; Phuong 1994). Sources to form the high- and low- Ti magmas in the Song Da structure are obviously different: the low-Ti magma was formed by melting of MORB-like depleted mantle, whereas the high- Ti type was produced by melting of an enriched mantle (Hoa 2002, 2005, 2007). Therefore, classifying both the magmas to a single formation may not be appropriate. Based on the geochemical characteristics the magmas in these areas may belong to two series, e.g., low- and high- Ti where the high-Ti is dominant (Hoa et al. 1998; Hoa 2002). On the other hand, mineralogical