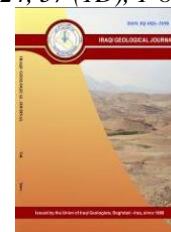




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The Petrographic Characteristics and U-Pb Zircon Isotope Age of Felsic Extrusive Rocks in the Western Thanh Hoa Area, Song Ma Suture Zone

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Abstract

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Felsic extrusive rocks are widely distributed in the western region of Thanh Hoa, primarily comprising rhyolite and rhyolitic tuff formations. They show porphyritic textures, and are composed of 15–25% phenocrysts and 75–85% groundmass. Phenocrysts are mainly euhedral–subhedral plagioclase (5–10 vol.%), K-feldspar (5–10 vol.%) and quartz (5–10 vol.%). The groundmass consists of plagioclase (30–45 vol.%), K-feldspar (25–40 vol.%), quartz (30–40 vol.%), and minor biotite with random distribution. In terms of geological context, these extrusive rocks overlie Silurian–Devonian sequences of sandstone and siltstone interbedded with shale and limestone lenses, and were intruded by the Early Triassic granite of the Song Ma complex. Zircons selected from rhyolite were LA-ICP-MS U-Pb dated, yielding an age of 253 Ma. This age is the timing of the magma crystallization, corresponding to the Late Permian - Early Triassic Indosinian tectonomagmatic event. These findings together with historical study results, prove that the Indosinian magmatic event widely occurred in the Truong Son belt, the Song Ma domain and the Kon Tum area. The eruption of the rhyolite is linked to the amalgamation between the South China and Indochina blocks.

Keywords: Rhyolite; Petrology; U-Pb zircon age; Song Ma suture zone

1. Introduction

The Late Permian - Early Triassic volcanic magmatic rocks are widely distributed in the Sam Nua zone. They are predominantly concentrated in the southwestern regions of Thanh Hoa, northern Nghe An, extending through Laos to the Nam Ban region in Song Ma, Thanh Hoa and Son La province. These rocks are also exposed to the south of Ha Tinh and the north of Quang Binh (Fig. 1a,b). Accompanying these volcanic formations are coeval intrusive igneous rocks ranging from gabbro to granite. The volcanic formations have previously been addressed in studies of DGMVN (1995); Trung et al. (2007); Tri and Khuc (2011); Shi et al. (2015); Hieu et al. (2017). The ages of these volcanic rocks have been determined based on its spatial relationship with other formations in the field and various quantitative analyses including (1) 218 Ma whole rock Rb-Sr radiometric dating, (2) 213 Ma K-Ar biotite dating (Trung et al., 2007) and (3) 251–256 Ma U-Pb zircon dating (Shi et al., 2015; Hieu et al., 2017). These volcanic formations are commonly categorized into the Dong Trau and the Muong Hinh complex.

Despite some published results, the majority of volcanic and intrusive magmatic formations in western Thanh Hoa have not been studied in detail. In this research, we determine the laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) U-Pb zircon ages of rhyolitic rocks

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exposed in the study area. By integrating the dating results with the field mapping data and laboratory petrographic analyses, this paper provides quantitative information about the timing of volcanic formations and the geological evolutionary history of the region.

2. U-Pb Zircon Dating Methodology

The processes of sample preparation and LA-ICP-MS U-Pb zircon analyses for this study was conducted at the Institute of Geophysics and Geology, Chinese Academy of Sciences. The samples were initially crushed to particle sizes ranging from 0.27 to 0.10 mm, followed by gravity separation to isolate minerals based on their specific densities. Subsequently, the Franz magnetic separator was employed to remove magnetic minerals. Representative zircon grains from the sample were handpicked using a microscope before being mounted in a 2.5cm epoxy resin puck for the next steps. Prior to the LA-ICP-MS analyses, the zircon grains were observed in cathodoluminescence (CL) images using a scanning electron microscope (SEM) to define its internal textures and zircon types.

The LA-ICP-MS U-Pb analyses were conducted on distinct domains within each zircon crystal, representing various tectonic regions. The laboratory setup included an inductively coupled plasma mass spectrometer (ICP-MS) and a laser ablation system for surface ablation. Helium or argon gas was utilized during the ablation process as the carrier gas, employing a single-spot ablation method with a spot size of 40 μm . The primary standard sample used for the analysis is 91500 (Wiedenbeck et al., 1995, $^{206}\text{Pb}/^{238}\text{U}$ age = 1065.4 ± 0.6 Ma) while the Glitter software (version 4.0, Macquarie University) was employed for age calculations, and Isoplot (version 2.49) was utilized to generate concordia diagrams. All pre-processing, analytical measurements, and isotopic age calculations were undertaken directly by the authors.

3. Regional Geology and Sample Selection

The Permian- Triassic volcanic formations are widely distributed across the provinces of Thanh Hoa, Nghe An, Ha Tinh, and Quang Binh, within the Northern Central part of Vietnam (Fig. 1a,b). The rock exposed in the Northwest - Southeast trending and mainly comprises andesitic porphyry, rhyolitic porphyry, quartz porphyry, and their associated tuffs (Tri and Khuc, 2011). The Permian - Triassic volcanic cover unconformably above Devonian-Permian sedimentary limestones (Phu et al., 2022; Thinh et al., 2022; Tuan et al., 2023). At the field, these formations are intruded by the Phase 3 granophyres of the Song Ma complex and granites of the Ban Muong complex (Tri and Khuc, 2011). The Permian - Triassic volcanic rocks in the study area were formerly classified in the Dong Trau and Muong Hinh stratigraphic group, and constitute real effusive, explosive, and volcanoclastic phenomena, consisting of andesitic porphyry, rhyolitic porphyry, quartz porphyry, and their tuffs. They are commonly found as lava flows or intercalations within sediments, with thicknesses ranging from tens to hundreds of meters.

Samples V2374 and V2376 were collected for this study, from the coordinates of $20^{\circ}10'08.5''\text{N}$ $104^{\circ}51'59.5''\text{E}$ and $20^{\circ}07'32.4''\text{N}$ $105^{\circ}12'56.4''\text{E}$, respectively (Fig. 1b). Thin sections of both two samples have been investigated under a microscopy while the sample V2376 has been LA ICP-MS U-Pb zircon dated.

4. Results and Discussions

4.1. Mineralogical Composition

Samples V2374 ($20^{\circ}10'08.5''\text{N}$, $104^{\circ}51'59.5''\text{E}$) and V2376 ($20^{\circ}07'32.4''\text{N}$, $105^{\circ}12'56.4''\text{E}$) are dark purple porphyritic rhyolites, which were collected in the western Thanh Hoa area, Song Ma suture

zone (Fig. 1b). They show porphyritic textures, and are composed of 15–25% phenocrysts and 75–85% groundmass (Fig. 2a, b).

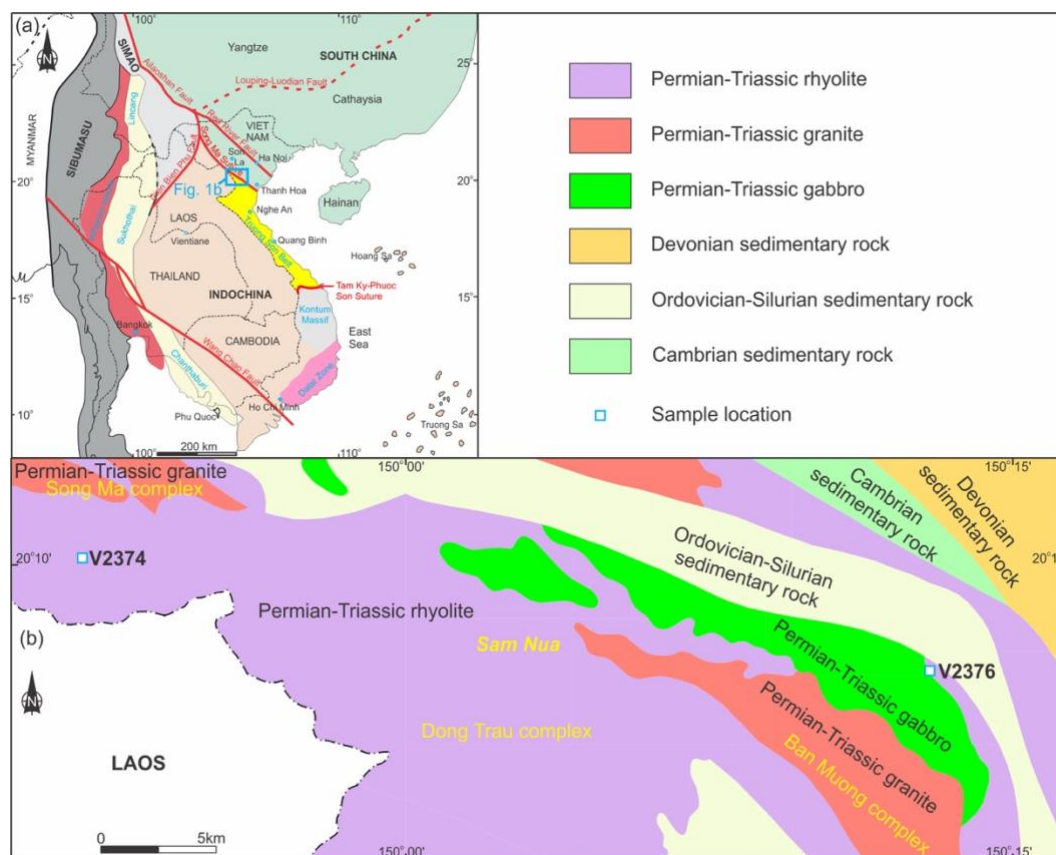


Fig.1. (a) Geological tectonic framework of Southeast Asia, showing three major structural zones (Dalat zone, Kontum Massif and Truong Son belt) in the Indochina block (Minh et al., 2022). (b) The geological map of the study area and sample locations are depicted based on the revised geological map of Ninh Binh - Thanh Hoa sheet, scaled 1:200,000.

Phenocrysts are mainly euhedral–subhedral plagioclase (5-10 vol.%), K-feldspar (5-10 vol.%) and quartz (5-10 vol.%). Plagioclases occur as euhedral–subhedral grains, display polysynthetic twinning and have been altered to sericite. The K-feldspar are subhedral tabular with developed chloritization on the surface. The quartz grains are anhedral with irregular erosion shapes. The groundmass consists of plagioclase (30-45 vol.%), K-feldspar (25-40 vol.%), quartz (30-40 vol.%), and minor biotite with random distribution. Plagioclases (<0.3mm) show lineation and have been altered to sericite and calcite. Quartz (<0.3mm) are anhedral and appear as filling among phenocrysts. Some groundmass matrix have been altered into scaly or acicular chlorite and biotite clusters. Common accessory minerals include zircon, apatite and sulfides (Fig. 2c, and d).

4.2. U-Pb Zircon Age

Figure 3a presents the cathodoluminescence image of zircon grains selected from sample V2376. Microscopic observation and cathodoluminescence imaging reveal that the zircon crystals have prismatic shapes with distinct zoning patterns that are typical characteristics of magmatic zircons (Wu and Zheng, 2004).

The LA-ICP-MS U-Pb zircon ages for the rhyolite porphyry (sample V2376) is summarized in Table 1. This dataset comprises 22 age data points obtained from 22 individual zircon grains. The

$^{206}\text{Pb}/^{238}\text{U}$ ages for 18 zircon grains are well-clustered along the concordia curve, ranging from 262 Ma to 239 Ma, with an average age of 253 Ma (Fig. 3b).



Fig. 2. Field images of rhyolite (sample V2374) and rhyolite porphyry (sample V2376) and microphotographs from their thin sections under a microscopy (magnification of 5x).

The Th/U ratios in the zircon crystals (> 0.1), ranging from 0.41 to 0.75 (Table 1), are indicative of a magmatic-sourced zircon (Wu and Zheng, 2004). Thus, the age of 253 Ma can be attributed to the formation of the rhyolite porphyry in the studied region. Four zircon analyses yielded inherited ages (i.e. older than 253 Ma) from 800 Ma ($^{206}\text{Pb}/^{238}\text{U}$ age) to 1.3 Ga, 1.9 Ga, 2.4 Ga and 2.8 Ga ($^{207}\text{Pb}/^{206}\text{Pb}$ ages). These ages are consistent with the ages of xenocrystic components from the Earth's crust (Hieu et al., 2022). During the intrusion of magma, surrounding rocks were assimilated and partially remelted. The ages of these xenocrysts (Neoproterozoic, Paleoproterozoic, and Archaean) within the sample are evidences of ancient magma activities, preserved in the rhyolite porphyry in western Thanh Hoa province. These ancient events align with similarly dated magma events recorded in northwest Vietnam, north central Vietnam and Kon Tum area. This Neoproterozoic magmatic event in the western Thanh Hoa province is well correlated with the Neoproterozoic, Paleoproterozoic, Archaean magmatic events recorded in the Phan Si Pan area, northwest Vietnam (Anh et al., 2015; Minh et al., 2021; Hieu et al., 2022), and in the Kon Tum area (Wang et al., 2022; Jiang et al., 2022).

Paleoproterozoic xenocrysts are widely distributed in the Phan Si Pan area and the Da Lat region (Thuy et al., 2004). In the study of Thuy et al. (2004) on the Dinh Quan granitoids, apart from the dominant age population of ~ 90 Ma, some inherited zircon grains aged 1.8 Ga were considered to have origins from the surrounding rocks trapped into the magmatic intrusion during the formation of the Dinh Quan - Deo Ca granitoid complexes.

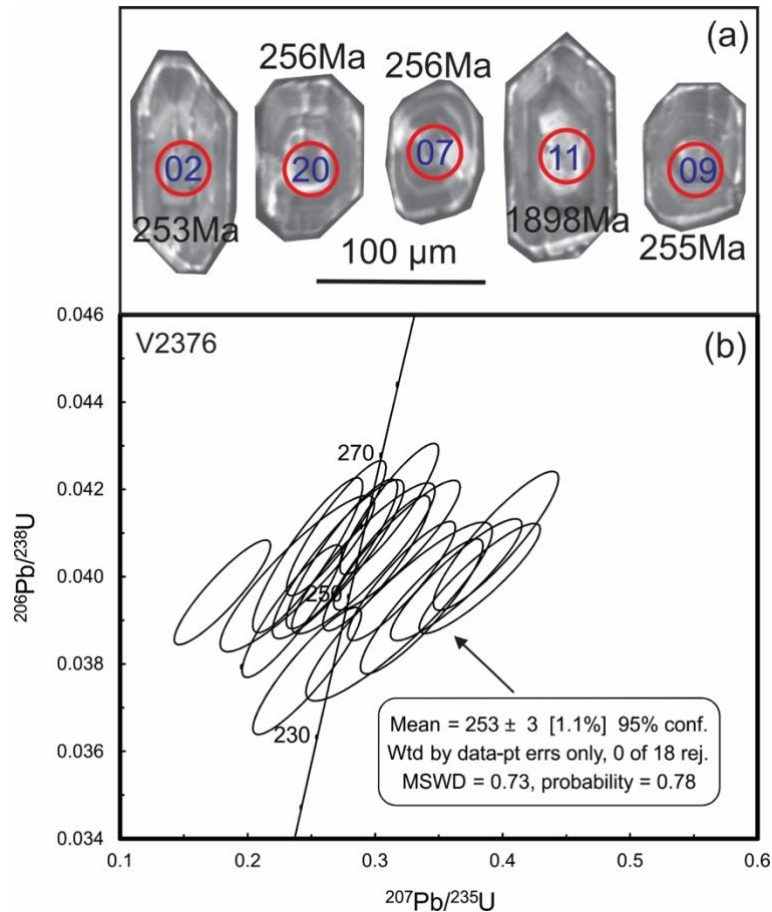


Fig. 3. (a) CL images of zircon from rhyolite porphyry with marks of analysis and ages and (b) the concordia plot for the LA-ICP-MS U-Pb zircon ages from the sample V2376. MSWD: mean square weighted deviation.

Table 1. Zircon U-Pb analytical data of the sample V2376. Note: $^{206}\text{Pb}/^{238}\text{U}$ ages are used for any zircon ages < 1000 Ma while $^{207}\text{Pb}/^{206}\text{Pb}$ ages are used for zircon ages are > 1000 Ma (i.e. four analyses ID: V2376-5; V2376-11; V2376-15 and V2376-19).

Sample	Th/U	Isotopes ratio						Age (Ma)			
		$^{207}\text{Pb}/^{206}\text{Pb}$	1σ	$^{207}\text{Pb}/^{235}\text{U}$	1σ	$^{206}\text{Pb}/^{238}\text{U}$	1σ	$^{207}\text{Pb}/^{235}\text{U}$	1σ	$^{206}\text{Pb}/^{238}\text{U}$	1σ
V2376-1	0.69	0.08276	0.00591	0.46619	0.03239	0.04082	0.00105	389	22	258	7
V2376-2	0.64	0.08390	0.00648	0.45353	0.03135	0.03996	0.00083	380	22	253	5
V2376-3	0.75	0.07186	0.00564	0.39219	0.02791	0.03990	0.00090	336	20	252	6
V2376-4	0.49	0.07935	0.00735	0.43513	0.03403	0.03993	0.00092	367	24	252	6
V2376-5	0.40	0.16068	0.00170	9.52304	0.10381	0.42982	0.00455	2463	10	2305	21
V2376-6	0.72	0.07646	0.00645	0.40802	0.03171	0.03932	0.00102	347	23	249	6
V2376-7	0.51	0.05800	0.00578	0.31860	0.02846	0.04049	0.00117	281	22	256	7
V2376-8	0.72	0.06603	0.00510	0.38257	0.02555	0.04155	0.00099	329	19	262	6
V2376-9	0.73	0.06921	0.00559	0.37254	0.02771	0.04031	0.00102	322	21	255	6
V2376-10	0.54	0.06925	0.00661	0.38858	0.03277	0.04072	0.00098	333	24	257	6
V2376-11	0.02	0.11616	0.00165	4.06492	0.04046	0.25379	0.00256	1898	8	1458	13
V2376-12	0.43	0.07477	0.00992	0.39030	0.04823	0.03920	0.00135	335	35	248	8
V2376-13	0.65	0.06253	0.00609	0.31814	0.02806	0.03784	0.00096	280	22	239	6

Sample	Th/U	Isotopes ratio						Age (Ma)			
		$^{207}\text{Pb}/^{206}\text{Pb}$	1 σ	$^{207}\text{Pb}/^{235}\text{U}$	1 σ	$^{206}\text{Pb}/^{238}\text{U}$	1 σ	$^{207}\text{Pb}/^{235}\text{U}$	1 σ	$^{206}\text{Pb}/^{238}\text{U}$	1 σ
V2376											
-14	0.49	0.06845	0.00762	0.36226	0.03708	0.04042	0.00114	314	28	255	7
-15	0.19	0.13701	0.00270	2.51713	0.04137	0.13325	0.00145	1277	12	806	8
-16	0.42	0.06316	0.00703	0.34247	0.03404	0.04040	0.00120	299	26	255	7
-17	0.73	0.05737	0.00563	0.30626	0.02584	0.03921	0.00100	271	20	248	6
-18	0.47	0.06282	0.00535	0.34097	0.02574	0.04111	0.00102	298	19	260	6
-19	0.59	0.19784	0.00345	14.75214	0.20041	0.54080	0.00592	2808	13	2787	25
-20	0.45	0.06366	0.00623	0.34540	0.02882	0.04052	0.00113	301	22	256	7
-21	0.44	0.05430	0.00793	0.31046	0.03995	0.04007	0.00118	275	31	253	7
-22	0.41	0.04605	0.00465	0.25165	0.02491	0.03964	0.00079	228	20	251	5

The ~1.8 Ga magmatic event has recently been identified in the Phan Si Pan area, northwest Vietnam (Zhao et al., 2002; Zhao et al., 2004; Anh et al., 2015; Hieu et al., 2022) and many inherited zircons of similar ages are also found in the Kon Tum area, Song Ma belt, and the Da Lat region. The inherited zircons aged ~1.8 Ga potentially provide new evidence of a coeval magmatic event during the late Paleoproterozoic in the Da Lat region. This event has possibly contributed to the formation of the ancient continental crust in the Da Lat region, followed by the Jurassic-Cretaceous magmatic events that rejuvenated and disrupted the ancient continental structure, subsequently shaping the present-day Da Lat region.

The Paleoproterozoic holds a position of utmost significance in the global geological evolution. Research indicates that the growth of Earth's continental crust primarily occurred during 1.8-2.0 Ga. Furthermore, numerous researchers have alluded to the amalgamation of the supercontinent Columbia during 1.8-2.1 Ga, after the protracted timeline of continental crustal development (1.3-1.8 Ga). Many geological blocks were separated from the supercontinent Columbia between 1.2 and 1.6 Ga, followed by their complete disassociation from it around 1.2 Ga (Condie, 1998; Zhao et al., 2002; Rogers and Santosh, 2002; Zhao et al., 2004).

In the context of the global geological structural map, when discussing the supercontinent Columbia, no indications of the Da Lat zone, northwestern Vietnam, or the Indochina block emerge. Recent investigations, however, reveal the presence of zircon ages around 1.8 Ga in northwestern Vietnam, the Dalat Belt, Kon Tum, the north central Vietnam, and the Truong Son Belt. In this study, these ages are indicative of magmatic activities during the 1.8-2.0 Ga. These zircon ages provide evidences suggesting a plausible linkage between the Indochina block and the supercontinent Columbia. However, more quantitative studies in the area and its adjacent environs are needed to support this idea.

The ages of rhyolitic porphyry formation in this study correspond to the Late Permian- Early Triassic magmatic event that has been linked with the amalgamation of the South China and Indochina blocks (Hoa et al., 2008; Can et al., 2020; Thanh et al., 2019; Hieu et al., 2020; Tuan et al., 2022). However, detailed investigation of whole rock geochemistry and its isotopic composition are needed for a better understanding of its genesis and tectonic environment, constructing detrital zircon age spectra versus the main tectono-magmatic events of the area, as in Aziz et al. (2021).

5. Conclusions

The LA-ICP-MS U-Pb zircon age of rhyolite porphyry rocks in the western Thanh Hoa region is 253 ± 3 Ma, corresponding to the regional Late Permian- Early Triassic magmatic event. These formations are likely associated with the amalgamation of the South China and Indochina blocks.

The formation of the Late Permian- Early Triassic magma incorporates xenoliths of Neoproterozoic, Paleoproterozoic and Archean ages, corresponding to coeval ancient magmatic events recorded in the Phan Si Pan area, northwestern Vietnam and the Kon Tum region.

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References

- Anh, H.T.H., Hieu, P.T., Tu, V.L., Son, L.M., Choi, S.H., Yu, Y., 2015. Age and tectonic implications of Paleoproterozoic Deo Khe Granitoids within the Phan Si Pan Zone, Vietnam. *Journal of Asian Earth Sciences*, 111, 781-791.
- Aziz, N.R., Sadiq, D.M., Aswad, K.J., 2021. U-Pb Zircon dating of Middle Eocene clastic rocks from the Gercus Molasse, NE Iraq: New constraints on their provenance, and tectonic evolution. *Iraqi Geological Journal*, 54 (1C), 1-15.
- Can, P.N., Anh, T.T., Hoa, T.T., Ly, V.H., Lien, P.T.P., Huong, N.T., 2020. Chemical compositions of amphiboles and their references to formation conditions of granitoids from Nam Rom and Song Ma massifs, Northwest Vietnam. *Vietnam Journal of Earth Sciences*, 42, 80-92.
- Condie, K.C., 1998. Episodic continental growth and supercontinents: a mantle avalanche connection? *Earth Planetary Science Letters*, 163, 97-108.
- Dovjikov, A.E., 1965. *Geology of Northern Vietnam*: Hanoi, Technical and Scientific Publisher (in Vietnamese).
- Hieu, P.T., Anh, N.T.Q., Minh, P., Thuy, N.T.B., 2020. Geochemistry, zircon U–PB ages and HF isotopes of the Muong Luan granitoid pluton, Northwest Vietnam and its petrogenetic significance. *Island Arc*, 29, e12330.
- Hieu, P.T., Lei, W.X., Minh, P., Thuy, N.T.B., Phuc, L.D., Luyen, N.D., 2022. Archean to paleoproterozoic crustal evolution in the Phan Si Pan zone, Northwest Vietnam: evidence from the U-Pb geochronology and Sr-Nd-Hf isotopic geochemistry. *International Geology Review*, 64, 96–118.
- Hieu, P.T., Li, S.Q., Yu, Y., Thanh, N.X., Dung, L.T., Tu, V.L., Siebel, W., Chen, F., 2017. Stages of late Paleozoic to early Mesozoic magmatism in the Song Ma belt, NW Vietnam: evidence from zircon U-Pb geochronology and Hf isotope composition. *International Journal of Earth Sciences*, 106, 855-874.
- Hoa, T.T., Anh, T.T., Phuong, N.T., Dung, P.T., Anh, T.V., Izokh, A.E., Borisenko, A.S., Lan, C.Y., Chung, S.L., Lo, C.H., 2008. Permo-Triassic intermediate–felsic magmatism of the Truong Son belt, eastern margin of Indochina. *Comptes Rendus Geoscience*, 340, 112-126.
- Jiang, W., Yu, J.H., Griffin, W., Wang, F., Wang, X., Pham, T., Nguyen, D., 2022. Where did the Kontum Massif in central Vietnam come from? *recambrian Research*, 377, 106725.
- Minh, P., Hieu, P.T., Thuy, N.T.B., Dung, L.T., Kawaguchi, K., Dung, P.T., 2021. Neoproterozoic granitoids from the Phan Si Pan Zone, NW Vietnam: geochemistry and geochronology constraints on reconstructing South China – India Palaeogeography. *International Geology Review*, 63, 585–600.
- Minh, P., Trung, H.P., Kawaguchi, K., Quynh, A.N.T., Le Duc, P., 2022. Geochemistry, zircon U-Pb geochronology and Sr-Nd-Hf isotopic composition of the Cha Val plutonic rocks in central Vietnam: Implications for Permian-Triassic Paleo-Tethys subduction-related magmatism. *Vietnam Journal of Earth Sciences*, 44, 301-326.
- Phu, H., Thao, N.L.N., Han, H.T.N., Thuy, C.M., 2022. Characteristic of Lang Son Karst Poljes in Vietnam and Geohazards. *Iraqi Geological Journal*, 55(2B), 170-182.
- Rogers, J.J., Santosh, M., 2002. Configuration of Columbia, a Mesoproterozoic supercontinent. *Gondwana Research*, 5, 5-22.
- Shi, M.F., Lin, F.C., Fan, W.Y., Deng, Q., Cong, F., Tran, M.D., Zhu, H.P., Wang, H., 2015. Zircon U–Pb ages and geochemistry of granitoids in the Truong Son terrane, Vietnam: Tectonic and metallogenic implications. *Journal of Asian Earth Sciences*, 101, 101-120.

- Thanh, T.V., Hieu, P.T., Minh, P., Nhuan, D.V., Thuy, N.T.B., 2019. Late Permian-Triassic granitic rocks of Vietnam: the Muong Lat example. *International Geology Review*, 61, 1823-1841.
- Thinh, P.H., Linh, N.T., Lam, D.H., Thanh, P.T., 2022. Risk of Land Subsidence Related to Underground Karst Caves and Solutions, North-South Vietnam Expressway. *Iraqi Geological Journal*, 55(1A), 40-51.
- Thuy, N.T.B., Satir, M., Siebel, W., Chen, F., 2004. Granitoids in the Dalat zone, southern Vietnam: age constraints on magmatism and regional geological implications. *International Journal of Earth Sciences*, 93, 329-340.
- Tri, T.V., Khuc, V., 2011. *Geology and earth resources of Vietnam*. Ha Noi, Vietnam, Publishing House for Science and Technology.
- Trung, N. M., Nuong, N. D., Itaya, T., 2007. Rb-Sr Isochron and K-Ar ages of igneous rocks from the Samnua Depression Zone in Northern Vietnam. *Journal of Mineralogical and Petrological Sciences*, 102, 86-92.
- Tuan, A.T., Trong, H.T., Ngoc, C.P., Shellnutt, J.G., Izokh, A., Phuong, L.P.T., Duangpaseuth, S., Soulintone, O., 2022. Petrology of the Permian-Triassic granitoids in Northwest Vietnam and their relation to the amalgamation of the Indochina and Sino-Vietnam composite terranes. *Vietnam Journal of Earth Sciences*, 44(3), 343-368.
- Tuan, L.C., Minh, P., Kien, L.T., Duong, D.V., 2023. The Use of Remote Sensing Technology in Geological Investigation and Mineral Detection in Ban Vang area, Kham District, Xieng Khoang Province, Laos. *Iraqi Geological Journal*, 56(1B), 233-245.
- Wang, Y., Cawood, P. A., Qian, X., Hieu, P.T., Yu, X., Xu, C., Zhang, F., 2022. Archean records in the Kontum Complex (Central Vietnam) and implications for Precambrian crustal evolution in Indochina. *Precambrian Research*, 383, 106919.
- Wiedenbeck, M., Alle, P., Corfu, F., Griffin, W., Meier, M., Oberli, F.V., Quadt, A. V., Roddick, J., Spiegel, W., 1995. Three natural zircon standards for U-Th-Pb, Lu-Hf, trace element and REE analyses. *Geostandards newsletter*, 19, 1-23.
- Wu, Y., Zheng, Y., 2004. Genesis of zircon and its constraints on interpretation of U-Pb age. *Chinese Science Bulletin*, 49, 1554-1569.
- Zhao, G., Cawood, P.A., Wilde, S.A., Sun, M., 2002. Review of global 2.1–1.8 Ga orogens: implications for a pre-Rodinia supercontinent. *Earth-Science Reviews*, 59, 125-162.
- Zhao, G., Sun, M., Wilde, S.A., Li, S., 2004. A Paleo-Mesoproterozoic supercontinent: assembly, growth and breakup. *Earth-Science Reviews*, 67, 91-123.