Petrochemistry and Geochronology of Ban Hatnga Basalt, Luang Phrabang, northern Lao PDR, Implication for Tectonic Setting

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Abstract

Basaltic rocks which are well exposed at Ban Haad Nga (3 sq km) and Ban Huai Lo (2 sq km) near Luang Prabang were selected for petrographic and geochemical investigation. These basalts occurred in association with Late Paleozoic carbonates. The main objective of this study is to compare these basalts petrochemically and tectonically with those of the Nan and Loei areas.

Two types of basalts were recognized namely massive basalts and pillow basalts. Petrographically, it was discovered that both types of basalts display similar textural and mineralogical characteristics. Pillow structures indicated that basalts were erupted in an aqueous environment. Both basalts are classified as olivine basalts with common trachytic, devitrified glasseous and porphyritic textures. Olivine, pyroxene, and Ca plagioclase are major phenocrysts whereas microlite, micropyroxene, and tiny olivine are present as essential ground mass.

Result of geochemical investigation of these basalts reveals that they are mainly tholeitic basalts and may have occurred as mid oceanic ridge basalts (MORB). Our Ar^{40} Ar^{39} age dating result reveals that the studied basalts may have been erupted during Permo-Triassic period and were subsequently overprinted by Late Mesozoic tectonic activity. It is quite likely that the studied basalts can be better correlated with the Permo-Triassic basalts in Loei area than those in the Nan area of northern Thailand. Our result also shows that the studied basalts in Luang Prabang area may have formed as the ocean floor remnant in the Paleotethys oceanic crust belonging to the Nakhon Thai tectonic block..

Key words: *Lunag Phrabang, basalts, petrography, geochemistry, Ar^{40}-Ar^{39} dating, tectonic, MORB*

1. Introduction

Two areas viz. Ban Hatnga (3 sq km) and Ban Huai Lo (2 sq km) villages, along the High Way number 13 in Luang Prabang Province (Figure 1 and 2), northern Lao PDR, are covered mainly by basaltic rocks. Regionally in northern Lao there are two well-defined volcanic belts that have been recognized for a long times one occurring in Vientien (Lao PDR) - Leoi (northeastern Thailand) in the north south trend and the other nearby Nan area of northern Thailand in the northeast southwest trend. These basalts in Luang Phrabang are newly discovered and mainly associated temporally and spatially with Late Paleozoic carbonates. However, the studied basalts are not ascertained if the rocks belong to the so called Loei Phetchabun volcanic belt (Jungyusuk and Khositanon, 1992, Intasopa, 1993) or the Nan volcanic zone (Charusiri et al., 1995, Stokes et al., 1996, Manaka et al., 2008, Sone and Metcalfe, 2007). So the objectives of this paper are of two fold one is to document the petrograhical and geochemical characteristic of the basalts and the other is to justify in terms of petrochemical characteristics and tectonic settings if the studied basalts belong to Loei or Nan volcanic belts.

2. Methodology

Satellite image interpretation using Landsat TM7 was applied to define rock distribution and lineament structures (Figure 2). Then geological survey and rock sampling were conducted for about two weeks in the dry season of 2009. Only fresh and least altered samples of about 16 basalt specimens were selected for petrographic and chemical analyses. XRF method was used for major and trace element analyses following the method described by Intasopa (1993). Ar^{40}-Ar^{39} step heating method was applied for a whole rock basalt sample using the method described by Duncan et al 1991. Subsequently the result were compared and discussed along with those published results and tectonic setting of the studied Lao basalts was determined in comparison with those of the Nan and Loei areas in Thailand.

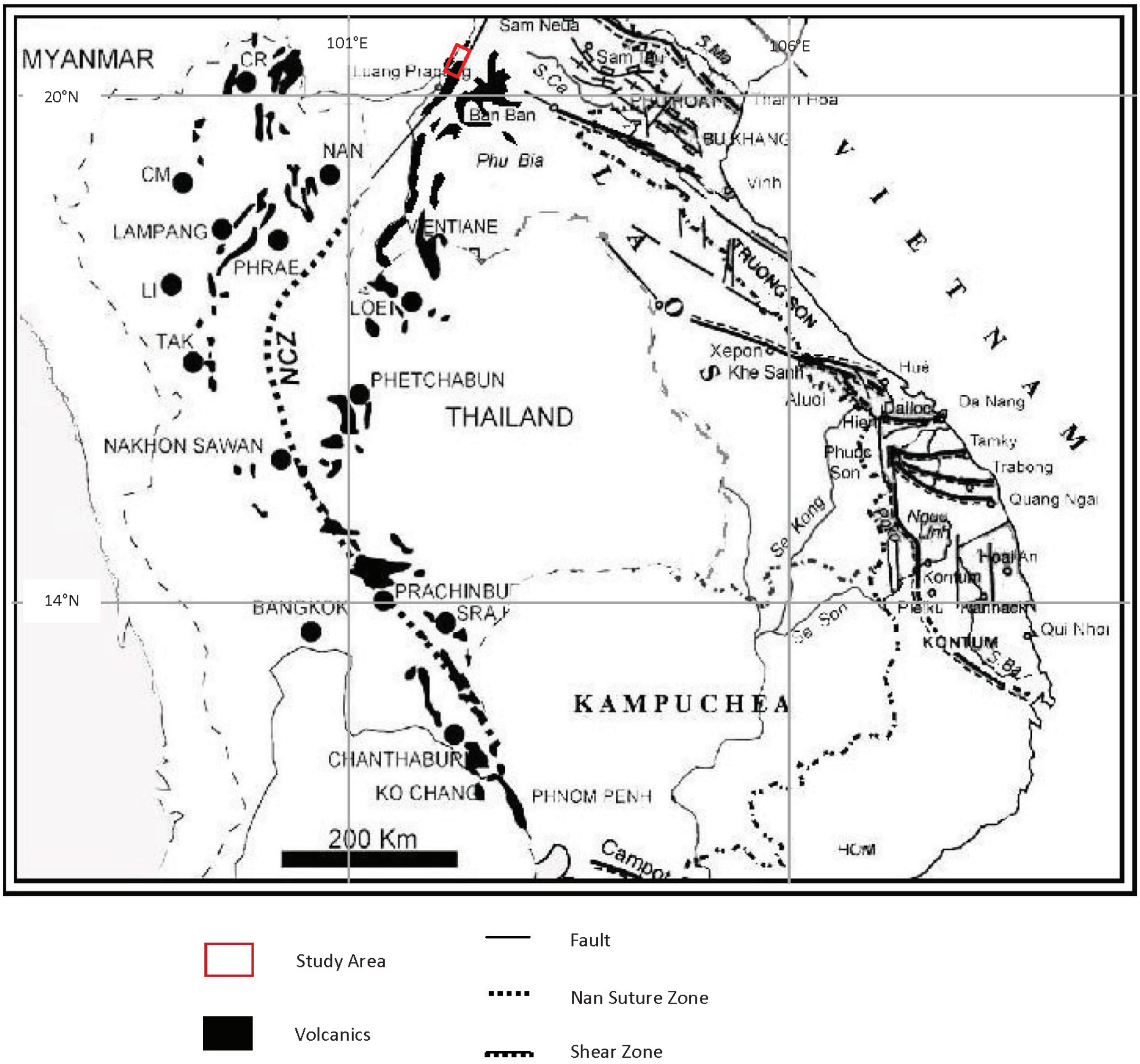

Figure 1 Regional geology and distribution of volcanic rock in Thailand and Lao PDR. (modified from Jungyusuk and Kositanon, 1992; Stoke and Smith, 1996 and Lepvrier et al., 2004)

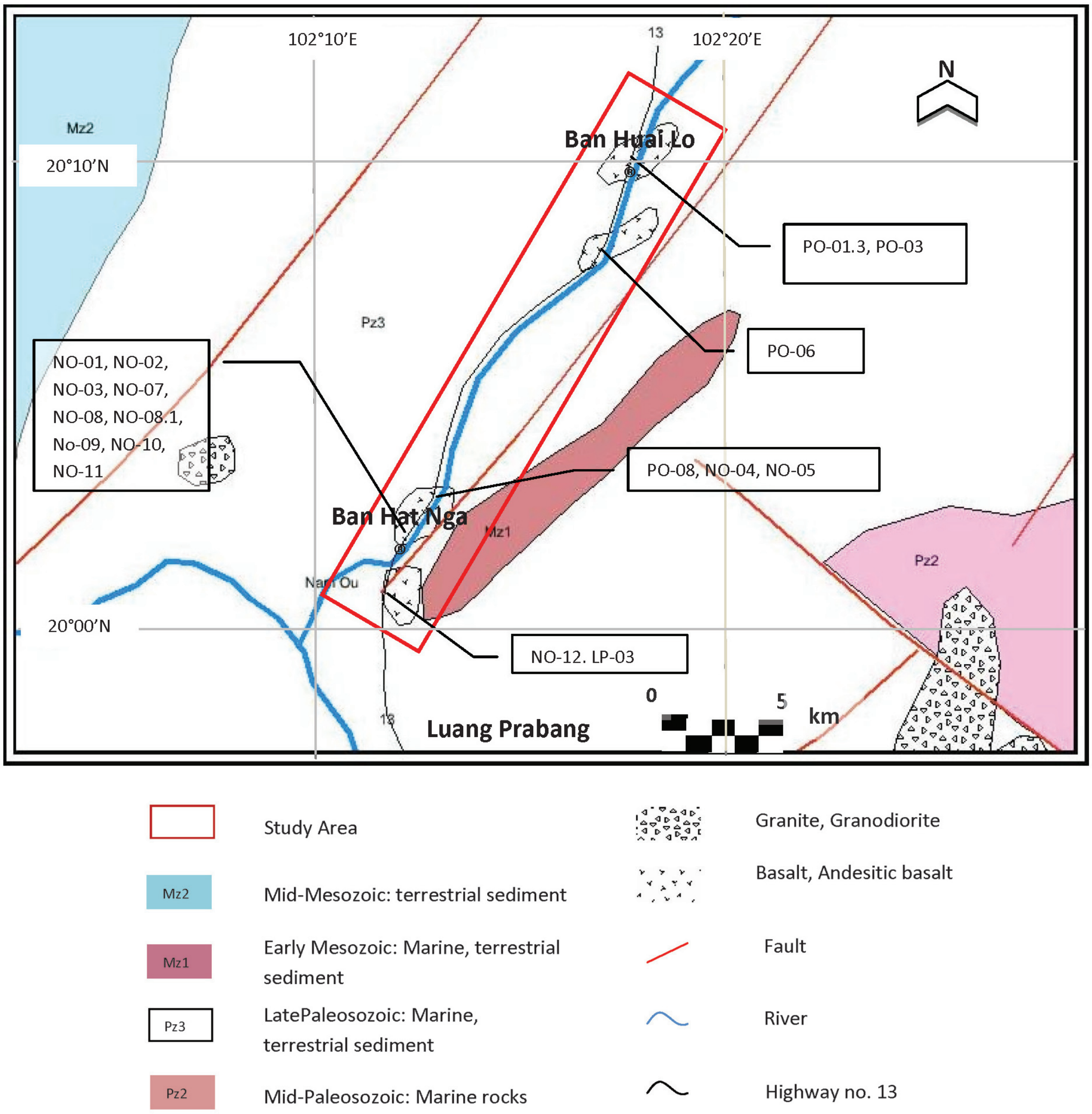

Figure 2 Local geology and distribution of volcanic rock in Luang Phrabang. (modified from UNESCAP 1998)

3. Results

3.1 Field Survey

Two kinds of basalts were recognized in the filed based on modes of occurrence and structures one is the massive basalt (Figure 3A) with the overall thickness of about 30 m and the other is the pillow basalt (Figure 3B) with diameters ranging from 0.3 to 1.5 m. They both are well exposed almost continuously along the Highway no. 13 for approximately 2-3 km. We found that the former has become much more common. However, the latter serves as a good evidence for eruption took place in an aqueous environment. Massive to bedded, partly well-deformed limestones with karstic and tower like structures are found in the vicinity of basalts. However, no contact zone has been observed. These limestones contain Permo-Carboniferous marine fossils, suggesting a good supporting evidence fpr marine involvement. Along the highway, there are some outcrops of clastic and metaclastic rocks as well as few outcrops of marble and dolomitic marble

Figure 3 Ban Hatnga basalt (A) road cut outcrop of basalt showing massive structure in location 20°05’20”N 102°15’47”E and (B) road cut outcrop of basalt showing pillow structure in location 20°05’07”N 102°15’53”

3.2 Petrography

Petrographically, both types of studied basalts are characterized by vitrophyric and porphyritic textures (Figure 4A and 4B). Trachytic, devitrified, amygaloidal, and mafic glasseous textures (Figure 5A and 5B) are common in some sections. Both basaltic types bear similar mineralogical constituents; they contain olivine and Ca plagioclase (An 45 to 60) as major phenocrysts (Figure 5B) with uncommon pyroxene and chromian spinel. Groundmass consists largely of fine-grained olivine, micropyroxene, small plagioclase flakes, and microlite. Both textural and mineralogical investigations suggest that the studied basalts are mainly similar to the tholeiitic basalts of the Atlantic - type analogue (Bryan et al., 1976).

3.3 Geochemistry

Table 1 shows major-oxide (in%) and some trace element (in ppm) compositions of the Ban Hatnga basalt of Luang Phrabang Province. It is observed that the compositional ranges of the studied basalts fall within those of the Atlantic basalts (Bryan et al., 1976). Trends of major and trace elements imply that the studied basalts were derived from a similar parental source as reported by .The TAS diagram (Figure 6) of the studied basalts shows that they are plotted mainly in the field of basalt. The Ti-Zr-Sr diagram (Figure 7) of the studied basalts indicates that they mainly occupy field of IAT. The Ti-Zr diagram (Figure 8) of the studied basalts indicates that they mainly occupy field of MORB. The MnO_2-TiO_2-P_2O_5 diagram (Figure 9) of the studied basalts indicates that they mainly occupy field of MORB and IAT. The MgO-Fe_2O_3-Al_2O_3 diagram (Figure 10) of the studied basalts indicates that they mainly occupy field of Ocean island, Ocea ridge and floor. So based on the geochemistry all the studied rocks are classified as basalts sensu stricto

3.4 Geochronology

Result of Ar^{40}- Ar^{39} dating of a basalt sample using step heating technique is displayed in Table 2. The spectrum shows an integrated age of about 110.11±0.61 Ma (Figure 12A). About 60% of the cumulative Ar gas release gives the plateau date at the range of temperatures from 650 to 1450 °C. It is also observed that at the first three steps starting from 650 to 800 °C, the cumulative Ar gas release of about 20% yield apparent dates considerably lower than the integrated age, viz. from about 61.6 to 102.4 Ma. However at the last few steps, i.e., at the high temperatures from 1300 to 1450 °C, the cumulative Ar gas release yields apparent ages much higher than the integrated age.

Figure 4 Rock slabs of Ban Hatnga basalts (A) sample no. PO-03 showing aphyric texture with veinlets of calcite and (B) sample no. NO-08 showing phyric slightly porphyric and amygaloidal texture. Note that the rock has parallel fracture filling calcite veinlets.

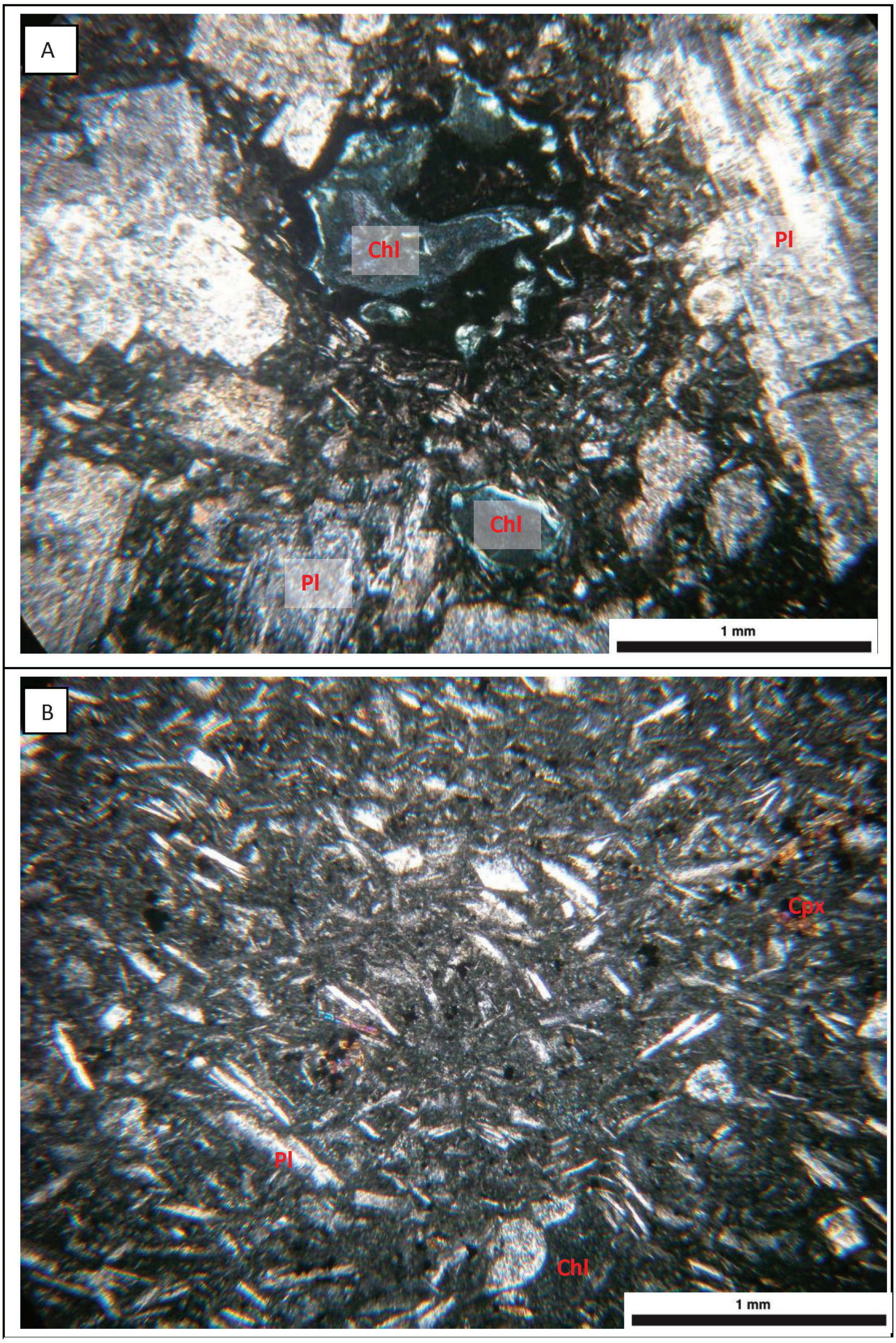

Figure 5 Photomicrographs of (A) vesicular basalt of massive basalt unit showing plagioclase phenocrysts enclosed by groundmass rich in glass and microlite. Note that vesicular were filled up by chlorite materials (sample no. NO-07) and (B) trachytic basalt of the pillow lava unit showing arrangement of microlite in glass on groundmass.

4. Discussion

4.1 Petrochemical Characteristics

Petrographically, basalts of the Luang Phrabang study area contain plagioclase as the dominant phase, accompanied by olivine. Pyroxene is relatively rare. Therefore bulk compositions are likely to be modified by plagioclase and olivine accumulation. In general, the studied basalts are mainly tholeiitic.

Geochemically, SiO_2 of the studied basalts shows a remarkably narrow range of composition (largely 44 to 49 %). They also show characteristically low concentration of incompatable elements, including Ti and P and LIL (large ion lithophile) elements (K, Rb, and Ba). These petrochemical characteristics of the studied basalts are compatible with those occurring in the MORB extensional tectonic setting. The geochemical evidence of MORB characteristics is documented by several discrimination diagrams shown in Figures 7, 8, 9, 10 and 11. The Ti-V diagram (Shervais, 1982) shows that the studied basalts are plotted in the field of Ti/V between 20 to 50 (Figure 11)., suggesting that they belong to MORB group. Ti Zr diagram of Pearce and Cann (1973)(Figure 8) displays that most studied basalts are within the filed of MORB. Similarly, the triangular variation diagram of Ti-Zr-Y as proposed by Pearce and Cann (1973) indicate that the studied Luang Phrabang basalts occupy much of the within-plate basalt field. Moreover, the MnO_2-TiO_2-P_2O_5 discrimination diagram illustrates that the studied basalts are mostly plotted in the field of MORB.

4.2 Geochronological Synthesis

Only one basalt sample was dated using Ar^{40}/Ar^{39} step-heating technique. The age spectrum derived from this basalt yields an integrated age of 107.3±0.6 Ma. However, we consider that this integrated age cannot represent an age of volcanic eruption. This is because there is only 60 % of the Ar release that show a plateau age. We infer that the old date (~ 240 Ma) from the last incremental step of Ar release may represent a more reliable age of eruption. If this age of about 240.2±21.1 Ma is the most probable age of volcanism, then it is likely that the studied Luang Phrabang basalt is younger than the Late Paleozoic associated carbonates. The occurrence of the recrystalline limestones and a few marble requires the subsequent heat source for their generation. So we believe that the most reliable age of the studied basalts is Permo Triassic to Early Triassic. We also interpret that the young date of the spectrum may represent a thermal overprint during the Cretaceous when Western Burma block interacted with the Shan Thai and associated terranes.

Table 1. Shows major-oxide (in %) and some trace element (in ppm) compositions of the Ban Hatnga basalt of Luang Phrabang Province.

Sample	NO-01	NO-02	NO-03	NO-04	NO-05	NO-07	NO-08	NO-08.1	NO-09	NO-10	NO-11	NO-12	PO-01.1	PO-03	PO-06	PO-08	LP-03.1*
SiO2	44.95	48.08	46.08	45.39	44.87	46.14	49.35	48.56	45.16	41.98	44.15	56.14	42.64	46.14	48.91	47.97	61.85
TiO2	1.32	1.1	1.53	1.15	1.36	1.36	1.18	1.17	1.26	1.55	1.47	1.15	2.51	1.22	1.02	1.17	0.99
Al2O3	14.57	14.15	14.98	14.98	14.75	15.68	14.26	17.06	14.31	14.01	13.5	15.64	12.32	13.86	15.33	15.32	15.4
Fe2O3	12.65	9.32	13.49	11.24	13.04	12.55	10.23	10.88	11.07	14.92	14.36	9.85	15.12	12.14	12	13.3	5.22
MnO	0.17	0.11	0.17	0.12	0.18	0.17	0.15	0.13	0.14	0.22	0.22	0.18	0.24	0.21	0.21	0.24	0.21
MgO	7.17	5.16	7.84	6.56	9.23	9.3	6.61	3.91	8.28	11.89	10.58	4.76	8.9	8.49	6.56	9.4	3.24
CaO	6.19	14.38	6.08	8.03	5.81	5.97	7.66	11.59	8.26	4.97	7.23	3.68	8.54	7.67	6.67	6.63	2.77
Na2O	3.17	2.3	2.1	1.84	2.81	3.05	3.1	2.39	2.62	1.62	2.72	4.03	2.4	3.15	2.4	3.81	5.41
K2O	0.25	0.12	1.2	1.83	0.57	0.43	0.33	0.77	0.66	1.39	1.94	1.63	0.13	0.36	0.5	0.5	1.94
P2O5	0.14	0.15	0.12	0.13	0.12	0.15	0.13	0.15	0.14	0.1	0.12	0.18	0.24	0.13	0.17	0.12	0.29
LOI	4.603	4.906	5.283	5.41	5.147	4.867	4.313	4.481	5.655	5.704	5.559	6.34	3.452	3.203	3.059	4.638	2.27
Total	95.183	99.776	98.873	96.68	97.887	99.667	97.313	101.091	97.555	98.354	101.849	103.58	96.492	96.573	96.829	103.098	99.59
Ti	7982.27	6599.39	9296.21	6925.76	8199.55	8223.63	7076.36	7053.48	7562.12	9369.39	8909.39	6875.45	15375.45	7358.03	6116.21	7017.42	n/a
V	278.21	213.61	321.98	248.16	299.21	284.92	245.44	249.68	264.65	331.15	323.29	194.29	480.1	255.86	232.25	264.5	n/a
Cr	84.06	59.06	109.06	60.27	82.12	61.88	80.1	81.8	61.64	90.51	125.35	38.73	235.51	176.48	86.8	97.93	n/a
Ni	16.09	12.21	26.81	nd	3.97	20.85	44.7	nd	25.55	22.37	14.83	nd	78.8	62.56	nd	nd	n/a
Cu	73.32	66.5	65.97	70.44	69.82	72.43	66.63	71.04	69.84	65.18	61.4	64.74	65.72	61.83	59.32	nd	n/a
Zn	38.82	30.5	28.5	40.16	54.5	56.02	46.07	32.45	47.61	47.2	33.3	85.23	41.52	52.57	13.95	51.41	n/a
Sr	347.42	94.45	462.94	605.28	813.93	914	524.04	448.49	697.48	431.43	362.46	448.95	159.4	217.07	353.73	294.41	n/a
Y	nd	nd	nd	12.09	nd	nd	nd	8.73	nd	10.3	9.15	nd	nd	nd	nd	nd	n/a
Zr	72.74	35.33	92.67	94.95	138.88	143.5	91.98	82.98	110.44	83.7	47.79	153.98	91.72	57.96	60.66	58.03	n/a

Major oxide in %wt; trace element in ppm., *data from Charusiri et al (2003), nd = not determined, n/a = no data

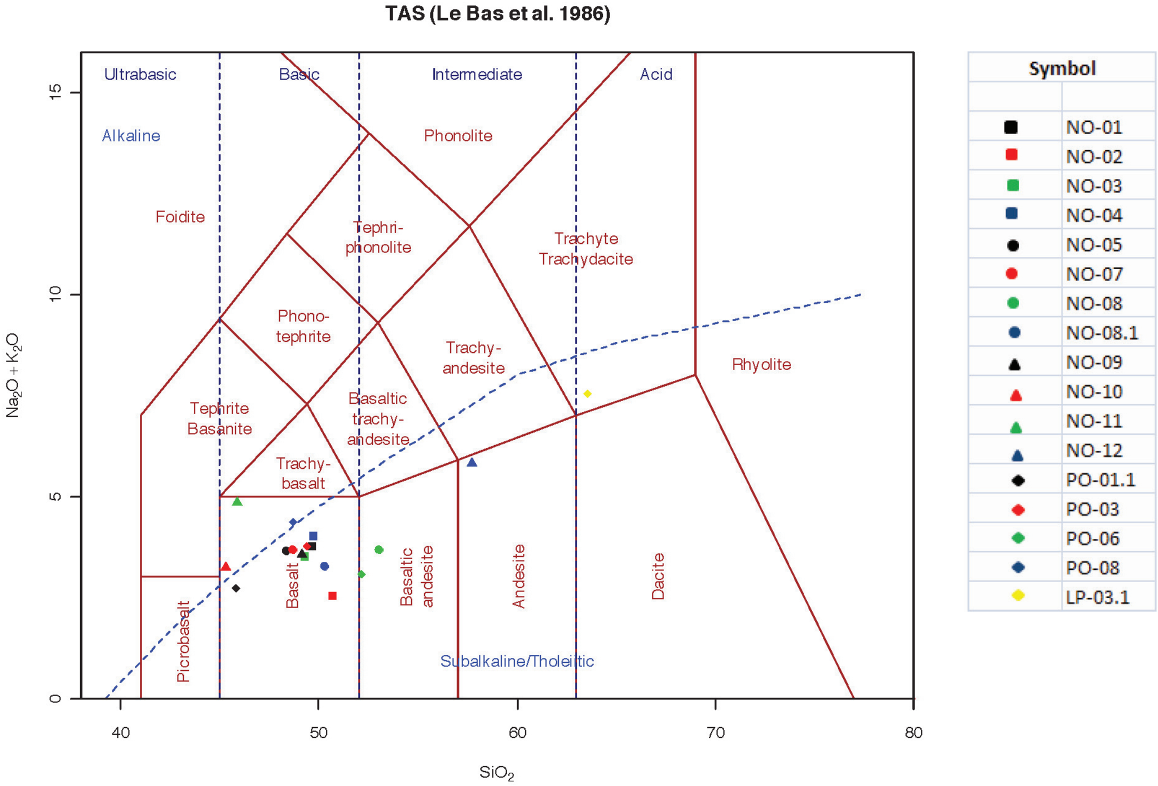

Figure 6 Ti-Zr-Sr discrimination diagram of Ban Hatnga basalt shows that they are plotted mainly in the field of basalt (Le Bas et al.1986)

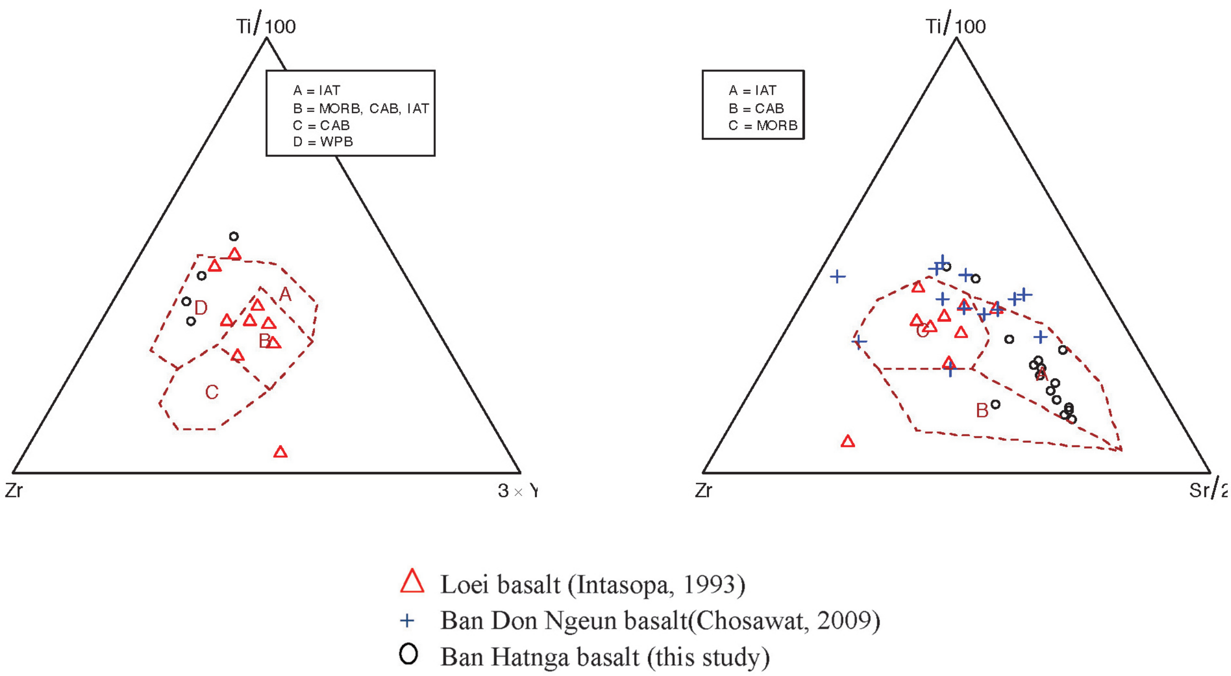

Figure 7 Ti-Zr-Sr discrimination diagram of Ban Hatnga basalt in comparison with Ban Don Ngeun basalt (Chosawat, 2009), northern Lao and Loei basalt (Intasopa, 1993)(Diagram after Pearce and Cann, 1973).

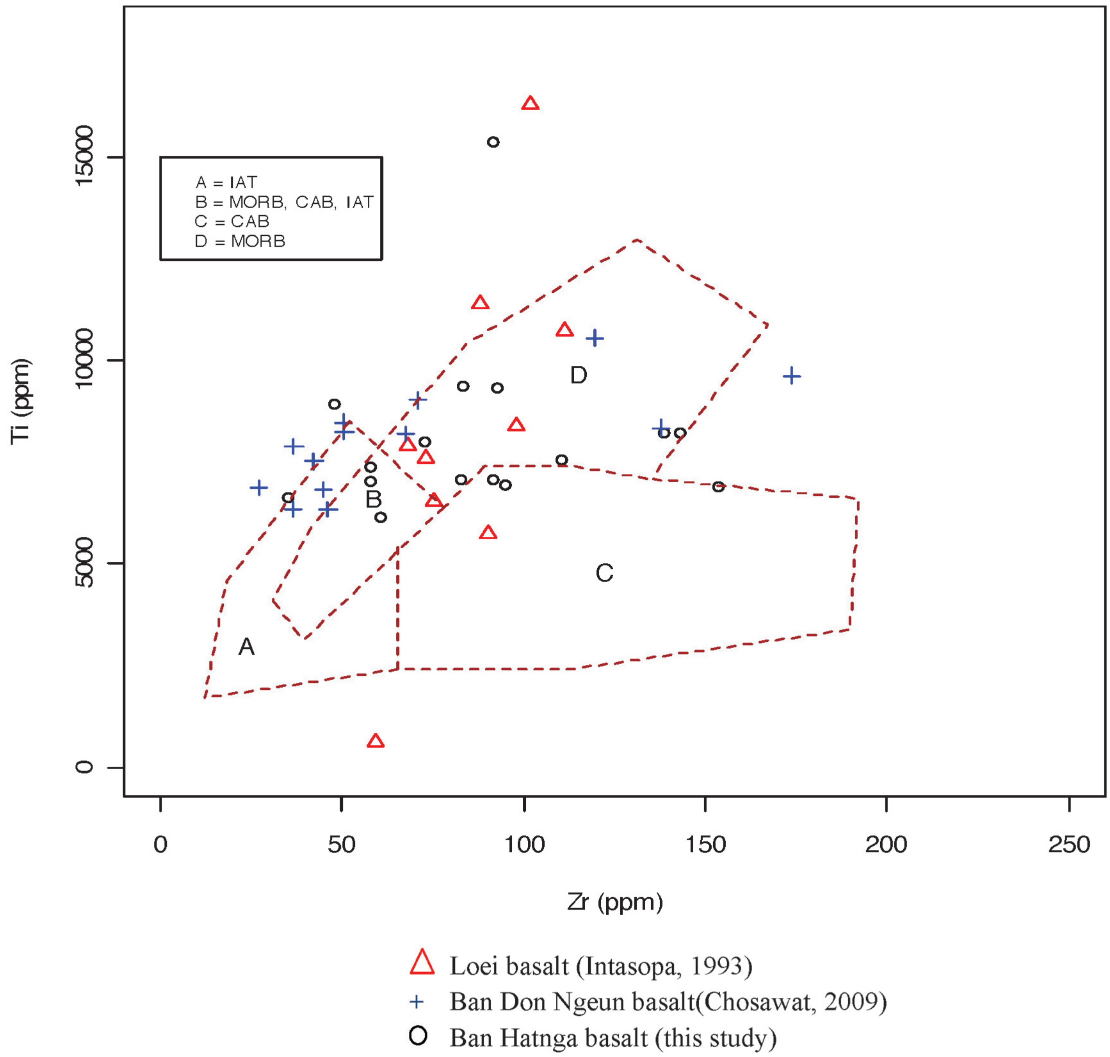

Figure 8 Ti-Zr diagram of Ban Hatnga basalt in coparison with Ban Don Ngeun basalt (Chosawat, 2009), northern Lao and Loei basalt (Intasopa, 1993). Diagram after Pearce and Cann, 1973

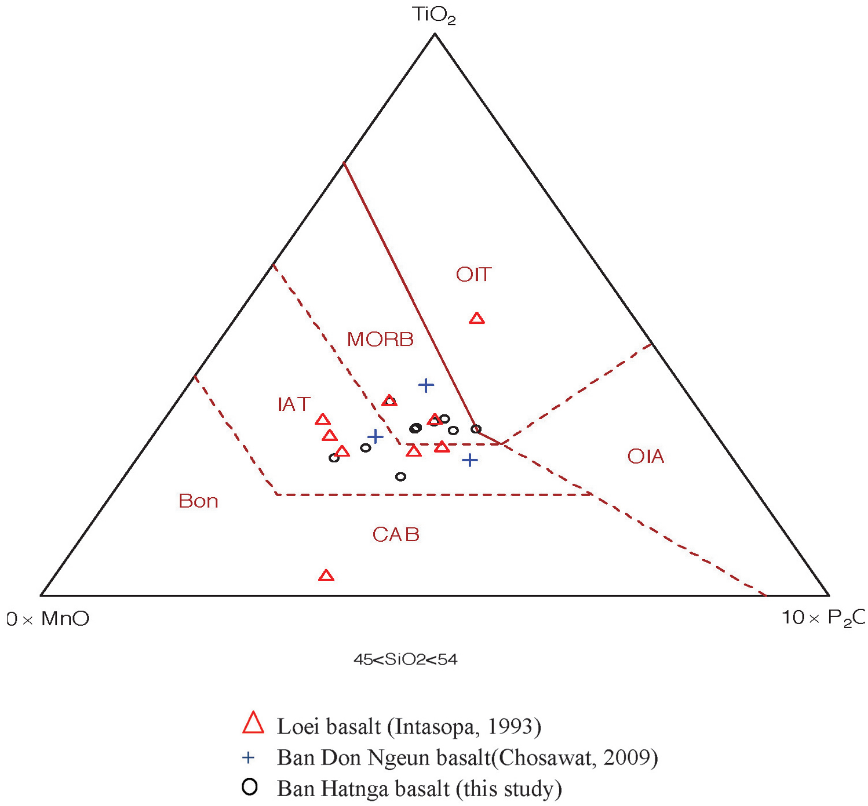

Figure 9 MnO_2-TiO_2-P_2O_5 discrimination diagram of Ban Hatnga basalt in coparison with Ban Don Ngeun basalt (Chosawat, 2009), northern Lao and Loei basalt (Intasopa, 1993) of northern Thailand. Diagram after Mullen, 1983

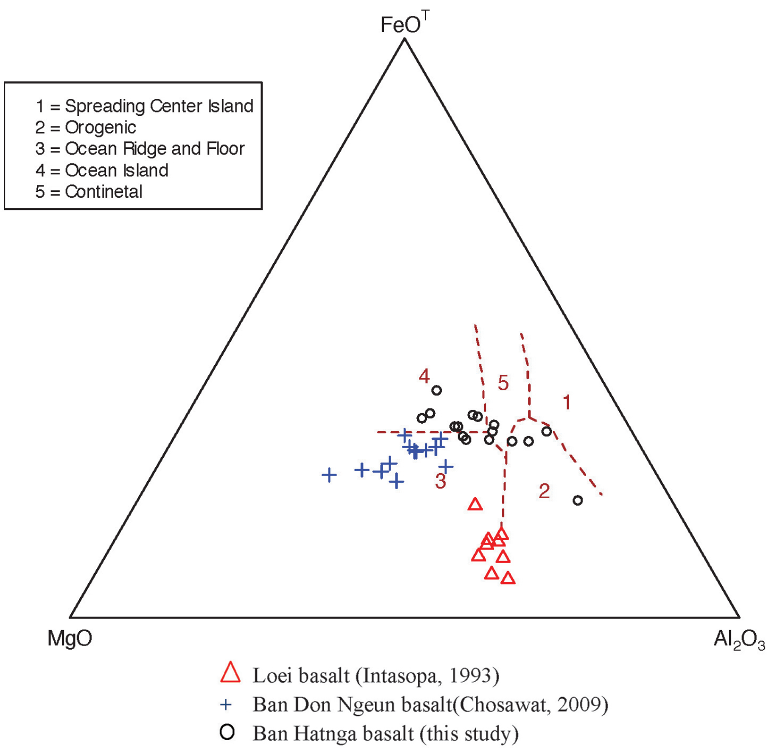

Figure 10 MgO-Fe_2O_3-Al_2O_3 discrimination diagram of Ban Hatnga basalt in coparison with Ban Don Ngeun basalt (Chosawat, 2009), northern Lao and Loei basalt (Intasopa, 1993) of northern Thailand. (Diagram after Pearce, 1977)

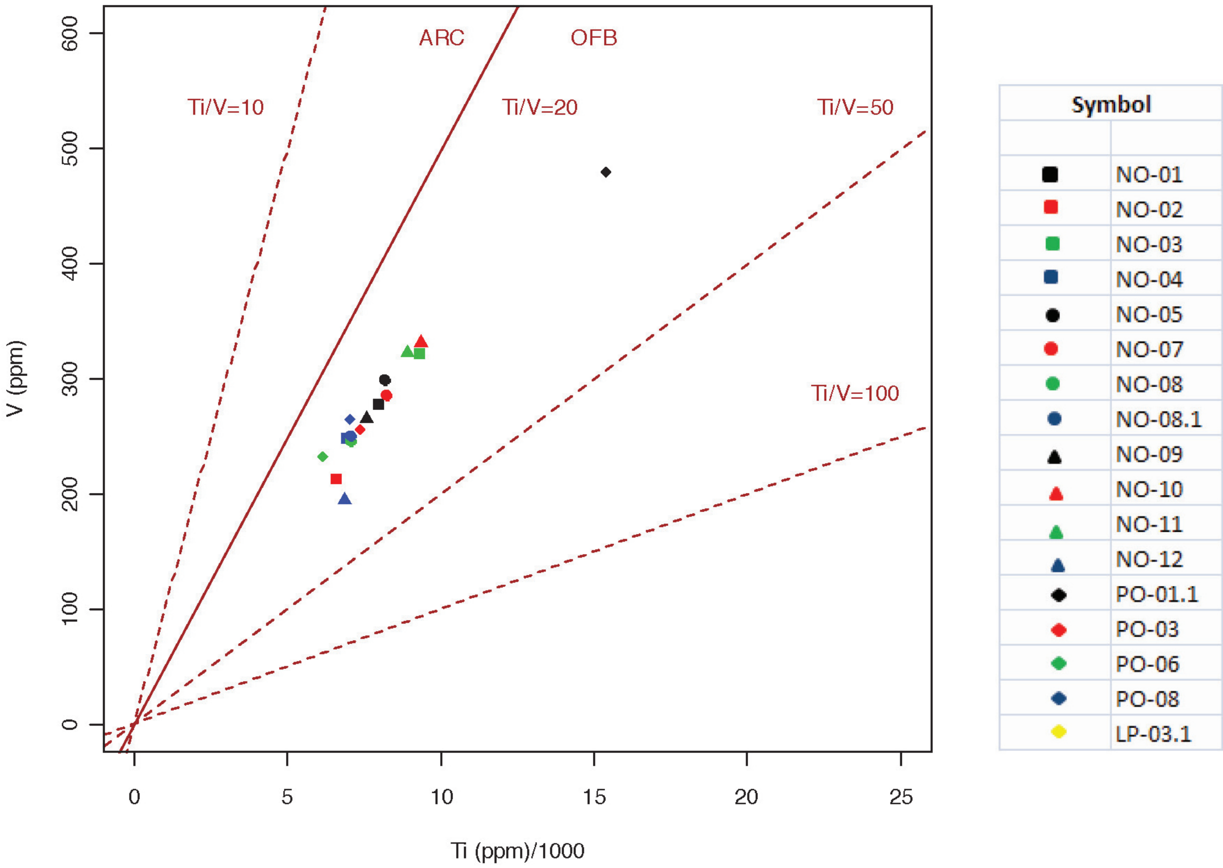

Figure 11 Ti-V discrimination diagram of Ban Hatnga basalt shows that they are plotted mainly in the field of basalt MORB (Shervais, 1982)

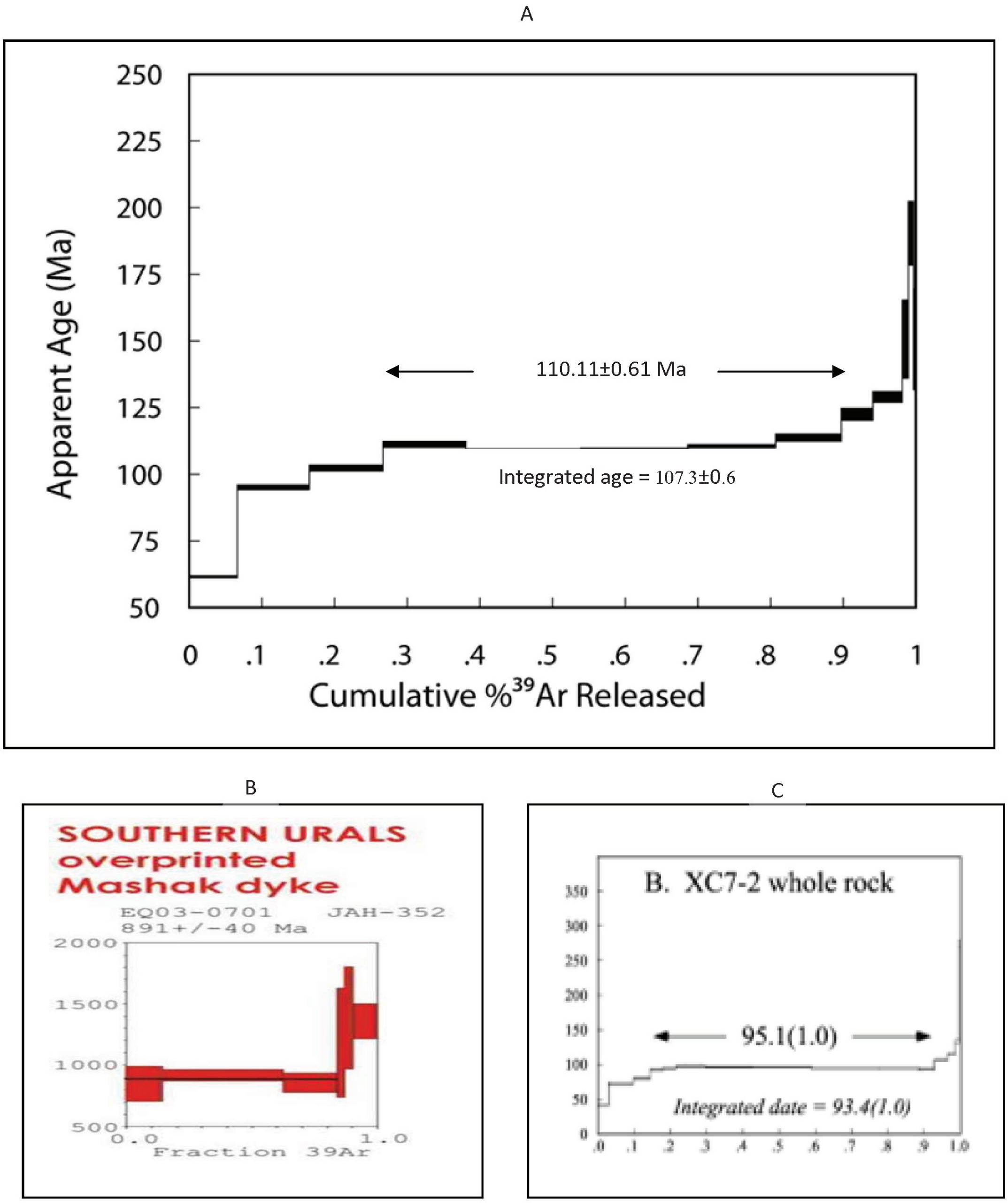

Figure 12 Ar-Ar age spectrum of Ban Hatnga basalt (A) in comparison with the overprinted dike of siuthern Urals (Earnst et al., 2006) (B) and the over printed basalt of southern China block (Ali et al., 2004) (C)

4.3 Tectonic Setting

Based on the overall results, we consider that the studied basalt may have formed in the rifting setting either as the rifting basalts or MORB during Permo Triassic Period. They represent a remnant of the north south trending Paleotethian seaway or paleo-oceanic crust. To southern Lao and northeast Thailand in Loei area, these ocean floor basalts become older (Middle Paleozoic age) as reported by Intasopa (1993) and may have formed in the Paleotethys Ocean, becoming the eastern part of the Nakhon Thai tectonic block (Charusiri et al., 2002). This suggests that the Paleotethys Ocean may have become closure from the south to the north of Nakhon Thai tectonic block. However, to the west of Nakhon Thai block near Nan suture, Panjasawatwong (2003) considered that the Permo-Triassic volcanic rocks are mainly calc-alkaline and have formed as a result of subduction setting, equivalent to the compression tectonics developed by interaction of Lampang Chiang Rai Plate and Nakhon Thai Plate (Charusiri et al., 2002).

5. Conclusion

Ban Hatnga basalts of Luang Phrabang province, northern Lao, are mainly massive and pillow tholeiitic basalts. They are spatially associated with Late Paleozoic marine carbonates. The basalts are characterized by phenocrysts of olivine, pyroxene, and Ca plagioclase and show typical trachytic, porphyritic, glassy, amygdaloidal, and devitrification textures. Geochemical data reveal that these basalts are of MORB-type and have formed in the ocean floor environment. Ar^{40}-Ar^{39} dating data show that the dated basalt occurred during Permo-Triassic Period. We consider that these basalts, which are parts of the Loei - Phetchabun volcanic belt, formed part of the Nakhon Thai plate and extends to the south to Loei area in northern Thailand.

Table 2 Summary of 40Ar/39Ar incremental heating experimental data of the dated of Ban Hatnga basalt (sample no. LP-03). J-value=0.003379650 ± 0.000015307; Integrated date=107.3 ± 0.6 Ma; Plateau age=110.11 ±0.61 Ma (850-1050°C)

T(°C)	cum.$^{39}Ar_k$	Atmos.(%)	$^{36}Ar/^{39}Ar$	$^{37}Ar/^{39}Ar$	$^{38}Ar/^{39}Ar$	$^{40}Ar/^{39}Ar$	$^{40}Ar/^{36}Ar$	Date (Ma)
650	0.066	41.066	2.42E-02	4.05E-06	1.78E-02	1.75E+01	7.21E+02	61.6±0.4
750	0.165	33.277	2.71E-02	2.30E-02	1.77E-02	2.41E+01	8.89E+02	95.2±0.9
800	0.267	37.419	3.50E-02	9.92E-02	1.89E-02	2.76E+01	7.90E+02	102.4±1.1
850	0.381	41.159	4.45E-02	2.35E-06	2.05E-02	3.20E+01	7.19E+02	111.2±1
900	0.539	47.128	5.54E-02	5.45E-03	2.23E-02	3.48E+01	6.28E+02	108.6±0.9
950	0.686	56.663	8.17E-02	1.82E-06	2.68E-02	4.26E+01	5.22E+02	109.2±0.7
1000	0.807	69.489	1.44E-01	5.50E-02	3.80E-02	6.13E+01	4.25E+02	110.5±0.6
1050	0.897	81.15	2.81E-01	2.99E-02	6.30E-02	1.02E+02	3.64E+02	113.8±1.4
1100	0.941	88.587	5.46E-01	2.93E-01	1.11E-01	1.82E+02	3.34E+02	122.5±2.3
1150	0.981	92.893	9.71E-01	6.67E-06	1.87E-01	3.09E+02	3.18E+02	129.1±2
1200	0.989	95.535	1.87E+00	2.25E-01	3.51E-01	5.77E+02	3.09E+02	150.7±14.7
1250	0.997	95.446	2.34E+00	1.18E-01	4.50E-01	7.24E+02	3.10E+02	190.5±11.9
1300	0.998	96.298	2.27E+00	1.45E-04	4.15E-01	6.96E+02	3.07E+02	150.6±18.9
1450	1	94.538	2.47E+00	1.93E+00	4.53E-01	7.71E+02	3.13E+02	240.2±21.1

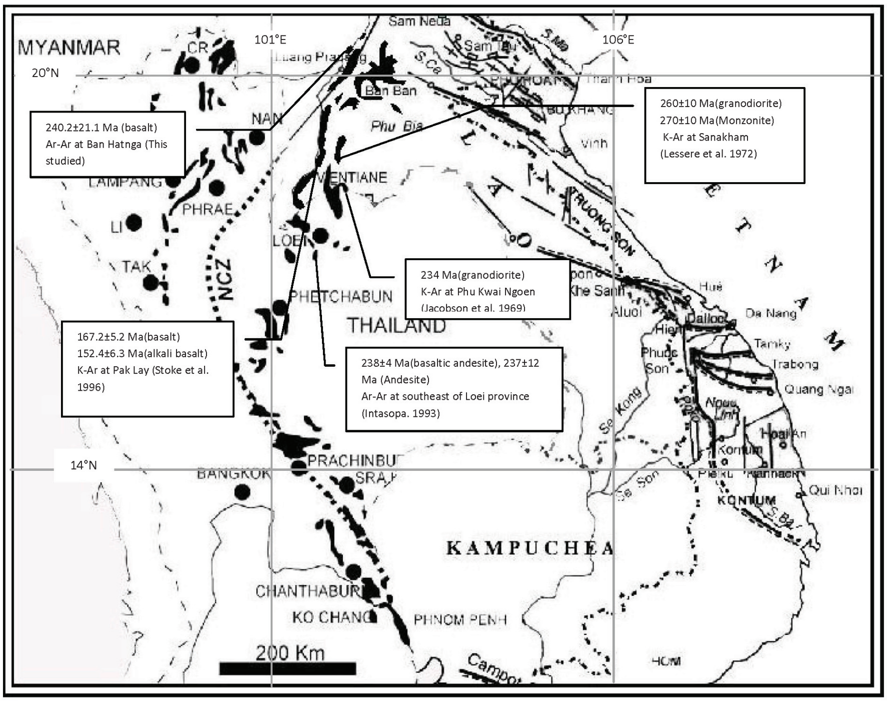

Figure 13 Index map of upper part of Thailand and Lao PDR showing distribution of volcanic rocks and their age data. Note that data attached line indicates Nan Suture Zone (NSZ) or Nan-Sra Keo suture (modified from Jungyusuk and Kositanon 1992, Stoke and Smith 1996 and Lepvrier et al 2004).

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