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Petrochemistry of Volcanic and Plutonic Rocks in Loei Province, Loei-Petchabun Fold Belt, Thailand

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Abstract. The petrography and geochemistry of Permo – Triassic volcanic and plutonic rocks of the Loei-Phetchabun Fold Belt located in Amphoe Wang Sa Phung and Maung areas, Loei Province were studied. These intermediate igneous rocks have calc-alkaline affinities and are characterized by moderately fractionated LREEs and relatively flat HREEs with negative Eu anomalies. Both volcanic and plutonic samples display positive Rb, Th, Ce, Sm and Y anomalies and negative Nb and Ti anomalies. The geochemical data indicate that fractional crystallization of plagioclase, hornblende, biotite, titanite and apatite and/or magma mixing were important processes during the generation of these igneous rocks. Therefore, the data indicate magmatism at an east-dipping continent–ocean subduction zone where a former ocean between the Indochina and Sibumasu blocks was subducted beneath the Indochina block. Available geochronology data indicate that subduction was active from at least 244-230 Ma. The subduction-derived melts were probably contaminated by the overlying continental crust.

Keywords: Loei-Phetchabun Fold Belt, Petrochemistry, Calc-alkaline, Thailand

1. Introduction

The Loei-Petchabun Fold Belt also known as the Petchaboon Volcanic Belt [1] or the Central Thailand Volcanic Belt [2] is located on the western edge of the Korat Plateau, Northeast Thailand. The fold-belt consists of diverse volcanic and plutonic rocks that may have been generated and deformed during ocean closure and collision between two micro-continents, Sibumasu and Indochina, during the Permian and Triassic [3]. This collision resulted in crustal shortening and thickening, the amalgamated continental block then drifted northward before colliding with the rest of Asia in the late Triassic to Jurassic.

The Loei-Petchabun fold belt hosts several important mineral deposits (e.g. the Chatree epithermal Au-Ag deposit, Thung Kam Cu-Au skarn deposit and Phu Lon Cu porphyry deposit). Epithermal, skarn and porphyry deposits are often closely related to igneous activity, this igneous activity is commonly a consequence of plate tectonics. In Thailand, previous plate tectonic studies have mainly focussed on sedimentary basin analysis and palaeo-biogeographic studies but there is limited data on the petrochemistry of volcanic and plutonic rocks and how they relate to the geodynamic setting. This paper presents new geochemical data from volcanic and plutonic rocks in the Western Loei area (Amphoe Wang Sa Phung and Maung, Loei Province) which we use to infer the magma source and tectonic setting.

2. Geology of the Study Area

The Loei-Phetchabun Fold Belt consists of sequences of Palaeozoic strata of which the oldest sequences are Silurian-Devonian meta-volcanic and meta-volcaniclastic rocks. These volcanic rocks are overlain by Carboniferous clastic and carbonate rocks which are intruded by Carboniferous granites. N-S trending

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Permian fossiliferous limestone and sediments overlay the Carboniferous sedimentary rocks and are themselves intruded by Permian granites. Unconformably overlying the Upper Permian limestone are the Mesozoic sedimentary rocks of the Khorat Group which include red-bedded sandstones, siltstones and shales with evaporites. The Mesozoic sequences include a transition from marine Triassic successions intruded by Late Triassic granites to continental Jurassic strata.

Traditionally, the volcanic rocks of the Loei-Petchabun Fold Belt have been divided into eastern, central and western belts based on trends in the volcanic rocks. The eastern Loei volcanic area is characterized by rhyolite and associated felsic pyroclastic rocks formed by crustal melting which have a Rb-Sr age of 384 Ma [2]. The central Loei volcanic belt consists of Late Devonian–Early Carboniferous basaltic rocks overlying an Upper Devonian tuff [4,5]). Khositanont et al. [6] reported zircon U-Pb ages of 433 ± 4 Ma and 425 ± 7 Ma for tuffs from Loei Province. Intasopa and Dunn [2] reported a 361±11 Ma $^{40}Ar/^{39}Ar$ age for a basalt from this belt. The basaltic rocks have Mid-Ocean Ridge Basalt (MORB) and oceanic island basalt (OIB) geochemical affinities [2,4]; consequently this belt has been interpreted as suture zone that marks a former ocean basin (Loei Suture; [7]). The Western Loei volcanic rocks are andesitic and dacitic in composition and are observed together with volcaniclastic rocks. One of the andesites has an K-Ar age of 237±12 Ma [2]. The andesitic rocks have a calc-alkaline composition and are interpreted to have formed by east-dipping subduction under Indochina [8]. In addition to the volcanic rocks, plutonic rocks are also found in the weastern Loei area. The Ban That granodiorite yielded a crystallization age of 230 ± 4 Ma by U-Pb dating of zircon [6], and similar results were obtained by LA-ICPMS U-Pb dating zircon from a quartz monzonite in the Phu Lon skarn deposit (northern Loei) yielded an age of 244 ± 4 Ma [9]. These volcanic and plutonic rocks have been interpreted to have formed by partial melting of mantle and lower crustal rocks above a subduction zone under extension [10].

3. Method

Twenty fresh representative volcanic and plutonic samples were collected from Amphoe Wang Sa Phung and Maung areas, Loei Province (Figure 1a). Thin-sections were prepared for petrographic analysis using a transmitted light microscope and the samples were prepared and analysed for Major and trace elements using a Philips PW 1480 X-ray Fluorescence Spectrometer at the University of Adelaide. Ten of the powdered samples were also analysed for REEs at the Genalysis in Adelaide, South Australia using a standard ICP-MS analytical package.

4. Result and Discussion

4.1. Lithopetrography

The volcanic and plutonic samples in this study (Figure 1a) are divided into five groups including volcanic rocks-porphyritic andesite, andesite, dacite and rhyolite; plutonic rocks-granodiorite, and diorite. Most samples have intermediate compositions.

4.1.1. Porphyritic andesites

Porphyritic andesites are pale to dark grey, fine-grained and inequigranular with tabular feldspar and prismatic hornblende phenocrysts and fine-grained groundmass. Petrographically, the andesitic rocks are typically porphyritic with phenocrysts of subhedral tabular plagioclase-andesine (15%, 5-20 mm), subhedral to euhedral hornblende (15%, 5-30 mm) and anhedral quartz (7%, 10-50 mm; occurred as a secondary mineral) and groundmass of plagioclase and K-feldspar (65%).

4.1.2. Andesites

The andesites are typically greenish grey, fine-grained and equigranular. They contain tabular andesine (72%, 3-8 mm), fine-grained hornblende (15%), anhedral quartz (8%, 10-50 mm; occurring as a secondary mineral) and a groundmass of opaque minerals (5%).

4.1.3. Dacite and rhyolite

The dacite is commonly pale grey, fine-grained and inequigranular. In thin section, this dacite is porphyritic with subhedral to euhedral prismatic K-feldspar and tabular plagioclase phenocrysts (35%, 5-30 mm), and a fine-grained groundmass of quartz (40%), feldspar (20%) and biotite (5%).

The rhyolite is pale purple, fine fine-grained and inequigranular made up of anhedral quartz (60% as phenocrysts and groundmass), plagioclase (20%) and K-feldspar (25%).

4.1.4. Granodiorite

Granodiorite is typically dark grey, medium-grained and equigranular. It contains feldspar, biotite and quartz. In thin section, the granodiorites are typically equigranular and comprise subhedral to euhedral tabular plagioclase-andesine to labradorite and K-feldspar (60%, 10-30 mm), anhedral quartz (30%, 3-25 mm) and subhedral biotite (10%, 5-20 mm). Apatite and titanite are also found as accessory minerals.

4.1.5. Diorite and gabbro

Diorite is typically dark grey, medium-grained and equigranular. In thin section, the diorites are typically equigranular and comprise subhedral to euhedral tabular plagioclase-labradorite to bytownite (70%, 10-30 mm), subhedral biotite (15%, 5-20 mm) subhedral hornblende (10%, 3-25 mm) and muscovite (5%, 5-15 mm). Apatite and titanite are found as accessory minerals.

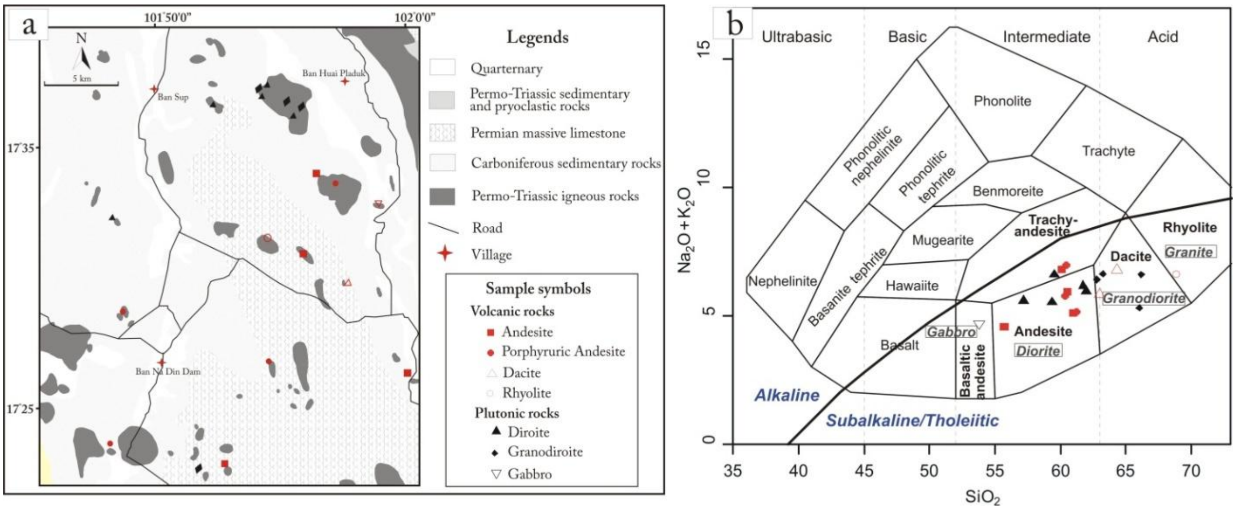

Fig. 1: Geologic map of the study area and Total-alkali-silica diagrams; a Geologic map and sample locations; b Classification and composition of Loei igneous rocks: TAS diagram after Cox et al. [11]; note sample symbols same as in 1a.

4.2. Geochemistry

The geochemical study of the Loei volcanic and plutonic rocks was undertaken by interpreting their characteristics, concentrations and relationships of major, trace and rare earth elements aiming to address petrogenetic characters and geological setting of the Loei igneous rocks.

Fourteen of the samples have intermediate compositions between 55 and 65 wt% SiO_2, one sample is basic whereas three are acidic. Based on the Total-alkali-silica diagrams after [11] (Figure 1b) all samples are sub-alkaline and tholeiitic with most being high K calc-alkaline series and calc-alkaline series. The binary plot after [12] shows that the Loei volcanic and plutonic rocks are metaluminous to peraluminous. Mg number (Mg#) of the rocks varies from 42 to 62 and Aluminium Saturation Index (ASI) also varies from 0.7 to 1.2. Selected Harker diagrams (SiO_2 versus major and trace elements) of the Loei igneous rocks are shown in Figure 2a to 2d. The Harker diagrams highlight geochemical variations. The Harker diagrams show mostly continuous negative trends for plots of SiO_2 against Al_2O_3, MgO, CaO, Ti_2O and Fe_2O_3. The SiO_2 versus Ba diagram has a positive trend (Figure 2d).

Spidergrams of REE data for the Loei rocks normalized to MORB [13] (Figure 2e) and normalized to values from [14] (Figure 2f); have similar patterns for both volcanic and plutonic samples.. In the spidergram (Figure 2e), all samples displays positive Rb, Th, Ce, Sm and Y anomalies and negative Nb and Ti anomalies. The REE pattern show moderately fractionated light rare earth elements (LREEs) and relatively flat heavy rare earth elements (HREEs; Figure 2f). Fractionation trends (La/Yb ratio) of the igneous rocks range from 6.3 to 13.6. Most samples have a negative europium anomaly with an average Eu/Eu* of 0.91.

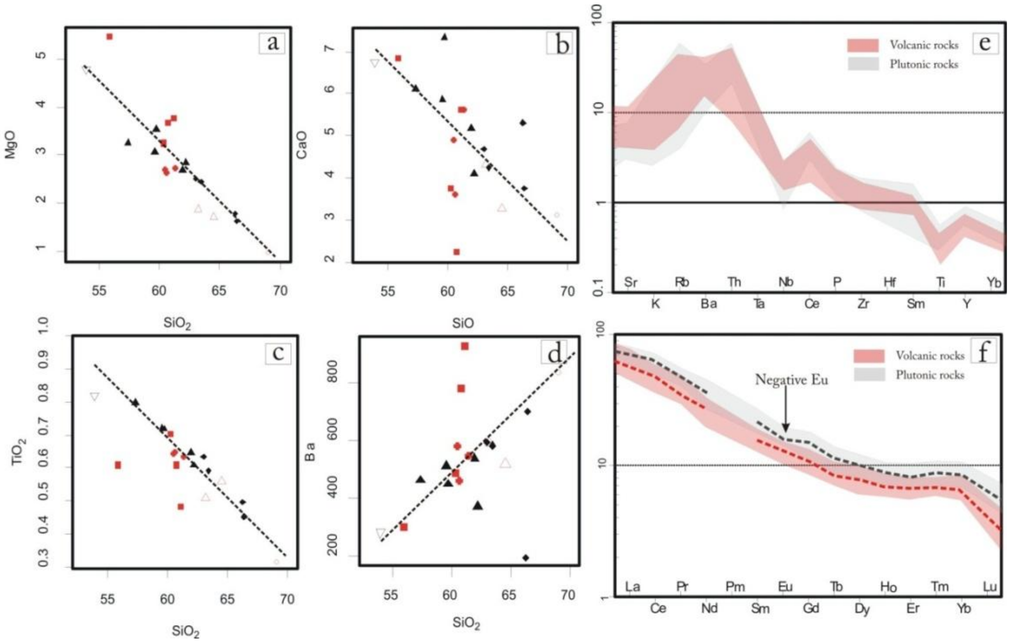

Fig. 2: Geochemical diagrams; a to d Harker diagrams (dashed lines-evolution trends); e. spidergram normalized to MORB of [13]; and f. REE pattern normalized to values of [14]; note sample symbols same as in 1a.

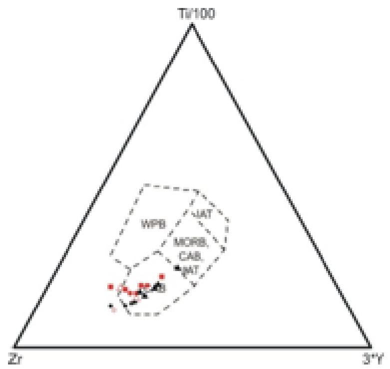

Fig. 3: Ti-Y-Zr diagram for Loei igneous rocks; note sample symbols same as in 1a.

4.3. Discussion and conclusion

The Loei igneous rocks in this study are mainly andesitic or intermediate in composition and are chemically similar. They can be correlated to the western Loei igneous rocks which are located nearby, have similar lithology and formed ~230-250 Ma [6]. They display similar and continuous trends in the Harker diagrams which suggest that they are co-magmatic. Continuous trends of SiO_2 versus MgO, CaO, TiO_2, and Ba, positive Rb, Th, Ce, Sm and Y anomalies and negative Nb and Ti anomalies for these rocks indicate magma mixing processes and/or fractional crystallization of plagioclase, K-feldspar, titanite, mica, apatite and hornblende.

The negative slope on the spidergrams and the enriched light REEs suggest partial melting of a normal mantle source or one that is slightly enriched in incompatible elements. Moreover, a negative Eu anomaly suggests a shallower plagioclase residue in the source region of these rocks. The geochemistry of the Loei igneous rocks can be used to constrain the tectonic setting under which they formed. A Ti-Y-Zr ternary discrimination diagram [15] suggests that the volcanic and plutonic suites from the Loei are classified as a calc-alkaline (Figure 3).

Typically, calc-alkaline magmas are restricted to subduction zone magmas, therefore these igneous rocks were generated as a result of the subduction of an ocean between the Indochina and Sibumasu blocks. Moreover, positive Pb, Rb and Th anomalies and Nb depletion in the spidergram indicate either contamination by continental crust or melting of LILE enriched lithospheric mantle. Given the tectonic setting, these geochemical data are likely to reflect the assimilation of thickened continental crust of the Indochina Block above a subduction zone.

5. Acknowledgements

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