The Geological Society of Thailand, a non-profit scientific organization was incorporated in Bangkok in March 1968 with head-quarters at the Department of Mineral Resources, Bangkok, Thailand. Its objectives are: to exchange knowledge and opinion among geologists and interested persons; to diffuse technical knowledge and results of investigation by publication and other activities; to cooperate with and to assist to any local and overseas society and organization; and to promote for the advancement of geological sciences.

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Preface

The GST Journal volume 2008-2009 is composed of several geological aspects concerning on some works of many geologists who expressed their knowledge in basaltic sandstone in Loei, molluck shell in Krabi, and also the Cenozoic mammals in Thailand.

The other geologists still focus on geological hazards which generally interested in tsunami of 26/12/2004, and the study of Sagaing fault in Myanmar. These geological applications should be the geo-standard for the publicity which is more valuable than non geologists who discussed over the facts of their matter before.

The last interested literature is approached to the hydroelectric power project at Nam Ngum, Lao, PDR. This geological application is not only published the information of the neighboring country but also correlated the geology of northeastern region to there.

The GST hopes that these literatures will provide the knowledge of geology, palaeontology, geological hazards, and geological application of the different areas for our technical activities and alert some geologists to create their geo-knowledge for the next Journal volume.

Araya Nakanart
President
Geological Society of Thailand
### Glossary of commonly-used Thai terms

<table>
<thead>
<tr>
<th>Term</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amphoe</td>
<td>Administrative district below a changwat</td>
</tr>
<tr>
<td>Ao</td>
<td>Gulf; bay</td>
</tr>
<tr>
<td>Ban</td>
<td>House; home; hamlet; village</td>
</tr>
<tr>
<td>Bang</td>
<td>Riverside or waterside village</td>
</tr>
<tr>
<td>Changwat</td>
<td>Province; prefix before the name of principal city within a changwat</td>
</tr>
<tr>
<td>Chiang</td>
<td>Town, city</td>
</tr>
<tr>
<td>Din</td>
<td>Soil</td>
</tr>
<tr>
<td>Doi</td>
<td>Mountain</td>
</tr>
<tr>
<td>Haad</td>
<td>Beach</td>
</tr>
<tr>
<td>Hin</td>
<td>Rock</td>
</tr>
<tr>
<td>Hua</td>
<td>Head; headland</td>
</tr>
<tr>
<td>Huai</td>
<td>Stream</td>
</tr>
<tr>
<td>Kaeng</td>
<td>Rapids</td>
</tr>
<tr>
<td>Khao</td>
<td>Mountain; hill</td>
</tr>
<tr>
<td>Khlong</td>
<td>River; waterway; canal</td>
</tr>
<tr>
<td>King Amphoe</td>
<td>Group of villages, but smaller than amphoe</td>
</tr>
<tr>
<td>Ko</td>
<td>Island</td>
</tr>
<tr>
<td>Laem</td>
<td>Headland</td>
</tr>
<tr>
<td>Lek</td>
<td>Small; little</td>
</tr>
<tr>
<td>Mae-nam</td>
<td>River</td>
</tr>
<tr>
<td>Muang</td>
<td>Town, river</td>
</tr>
<tr>
<td>Nam</td>
<td>Water</td>
</tr>
<tr>
<td>Nam-tok</td>
<td>Waterfall</td>
</tr>
<tr>
<td>Nong</td>
<td>Swamp, fen, pond, reservoir</td>
</tr>
<tr>
<td>Pha</td>
<td>Hill or mountain with cliff</td>
</tr>
<tr>
<td>Phu-khao</td>
<td>Mountain</td>
</tr>
<tr>
<td>Pong</td>
<td>Salt lick</td>
</tr>
<tr>
<td>Rong-rian</td>
<td>School</td>
</tr>
<tr>
<td>Rong-raem</td>
<td>Hotel</td>
</tr>
<tr>
<td>Ran-ahaan</td>
<td>Restaurant; eating place</td>
</tr>
<tr>
<td>Talay</td>
<td>Sea</td>
</tr>
<tr>
<td>Tambon</td>
<td>Group of villages</td>
</tr>
<tr>
<td>Tham</td>
<td>Cave</td>
</tr>
<tr>
<td>Yai</td>
<td>Big; large</td>
</tr>
<tr>
<td>Yao</td>
<td>Long</td>
</tr>
<tr>
<td>Wat</td>
<td>Temple; monastery</td>
</tr>
</tbody>
</table>

Note: Thai is a tonal language with vowel and consonant sounds not present in spoken English; no attempt is made here to describe the correct pronunciation of words. The above romanised transliterations of the Thai are those commonly used, but other versions are
Basaltic Sandstone from the Loei Suture, Northeast Thailand

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Abstract

Serpentinite bodies, mainly serpentinized dunite and harzburgite, occur within Devonian metamorphic rocks along the Loei suture between the Indochina and Nakhon Thai continental blocks in Northeast Thailand. In the present study, we describe a block of basaltic sandstone found within an outcrop of highly serpentinized and sheared dunite. The basaltic sandstone is composed mostly of fragments of basalt and serpentine, along with abundant detrital chromian spinels. The chemistry of chromian spinels in the sandstone and surrounding serpentinite was analyzed using EPMA. The detrital spinels have relatively high values of Cr / (Cr + Al), Fe3+ / (Cr + Al + Fe3+), and TiO2, making them similar to spinels within serpentinized dunite and olivine basalt found along the Loei suture. The detritus within the sandstone was largely supplied by olivine basalt and serpentinized dunite along the Loei suture, but not serpentinized harzburgite. Spinel chemistry indicates that the source rocks of the detrital spinels found in the basaltic sandstone formed in an arc setting. It is inferred that the serpentinite and basalt that occur along the Loei suture comprise an ophiolite complex, and that the sandstone is a tectonic block within the complex. The spinels found in the basaltic sandstone and serpentinites along the Loei suture are similar to the detrital chromian spinels within the Lower Permian Nam Maholan Formation in the Loei area and the Middle Permian Nam Duk Formation in the Phetchabun area in terms of chemistry. The serpentinites and basaltic sandstone located along the Loei suture were probably emplaced in or prior to the Early Permian.

Keywords: detrital chromian spinel, basaltic sandstone, serpentinite, Loei suture, NE Thailand

Introduction

Geologically, Thailand is made up of two microcontinents: the Shan-Thai (or Sibumasu; Metcalfe, 1984) and Indochina blocks (Bunopas, 1981; Bunopas and Vella 1983). These blocks are allochthonous to Southeast Asia and are considered to represent fragments of Gondwana (e.g., Metcalfe, 1996). The boundary between the blocks is termed the Nan suture (Bunopas, 1981) or Nan River suture (Barr and Macdonald, 1987).

Charusiri et al. (2002) proposed a revised tectonic framework for Thailand (Fig. 1), in which North Thailand is subdivided into four terranes (Shan-Thai, Lamang-Chiang Rai, Nakhon Thai, and Indochina) that are bounded by three north–south trending sutures (from west to east, the Chiang Mai, Nan, and Loei sutures) (Fig. 1). The Shan-Thai and Indochina terranes are considered to represent fragmented microcontinents derived from Gondwana; a paleo-ocean named Paleotethys lay between the belts prior to their collision. The Nakhon Thai and Lamang-Chiang Rai terranes are interpreted to represent a subduction zone that was located adjacent to the Indochina block, and a volcanic arc that was associated with the other subduction zone, respectively (Charusiri et al., 2002). The four terranes that make up North Thailand were amalgamated during the Triassic (Charusiri et al., 2002).

In Northeast Thailand, Silurian to Devonian greenschist–facies metamorphic rocks are distributed along the Loei suture. These rocks are interpreted as volcanic arc sediments or sediments that were off-scraped during subduction of the Paleotethys (Charusiri et al., 2002); they characteristically contain serpentinite bodies (Chairangsee et al., 1990). In the present study, we describe a block of chromian-spinel-bearing basaltic sandstone discovered within a serpentinite
Fig. 1 Map of the tectonic framework of Thailand (modified after Charusiri et al., 2002)
Fig. 2 Geological map of the Loei area (DMR, 1999); locations 1-3 indicate the sampling sites of basaltic sandstone and serpentinite, serpentinite, and chromian-spinel-bearing sandstone reported by Sugiyama et al., 2000, respectively.
Fig. 3 Field occurrence of the basaltic sandstone at Loc. 1.
Serpentinite bodies occur at several localities along the Loei suture and the chemistry of detrital chromian spinel has been analyzed previously in provenance studies (Arai and Okada, 1991; Hisada and Arai, 1993; Cookenboo et al., 1997), and several studies have described detrital chromian spinel found in Thailand (Sugiyama et al., 2000; Chutakositkanon et al., 2001; Hisada et al., 2004).

The petrology of basaltic sandstone found along the Loei suture and the chemistry of detrital chromian spinel found within the sandstone were examined and studied. In this context, the tectonic significance of the sandstone in relation with the Loei suture and the chemistry of detrital chromian spinel were discussed.

**Geology of Sampling Localities**

Serpentinite bodies occur at several localities along the Loei suture (Fig. 2), surrounded by Devonian metasediments (Department of Mineral Resources, 1999). The metasediments are quartzite and phyllite that are elongated in a north–south direction (Chairangsee et al., 1990). The serpentinites are highly sheared, with antigorite being the dominant mineral. Pseudomorphs of plagioclase, pyroxene, chlorite, and opaque iron oxides are also found (Chairangsee et al., 1990).

The field study revealed that the basaltic sandstone found within an outcrop of serpentinite (Fig. 2, Loc. 1: N17° 32’ 26” E) occurred as a highly weathered massive block within soil (Fig. 3) and grayish-green in color. The block is more than 30 cm in diameter. The sandstone is coarse-grained and grayish-green in color. The block is more than 30 cm in diameter. The sandstone is coarse-grained and grayish-green in color. The block is more than 30 cm in diameter.

Chromian spinel is an accessory mineral within mafic and ultramafic rocks, and its chemistry reflects the physio-chemical conditions of the formation and modification of the host rock (Irvine, 1965, 1967; Dick and Bullen, 1984; Arai, 1992; Barnes and Roeder, 2001; Arai et al., 2006). Chromian spinel in serpentinites is especially important as it is frequently the only mineral that records information on the original peridotite. In addition, chromian spinel is more resistant to chemical and physical weathering than other minerals in mafic and ultramafic rocks such as olivine and pyroxenes, and is sometimes found in sediments derived from mafic and ultramafic rocks. The chemistry of detrital chromian spinel has been analyzed previously in provenance studies (Arai and Okada, 1991; Hisada and Arai, 1993; Cookenboo et al., 1997), and several studies have described detrital chromian spinel found in Thailand (Sugiyama et al., 2000; Chutakositkanon et al., 2001; Hisada et al., 2004).

The value of Mg# \[= \frac{Mg}{(Mg + Fe^{2+})}\] atomic ratio of the analyzed detrital chromian spinels varies greatly from 0.20 to 0.68 (Fig. 5a). The range of Cr# \[= \frac{Cr}{(Cr + Al)}\] atomic ratio is 0.55 to 0.85, with most spinels having a value of Cr# higher than 0.7 (Fig. 5a); the obtained values of Fe3+\# \[= \frac{Fe^{3+}}{(Al + Cr + Fe^{3+})}\] atomic ratio are mostly between 0.05 and 0.20 (Fig. 5b). The TiO2 content is generally less than 0.6 wt%, but several grains record values are higher than 1.0 wt% (Fig. 5c).

The serpentinites and olivine basalt differ in terms of spinel chemistry (Figs. 5a–c). The chromian spinels in serpentinitized dunite at Loc. 1 are characterized by relatively high Cr# (0.50–0.85), relatively high TiO2 content (0.2–1.3 wt%), and high Fe3+\# (0.05–0.24). The chromian spinels in metamorphosed olivine basalt have high Cr# (0.65–0.93), high TiO2 content (0.7–2.3 wt%), and high Fe3+\# (0.15–0.24). The spinels in serpentinitized harzburgite at Loc. 2 have low Cr# (0.38–0.50), low TiO2 content (< 0.2 wt%), and low Fe3+\# (generally < 0.06).

Serpentinite at Loc. 1 (Fig. 2) is intensely sheared and partly schistose. Based on the texture of the serpentinite and chromian spinel, the parent rock of the serpentinite at Loc. 1 was probably dunite (Fig. 4b). Float of metamorphosed olivine basalt is also found at Loc. 1 (Fig. 4c).

**Chromian Spinels**

Detrital chromian spinel in the basaltic sandstone is commonly angular to subangular, with some grains being largely euhedral (Fig. 4a). Most of the grains are opaque, but some are dark reddish-brown in thin section. The grains range in diameter from 0.07 to 0.59 mm.

The detrital chromian spinels were analyzed using a microprobe (JXA8621 Super Microprobe; JEOL, Tokyo, Japan) at the Research Facility Center for Science and Technology of the University of Tsukuba, Japan. The operating conditions were 20-kV accelerating voltage, 10-nA specimen current, and 10-μm beam diameter. A total of 75 detrital chromian spinel grains were analyzed; selected analyses are listed in Table 1. Ratios of Fe2+ and Fe3+ were calculated assuming spinel stoichiometry. All Ti was assumed to form the ulvospinel molecule, Fe2TiO4, on calculation. Chemical zoning was not detected in the chromian spinels; consequently, only the core of each grain was probe. In comparison with the detrital grains, the analyses of chromian spinels from the serpentinitized dunite and olivine basalt at Loc. 1 and spinel from serpentinitized harzburgite (Fig. 4d) at Loc. 2 (Fig. 2) were performed and discussed.
Fig. 4 Photomicrographs of the basaltic sandstone and serpentine: a) basaltic Sandstone, Loc. 1; b) serpentinized dunite, Loc. 1; c) metamorphosed picrite, Loc. 1; and d) serpentinized harzburgite, Loc. 2; open nicols, scale bars are 0.5 mm long.
Provenance of Basaltic Sandstone

The basaltic sandstone is mainly composed of fragments of basalt and serpentine. It is inferred that the fragments of serpentine originated from olivine judging from their texture. Accordingly, the detritus within the sandstone was derived from either a single rock type, that is, olivine-rich (picritic) basalt, or several rock types such as basalts and serpentinites.

The chemistry of chromian spinel from the basaltic sandstone is similar to that of spinel from the serpentinized dunite and olivine basalt at Loc. 1, but is dissimilar to detrital chromian spinel from serpentinized harzburgite at Loc. 2 (Figs.5a–c). Based on the framework composition of the sandstone and the chemistry of detrital chromian spinel revealed that the basaltic sandstone was mainly derived from the serpentinized dunite and olivine basalt found at Loc. 1.

Chromian spinel in the basaltic sandstone is characterized by relatively high Cr#, TiO2 content, and Fe3+# (Figs. 5a–c). These characteristics are typical of spinel found in magmatic arcs (e.g., Arai, 1992; Barnes and Roeder, 2001). The Cr / TiO2 plotted on the discrimination diagram proposed by Arai (1992), the detrital chromian spinels in the basaltic sandstone plots are located in the field of island–arc basalts (Fig. 5c). Therefore, it is likely that the source rocks of the basaltic sandstone originated in an arc setting.

Emplacement of The Basaltic Sandstone Block

As the serpentinites found along the Loei suture are composed of several types of serpentinized peridotite and contain basal rock, it is inferred that they represent an ophiolite complex. None of the detrital chromian spinel from the basaltic sandstone originates from the serpentinized harzburgite found along the Loei suture; instead, it was probably deposited prior to the emplacement of the ophiolite complex to its present position. It is the most likely that basaltic sandstone is a tectonic block within the serpentinite, as the lithology of the sandstone is completely different to that of the Devonian sandstone surrounding the ophiolitic complex and the block of sandstone was found within an outcrop of serpentinite.

Other than in the Loei suture, one example is known in which tectonic blocks of sandstone within sheared serpentinite contain serpentinite grains supplied from the host rock. Sheared serpentinites in the Mineoka Belt, central Japan,
contain numerous tectonic blocks of basalt, gabbro, metamorphic rocks, and sedimentary rocks such as limestone, chert, and serpentinite-rich sandstone (Ogawa, 1983; Ogawa et al., 1985; Hirano et al., 2003). The serpentinite-rich sandstone contains fragments of serpentinite, basalt, gabbro, and metamorphic rocks. The chemistry of detrital chromian spinel indicates that the sandstone was mainly derived from the surrounding serpentinite (Arai and Okada, 1991). Following sedimentation, the sandstone block was transported into the serpentinite during a tectonic event.

The detritus within the basaltic sandstone found along the Loei suture was also supplied from the surrounding serpentinite and basalt. As with the serpentinite-rich sandstone within the Mineoka Belt, it is possible that the basaltic sandstone found along the Loei suture was incorporated into the serpentinite during a tectonic event subsequent to sedimentation.

It is difficult to determine the timing of deposition of the basaltic sandstone and its emplacement as a tectonic block within the serpentinite; however, it is possible to constrain the timing of emplacement of the ophiolite complex along the Loei suture. The chemistry of detrital chromian spinels has form two formations distributed along the Loei suture; that is, the Lower Permian Nam Maholan Formation in the Loei area (Fig. 2, Loc. 3; Sugiyama et al., 2000) and the Middle Permian Nam Duk Formation in the Phetchabun area (Fig. 1; Chutakositkanon et al., 2001). These earlier studies concluded that the detrital spinels were supplied from volcanic rocks and harzburgite that formed in an arc setting, which indicated that the detrital spinels being supplied from volcanic rocks in the Loei-Phetchabun-Ko Chang volcanic belt. The volcanic rocks in the Loei volcanic province in the northern part of this belt are Middle Devonian–Early Carboniferous and Permo–Triassic in age (Intasopa and Dunn, 1994). The Middle Devonian–Early Carboniferous volcanic rocks consist of rhyolite and minor MORB-type basalt (Intasopa and Dunn, 1994), while the Permo–Triassic volcanic rocks consist of andesite and dacite and are underlain by the Upper Permian sediments (Mineral Resources Development Project, 1988). The evidences from this study indicated that the detrital chromian spinels in the basaltic sandstone in the Nam Maholan and Nam Duk Formations are inferred to have been mainly supplied from mafic volcanic rocks formed in an arc setting, it is unlikely that all of these detrital chromian spinels were derived from volcanic rocks of the Loei volcanic province.

Most of the detrital chromian spinels in the two formations have similar chemistries to those of chromian spinels in the basaltic sandstone, serpentinized dunite, and olivine basalt at Loc. 1 (Figs. 5a–c), and some have similar chemistry to that of spinel in serpentinized harzburgite at Loc. 2 (Figs. 5a–c). It is suggested that the detrital chromian spinels in the Nam Maholan and Nam Duk Formations were derived from the ophiolite complex found along the Loei suture. In other words, the ophiolite complex along the Loei suture was probably emplaced in or prior to the Early Permian. The block of basaltic sandstone, which was tectonically emplaced into the ophiolite complex, might also have been deposited in or prior to the Early Permian. As stated above, it is concluded that the source rocks of the basaltic sandstone formed in an arc setting. Charusiri et al., (2002) inferred a Silurian–Permian magmatic arc on the western margin of the Indochina block. It is likely that the source rocks of the basaltic sandstone formed within this arc.

Conclusion

The detritus within a block of basaltic sandstone found in an outcrop of serpentinite along the Loei suture, Northeast Thailand, and described here for the first time, is composed mainly of fragments of basalt and serpentinite as well as abundant detrital chromian spinel. The chemistry of the spinel is similar to that of spinel in the surrounding serpentinitized dunite and olivine basalt. The spinel chemistry indicates that the source rocks of the basaltic sandstone formed in an arc setting. None of the detrital chromian spinel from the basaltic sandstone originated from serpentinized harzburgite found along the Loei suture. It is inferred that the serpentinites along the Loei suture represent an ophiolite complex and that the basaltic sandstone represents a tectonic block within the serpentinite. Based on the fact that the basaltic sandstone does not contain detrital chromian spinel derived from the serpentinized harzburgite found along the Loei suture, the sandstone is inferred to have been deposited prior to emplacement of the ophiolite complex to its present position. The Lower Permian Nam Maholan Formation in the Loei area and the Middle Permian Nam Duk Formation in the Phetchabun area contain detrital chromian spinels that originated from serpentinite and basalt located along the Loei suture. The serpentinites found along the Loei suture were emplaced in or prior to the Early Permian.

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