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PROTOLITH OF SERPENTINITE UNITS AT YEGA-INN AND KANNBYU AREAS SAGAING REGION, MYANMAR

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Abstract

The study area is situated along the Sagaing Fault between the Kannbyu and Yega-Inn areas. The main objective of this study is to emphasize the serpentinite unit of ophiolite suite (Central Ophiolite Belt) along the Sagaing Fault and to discuss their protolith that is related to fault activity. The Sagaing Fault is located at the continental plate boundary between the Myanmar Plate and Sundaland Plate. It is an active fault that causes seismic damage in the major cities of Myanmar. Small outcrop of serpentinites are found in the Kannbyu area and massive bolder in the Yega-Inn (lake) area. They occurred along this fault, and examined the highly sheared serpentinite bodies in the Kannbyu and Yega-Inn areas by the Electron probe micro-analyzer (EPMA). Rock samples from these areas have not been yet up to now by EPMA laboratory analyzed method especially serpentinite units that have not been done in Myanmar. Sheared serpentinites and related rocks: such as talc and chlorite-bearing rocks, show the foliation is defined by alignments of small rock fragments. Sporadically serpentinite units in this area are completely serpentinized, weathered, the morphology and chemistry of their spinels, coupled with micro-texture, indicate that the protolith of these serpentinites are mainly harzburgite and dunite and these units are cut by gabbroic veins in places. Chrome spinel samples showed the variable in chemical composition range of fore-arc peridotites, and they are similar to those in the mantle section of nearby ophiolites. Antigorite serpentine mineral is the main phase of the studied samples. No shape preferred orientation of the antigorite is present, indicating that the serpentinization occurred at ~ 500 °C under relatively static conditions. Locally, these serpentinites were deformed and it is probably due to the activity of the Sagaing Fault, resulting in the formation of serpentinite schist. Serpentinized peridotite and related minerals such as talc and saponite in the research area is probably linked to variations in the activity of the Sagaing Fault.

Keywords: Protolith of serpentinites, Chemical variations of spinels, Sagaing Fault activity,

Introduction

The study areas: The Kannbyu and Yega-Inn along the Sagaing Fault is prone to earthquakes because it lies along the continental plate boundary between the Burma Plate and Sundaland Plate (Win Swe, 1981). The Sagaing Fault is the dextral strike-slip fault that acts as a part of a 3700 km long oblique subduction at the Sunda Trench, and it has a slip rate of 10~23 mm/year (Maurin et al., 2010; Vigny, 2003; Wang et al.,2011). The Greater Indian continent against the southeastern Asian collision caused the clockwise rotation of the subduction zone, which resulted in strike-slip faulting. Understanding of the factors controlling the pattern of seismicity along the Sagaing Fault is therefore very important for seismic risk mitigation in the major cities of the Myanmar (Fig. 1). About the magnitude (7.0 – 7.5) of earthquakes with have been produced by this fault, causing severe damages (Maurin et al., 2010; Hurukawa and Maung, 2011; Wang, 2014; Wang et.al.,2011). Isolated serpentinite bodies are found intruding all the rock types along the northern part of the Sagaing Fault, especially Kannbyu and Yega-inn areas, and they are part of the Central Ophiolite Belt (Hla Htay et al., 2017). Some rocks and serpentinite units containing similarly ductile minerals are commonly believed to be the cause of the creep and low strength of the San Andreas Fault, California, USA, which is another example of a long strike-slip fault, which extends roughly 1,200 km along the tectonic boundary between the Pacific and North American Plates (Moore and Rymer, 2007; Lockner et al., 2011). The main objective of this study was to know about the protoliths of serpentinites along the Sagaing Fault and to discuss the fault activity by analyzing rock samples with the aid of EPMA method.

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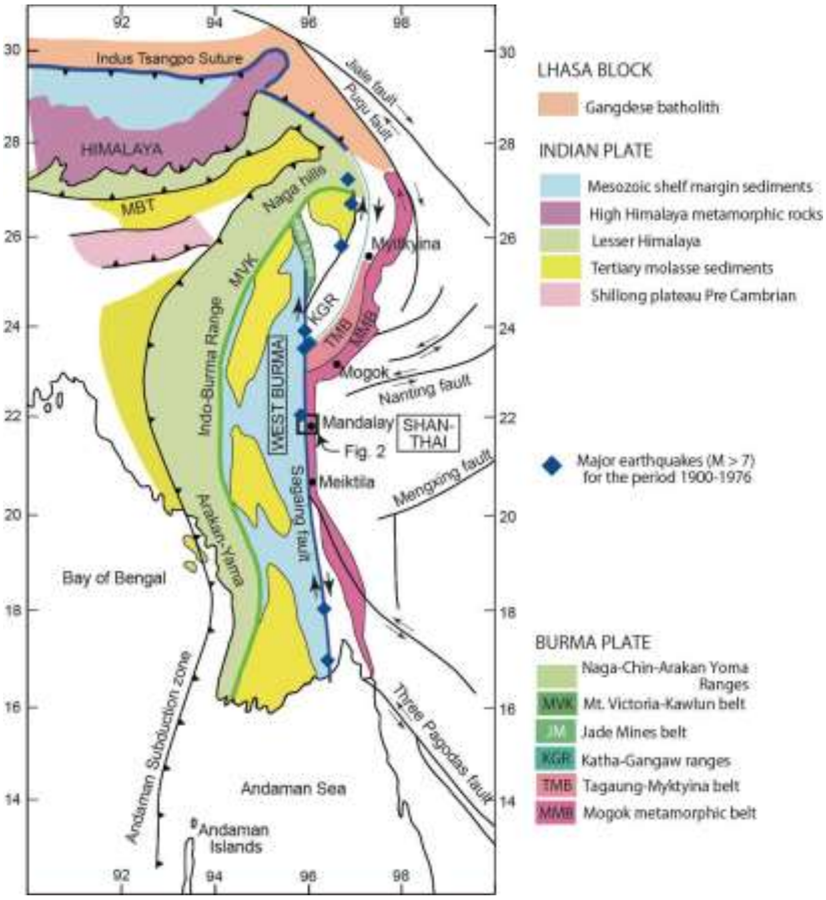

Figure 1 Showed the geological and tectonic map around the Sagaing Fault (after Searle et al., 2007) can see the hypocenter of previous earthquakes with magnitude ≥ 7.0 for the period of 1900-1976 (after Sloan et al., 2017).

1.1 Background geology of the study areas

The study area is covered by sedimentary rocks, but metamorphic rocks of the Mogok Metamorphic Belt (MMB) occurred on the eastern side of the central part of the Sagaing Fault. Serpentinite units along the Sagaing Fault area are member of ophiolite suite especially in the Kannbyu and Yega-Inn areas, Sagaing region. Geological maps of the study areas are shown in (Fig.2).

1.1.1 Sagaing, Minwun and Kannbyu Areas

There is the Sagaing ridge of fairly high hills trending NNW-SSE with east dips of moderate to high angle in the east and the Minwun ridge of rolling hills with eastwards subvertical dips in the west. **They** are parallel and separated by a narrow straight valley that turns out to be the Sagaing Fault valley. The Sagaing Metamorphics from bottom to top are hornblende gneiss unit, marble unit and marble-gneiss interbedded unit. Hornblende gneiss unit consists of hornblende gneiss, biotite-hornblende gneiss, amphibolite and hornblendite. Pegmatite and quartzofeldspathic veins cut a crossed the gneisses in some places. Marble unit contains forsterite-phlogopite marble, diopside marble, and calc-silicate rocks. The grade of the Sagaing Metamorphic is ranging from amphibolite to granulite facies. Due to the radiometric dating of a phlogopite mineral by Ar-Ar method, their age of metamorphism is possibly 21 Ma (Early Miocene) (Bertrand *et al.* 1996) and the age of the Sagaing Metamorphic is Proterozoic to Late Paleozoic (Myint Thein *et al*. 2017). Carbonates and shale formed in a shallow, warm sea were the protoliths of these metamorphic rocks. Sagaing Metamorphic can be correlated with Ordovician units which were exposed in the Shan State.

The Minwun Metamorphics occupy a narrow linear belt and it consists of garnet muscovite schist, kyanite muscovite schist, actinolite schist and talc chlorite schist. At Yega-Inn (lake) area serpentinite bodies are found as patches in all rock types. Slightly metamorphosed limestones (mylonitized limestones) with orbitolinid were exposed as blocks and interleaved with the greenschist units (Myint Thein 2009) in this area. Carbonate rocks, mud rocks and basic igneous rocks were the protoliths of the Minwun Metamorphic and the grade of metamorphism in the study area is from greenschist to amphibolite facies according to Kan Saw (1973). The Minwun Metamorphics is Middle to Late Triassic in age after Myint Thein (2017).

The Kannbyu area is located along the Sagaing Fault zone and it is the northern continuation of the Sagaing area. Two-third of that area is covered by sedimentary and metamorphic rocks with an ophiolite suite of the Central Ophiolite Belt (COB). Igneous rocks in this area are pyroxenite, serpentinized peridotite, serpentinites, dolerite, plagiogranite and pillow basalt. Small serpentinite bodies are intruding all the rock types except the Pleistocene terrace deposits of the study area. They are closed association with greywacke, bedded red chert and siliceous limestones. According to the occurrence of colonial rugosa corals in limestone unit, the age of this is probably Permian to Lower Triassic (Than Htut Lwin, 2008).

The Male Formationis at the Kannbyu area consists of interbedded gritty fine-grained sandstone, siltstone and locally variegated shale with leaf fossils. Due to the U – Pb dating method for the detrital zircon from this formation is about 48 Ma (Eocene) (Myint Thein, 2017). The Minwun Metamorphics rocks are overlying by a sedimentary stratum which is assigned to the Upper Pegu Group (Miocene) (Maung Maung 1982; Myint Thein et al. 1982). Outcrops of sandstone unit in the Irrawaddy Formation occurred as a narrow linear belt between the Sagaing Metamorphic rocks and the Ayeyarwady River. The Irrawaddy Formation consists of fluvial deposits (upper part) and fanglomerate unit (lower part) in which vertebrate fossils assemblages are found (Myint Thein 2017). Terrace deposits are widespread along the Ayeyarwady River. Due to above finding vertebrate fossils; the probable age of this unit is Middle to Upper Pleistocene (Than Htut Lwin, 2008). Alluvial deposits covered in the study area especially along the valley of the Sagaing Fault.

1.1.2 Central Ophiolite Belt (COB)

The study area lies in the Central Ophiolite Belt (COB) and it is located in the northern part of the Myanmar which is also between the Western and Eastern Inner-Burma Tertiary Basins (Hla Htay et al., 2017). It extends from the Putao area of Kachin State in the north, through the Phakant-Tawmaw and to the Sagaing-Minwun ranges in the south and terminates at central part of the Myanmar. There are four ophiolite occurrences so far from south to north, the Minwun range, Kyaukpahto area, Indawgyi area and Phakant-Tawmaw area.

According to Hla Htay et al., (2017) the Central Ophiolite Belt (COB) is dismembered incomplete ophiolite composing of peridotite and serpentinites. The mafic cumulate part of ophiolite sequence at the Indawgyi area, however the mafic sheet dyke complex is almost missing. As metamorphic fabric, the Katha Metamorphics (Triassic), greenschist can be observed in the south, the amphibolites schist present at the Indawgyi area in the middle and Glaucophene schist at jade mine area in the north. The metamorphism increases from south to north. The associated sedimentary rocks are mostly greywacke, argillite, chert of the Ngapyawdaw Chaung Formation in the Kyaukpahto and Minwun areas, and molassic sedimentary rocks just covered the Indawgyi and jade mine areas. Jade mines are present in the north of this belt particularly the Phakant-

Tawmaw area. Small amount of chromite, magnetite, gold and platinum group minerals (PGM) are found in this belt.

Sample Interpretation

2.1 Serpentinite unit

In the study area, serpentinite is a member of ophiolite siute which lies in the Central Ophiolite Belt (COB). Serpentinite outcrops along the Sagaing Fault are irregular bodies sporadically exposed at the Kannbyu and Yega-Inn (lake) areas (Fig.3). They are green to dark green in both on fresh and weathered surface and a characteristic soapy appearance is common in light green or dark green serpentinite exposures. Microscopically, serpentine minerals can be divided into three such as lizardite, antigorite and chrysotile and relict olivine, magnetite and chromite occurred as accessories minerals. Pseudomorphic, non-pseudomorphic and serpentine veins are three types of serpentine textures under microscope. Lizardite is abundant in pseudomorphic texture and more antigorite found in non-pseudomorphic texture. Chrysotile occurred as veins serpentine. Among them non-pseudomorphic texture is common in antigorite serpentine. Antigorite found as anhedral grains or aggregates of lamellar flakes in most thin section study (Fig.11).

In the Yega-Inn area, the fault traces steps to the right in a relay on the east side of the lake (Fig.4). Some parts of the serpentinites are extensively sheared (Fig.5), and serpentinite-related rocks, such as talc and/or chlorite-bearing rocks are also observed. Greywacke (Fig.6), chert (Fig.7), limestone (Fig.8), and gabbroic (Fig. 9) rocks are observed around the ourcrops of serpentinite and these rocks are interpreted to represent a dismembered ophiolitic suite (Hla Htay et al., 2017). A foliation defined by the alignments of small rock fragments and minerals in the sheared serpentinite strikes nearly N-S trends and dips to the east (Fig.5). Carbonate veins are common in the Kannbyu area (Fig.10). Specimens collected relatively from massive blocks in the sheared zones, including three serpentinized blocks (samples KC, KE and KF) from the Kannbyu area, and three serpentinized blocks (samples YK, YL and YP) from the Yega-Inn area.

The presumed primary silicate minerals of the original ultramafic rocks, such as olivine and pyroxenes are absent from the study samples due to serpentinization and weathering. The main serpentine phase in the study samples was confirmed to be aggregates of lamellar flakes antigorite (Fig.11) by Raman micro-spectrometry at Kanazawa University, Japan. Although it is difficult to know the primary structure before serpentinization, aggregates of magnetite is sometimes aligned in sub-millimeter-sized and they probably represent the lamellae of pyroxene (bastite-like texture) (Figs.12a and 12b). The antigorite is light green to colorless and show no shaped-preferred orientation in most samples (Figs. 12a and 12b), but sample KC shows a slight shape-preferred orientation of antigorite in the form of an anastomosing network (Figs. 12c and 12d). Weathered olivine was also observed in sample KC (Figs 12e and 12f). A dusty serpentine with yellowish interference color occurs rarely in veinlets and/or networks (Figs. 12a and 12b). Sample YK exhibits dusty-colored fine-grained mineral networks of tremolite and chlorite with an alignment that is parallel to the anastomosing network of antigorite (Figs 12g and 12h). Grains of spinels are partly to completely altered, but they have retained their original shape (Fig.13a). The spinels are subhedral to vermicular texture involving magnetite along their rims (Fig.13b-f).

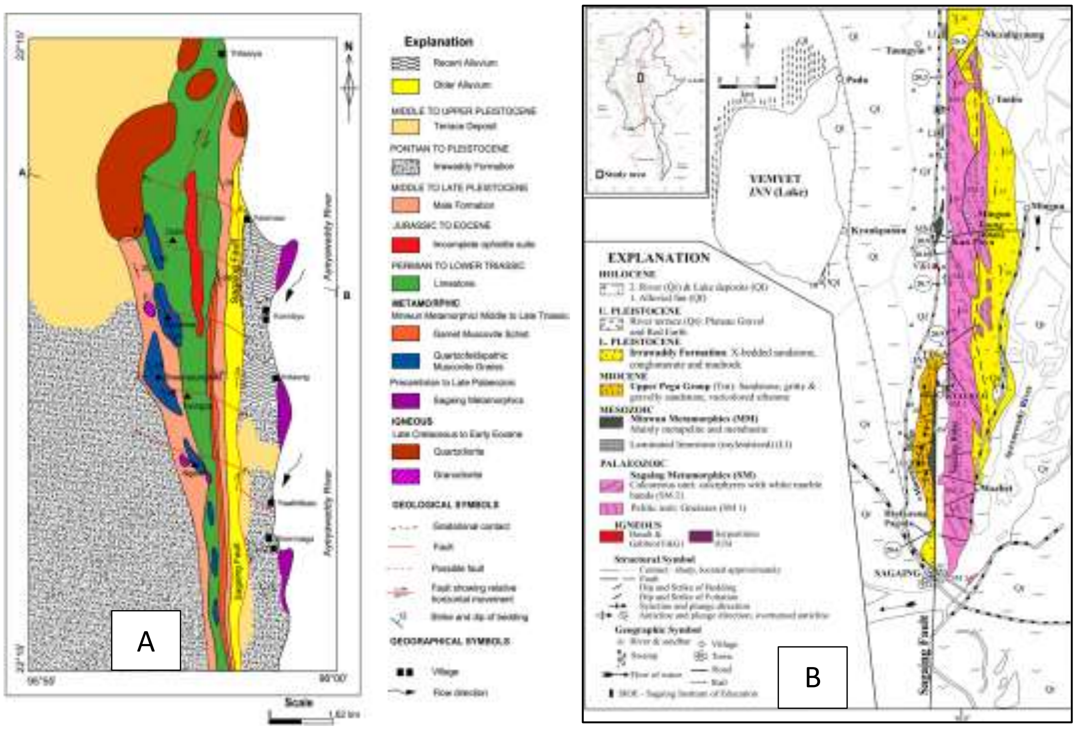

Figure 2 (A & B) Geological map of the Kannbyu and Yega-Inn areas, Sagaing Region. (A) after Hla Htay et.al, (2017) and (B) Myint Thein (2017).

(source: Google).

Figure 3 Location of serpentinite outcrops at Kannbyu and Yega-Inn areas

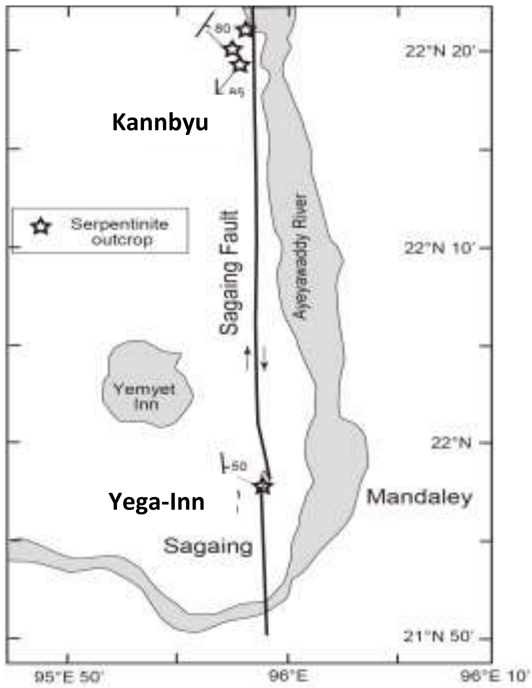

Figure 4 Locality of serpentinite outcrops showing direction of sheared plane.

Figure 5 Exposures of serpentinite schists at the Kannbyu area and the Yega-Inn areas.

Figure 6 Well joint sets in greywacke unit exposed at Kannbyu area.

Figure 7 Highly brecciated nature of chert unit outcrop at Kannbyu area.

Figure 8 Massive type limestone unit exposed at Kannbyu area.

Figure 9 Bold massive unit of gabbro exposed at Kannbyu area.

Figure 10 N-S trending carbonate vein near serpentinite unit at Kannbyu area.

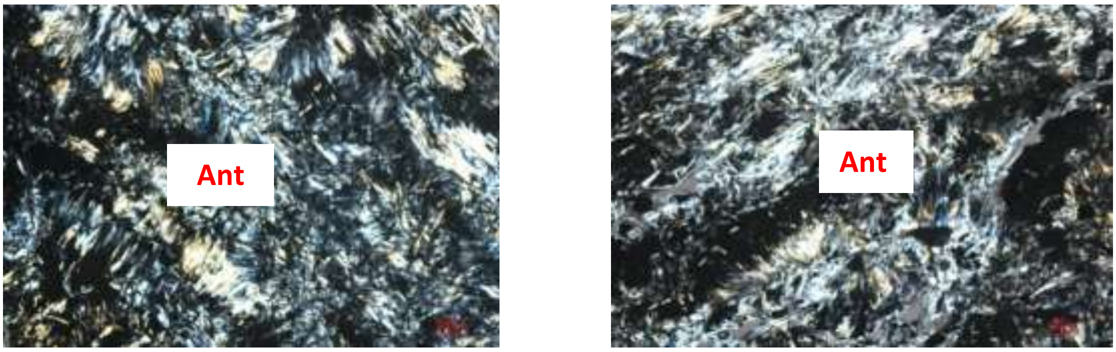

Figure 11 Photomicrographs showing the non-pseudomorphic texture of antigorite (Ant) in serpentinite unit at Kannbyu area.

Chemical Analysis of Serpentenite Minerals

3.1. Analytical method

The study of major-element compositions of minerals in the research area were decided using an electron probe micro-analyzer (EPMA) (JEOL JXA-8800 Superprobe, JEOL) at Kanazawa University, Japan. The analytical data were performed with an accelerating voltage of 20 kV and beam current of 20 nA. A beam diameter of 3 µm was applied to all analytical points. Natural and synthetic mineral standards provided by JEOL were applied for data reduction, using ZAF corrections of JEOL software. In-house mineral standards (chromian spinel, olivine, diopside and Potash feldspar) were analyzed repeatedly to check daily data quality on a daily basis. The measured concentrations of all elements in these in-house minerals are consistent with the averaged values from long-term analyses and are within the standard deviation. Data precision, confirmed by multiple analyses of single points of standard minerals prepared in-house, was better than 5% and 10% relative standard deviation from the averaged values for elements with contents >0.5 wt% and <0.5 wt%, respectively. The major element compositions of analyzed minerals are listed in Table 1-3.

3. 2. Analytical results

The Al_2O_3 content of serpentines varies from < 0.02 to 3.4 wt% (Table-1). The NiO content of the serpentine is usually <0.3 wt%, but for the dusty serpentine it is >0.6 wt% (up to 1.5 wt%) (Table-1). The XMg (= Mg/(Mg + Fe total) atomic ratio) values of serpentine ranges from 0.96 to 0.99 for sample KF (one analysis for sample SC gave a similar composition), and 0.92 to 0.95 for samples YK, YL and YP, respectively (Table-1). The values of Mg# (= Mg / (Mg+ Fe_2+) atomic ratio) and Cr# (= Cr / (Cr + Al) atomic ratio) in the spinel cores are respectively 0.353 - 0.413 and 0.798 - 0.818 for sample KC, 0.460 - 0.587 and 0.681 - 0.695 for sample KE and 0.372 - 0.555 and 0.777 - 0.803 for sample KF (Fig.14). The chrome spinel in samples YK, YL and YP are generally having high contents of Fe^{3+}, even in the core of grains (i.e., ferritchromite, Cr-magnetite and magnetite (Fig.14). The cores of chrome spinels in sample KC, KE and KF have low contents of Fe^{3+} [$YFe^{3+} < 0.1$, where $YFe^{3+} = Fe^{3+} / (Fe^{3+} + Al + Cr)$ atomic ratio, and they have ferritchromite and Cr-magnetite rims. The TiO_2 contents of the core of chrome spinel in samples KC, KE and KF are <0.05 wt%. The Cr-magnetite in sample YK has a higher TiO_2 content (up to 1.2 wt%) than in the other samples (Table-2). Amphibole in sample YK is tremolite (Table-3).

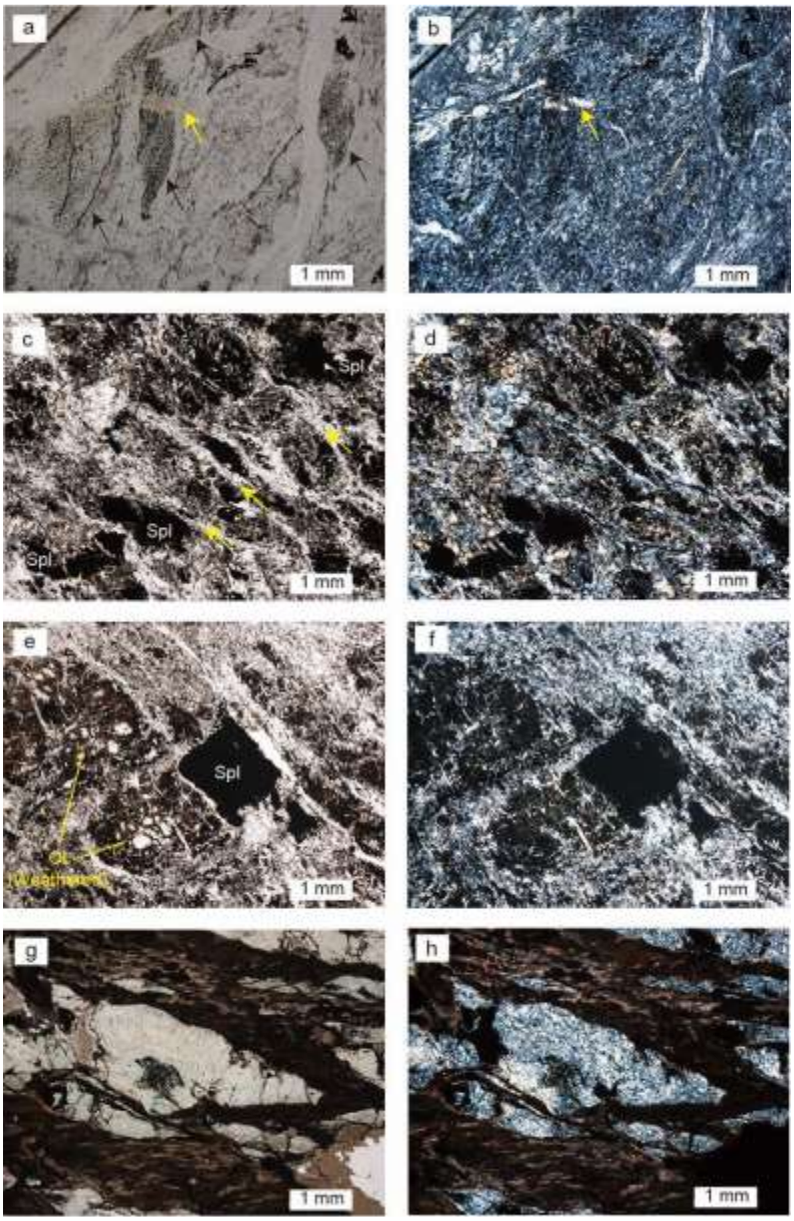

Figure 12 Photomicrographs of the studied serpentinite blocks. (a) Magnetite aggregates (black arrows) in antigorite matrix. Dusty serpentine veinlet is also observed (yellow arrow), between P.P.L (b) under X.N. (c) Antigorite network parallel to the direction of antigorite elongation (yellow arrows) between P.P.L (d) under X.N (e) Weathered olivine in antigorite matrix, between P.P.L (f) under X.N. (g) Chlorite-tremolite network (dark-colored) in antigorite matrix, between P.P.L (h) under X.N.

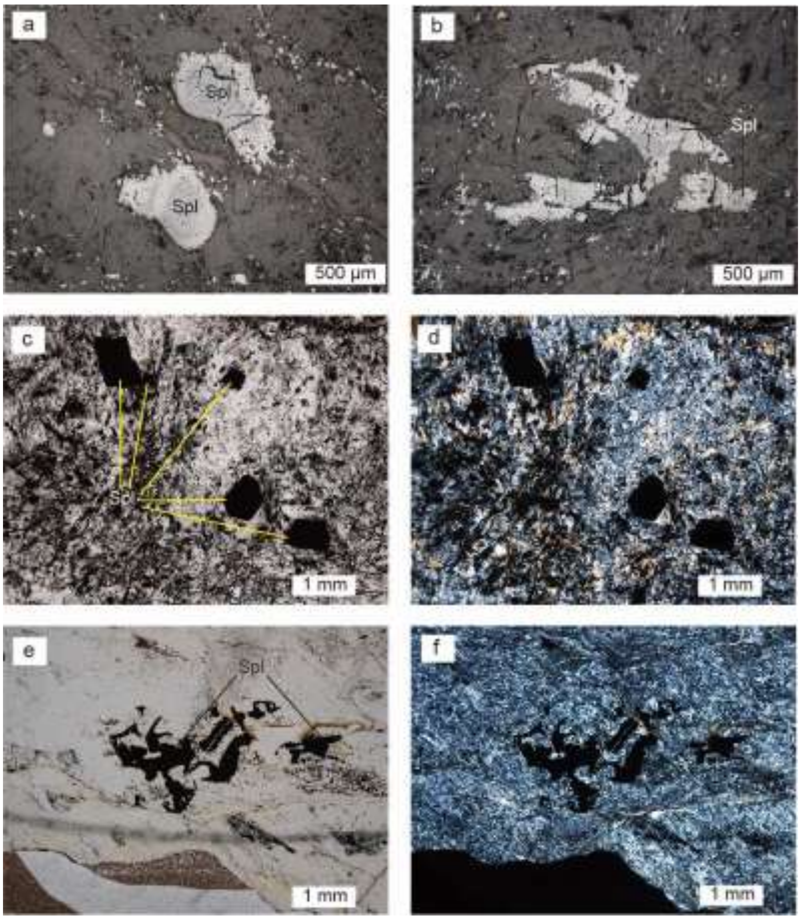

Figure 13 Photomicrographs showing occurrence and shape of chrome spinels. Reflected light image of subhedral chrome spinel (a) vermicular chrome spinel, (b) showing zoning, (c) Euhedral to subhedral shaped chrome spinel between P.P.L (d) under X.N. (e) Vermicular-shaped spinel between P.P.L (f) under X.N.

Table 1 Representative Olivine compositions (Serpentine composition)

Locality	**Kannbyu**					
Sample	**KF**	**KF**	**KF**	**KF**	**KF**	**KF**
Area	1	1	1	2	2	3
Note		Blade	brown	blade		Blade
SiO_2	44.30	45.60	45.90	44.80	45.40	44.60
TiO_2	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
Al_2O_3	1.73	0.03	< 0.03	1.31	<0.03	1.43
Cr_2O_3	0.79	0.05	0.05	0.18	<0.05	0.08
FeO	1.61	1.80	0.84	2.42	0.54	2.62
MnO	<0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
MgO	38	40.10	41.20	39.30	39.80	38.70
CaO	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Na_2O	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
K_2O	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
NiO	0.13	0.28	0.15	0.15	0.22	0.16
Total	87.80	88.20	88.10	88.30	86.10	87.90
Mg	0.98	0.96	0.98	0.97	0.99	0.96
Note: Mg# = Mg/(Mg + Fe) atomic ratio						

Table 2 Representative chrome spinel compositions (Serpentine composition)

Locality	Kannbyu					
Sample	**KC**	**KC**	**KC**	**KC**	**KE**	**KE**
Area	1	1	3	7	1	1
Note	Core	Rim	Core	Core	Core	Core
SiO_2	< 0.03	0.27	< 0.03	< 0.04	< 0.03	< 0.03
TiO_2	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04
Al_2O_3	8.77	0.00	9.27	9.82	16.26	15.55
Cr_2O_3	58.30	0.30	57.50	57.60	51.60	52.70
FeO	23.70	87.60	22.80	23.80	21.50	16.70
MnO	0.76	0.29	0.73	0.56	0.70	0.92
MgO	8.17	2.46	7.98	6.92	9.46	11.47
NiO	0.02	1.55	0.04	0.03	0.05	0.02
Total	99.50	92.30	98.40	98.80	99.60	97.50
XMg	0.41	0.14	0.41	0.35	0.46	0.55
Cr	0.82	1.00	0.81	0.79	0.68	0.68
YCr	0.77	0.03	0.76	0.78	0.66	0.67
YAl	0.18	0.00	0.19	0.17	0.32	0.31
YFe^{3+}	0.04	0.98	0.04	0.02	0.02	0.01

Note: Fe^{3+} was calculated based on stoichiometry. XMg = Mg/(Mg + Fe2+), Cr# = Cr/(Cr + Al), YCr =Cr/(Cr Table-2-serpentine composition.

Table 3 Representative amphibole compositions.

Locality	Yega-Inn			
Sample	**YK**	**YK**	**YK**	**YK**
Area	1	1	2	2
Note	brown		brown	
SiO_2	57.90	57.90	57.60	58.50
TiO_2	0.05	< 0.04	< 0.04	< 0.04
Al_2O_3	0.08	0.10	0.12	0.06
Cr_2O_3	< 0.05	< 0.05	< 0.05	< 0.05
FeO	3.02	4.09	4.05	2.76
MnO	0.09	0.00	0.11	0.08
MgO	22.60	21.9	22.10	23.00
CaO	12.90	12.70	12.40	12.90
Na_2O	< 0.03	0.05	< 0.03	0.06
K_2O	0.03	0.03	0.04	< 0.03
NiO	0.08	0.10	0.13	0.10
Total	96.80	97.00	96.50	97.40
XMg	0.93	0.91	0.91	0.94

Note: XMg = Mg/(Mg + Fe) atomic ratio

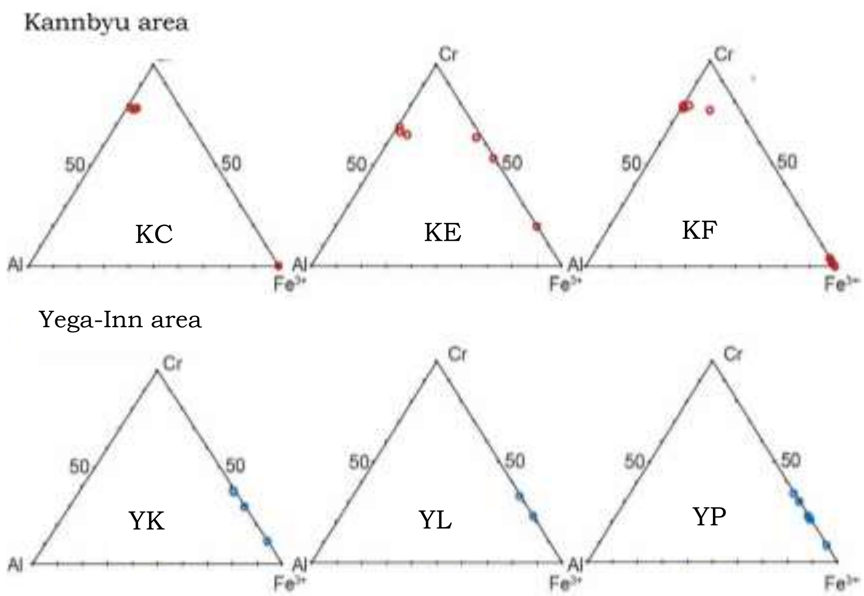

Figure 14 Trivariant cation ratio of chrome spinel groups in serpentinites from the Kannbyu area (samples KC, KE and KF) and the Yega-Inn area (samples YK, YL and YP).

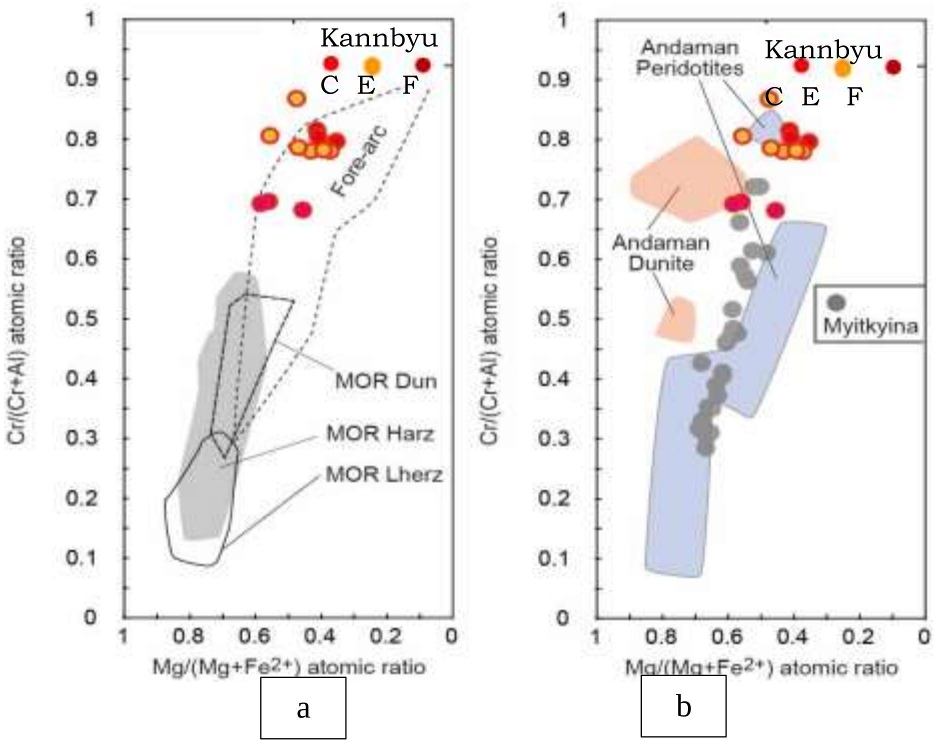

Figure 15 Relationships between XMg (= Mg/(Mg + Fe2+) atomic ratio) and Cr# (= Cr/(Cr + Al) atomic ratio) of the less altered spinels with < 0.1 YFe3+ (= Fe3+/(Fe3+ + Al + Cr) atomic ratio) from the Kannbyu area. (a) Comparison between the studied samples and the compositional ranges of mid-ocean ridge-related abyssal peridotites and fore-arc peridotites (broken line). Data are from Warren (2016) for mid-ocean ridge abyssal peridotites, and Ishii et al. (1992) and Parkinson and Pearce (1999) for fore-arc peridotites, respectively. (b) Comparison between the studied samples and chrome spinels from the mantle section of the Andaman ophiolite (Ghosh et al., 2013) and the Mytikyina ophiolite (spinel peridotites from Liu et al., 2016).

Discussions

4.1. Protolith of the serpentinite

Although the studied serpentinites are highly serpentinized, spinel morphology indicates the protolith of chrome spinel peridotite (Matsumoto and Arai, 2005). The samples with bastite-like texture (Figs.12a and 12b) and vermicular to anhedral shaped chrome spinel (Fig.13) indicates that the protoliths were pyroxene-bearing peridotites. The less altered spinel cores in these samples are characterized by high values of Cr# and low contents of TiO_2. We concluded, therefore, that the protolith of the studied serpentines was mainly a residual harzburgite that formed after a high degree of partial melting. Sample KF contains chrome spinel with subhedral to euhedral shape (Figs. 13c and 13d) and no bastite-like textures, and its protolith was probably dunite. The chrome spinels in sample KF are also characterized by high values of Cr#. Sample YK is characterized by the presence of tremolite-chlorite networks, and some of the Cr-magnetites show high TiO_2 contents, indicating a local enrichment of TiO_2 related to the network formation. The tremolite chlorite networks (Figs. 12g and 12h), coupled with high contents of TiO_2 in the chrome spinels, indicate that the protolith of sample YK was a peridotite with gabbroic veins, with the veins now replaced by tremolite and chlorite.

4.2. Serpentinites Origin

The chemical compositions of the less altered spinel grains in the studied samples do not much those of chrome spinels in abyssal peridotites from a mid-ocean ridge setting, but they are similar to those of chrome spinels in fore-arc peridotites (Fig.15a). Antigorite is generally interpreted to be stable under higher-temperature conditions (~500°C) than lizerdite/crysotile, and mantle wedge peridotites are likely to be affected by hydration under the conditions at which antigorite is stable (e.g, Peacock and Hyndman, 1999; Mizukami et al., 2014). Peridotites with high Cr# spinel have been reported from the mantle section of ophiolites located regionally close to the present study area (e.g., the Myitkyina ophiolites: Liu et al., 2016; the Andaman ophiolite: Ghosh et al., 2017) (Fig.15b). The highly refractory harzburgites (± dunite) in these ophiolites are interpreted as arc-related magmatic modifications of the mantle. Serpentinized peridotites in the Jade Mines Belt are antigorite serpentinite (Shi et al.,2005 MM), and they are mainly harzburgite, dunite and wehrlite (Searle et al., 2017).

Conclusions

The study samples were collected from massive outcrops in highly sheared zone, along the Sagaing Fault. These outcrops do not usually show preferred orientation of antigorite. Peridotite unit of the Jade Mines Belts and ultramafic rocks (peridotites) and nearby ophiolites of the study area are not clear, it is expected that serpentinization of ophiolitic mantle materials was initiated under static conditions prior to shearing along the Sagaing Fault, and that the serpentinites were then exhumed to the surface, probably as a result of movement on the fault. One of the important factors controlling fault behavior is the presence of weak materials such as serpentinite (e.g., Moore and Rymer, 2007), and studies of the San Andreas Fault revealed that serpentine-related minerals such as talc and saponite exist along the fault and their sliding behavior might cause fault creep (Moore and Rymer, 2007; Lockner et al., 2011). It is clear, therefore, that further investigation of the relationships between the activity of the Sagaing Fault and local geology is required for a better understanding of further seismic risk along this fault zone in Myanmar. This research is also emphatically meant to stimulate the interest of the future workers for improving the current findings with better expositions.

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References

Bertrand, G., Rangin, C., Maluski, H., Bellon, H. & Giac Party, (1996). Diachronous cooling along the Mogok Metamorphic Belt (Shan Scarp, Myanmar): the trace of northward migration of theIndian syntaxis. Journal of Asian Earth Sciences, 19, 649–659.

Curray, J.R., (2005). Tectonics and history of the Andaman Sea region 25. https://doi.org/10.1016/j.jseaes.2004. 09.001.

Ghosh, B., Morishita, T., Bhatta, K., (2013). Significance of chromian spinels from the mantle sequence of the Andaman Ophiolite, India: Paleogeodynamic implications. Lithos 164–167, 86–96. https://doi.org/10.1016/ j.lithos.2012.08.004

Ghosh, B., Bandyopadhyay, D., Morishita, T., (2017). Andaman–Nicobar Ophiolites, India: origin,evolution and emplacement. Geol. Soc. London, Mem. 47, 95–110. https://doi.org/10.1144/M47.7

Hla Htay, Khin Zaw, Than Than Oo, (2017). The mafic–ultramafic (ophiolitic) rocks of Myanmar.Geol. Soc. London, Mem. 48, 117–141. https://doi.org/10.1144/M48.6

Hurukawa, N., Maung, P.M., (2011). Two seismic gaps on the Sagaing Fault, Myanmar, derived from relocation of historical earthquakes since 1918 38, 1–5. https://doi.org/10.1029/2010GL046099.

Ishii, T., Robinson, P.T., Maekawa, H., Fiske, L., (1992). Petrological studiesof peridotites from serpentinite diapiric seamounts in the Izu-Ogasawara-Mariana fore arc, ODP Leg 125. In: Fryer, P., Pearce, J.A., Stokking, L.B., et al. (Eds.), Proceedings of the Ocean Drilling Program, Scientific Results, 125, College Station, Texas (Ocean Drilling Program), 445–485.

Kan Saw (1973). Geology of the Northern Mingun-Kabwet area. MScthesis, Mandalay University.

Le Dain, A.Y., Tapponnier, P., Molnar, P., (1984). Active faulting and tectonics of Burma and surrounding regions. J. Geophys. Res. 89, 453. https://doi.org/10.1029/JB089iB01p00453.

Liu, C., Zhang, C., Xu, Y., Wang, J., Chen, Y., Guo, S., Wu, F., Sein, K., (2016). Petrology and geochemistry of mantle peridotites from the Kalaymyo and Myitkyina ophiolites (Myanmar): Implications for tectonic settings. Lithos 264, 495–508. https://doi.org/10.1016/j.lithos.2016.09.013.

Lockner, D.A., Morrow, C., Moore, D., Hickman, S., (2011). Low strength of deep San Andreas fault gouge from SAFOD core. Nature 472, 82–86. https://doi.org/10.1038/nature09927.

Matsumoto, I., Arai, S., (2001). Morphological and chemical variations 199 of chromian spinel in dunite-harzburgite complexes from the Sangun zone (SW Japan): implications for mantle /melt reaction and chromitite formation processes. Mineral Petrol. 73, 305-323.https://doi.org/10.1007/s007100170004

Maung Maung (1982). The geology of Kyaukta area. Paper presented at the Natural Science Research Congress, 21 June 1982, Rangoon.

Maurin, T., Masson, F., Rangin, C., Min, U.T., Collard, P., (2010). First global positioning system results in northern Myanmar: Constant and localized slip rate along the Sagaing fault. Geology 205 38, 591–594. https://doi.org/10.1130/G30872.1.

Mizukami, T., Yokoyama, H., Hiramatsu, Y., Arai, S., Kawahara, H., Nagaya, T., Wallis, S.R., (2014). Two types of antigorite serpentinite controlling heterogeneous slow-slip behaviours of slab mantle interface. Earth Planet. Sci. Lett. 401, 148–158. https://doi.org/10.1016/j.epsl.2014.06.009.

Moore, D.E., Rymer, M.J., (2007). Talc-bearing serpentinite and the creeping section of the San Andreas fault. Nature 448, 795–797. https://doi.org/10.1038/nature06064.

Myint Thein, Kyaw Tint & Kan Saw (1982). Geology of the easternmargin of the Central Burma Belt between Sagaing and Tagaung.Research Titles, Geoscience Group. Policy Directing Committeeon Research Projects, Burma, 259–303.

Myint Thein (2009). Age, petrography and deformation of Laminated Limestone Unit the west side of the Sagaing Fault, Sagaing Division. Abstract presented at the Research Seminar, Myanmar GeosciencesSociety, 28 November 2009, Yangon.

Myint Thein (2017). Current tectonic activity along the Sagaing Fault, Myanmar indicated by alluvial fans. In: Barber, A.J., Khin Zaw& Crow, M.J. (eds) Myanmar: Geology, Resources and Tectonics. Geological Society, London, Memoirs, 48, 443–452, https://doi.org/10.1144/M48.20

Parkinson, I.A.N.J., Pearce, J.A., (1998). Peridotites from the Izu – Bonin – Mariana Forearc (ODPLeg 125): Evidence for Mantle Melting and Melt – Mantle Interaction in a Supra-Subduction Zone Setting 39, 1577–1618. https://doi.org/ 10.1093/petroj/39.9.1577.

Peacock, S.M., Hyndman, R.D., (1999). Hydrous minerals in the mantle wedge and the maximum depth of subduction thrust earthquakes. Geophys. Res. Lett. 26,2517–2520.https://doi.org/10.1029/1999GL900558.

Searle, M.P., Noble, S.R., Cottle, J.M., Waters, D.J., Mitchell, A.H.G., Hlaing, T., Horstwood, M.S.A., (2007). Tectonic evolution of the Mogok metamorphic belt, Burma (Myanmar) constrained by U-Th-Pb dating of metamorphic and magmatic rocks. Tectonics 26, n/a-n/a.https://doi.org/10.1029/2006TC002083.

Shi, G.H., Stöckhert, B., Cui, W.Y., (2005.)Kosmochlor and chromian jadeite aggregates from the Myanmar jadeitite area. Mineral. Mag. 69, 1059–1075. https://doi.org/10.1180/0026461056960308.

Sloan, R.A., Elliott, J.R., Searle, M.P., Morley, C.K., (2017). Active tectonics of Myanmar and the Andaman Sea. Geol. Soc. Mem. 48, 19–52. https://doi.org/10.1144/M48.2

Soe Thura Tun, Watkinson, I.M., (2017). The Sagaing Fault, Myanmar. Geol. Soc. London, Mem.48, 413–441. https://doi.org/10.1144/M48.19.

Than Htut Lwin (2008.) Geology and gold mineralization in Sheinmagar area, WetleTownship, Sagaing Division. PhD thesis, Department of Geology,University of Yangon.

Vigny, C., (2003). Present-day crustal deformation around Sagaing Fault, Myanmar. J. Geophys. Res. 108. https://doi.org/10.1029/2002jb001999.

Wang, Y., 2014 (). Active tectonic and earthquake Myanmar region. J. Geophys. Res. Solid Earth 3576–3822. https://doi.org/10.1002/2013JB010762.

Wang, Y., Sieh, K., Aung, T., Min, S., Khaing, S.N., Tun, S.T., (2011). Earthquakes and slip rate of the southern Sagaing fault: Insights from an offset ancient fort wall, lower Burma (Myanmar).Geophys. J. Int. 185, 49–64. https://doi.org/10.1111/j.1365-246X.2010.04918.x.

Warren, J.M., (2016). Global variations in abyssal peridotite compositions. Lithos. https://doi.org/10.1016/j.lithos. 2015.12.023.

Win Swe (1981). A major strike-slip fault in Burma. Contributions to Burmese Geology. Department of Geological Survey and Exploration,February 1981, Myanmar, 63–72.