J. Myanmar Acad. Arts Sci. 2021 **Vol. XIX. No.5A**

THE EXISTANCE OF HERCYNITE IN METAPELITES FROM MOGOK METAMORPHIC BELT

Wai Yan Lai Aung[1] and Thet Tin Nyunt [2]

Abstract

Hercynite observed in the metapelitic rocks; sillimanite-garnet-biotite gneiss and felsic granulite rocks from Mogok and Momeik area. It is one of the spinel group minerals with the formula $FeAl_2O_4$. The present contribution provided and confirmed the presence of hercynite in pelitic rocks (gneiss and granulite) and pair essential assemblage of [Spinel (Hercynite)+Quartz)] in Mogok Metamorphic Belt indicate that these rocks were experienced in/ developed under UHT metamorphism.

Keywords: Hercynite, Metapelitic, Granulite, Spinels, UHT metamorphism

Introduction

Hercynite is one of the end-members of the spinel group in the spinel mineral series with the formula $FeAl_2O_4$. Chemical formula of common spinel is $MgAl_2O_4$ and it is a Magnesium (Mg) spinel though hercynite is Iron (Fe) spinel. The Mg may be partially or fully replaced by Fe, Zn, and/or Mn. This leads to a mineral series with the formula (Mg,Fe,Zn,Mn) Al_2O_4. It was first described in 1847 and its name originates from the Latin name for the Harz, Silva Hercynia, where the species was first found (Anthony, 1990), is a spinel of regular symmetry and normal cation distribution, but some disorder occurs in its structure. It consists of ferrous (Fe^{2+}) ions and aluminium ions (Al^{3+}), however some ferric ions (Fe^{3+}) may be located in the structure of hercynite (Jastrzębska, 2015). General information of spinel mineral series is described in Table 1. Hercynite occurs in high-grade metamorphosed iron argillaceous sediments as well as in mafic and ultramafic igneous rocks (Anthony, 2001). The purpose of this paper is to provide and confirm the determination of metamorphic grade and facies and estimating *P-T* conditions of hercynite bearing pelitic rocks of Mogok Metamorphic Belt on the basis of mineral assemblages.

Table 1 General information of the spinel mineral series (www.mineral.net)

The Spinel Mineral Series
<u>Chemical Formula</u> : $MgAl_2O_4$
The Mg may be partially or fully replaced by Fe, Zn, and/or Mn. This leads to a mineral series with the formula (Mg,Fe,Zn,Mn) Al_2O_4.
The end-members of the Spinel group
Spinel (or Magnesium Spinel) - $MgAl_2O_4$
Gahnite (Zinc Spinel) - $ZnAl_2O_4$
Hercynite (Iron Spinel) - $FeAl_2O_4$
Galaxite (Manganese Spinel) - $MnAl_2O_4$
<u>Composition</u> : Series of magnesium, iron, zinc, and/or manganese aluminum oxide.

[1] Dr, Demonstrator, Department of Geology, University of Yangon (waiyanlaiaung@gmail.com)

[2] Dr, Director General, Department of Geological Survey and Mineral Exploration, Ministry of Natural Resources and Environmental Conservation

Materials and Methods

Although spinels are widely distributed in nature, hercynite was analyzed by electron probe as a Fe Spinel and identified with the aid of petrological microscope. Minerals were analysed using the Electron Probe Micro Analyser (EPMA) Jeol, JXA 8200, equipped with SE- and a BSE-detector, 5 WDS crystal spectrometer and an EDS-analyser at Swiss Federal Institute of Technology (ETH) in Zurich, Switzerland. Operation conditions were: 15.0 kV applied accelerating voltage, 100 µm beam size and 10 or 20 nA depending on the stability of the analyzed minerals under the electron beam. Hercynite bearing thin sections of different rock units exposed in the research area were analysed by means of polarizing microscope. Determination of metamorphic grade and facies and estimating *P-T* conditions of hercynite bearing pelitic rocks of Mogok Metamorphic rocks based on mineral assemblages and comparison is carried out on the literature and previous works of the area.

Geology

The research area is situated within the northern part of Mogok Metamorphic Belt (MMB) of Searle and Haq, 1964 and Searle et. al., 2017. With reference to provided regional geological map (Myanmar Geosciences Society, 2014) (Fig. 1), rocks in the investigated area are categorized into medium-to-high grade metamorphic rock units and younger igneous intrusion. In metamorphic units, medium-to-high grade rocks consisting of marble, calc-silicate rocks, gneiss and granulite are exposed (Wai Yan Lai Aung, 2016) in the research area. Among them, hercynite can be noted from argillaceous pelitic rocks such as sillimanite-garnet-biotite±ilmenite gneisses and felsic granulite. Location map is shown in (Fig. 2).

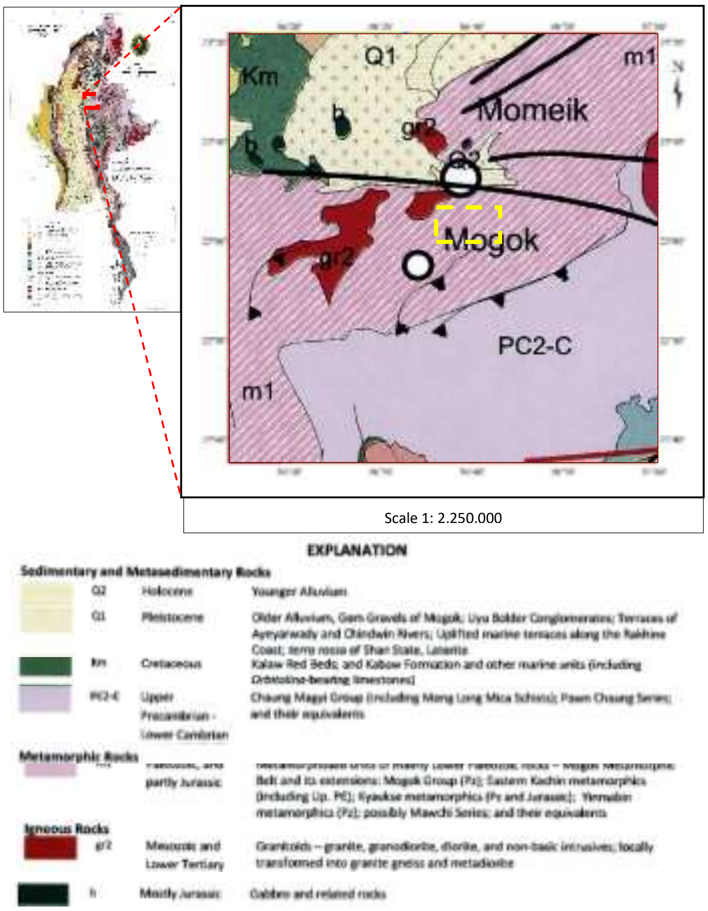

Figure 1 Regional geological map of the research area and its environs (AfterGeological Map of Myanmar Geosciences Society, 2014).

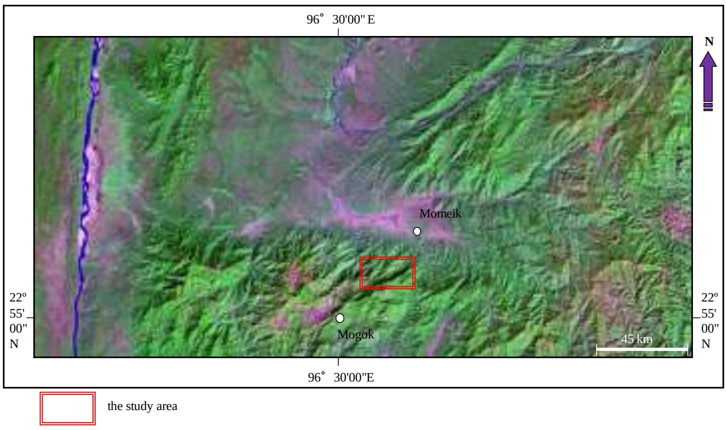

Figure 2 Location map of the research and surrounding areas.

Results

Mineralogy

Hercynite is the predominant mineral of the sillimanite-garnet-biotite gneiss and felsic granulite units within the research area. In hand specimen, it is not distinct. Under the microscope, hercynite is characterized by its colour (greenish and black), medium- to coarse-grained subhedral to euhedral form, no cleavage and high relief in PPL. Isotropic nature is pronounced between XN (Kerr, 1977). In sillimanite-garnet-biotite gneiss, spinels (hercynite) show green and euhedral form (Fig. 3), which may probably formed by the releasing of alumina.

Mineral assemblages recognized in the sillimanite-garnet-biotite±ilmenite gneiss are (Fig. 4) :

Quartz + orthoclase + biotite + plagioclase + almandine + sillimanite + diopside + ilmenite + **spinel** + zircon + apatite + sphene + hypersthene

Quartz + orthoclase + plagioclase + biotite + almandine + sillimanite + ilmenite + **spinel**

Quartz + orthoclase + plagioclase + biotite + almandine + sillimanite + **spinel** + opaque + sphene

In some xenoblastic garnets, hercynites are observed as inclusions associated with small anhedral quartz grains, tabular biotite flakes and sillimanite as inclusions (Fig. 5)

Mineral assemblages of granulite rocks in the study area are:

orthopyroxene + alkali feldspar + biotite + plagioclase + chlorite + garnet + quartz + rutile + sapphirine + ilmenite + **hercynite** + sillimanite + zircon.

Hercynites, iron alumina spinels, are found as equant grains (Fig. 6). They show high relief, pale green under plane-polarized light and isotropic between cross nicols.

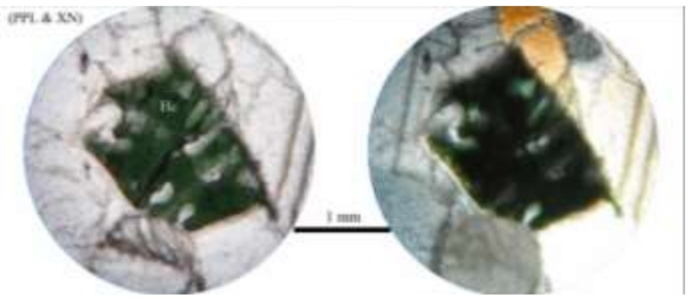

Figure 3 Euhedral spinel (hercynite) in sillimanite-garnet-biotite gneiss

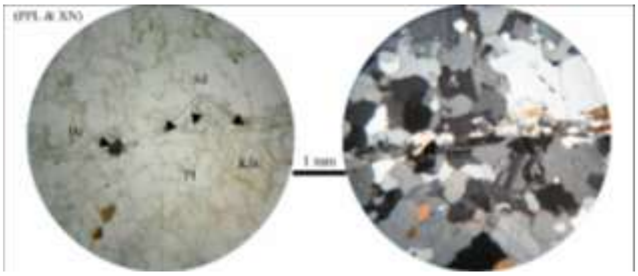

Figure 4 Mineral assemblages of sillimanite, hercynite, quartz and feldspars in sillimanite-garnet-biotite-ilmenite gneiss

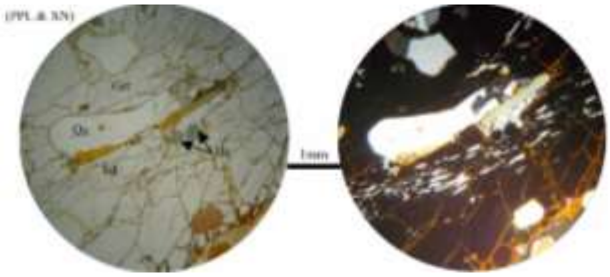

Figure 5 Coarse-grained xenoblastic garnet with various inclusions (sillimanite trails, hercynite, quartz and biotite).

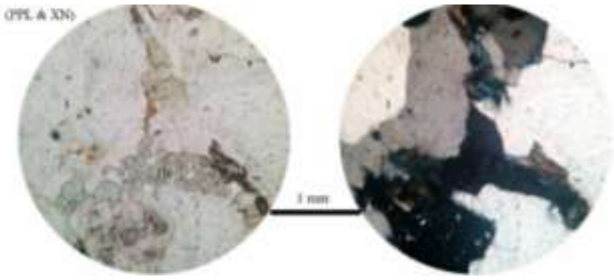

Figure 6 Grains of hercynite in felsic granulite.

Geochemistry

Ilmenite and hercynite are diagnostic minerals of some acid granulitic assemblages. Electron microprobe analyses of spinel and ilmenite in sillimanite-garnet-biotite gneisses (Fig. 7) are shown in Table 2. Spinels in research area are ferroan aluminium spinel, hercynite. Deer, Howie & Zussman, 1992, explained that the experimental investigation on the system $FeAl_2O_4$ (hercynite) – Fe_3O_4 (magnetite) shows there has complete solid solution above 858ºC, but below this temperature, the two-phase region of exsolution widens with decreasing temperature. Hercynite forms complete solid solution with chromite and spinel but only limited solid solution with magnetite (Rutley, 1991). Hercynite of spinel series and ilmenite from the microprobe data are plotted as colourful dots on ternary diagrams of Butler, 1998 (Fig. 8).

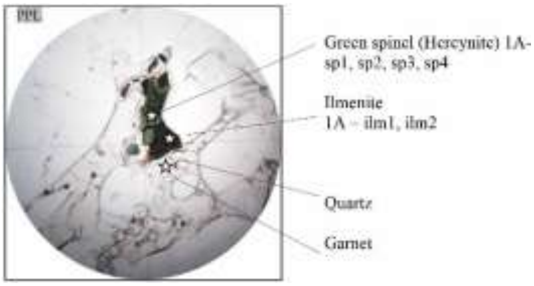

Figure 7 Electron microprobe analyses of spinel and ilmenite in sillimanite- garnet- biotite gneisses

Table 2 Analytical data of spinel and ilmenite in sillimanite-garnet- biotite gneiss

Name	1A-sp1	1A-sp2	1A-sp3	1A-sp4	1A-ilm1	1A-ilm2
Symbol	●	●	●	●	●	●
SiO_2	0.030	0.030	0.071	0.022	0.023	0.082
TiO_2	0.093	0	19.300	0.154	46.410	43.740
Cr_2O_3	0	0	0	0.552	0	0
Al_2O_3	59.500	59.61	0.377	0	0.090	0.079
Fe_2O_3	2.407	2.291	28.527	67.986	0	0
FeO	27.844	27.648	46.879	30.992	50.120	52.600
MnO	0.265	0.264	0.122	0.014	0.653	0.482
NiO	0	0	0	0	0	0
MgO	8.43	8.48	0.422	0.037	1.065	0.938
CaO	0.039	0.008	0.002	0.019	0.010	0.024
Na_2O	0	0	0.020	0.006	0	0
K_2O	0.018	0.02	0.028	0.013	0.028	0.030
Total	98.626	98.352	95.748	99.794	98.398	97.975
$FeAl_2O_4$ (Hercynite)	0.627	0.627	0.009	0	-1.524	-1.613
$MgAl_2O_4$ (Spinel)	0.338	0.343	0	0	-0.058	-0.051
$MnAl_2O_4$ (Galxite)	0.006	0.006	2.247	0	-0.020	-0.015
$FeFe_2O_4$ (Magnetite)	0.016	0.015	0.411	0.983	0	0
$MgFe_2O_4$ (Mg-Ferrite)	0.009	0.008	0.007	0.002	0	0
$MnFe_2O_4$ (Jacobsite)	0	0	0.001	0	0	0

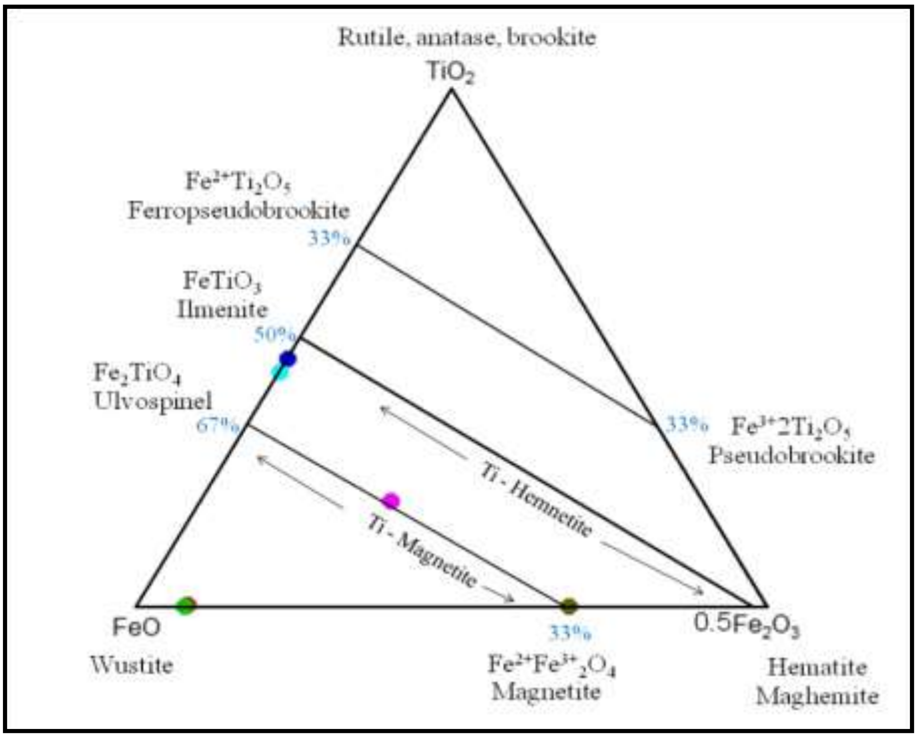

Figure 8 The system FeO-Fe_2O_3-TiO_2 showing the major high-temperature solid solution series magnetite-ulvospinel, hematite-ilmenite, pseudobrookite-$FeTi_2O_5$ plotted on a mol per cent basis (After Butler, 1998).

Discussion

Occurrences

Protolith of spinel-bearing rocks were clayey limestones and calcic limestones, which may become dolomitic limestone by metamorphism (Gübelin & Koivula, 2005). Spinel was formed both mafic igneous rock and metamorphic rock which found in carbonate series underwent high temperature amphibolite to lower granulite grade regional metamorphism (Malsy & Klemm, 2010). At Mogok, spinel was formed as a result of contact metamorphism or skarn metasomatism within regionally metamorphosed basement rocks where the presence of fluids played an important role (Iyer, 1953; Themelis, 2009), where, high temperature regional metamorphism and then larger - scale transformation of carbonate rocks, high mobilization and migration of many chemical elements and containing Al and Cr in the dynamothermal metamorphism of carbonate rocks (Kisin et al., 2016). Wai Yan Lai Aung, 2016, reported that, in Loi-Sau and its environs, sillimanite-garnet-biotite±ilmenite gneiss including spinel are high-grade gneiss and they are included in granulite facies. Moreover, she also contributed on granulite in Mogok and Momeik area.

In Mogok, Jedi spinel (Hot spinel) occurs as bright neon red spinel crystals and found in both Mogok Valley and the Namya area (Pardieu, 2014). Moreover, Man Sin Hot spinel in Mogok occurs as porphyroblast in marble and due to the presence of Cr (Thet Tin Nyunt and Phyu Phyu Win, 2018).

Ternary spinels in the system (Fe, Zn, Mg) Al_2O_4 are apparently relatively common and widespread constituents of some metamorphic rocks in the amphibolite and granulite facies (Stoddard, 1979). High-grade metamorphic rocks of upper-amphibolite and granulite facies were reported in the Mogok metamorphic belt, central Myanmar (Yonemura et al., 2013; Maw Maw Win et al., and Wai Yan Lai Aung, 2016).

P-T Condition

The temperature of spinel is about from 600˚C and depending on the amount of magnesium which played an important factor during the genesis of spinel (Widmer, 2014). In Mogok Metamorphic Belt, Mitchell et. al., (2006) constrain that the K-feldsapr augen gneisses represents at 4.9 ±1.7 kbar and about 680 ºC and Searle et. al., (2017) imply high-temperature sillimanite+muscovite metamorphism peak at 4.9 ± 1.7 kbar and 680ºC, and based on the result of EPMA. Yonemura et. al., (2013) found Grt-Opx granulite in the Mogok area, which was formed under pressure-temperature (*P-T*) conditions estimated as being 6.5-8.7 kbar and 800-950 ºC with the aid of EPMA. Wai Yan Lai Aung and Maw Maw Win, et al., (2016) estimated petrologically and mineralogically that the metamorphic *P-T* conditions of pelitic gneisses in regional Mogok metamorphic belt with garnet-biotite-plagioclase-sillimanite-quartz assemblage and its peak metamorphic stage is 6–10 kbar and 780–850 °C. Ye Kyaw Thu, et al., (2016) reported a paragenesis with a spinel + quartz assemblage coexisting with Ti-rich biotite (up to 6.9 wt% TiO_2) that formed under granulite facies conditions. They also suggest in (2017) that the *P-T* conditions of granulite facies paragenesis with Grt-Bt-Pl-Sil-Qtz and Grt+Crd+Sil+Bt+Qtz from the middle segment of the Mogok metamorphic belt is 6 – 7.9 kbar/ 800 – 860 °C and 6.5 kbar/ 820 °C, resprctively. Wai Yan Lai Aung, (2017) calculated two occurrences of sillimanite-garnet-biotite gneiss with and without of pyroxene and hercynite minerals by using normalized composition of garnet, biotite and plagioclase from X-ray Fluorescence and Electron Microprobe analyses with Pseudosection and Perple_X software. The *P-T* equilibration of hercynite bearing gneiss is higher than that of without; 6.5-9.3 kbar, 740-810 ºC. In (2018), She also contributed the possible *P-T* condition of granulite rocks in Mogok and its environs, and the presence of spinel relics in sapphirine are shown in symplecitic intergrowths of the two minerals. Its development can be explained by the simple reaction: Spinel + Silica = Sapphirine (Deer, Howie & Zussman, 1992).

Schollenbruch, et al., (2010) investigated experimentally the stability of hercynite ($FeAl_2O_4$) at high pressure and temperature between 7-24 GPa and 900-1700 °C. Hercynite breaks down to its constituent oxides at 7- 8.5 GPa and temperatures > 1000 °C. Zn-rich spinel is associated with quartz in the Al-rich metapelites of the Mashan complex, NE china and Al-rich metapelites from Mashan khondalite series are characterized by the assemblage Spl+Grt+Sil+Crd+Bt+Pl(An_{72})+Kfs+Quartz+graphite peak *P-T* condition is 820 °C and 8.0 kb (Guo, 2008). Spl + Qtz assemblage requires at least 840 °C (Bucher & Frey, 1994) and stated that hercynite spinel is present in metapelites with high X_{Fe} at 860 °C (Bucher, 2010). The rocks loose quartz between 620 °C (Mg-rich) and 670 °C (Fe-rich). At about 700 °C (at 600 °C), upper amphibolite facies, spinel appears at medium X_{Fe} in assemblages such as Spl + Grt + Crd. Spinel appears at a temperature 250 °C lower than in Qtz-saturated rocks. The assemblage Grt + Crd + Opx + Spl is characteristic for ultra-high grade metamorphism in Qtz-bearing rocks. In contrast, the temperature of Qtz-free rocks is as low as 700 °C. This shows that the pair Spl + Qtz is the essential assemblage for UHT metamorphism (Bucher, 2010). Hercynite from research area is associated with quartz and analysed by EPMA. Comparison of *P-T* analytical data and possible *P-T* condition in Mogok Metamorphic Belt (MMB) are shown in Table 3 and (Fig 9).

The spinels observed in the metapelitic rocks; sillimanite-garnet-biotite gneiss and felsic granulite of Mogok and Momeik area were identified as hercynite. A study of the chemical composition confirmed that it is iron aluminium spinel and the colour due to the Fe. In research area, hercynite bearing high-grade gneiss and felsic granulite indicate granulite facies and high-grade metamorphosed iron rich argillaceous sediments. The present study proved that hercynite in pelitic rocks (gneiss and granulite) and pair essential assemblage of [Spinel (Hercynite)+Quartz)] in Mogok Metamorphic Belt were experienced in/ developed under UHT metamorphism.

Table 3 Comparison of *P-T* analytical condition and mineral assemblages in Mogok Metamorphic Belt (MMB)

Reference	Rock Units of MMB	Analytical Methods	Calculated mineral assemblages	P / T
Mitchell et al., 2006	K-spar augen gneiss	EPMA	Bt-Sil-Pl-Kfs-Qtz	4.9 ±1.7 kbar/ & 680 °C
Searle et al., 2007	Sillimanite gneiss	EPMA	Sil-Mus	4.9 ± 1.7 kbar/ 680 °C
Yonemura et al., 2013	Granulite	EPMA	Grt-Opx	6.5 – 8.7 kbar/ 800 – 950 °C
Maw Maw Win et al., 2016	Pelitic gneisses	Petrology/ Mineralogy	Grt-Bt-Pl-Sil-Qtz	6 – 10 kbar/ 780 – 850 °C
Wai Yan Lai Aung, 2016	Sillimanite-garnet-biotite-ilmenite gneiss	EPMA	Grt-Sil-Bt-Pl-Kfs-Qtz	6.5 - 9.3 kbar/ 740 - 810 °C
Wai Yan Lai Aung, 2017	Sillimanite-garnet-biotite gneiss	EPMA	Grt-Sil-Bt-Pl-Kfs-Qtz	6.2 - 8 kbar/ 750 - 790 °C
Ye Kyaw Thu et al., 2017	Metasedimentary rocks	EPMA	Grt-Bt-Pl-Sil-Qtz	6 – 7.9 kbar/ 800 – 860 °C
Ye Kyaw Thu et al., 2017	Metasedimentary rocks	EPMA	Grt-Crd-Sil-Bt-Qtz	6.5 kbar/ 820 °C
Wai Yan Lai Aung, 2018	Felsic granulite	Petrology/ Mineralogy	Opx-Grt-Bt-Rt-Sil-Plg-Kfs-Spr-Spl-Qtz-Zir-Ilm	*P-T* is greater than gneisses
Wai Yan Lai Aung, 2018	Mafic granulite	Petrology/ Mineralogy	Cpx-Ca-Plg-Kfs-Qtz-Bt-Opx-Sp-Opq	*P-T* is greater than gneisses

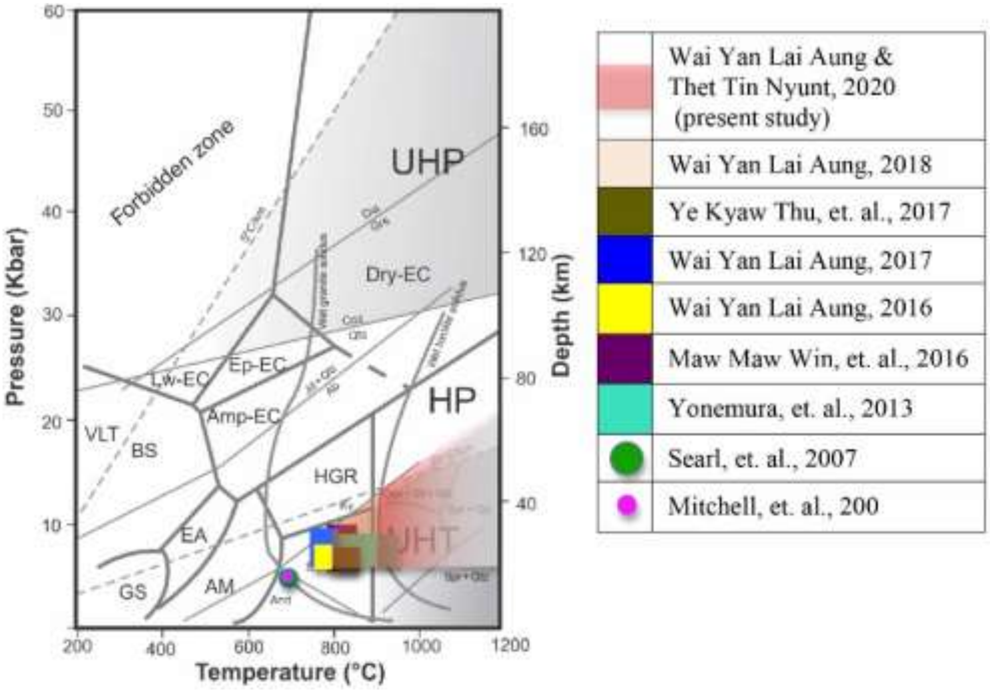

Figure 9 *P-T* diagram showing the comparison of analytical data and possible *P-T* condition in Mogok Metamorphic Belt (After Liau et al., 1998, Harley, 1998, Okamoto and Maruyama,1999, and Harley, 2004) UHP – ultrahigh pressure; UHT – ultrahigh temperature; VLT – very low temperature; AM – amphibolite; Amp-EC – amphibolite–eclogite; BS – blueschist; EA – epidote amphibolite; EC – eclogite; Ep-EC – epidote-eclogite; GR – granulite; GS – greenschist; HGR – high-grade granulite; Lw-EC – lawsonite-eclogite.

Conclusion

The spinels observed in the metapelitic rocks; sillimanite-garnet-biotite gneiss and felsic granulite of Mogok and Momeik area were identified as hercynite. A study of the chemical composition confirmed that it is iron aluminium spinel and the colour due to the Fe. In research area, hercynite bearing high-grade gneiss and felsic granulite indicate granulite facies and high-grade metamorphosed iron rich argillaceous sediments. The present study proved that hercynite in pelitic rocks (gneiss and granulite) and pair essential assemblage of [Spinel (Hercynite)+Quartz)] in Mogok Metamorphic Belt were experienced in/ developed under UHT metamorphism.

Acknowledgements

The authors would like to express our sincere thanks to Dr. Day Wa Aung, Professor and Head, Department of Geology, University of Yangon for their permission to take this research. We would like to extend our sincere thanks to Prof. Hla Kyi, Part-time Professor, Applied Geology Department, University of Yangon, for his encouragement and advice. We would like to deeply grateful to Prof. Dr Christoph A. Heinrich and Prof. Dr Lucie Tajčmanová, Department of Earth Sciences, Institute of Geochemistry and Petrology, ETH Zurich for EPMA Analyses.

References

Anthony, J.W., (1990). *Handbook of mineralogy* (Vol. 4). Mineral Data Publishing.

Anthony, J.W., Bideaux, R.A., Bladh, K.W. and Nichols, M.C., (2001). *Handbook of mineralogy*, Mineralogical Society of America. *Chantilly, VA*, pp.20151-1110.

Bücher, K. and Frey, M., (1994.)*Petrogenesis of Metamorphic Rocks*, Springer-Verlag Berlin Heidelberg GmbH, pp.318.

Bucher, K. and Grapes, R., (2011). *Petrogenesis of metamorphic rocks*. Springer Science & Business Media.

Butler, C.J. and McCartney, D.G., (1998). An experimental study of phase transformations and a comparison with calculated phase equilibria in Ti–Al–Mn alloys. *Acta materialia*, *46*(6), pp.1875-1886.

Deer, W.A., Howie, R.A. and Zussman, J., (1992). *An introduction to the rock-forming minerals*, vol.696. London: Longman, pp.696.

Guo, X., Takasu, A., Liu, Y. and Li, W., (2008). Petrological research of the high-T Al-rich pelitic rocks in the Mashan compex, NE China. In *Abstracts for Annual Meeting of Japan Association of Mineralogical Sciences 2008 Annual Meeting of Japan Association of Mineralogical Sciences* (pp. 65-65).

Gübelin, E.J & Koivula, J.I., (2005). *Photoatlas of inclusions in Gemstones*, Opinio Verlag, Basel, vol.2, pp.829.

Harley, S.L., (1998). On the occurrence and characterization of ultrahigh-temperature crustal metamorphism. *Geological Society, London, Special Publications*, *138*(1), pp.81-107.

Harley, S.L., (2004). Extending our understanding of ultrahigh temperature crustal metamorphism. *Journal of Mineralogical and Petrological Sciences*, *99*(4), pp.140-158.

Iyer, L.A.N., (1953). The geology and gem-stones of the Mogok Stone Tract, Burma. *Geological Survey of India Memoir, 82*, pp.100.

Jastrzębska, I., Szczerba, J., Stoch, P., Błachowski, A., Ruebenbauer, K., Prorok, R. and Śnieżek, E., (2015). Crystal structure and Mössbauer study of $FeAl_2O_4$. *Nukleonika, 60*(1), pp.47-49.

Kerr, P. F., (1977). *Optical Mineralogy*, 4th edt., Mc Graw-Hill, New York, pp.492.

Kisin, A.Y, Murzin, V.V, Tomilina, A.V and Pritchin, M.E., (2016). *Ruby- sapphire- spinel mineralization in marble of the middle and southern Urals: Geology, Mineralogy, and Genesis*, Pleiades Publishing, Ltd., vol.58, no.4, pp.385-402.

Malsy, A. and Klemm, L., (2010). Distinction of gem spinels from the Himalayan mountain belt. *CHIMIA International Journal for Chemistry*, *64*(10), pp.741-746.

Myanmar Geosciences Society, (2014). Geological Map of Myanmar.

Okamoto, K. and Maruyama, S., (1999.) The high-pressure synthesis of lawsonite in the MORB+H_2O system. *American Mineralogist*, *84*(3), pp.362-373.

Pardieu, V., (2014). Hunting for "jedi" spinels in Mogok. *Gems & Gemology*, *50*(1), pp.46-57.

Rutley, (1991). *Element of Mineralogy*. 27th edt., revised by C.D.Gribble, pp.482.

Schollenbruch, K., Woodland, A.B. and Frost, D.J., (2010). The stability of hercynite at high pressures and temperatures. *Physics and Chemistry of Minerals*, *37*(3), pp.137-143.

Searle, D. L. & Ba Than Haq, (1964). The Mogok Belt of Burma and its relationship to the Himalayan Orogeny.*In Int. Geol. Cong. India,* Twenty-Second Sec., India, Himalayan and Alpine Orogeny, Sec.11, pp.132-161.

Searle, M.P., Morley, C.K., Waters, D.J., Gardiner, N.J., Htun, U.K., Nu, T.T. and Robb, L.J., (2017). Tectonic and metamorphic evolution of the Mogok Metamorphic and Jade Mines belts and ophiolitic terranes of Burma (Myanmar). *Geological Society, London, Memoirs*, *48*(1), pp.261-293.

Stoddard, A. and Osborn, J.F., (1979). Scheuermann's disease or spinal osteochondrosis: its frequency and relationship with spondylosis. *The Journal of Bone and Joint Surgery. British volume*, *61*(1), pp.56-58.

Themelis, T., (2008). *Gems & Mines of Mogôk: Fascinating Glimpses Into the Gemology, Geology and Gem Mining of Mogok, Myanmar (Burma)*. T. Themelis, pp.352.

Thet Tin Nyunt and Phyu Phyu Win, (2018). The Chemical Characteristics of Man Sin Spinel, Mogok, *Journal of the MAAS, Myanmar*, Vo.XVI, No.5, pp.167-180.

Thu, Y.K., Pa, W.P., Sagisaka, Y. and Iwahashi, N., (2016). Comparison of grapheme-to-phoneme conversion methods on a myanmar pronunciation dictionary. In *Proceedings of the 6th Workshop on South and Southeast Asian Natural Language Processing (WSSANLP2016),* pp.11-22.

Thu, Y.K., Enami, M., Kato, T. and Tsuboi, M., (2017). Granulite facies paragneisses from the middle segment of the Mogok metamorphic belt, central Myanmar. *Journal of Mineralogical and Petrological Sciences*, *112*(1), pp.1-19.

Wai Yan Lai Aung, (2016). *Mineralogy and Petrology of the Igneous and Metamorphic Rocks of the Mount Loi-Sau and Its Environs, Momeik Township, Shan State (North)*, (Doctoral dissertation, Ph.D, Thesis) Department of Geology, University of Yangon (Unpublished), pp.169.

Wai Yan Lai Aung, (2017) Petrology, Phase Equilibria Modelling and *P-T* Conditions of High-Grade Gneiss from the Mount Loi-Sau and its Environs, Mogok Township, Mandalay Region and Momeik Township, Shan State (North), *Journal of the MAAS, Myanmar,* Vo.XV, No.5, pp.97-113.

Wai Yan Lai Aung, (2018), Granulite and its *P-T* Condition of the Mount Loi-Sau and its Environs, Mogok Township, Mandalay Region and Momeik Township, Shan State (North), *Journal of the MAAS, Myanmar*, Vo.XVI, No.5, pp.131-150.

Widmer, R., Malsy, A.K. and Armbruster, T., (2015). Effects of heat treatment on red gemstone spinel: single-crystal X-ray, Raman, and photoluminescence study. *Physics and chemistry of minerals, 42*(4), pp.251-260.

Win, M.M., Enami, M. and Kato, T., (2016). Metamorphic conditions and CHIME monazite ages of Late Eocene to Late Oligocene high-temperature Mogok metamorphic rocks in central Myanmar. *Journal of Asian Earth Sciences*, *117*, pp.304-316.

Yonemura, K., Osanai, Y., Nakano, N., Adachi, T., Charusiri, P. and Zaw, T.N., (2013). EPMA U-Th-Pb monazite dating of metamorphic rocks from the Mogok Metamorphic Belt, central Myanmar. *Journal of Mineralogical and Petrological Sciences*, *108*(3), pp.184-188.