THE CHEMICAL CHARACTERISTICS OF MAN SIN SPINEL, MOGOK, MYANMAR

Thet Tin Nyunt[*] and Phyu Phyu Win[**,***]

Abstract

Man Sin is located about 5 km to the northeast of Mogok. It is bounded by Latitudes 22 ° 57′ 05″ to 22°58′ 30″ N and Longitudes 96° 32′ 00″ to 96° 33′ 00″ E, in part of UTM Map 47Q KF 2296- 09. Jedi spinel (Hot spinel) was first discovered at Man Sin mine in 2009. This mine produces as varieties of coloured spinel, but most of them are intense red spinel principally Jedi spinel (Hot spinel).Chemical analyses of Man Sin

spinel indicate that Al_2O_3ranges from (71.5 – 60.5 wt %) and MgO from (26.6 – 18.5 wt %). The high concentrations of elements were Cr (3.66 – 0.008 ppm), V (0.633 – 0.005 ppm), Fe (2 – 0.03 ppm), Zn (0.725- 0.038) and Zr (1.103 – 0.219 ppm) respectively. Ti (0.113 – 0.008 ppm) and Ga (0.052 – 0.003 ppm) are generally low in concentration. Fe+TivsV+Cr and Cr+TivsV+Fe plots indicate that they are negatively associated. In Fe-V- Cr Ternary diagram, the red spinel from the Man Sin mine has two population: one is coloured by higher Cr content (> 80 ppm) and V content (> 40 ppm) but Fe content is (12 to < 10 ppm) in red spinel. The other group has average value of Cr and V ranging from (40-60 ppm). In these two groups, one which has higher Cr content shows more attractive red colour. Moreover, pink spinel also shows two groups. One is rich in Cr and other is rich in V. Fe concentration in these two groups is intermediate (35-55 ppm). One sample shows the significantly excessive Fe concentration (nearly 100 ppm) and thus the colour of this spinel is greenish blue. Trace elements (V, Ti and Zr) are positively associated with Cr but other trace elements such as Fe, Ga and Zn are negatively associated with Cr, which display increase of Cr content with decrease of Fe, Ga and Zn contents. Conversely, red spinel from Htayan Sho mine indicates that Fe content is (> 40 ppm) and the amount of V and Cr contents is (< 60 ppm). So, the constraint on the attractive colour of Man Sin Hot spinel is due to the Cr rather than other trace elements such as V and Fe; pink and purple spinel are due to Fe and Cr, V and Ti, and the green spinel is due to the Fe. On the other hand, red spinel from Htanyan Sho is due to the average concentration of Fe and V rather than Cr and the purple spinel is due to higher concentration of Fe than V respectively.

Key words: Man Sin, Htayan Sho, Jedi Spinel, Hot Spinel, Mogok, Myanmar

[*]. MRes (Mineralogy Specialization)
[**]. Lecturer, Department of Geology, University of Yangon
[***]. Director, Professor, Applied Geology Department

Introduction

Spinel has been used as a gemstone and was mistaken for ruby in the past and can be ranked next to ruby and sapphire due to lack of cleavage, higher dispersion and wide range of colour. It mostly occurrs in metamorphosed impure dolomitic limestone where the protolith was partly incorporated with clayey materials. These rocks were later affected by higher temperature regional metamorphism. One of the attractions of spinel is wide range of its elegant colours. For red spinel, the finest colors tend to be similar to ruby. However, Spinel tends to be slightly more bright-red colour than ruby and is called ***'Ruby Spinel'*** (Balas Ruby). Some spinel colours are more rare and valuable than others. In Myanmar, the finest spinels were producedfrom Man Sin mine in Mogok which was operated about 12 years ago, but pocket of ***jedi spinel (hot spinel)*** was first found only in 2009 (Pardieu, 2014). Although it was found in 2009 as famous attractive coloured spinel, the composition of such a beautiful gemstones from Man Sin area has not yet been studied in detail.

Location and Size

The research area is located in Mogok Township, Pyin Oo Lwin District, Mandalay Region. It is situated approximately 205 km to the northeast of Mandalay and 5 km to the northeast of Mogok. It is bounded by latitudes 22 ˚ 57′ 05″ to 22˚58′ 30″ N and longitudes 96˚ 32′ 00″ to 96˚ 33′ 00″ E. This area also lies between horizontal grids 400 to 425 and vertical grids 470 to 490 in UTM Map 47Q KF 2296- 09.The research area is about 2.5 km in N-S and 2km in E-W and the total area coverage is about 5 square km. Location map of the study area is shown in (Fig. 1).

Methods of Study

Field Work

Field work was carried out with conventional methods together with some modern equipment such as GPS which were plotted on Google Earth Map. Samples were collected from the Man Sin primary deposit as well as secondary deposit. Moreover, spinel samples from Htayan Sho mine were collected for comparative study (Fig. 2 A-D).

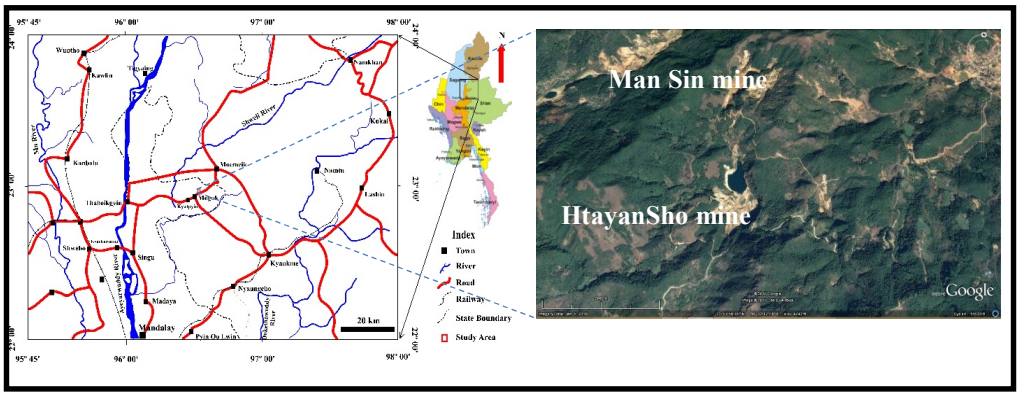


Figure 1. Location map of the Man Sin and its environs.

Figure 2 (A-C) Hot spinel crystals from Man Sin mine and (D) Spinel crystals from Htayan Shomine.

Laboratory Work

Analytical Method

For the present study, sixteen collected spinel were selected for analysis which includes thirteen samples from Man Sin mine and three samples from Htayan Sho mine. They sent to DGSE and MGJEA Labs. The major oxide and trace element concentrations of spinel samples were analyzed by using ED-XRF (X- Ray Fluorescence Spectrometry) method.

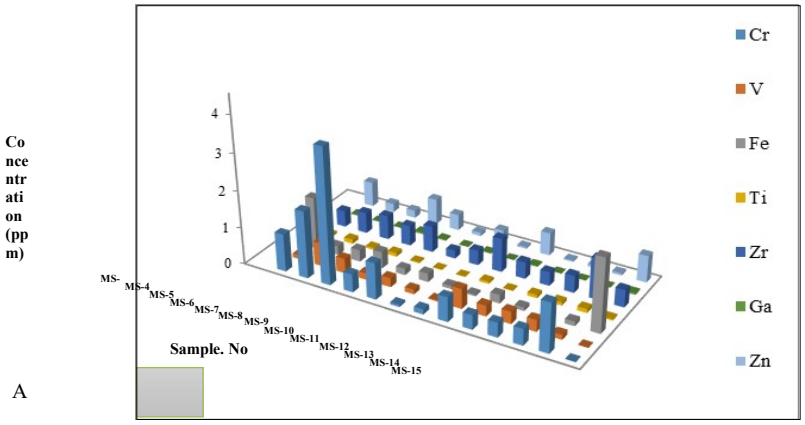
Chemical Composition of Man Sin Spinel

Analysed EDXRF results for major oxides and trace element concentrations are shown in Table1. These samples, in general, have Al_2O_3 (71.5 – 60.5 wt %) and MgO (26.6 – 18.5 wt %).The high concentrations of elements were Cr (3.66 – 0.008 ppm), V (0.633 – 0.005 ppm), Fe (2 – 0.03 ppm), Zn (0.725- 0.038) and Zr (1.103 – 0.219 ppm) respectively. Ti (0.113 – 0.008 ppm) and Ga (0.052 – 0.003 ppm) are generally low in concentration. The concentrations of these elements are graphically presented in (Fig. 3). Fe+Ti and V+Crare used to interpret the colour variation in Man Sin spinel and the plot indicates that they are negatively associated (Fig. 4). Moreover, Cr+Ti and V+Feare used to interpret the colour variation in Man Sin spinel and the plot indicates that they are negatively associated (Fig. 5).

In Fe- V- Cr Ternary diagram, the red spinel from the Man Sin mine has two population (Fig. 6). One is coloured by higher Cr content (> 80 ppm) and V content (> 40 ppm) but Fe content is (12 to < 10 ppm)in the red spinel. The other group of red spinel has average value of Cr and V ranging between (40-60 ppm). In these two groups, one which has higher Cr content shows more attractive red colour than the other group which is coloured by average contents of Cr and V. In these two groups, Fe plays a minor role. Moreover, pink spinel also shows two populations. One is rich in Cr and other is rich in V. Fe concentration in these two groups is intermediate (35-55 ppm). One sample shows the significantly excessive Fe concentration (nearly 100 ppm) and thus the colour of this spinel is greenish blue.

Table . Concentration of Major Oxides and Trace Elements of Man Sin Spinel

Sample. No	MS- 3	MS-4	MS- 5	MS- 6	MS- 7	MS- 8	MS- 9	MS- 10	MS- 11	MS- 12	MS- 13	MS- 14	MS- 15
Major Oxide (%)/Colour	Pink	Red	Red	Purple	Red	Pale pink	pink	Deep Red	Deep Red	Deep Red	Deep Red	Red	Greenish Blue
Al_2O_3	60.5	63.4	62.1	70.3	68.6	70.1	69.7	71.5	71	70.2	71.1	66.2	66.5
MgO	19.7	18.5	22.7	24.9	25.5	26.6	26	24.2	25	26.2	26.1	23.4	24.8
SiO_2	12.9	12.2	6.97	1.09	1.79	1.13	2.68	0.681	0.978	1.49	0.603	5.76	3.05
SO_3	0.195	0.188	0.119	0.0876	0.23	0.258	0.134	0.0718	0.069	0.0651	0.0533	0.25	0.278
K_2O	0.931	0.0753	0.0759	0.0176	0.0739	0.0481	0.0552	0.0156	0.0223	0.0255	0.0153	0.122	0.123
CaO	0.132	0.149	0.131	0.0213	0.0444	0.306	0.0655	ND	0.0305	0.0222	0.0268	0.108	0.11
MnO	ND	ND	0.0234	ND	ND	0.0036	0.0019	0.0176	ND	ND	ND	0.0106	0.0275
Trace Elements (ppm)													
Cr	1.019	1.82	3.66	0.493	0.985	0.058	0.138	0.666	0.395	0.4	0.442	1.341	0.008
V	0.113	0.633	0.398	0.171	0.248	0.127	0.033	0.543	0.292	0.333	0.315	0.132	0.005
Fe	1.406	0.239	0.317	0.45	0.174	0.233	0.083	0.044	0.234	0.093	0.03	0.124	2
Ti	0.065	0.113	0.058	0.098	0.03	0.014	0.008	0.062	0.016	0.089	0.088	0.105	0.04
Zr	0.444	0.566	0.65	0.547	0.707	0.219	0.399	0.911	0.452	0.37	0.466	1.103	0.473
Ga	0.027	0.012	0.014	0.052	0.031	0.02	0.018	0.004	0.028	0.004	0.003	0.01	0.042
Zn	0.68	0.228	0.204	0.693	0.428	0.092	0.332	0.049	0.619	0.038	0.065	0.056	0.725
Sum	98.112	98.1233	97.4203	98.9205	98.8413	99.2087	99.6476	98.765	99.1358	99.3298	99.3074	98.7216	98.1815



A

Figure 3. Trace elements variation diagram of spinel from Man Sin mine

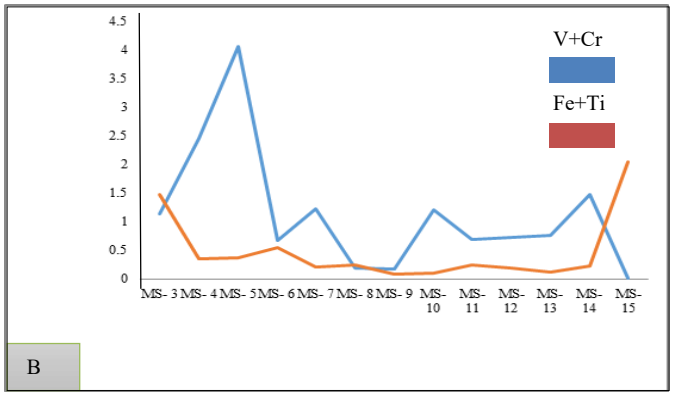


Figure 4. V+Cr and Fe+Ti plot indicates that they are negatively associated for the colour variation in Man Sin spinel

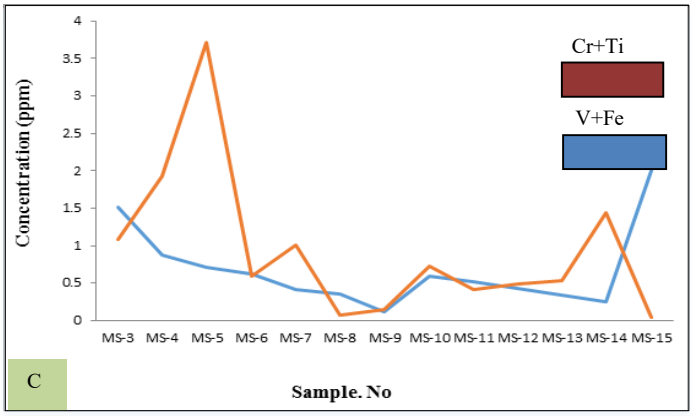


Figure 5. Cr+Ti and V+Feplot indicates that they are negatively associated for the colour variation in Man Sin spinel

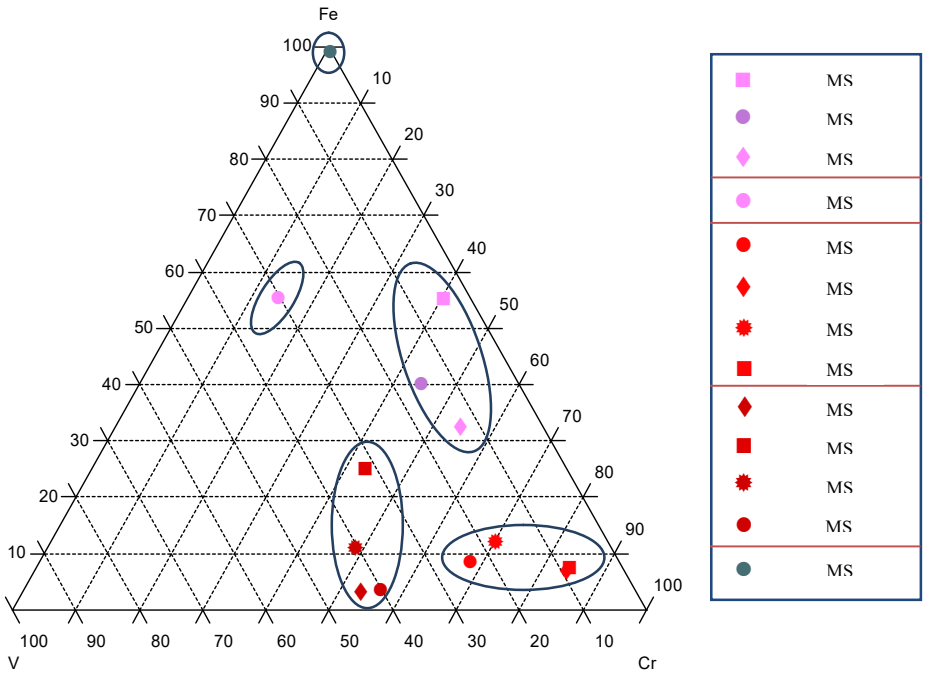


Figure6. Fe- V- Cr Ternary diagram showing increasing Cr contents in red spinel with two groups, and increasing Fe content in pink spinel with Cr rich and V rich groups and higher Fe concentration in greenish blue spinel from Man Sin mine. See also Table 1.

The present study typically indicates that Cr content is higher than V and Fe contents in red to pink spinel, but more Fe content in greenish blue spinel. According to chemical analyses and Ternary diagram, the colour of Man Sin spinel depends on Cr with minor influence of V and Fe.

Moreover, trace elements (V, Fe, Ga, Zr, Zn and Ti) versus Crvariation diagrams also explain the correlation of these elements in the Man Sin spinel (Fig. 7 A-E). In these diagram, trace elements (V, Ti and Zr) are positively associated with Cr but other trace elements such as Fe, Ga and Zn

are negatively associated with Cr, which display increase in Cr content with decrease in Fe, Ga and Zn contents.

Comparison of Man Sin Spinel with HtanyanShoSpinel

The comparison of trace elements (Cr, V, Fe and Ti) of spinel from Man Sin with HtayanSho is shown in Table 2.

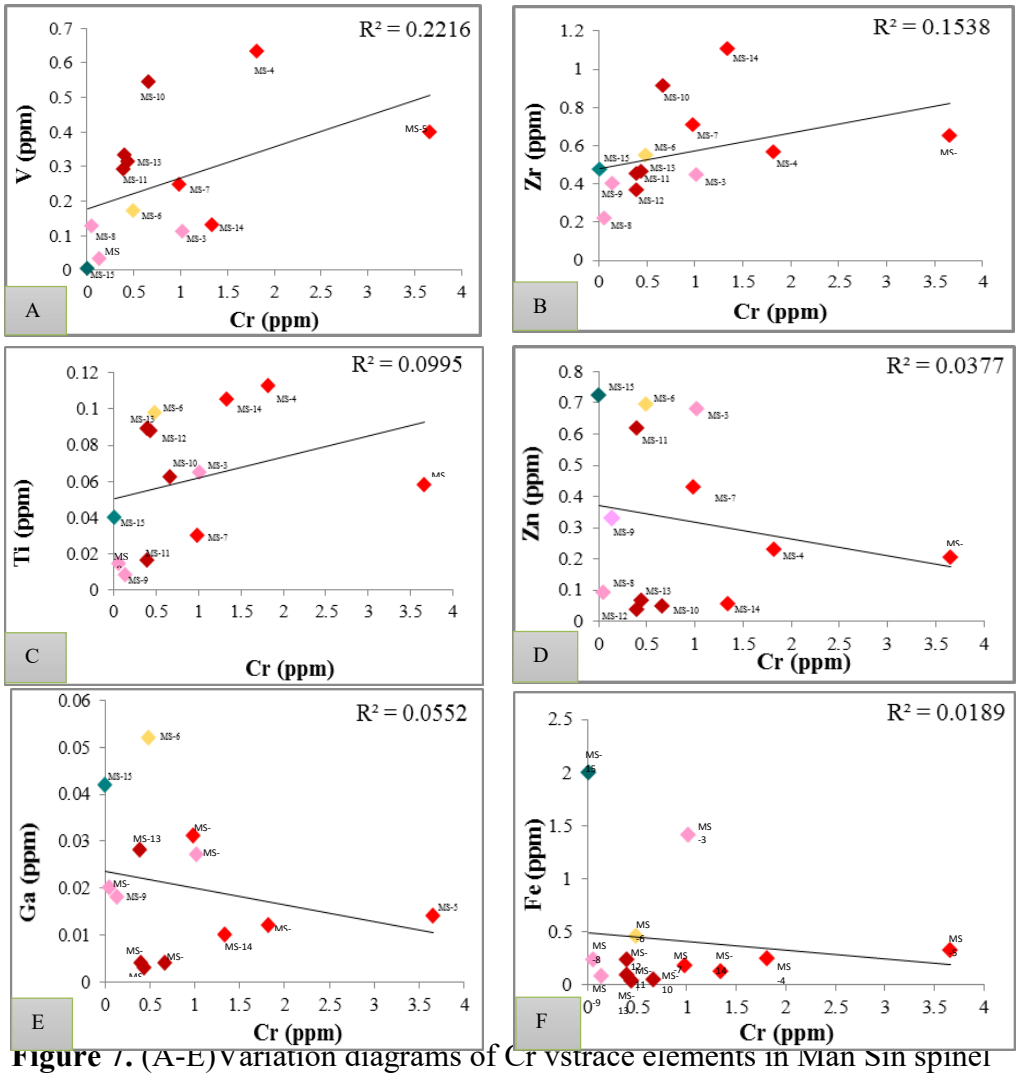


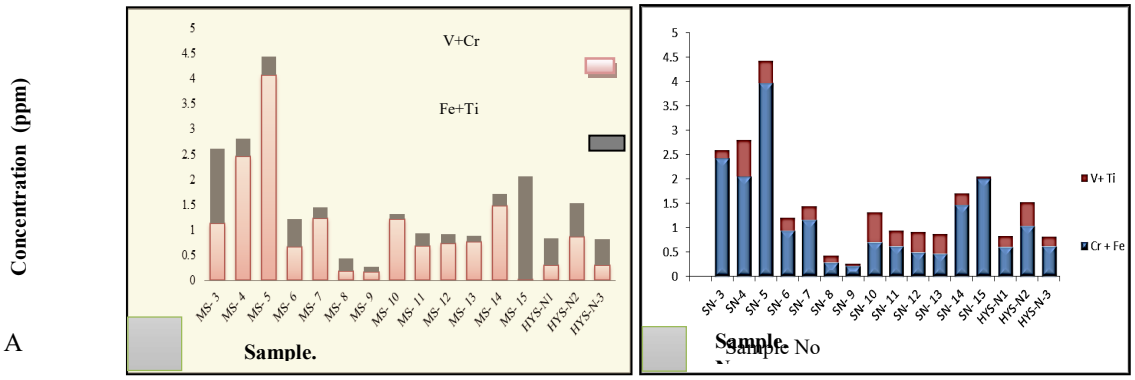
Figure 7. (A-E)Variation diagrams of Cr vstrace elements in Man Sin spinel

In the variation diagram, the concentration of trace elements Fe+Ti and V+Cr are used to interpret the colour variation of spinel from two mine sites(Fig. 8 A, B). This diagram shows that colour variation in Man Sin mine has higher concentration of Cr with V contents than those of HtayanSho mine but the amount Fe with Ti concentrations are less.

Fe- V- Cr Ternary diagram shows that the increasing amount of Cr content with decreasing amount of Fe and V contents in red to pink spinel from Man Sin mine than Htanyan Sho mine (Fig. 9). Spinel from Htayan Sho mine indicates that Fe content is (> 40 ppm) and the amount of V and Cr contents are (< 60 ppm).

Table 2. Comparison of Trace Elements (Cr, V, Fe and Ti) of Man Sin Spinel and Htayan Sho Spinel

Mine Site		Man Sin												Htayan Sho		
Sample. No	MS-4	MS- 5	MS-7	MS-14	MS-10	MS-11	MS-12	MS-13	MS- 3	MS- 8	MS- 9	MS- 6	MS- 15	HYS-N1	HYS-N2	HYS-N3
Location (UTM 47Q KF)	481425													478414		
Colour / Elements (ppm)	Red	Red	Red	Red	Deep Red	Deep Red	Deep Red	Deep Red	Pink	Pale Pink	Pink	Purple	Green-ish Blue	Red	Orange Red	Purple
Cr	1.82	3.66	0.985	1.341	0.666	0.395	0.4	0.442	1.019	0.058	0.138	0.493	0.008	0.413	0.116	0.142
V	0.633	0.398	0.248	0.132	0.543	0.292	0.333	0.315	0.113	0.127	0.033	0.171	0.005	0.449	0.180	0.156
Fe	0.239	0.317	0.174	0.124	0.044	0.234	0.093	0.03	1.406	0.233	0.083	0.45	2	0.625	0.497	0.484
Ti	0.113	0.058	0.03	0.105	0.062	0.016	0.089	0.088	0.065	0.014	0.008	0.098	0.04	0.04	0.034	0.031



A

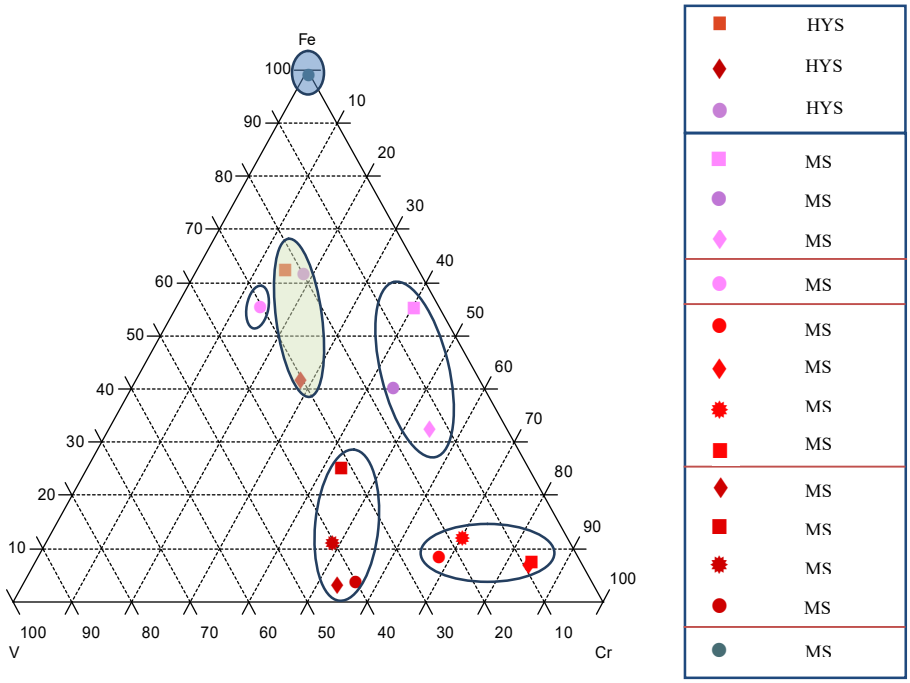


Figure 9. Fe- V- Cr Ternary diagram of Man Sin and HtayanSho spinel. See also Table 2

Conclusions

Spinel deposits are located from central to south east Asia and associated within the Himalayan mountain belt which was formed by continental collision between the India and Eurasia during the Tertiary. Spinel was formed both mafic igneous rocksand metamorphic rocks which occurred in carbonate series and underwent high temperature amphibolite to lower granulite grade regional metamorphism (Malsy & Klemm; 2010). The spinel is formed at temperatures 600˚- 700˚C. Depending on the amount of magnesium which played an important factor for colouring during the genesis of spinel. Spinel would form when magnesium exceeds aluminium (Themelis, 2009).

At Mogok, spinel was formed as a result of contact metamorphism or skarnmetasomatism within regionally metamorphosed basement rocks where the presence of fluids played an important role (Iyer, 1953; Themelis, 2009). Spinel occurs within a relatively narrow aluminium rich layer in the marble. It is very resistant to chemical and physical weathering but its host marble is much less resistant to weathering. Therefore spinel is easily liberated from the marble and transported by streams and occurred as alluvial deposits.

Jedi spinel (Hot spinel) was first discovered at Man Sin mine in 2009. This mine produces varieties coloured spinel, but most of them are intense red spinel and principally Jedi spinel (Hot spinel*)* (Pardieu, 2014). Moreover, it is an only active source for hot spinel in Mogok. At Man Sin, spinel occurs as porphyroblasts in marble as primary deposit and also excavated from gem-bearing gravel in alluvial (secondary deposit). The primary rocks were clayey limestones and calcic limestones. They may become dolomitic limestone by metamorphism (Gübelin & Koivula, 2005) where, high temperature regional metamorphism and then larger- scale transformation of carbonate rocks, high mobilization and migration of many chemical elements containing Al and Cr in the dynamothermal metamorphism of carbonate rocks (Kisin et al., 2016) occurred.

The formation of Man Sin spinel in the marble is due to the presence of certain amount of magnesium in the spinel- graphite marble. Graphite and spinel association in the marble indicates that this marble (limestone for the protolith) was deposited in the carbon and magnesium rich environment.

The chemical analyses indicate that the constraint on the attractive colour of Man Sin Hot spinel is Cr rather than other trace elements such as V and Fe; pink and purple spinel are due to the concentration of both Fe and Cr, V and Ti and the green spinel is due to Fe. Conversely, red spinel from HtanyanShois due to the average concentration of Fe and V rather than Cr and the purple spinel from HtayanSho is due to higher concentration of Fe than V respectively.

Acknowledgement

We are very grateful to Prof. Dr. Daywa Aung, (Head of Geology Department, Yangon University) for his permission to carry out the investigation of this area. We would like to extend our sincere thanks to Prof. Dr. Phyu Phyu Lwin, (Head of Geology Department (Retired), Dagon University) and Prof. Dr. Cho Cho Aye, (Head of Geology Department, East Yangon University) for their encouragement and advice. Thanks are also extended to Major Aung Nyunt Thein, Managing Director, Myanma Gems Enterprise, Nay Pyi Taw, U Hla Aung (Assistant Director), U Win Htay (Deputy Director) and Major Aung Kyaw Moe (Assistant Director), Major Tun Wai (Assistant Director)and all staffs from Myanma Gems Enterprise, Mogok for their help. Dr. Ye Myint Swe, (Director General, DGSE), for his permission on XRF measurement and also thanks are extend to Daw Ye Ye Mon (F.G.A, London), (Former Research Officer, Myanmar Gems and Jewellery Entrepreneur's Association Lab.) for EDXRF Analyses. We are very grateful to U Kyaw Thu and U Si Thu (Directors of "Mani Yadanar Aung" gems and jewellery Co.Ltd.) and UAungNaing Win (Director of "Nanda Aung" Co. Ltd.)and U Than Naing (Chairman, San Taw Win Co.Ltd.)for their kind permission to study in the mine and collected gem samples.

The last author is also grateful to Dr. Kyaw Thu for his advice and deeply thankful to Dr. Kyaw Khaing Win for his help in her field works, providing valuable advice and discussion. She also would like to extend her sincere thanks to Dr. Myat Thuzar Soe, Director, (AGD), Prof. Dr. Ohn Thwin, (Rtd), Dr. Su Su Hlaing and Dr. Aung Zaw Myint (Lecturers, Geology Department, Yangon University) and Dr Tin Myint Oo (Lecturer, Geology Department, AGD), Dr. Win Min Oo, (Lecturer, East Yangon University) and Dr.Mi Paik (Lecturer, Sittway University)for their advice, helpful suggestions and comments. Last, but not least, Mg Zaw Hteik for map preparation and Mg Myo Myint Tun, Mg Min Ye Kyaw, and Ko Phyu Phwe (Mogok) for their indefagtigable help during the field work are acknowledged.

References

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

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

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, p 385- 402.

Malsy, A, and Klemm, L, (2010), Distinction of gem spinels from the Himalaya Mountain Belt, *Chimia 64*, p 741- 746.

Pardieu, V, (2014), Hunting for "Jedi" spinels in Mogok, *Gems and Gemmology*, **50**(1), p 46-57, http://dx.doi.org/10.5741/GEMS.50.1.46.

Themelis, T, (2008), *Gems and Mines of Mogok*, Thailand, 352p.

Webster. R, (1962), *Gems, their sources, descriptions and identification*, Butterworths, p 464.