Paper 1:

THE ROLE OF FLUORINE IN THE FORMATION OF COLOR ZONING IN RUBIES FROM MONG HSU, MYANMAR (BURMA)

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ABSTRACT: Mong Hsu rubies are characterized by a black sapphire core and a ruby rim. This color zoning has been correlated with the presence of the trace elements Ti (violet to black) and Cr (red). Some examples of Mong Hsu rubies show a complex chemical zonation, which results in multiple zones of rubies, violet sapphires and black sapphires within one particular crystal. Rubies of this type have been studied by analyzing the solid and fluid inclusions as well as their chemical zoning. Minerals accompanying the rubies, such as tourmaline (dravite) and tremolite have also been analyzed. The formation conditions of the rubies have been reconstructed following the study of mineral associations and fluid inclusion analyses. Mong Hsu rubies were formed at 2-2.5 kbars and at temperatures between 500^o and 550^{o}C. The fluids were found to be water-bearing and multi-volatile CO_2-rich (multivolatile = composed of CO_2, CH_4 and other components, possibly N_2, H_2S and HF). Fluorite inclusions in the rubies indicate that fluids must have contained some HF. During the study of the homogenization temperatures in different populations of fluid inclusions, it was concluded that no major variations in temperature and pressure occurred during the growth of Mong Hsu rubies. However, the chemical zonation patterns found in Mong Hsu rubies and accompanying tourmalines are indicative of variations in the composition of the fluids e.g. in contents of F, Ti and Cr. A preliminary model is proposed, which explains the cyclic growth of Mong Hsu rubies, with formation of alternating zones of ruby and sapphire by variation in HF concentration in the surrounding fluids. The possible multiple infiltration of fluids from metapelites into dolomites is discussed.

0 INTRODUCTION

A new source of rubies with commercial importance was declared in 1991 at Hong Hsu in the Shan state of Eastern Burma more than 200km from the classical ruby mine at Mogok. The main metamorphic rocks in the mining district are composed of metacarbonates (dolomites, marbles, calcsilicate rocks) and metapelitic rocks (schists, gneisses, phyllites). Mong Hsu rubies are mined in secondary deposits and in primary deposits in the dolomite marbles.

The most characteristic feature of the Mong Hsu rubies is their color zoning, with a violet to black core (Figure 1) and a red rim. The cores consist of zones enriched in TiO_2 and Cr_2O_3 along with only small concentrations of FeO. The color zones in the Mong Hsu rubies occur in repeated cycles of violet/black and red along with changes in the crystal habit (Figure 2a, b). The factor most relevant to the commercial importance of the Mong Hsu rubies is that the violet to black zones can be removed by heat-treatment (Figure 3). Typical examples of such heat-treated fine quality and faceted rubies are shown in Figure 4.

This study concentrates on attempting to determine the conditions under which Mong Hsu rubies were formed and on the genetic reasons for the presence of violet to black zones in the Mong Hsu rubies.

Figure 1 Non-heat-treated Mong Hsu rubies, partly with polished facets, showing black to violet cores. Rubies between 0.50 and 2.00ct

Figure 2a. Typical color zoning in Mong Hsu ruby which has not been subjected to heat-treatment. Central violet to black zones are correlated with high concentrations of titanium and chromium. Ruby cut parallel to the c-axis. Magnification on slide is 40´. Ruby approx. 2ct

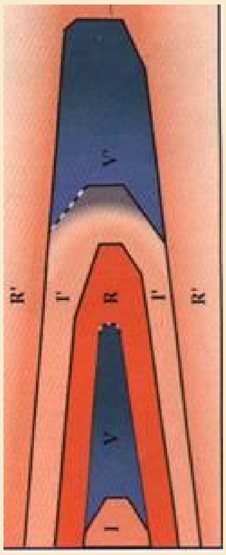

Figure 2b. Classification of the color zoning of the Mong Hsu ruby of Figure 2a. Growth phases are described as I, R and V. Compare with Figure 10.

Figure 3. Heat-treated Mong Hsu rubies. The original violet to black cores have been completely removed and transformed to intense red. Rubies between 1 and 3ct

Figure 4. A set of cut stones showing different color shades obtainable from Mong Hsu rubies after heat-treatment. Sizes of rubies around 1ct each

1 MINERALS ACCOMPANYING THE MONG HSU RUBIES IN THE ALLUVIAL DEPOSITS

The materials for this study were sampled during expeditions to Northern Thailand (Mae Sai) and Burma in the summers of 1993 and 1995 (Figure 5). However, direct field work at the primary mine in Mong Hsu was not possible because of security risks which are still pertinent. In order to obtain further information concerning associated minerals, large parcels of mineral concentrates from the Mong Hsu ruby deposits have been checked. Some of the results are shown in Figure 6, namely, the presence of brownish-green dravite, quartz, alamandine intergrown with white mica, and andalusite. Garnet, green tourmaline, white mica and quartz have already been described by Hlaing, but in addition he described staurolite as a mineral that can be found in the alluvial deposits. Green tourmaline was also reported to occur as an intergrowth with ruby. Tremolite is particularly frequent in the alluvial deposits.

Figure 5. A Mong Hsu ruby in the host rock. The ruby is formed in a vein consisting of corundum, sapphire, ruby, calcite, Mg-chlorite, fuchsite and opaque minerals. The vein itself is embedded in a dolomite marble (area of lower left corner) which shows signs of metamorphic recrystallization (equal sized dolomite crystals, 2mm in size). A calcite crystal is shown in reflected light in the figure. It is formed at the border zone of the vein, in contact between the dolomite marble and the ruby. Minerals identified by SEM-EDS analyses. Length of Mong Hsu ruby is 8mm.

In general, neither the Mong Hsu rubies nor the minerals accompanying the Mong Hsu rubies are water-worn (Figure 6). It is therefore most likely that the minerals occurring with the rubies in the alluvial deposits originate from the primary ruby deposits or from country rocks close to them.

In order to obtain more information about their host rock types, dravite, almandine and tremolite crystals have been chemically analyzed by means of electron microprobe analyses (Table 1). Mong Hsu tremolites show traces of chromium (Cr), vanadium (V) and fluorine (F), but iron (Fe) and nickel (Ni) were below detection levels. Green tremolite from Mong Hsu is chemically zoned with some areas more enriched in V and Cr than others; these elements seem to be responsible for the variable intensities of green found in the mineral (Figure 7). Increasing Cr-concentrations in the tremolites are correlated with increasing V-concentrations with a Cr/V atomic ratio of 10:1. Furthermore, considerable concentrations of fluorine were found in the Mong Hsu tremolites. Such tremolites may be typically found in metasomatic veins in dolomitic marbles such as those described by Mercolli et al. Chemically different from tremolites originating from marble deposits are those from metamorphosed ultramafic rocks. Their chemical composition is characterized by traces of Ni and higher concentrations of Fe but without traces of F (Table 1). The most common accessory mineral found in the lots of Mong Hsu rubies was brown to green dravite. These tourmalines contain trace amounts of Cr, V and F (Figure 8 and Table 1).

Figure 6. Minerals found in the lots of Mong Hsu rubies including one green chromium-dravite (top), three brownish dravites (middle), andalusite (lower left corner) and two almanines (lower right side). Note that the crystals are not water-brown; length of green chromium-dravites is 6mm

Figure 7. Fragments of greenish tremolite from the Mong Hsu ruby mine. The green is due to Cr- and V-concentrations in tremolite. Transmitted light. Length of crystal is 2mm (crystals immersed in epoxy, polished on one side)

Figure 8. Brownish-green dravite containing traces of Cr, V and F. Transmitted light. Length of crystal is 5mm

The chemical compositions of the associated minerals gives some indication of their formation in different rock types. Almandine and white mica (as overgrowth on garnet) typically occur in a range of rocks including metapelites (metamorphosed gneisses or schists), while staurolite and andalusite occur almost exclusively in metapelites. This mineralogical assemblage is typical for regionally metamorphosed or contact metamorphosed metapelites which have undergone amphibolite facies conditions. Additionally, the formation of tremolite is consistent with this degree of metamorphism. It is also known that tremolite can be formed under these metamorphic conditions in veins within dolomites. Cr-, V- and F-bearing dravites also probably formed in the same or similar metasomatic veins. The observed intergrowth of tourmaline with Mong Hsu rubies and their typical occurrence in other ruby deposits supports this idea.

2 CHEMICAL ZONING IN MONG HSU TOURMALINE

Strong fluctuation of the chromium content occurred during the crystal growth of green dravite, ranging from 0.2 to 2.2 wt% Cr_2O_3 (Table 1). These variations are related to the color zoning with light green indicating low Cr-concentrations and intense green being related to relatively high Cr-concentrations. As shown in Figure 9, several abrupt changes in Cr-concentration occurred during the growth of the tourmaline crystal. Increasing Cr-concentration is correlated with increasing F-concentrations. They are also correlated with increasing V-concentrations.

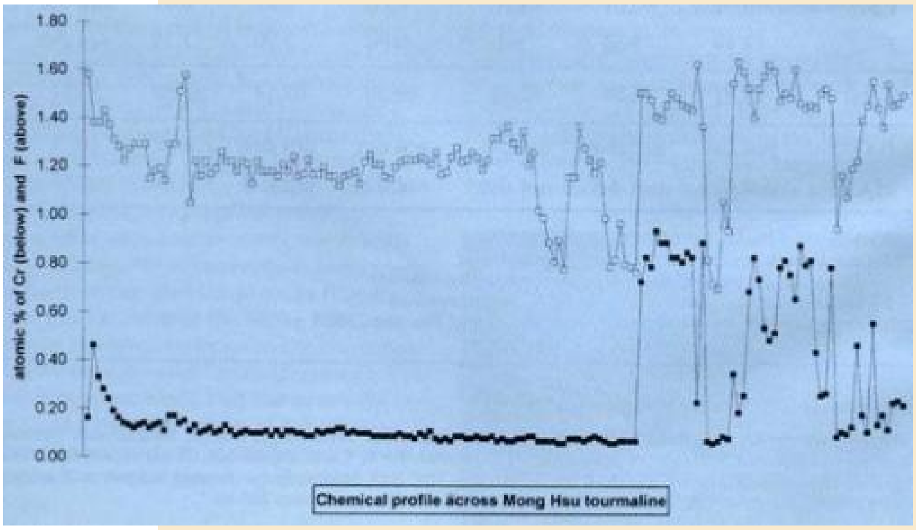

Figure 9. chemical profile across a green dravite originating from Mong Hsu (perpendicular to c-axis) showing F and Cr-concentrations. Note strong fluctuations of Cr along with F at distinct phases of growth towards the edge of the crystal. Increasing Cr-concentrations are correlated with increasing F-concentrations

3 CHEMICAL ZONING IN MONG HSU RUBY

Figure 10 shows in an idelized way the chemical oscillations in a selected Mong Hsu ruby sample and its color zoning as seen in the immersion microscope (Figure 2a). The concentrations of the trace elements are taken from Peretti et al. Many other samples showed a similar color zoning, although the full sequence of growth shown in Figure 10 may not always be present. Color zoning in Mong Hsu ruby is correlated with different growth phases of the crystal, designated as 'I' (intermediate), 'V' (violet), and 'R' (red) as defined in Peretti et al. Growth phase 'I' is characterized by relatively low to medium Cr_2O_3-concentrations, along with relatively low or absent TiO_2-concentrations; growth phase 'V' by relatively high TiO_2 and high Cr_2O_3-concentrations; growth phase 'R' by relatively high Cr_2O_3-concentrations with no presence of TiO_2. During phase 'I', pink or violet sapphire to ruby layers are formed; during growth phase 'V' violet to black sapphire layers are formed; and during phase 'R', ruby layers are formed. This successive growth is repeated at least twice during the formation of a typical Mong Hsu ruby. A dramatic habit change in the Mong Hsu ruby crystal occurs at the transition of growth phase 'V' to 'R' and the highest vanadium concentrations are found in the 'V' zone.

Table 1. Chemical compositions of minerals associated with Mong Hsu rubies in comparison with those from other localities

	Tremolite (1)	Tremolite (1)	Tremolite (2)	Almandine (1)	Dravite (1)	Dravite (1)	Dravite (3)
MgO	24.05	24.32	24.83	1.09	12.65	13.26	13.67
CaO	13.55	13.43	12.61	0.50	2.82	1.89	2.41
Na2O	0.95	1.01	0.21	0.00	1.55	1.96	1.63

K2O	0.07	0.07	0.00	0.00	0.00	0.00	0.09
SiO2	53.07	53.31	57.88	35.15	35.46	37.57	35.96
Al2O3	3.65	2.32	0.00	20.38	30.52	31.13	30.85
TiO2	0.05	0.04	0.00	0.005	0.13	0.15	0.14
FeO	0.00	0.01	1.76	42.06	0.04	0.09	0.76
MnO	0.00	0.03	0.00	0.07	0.00	0.01	Not det
Cr2O3	0.63	0.60	0.15	0.00	2.17	0.22	Not det
V2O3	0.05	0.04	bd	0.00	0.00	0.06	Not det
NiO	0.00	0.00	0.07	0.00	0.00	0.00	Not det
Cl	0.01	0.01	bd	0.00	0.01	0.01	Not det
F	3.49	3.50	bd	0.00	1.79	1.15	Not det
Total	98.57	98.79	97.51	99.30	87.14	87.50	85.51
B2O3	Not det	Not det	Not det	Not det	Not det	Not det	10.73
H2O	Not det	Not det	Not det	Not det	Not det	Not det	4.16

Notes
Not det = not determined, bd = below detection limit
1 = tremolite, dravite and almandine from Mong Hsu (Burma)
2 = Malenco serpertinite (amphibolite facies metamorphism)
3 = Brown dravite, dolomite marble

4 SOLID INCLUSIONS IN MONG HSU RUBIES

Various minerals have been identified as inclusions in the ruby rough; these include layered silicates (white mica, fuchsite, Mg-chlorite, Figure 11), silicates (plagioclase and aluminosilicates), halides (fluorite, Figure 12a-c), oxides (rutile, Figure 13), carbonates (dolomite) and phosphates (apatite). Aluminum-hydroxide (boehmite or diaspore) has been identified as a daughter mineral in fluid inclusions and tiny dispersed diaspore inclusions occur elsewhere in the Mong Hsu rubies. Fluorite and rutile inclusions have been found in the sequence of crystal growth labelled 'R'. However, because fluorite and rutile are only found extremely rarely, it cannot yet be confirmed that they occur repeatedly in different 'R' zones in the crystals and never in the 'I' and 'V' zones. Fine dispersed diaspore occurs repeatedly in the 'R' to 'I' zones of the crystal (Figure 14). Further study is necessary to indicate whether other hydrous silicates or even submicroscopic fluoride particles are located in these zones also. Examination of the occurrence of diaspore inclusions in the 'V' zones of Mong Hsu rubies is currently under re-examination. Dolomite crystal inclusions occur in large numbers in some Mong Hsu ruby crystals and their distribution does not seem to be restricted to any particular zone.

Fuchsite, Mg-chlorite and white mica have been detected as overgrowths on Mong Hsu rubies or as inclusions in the marginal parts of the rubies, in the outer 'R' to 'I' zones (Figure 11 and 16).

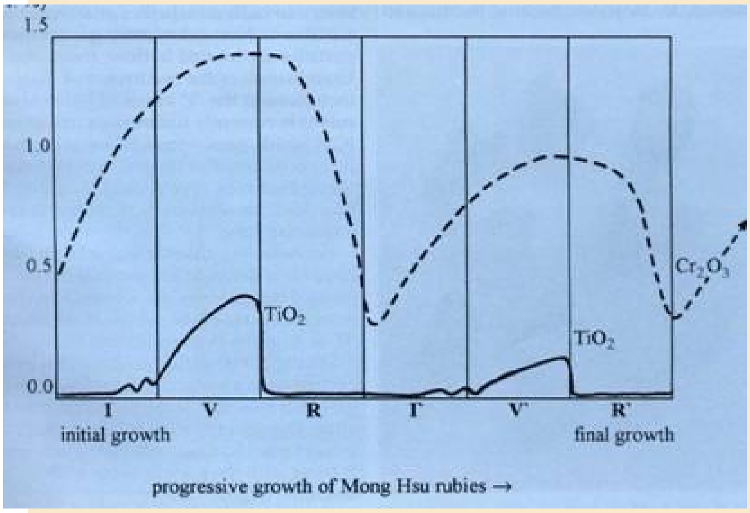

Figure 10. Zoning patterns in Mong Hsu rubies as schematically reconstructed from color zoning and chemical profiles; different growth stages are defined as I, V, R and are characterized by a typical trace element pattern and crystal habit. I = alternation of pink sapphire and violet sapphire, V = black sapphire, R = ruby. Note the repeated oscillation of Cr and Ti during the growth history of the Mong Hsu ruby

Figure 11. Mong Hsu rubies intergorwn with fuchsite (top three crystals) and light green Mg-chlorite and white mica. Crystal length of lower left ruby is 9mm

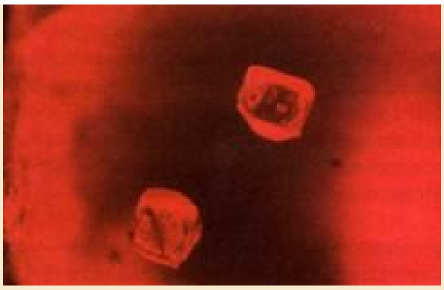

Figure 12a. Fluorite inclusion, 0.2mm across, lower left of center occurring in a Mong Hsu ruby in transmitted and reflected light

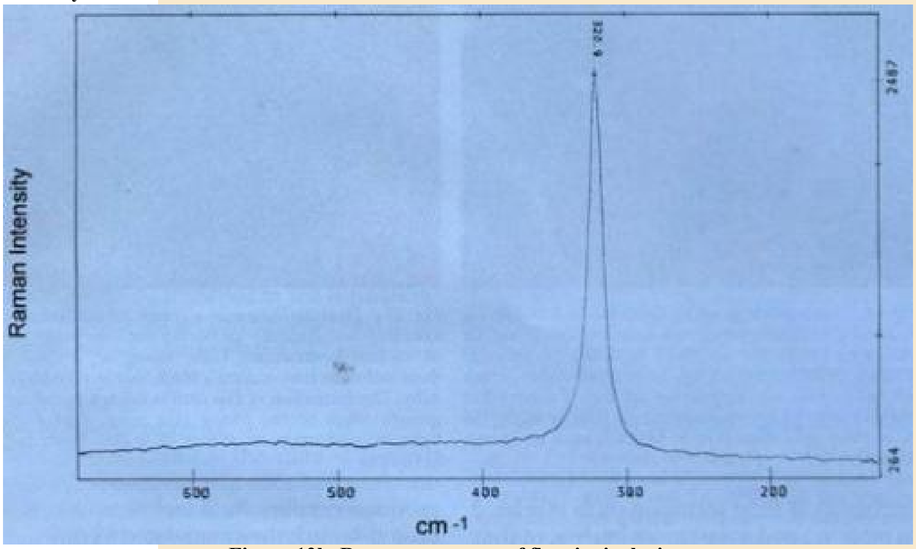

Figure 12b. Raman spectrum of fluorite inclusion

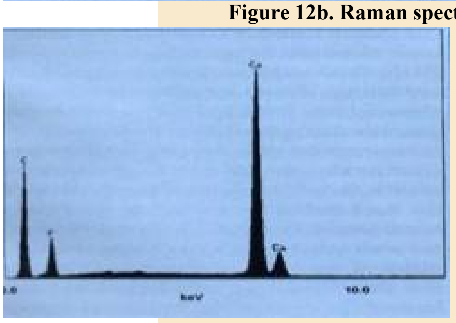

Figure 12c. Analysis of fluorite by energy-dispersive technique on an electron microscope

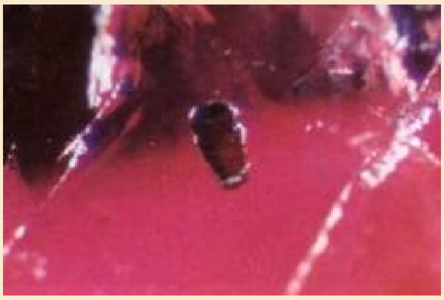

Figure 13. Microphotograph of a rutile inclusion in a non-heat-treated Mong Hsu ruby. Note that this rutile inclusion is localized in the red portion of the ruby

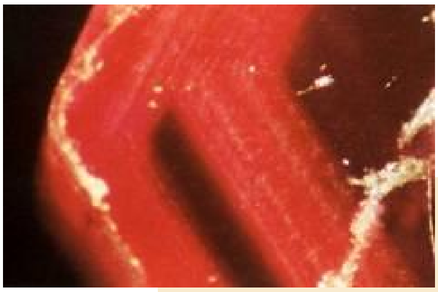

Figure 14. Microphotograph of a non-heat treated Mong Hsu ruby with alternating zones enriched in Ti and Cr (violet to black) and Cr (red). Note the presence of whitish reflecting inclusions in reddish zones which are most probably hydroxides such as diaspore but may possibly be hydrous silicates or fluorite. Reflected light. Fibre optic illumination. Magnification on 35mm slide 60´

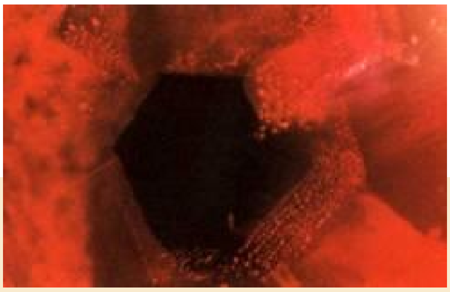

Figure 15. Healing fissure in a rough ruby from Mong Hsu (not-heat-treated) containing fluid inclusion trails of various generations. Note 'hexagonal outline' of fluid inclusions trail around a black core in a Mong Hsu ruby. The formation of this trail is related to the early growth stage of the Mong Hsu ruby. Transmitted light, magnification on 35mm slide 60´

Hlaing pictured Mong Hsu rubies occurring in a matrix of dolomite, with greenish minerals occurring in the contact zone. Our investigation indicates that these minerals are hydrous silicates which were formed with the ruby in veins within dolomite (Figure 5).

5 FLUID INCLUSIONS ANALYSES

Fluid inclusions are frequently present throughout a ruby, from core to rim. The formation of fluid inclusion trails is related to cracking and subsequent healing of the ruby by fluids during its growth. Figure 15 shows an early formed fluid inclusion trail, which is located in the first 'R' growth phase of the ruby. As a result of continued growth, the secondary fluid trails are completely contained within the ruby core denoted by a hexagonal outline. This type of secondary inclusion is called pseudosecondary as the inclusions represent fluids present during a particular stage of the ruby growth. Different populations of pseudosecondary fluid inclusions have been detected; they are related to different growth stages of rubies.

In the single isolated tube shown in Figure 16 there are three phases present at room temperature, including a CO_2-liquid, CO_2-rich multi-volatile vapor and one daughter minerals. The daughter mineral is most probably diaspore. This conclusion is based on the habit and intergrowth within corundum found in other samples which were identified by Raman spectroscopy. In all the fluid inclusion feathers studied, similar liquid/vapor ratios were found, showing that there had been a very homogeneous fluid population. Preliminary measurements on a freezing-heating stage were carried out, in order to obtain information about the chemical composition of the fluid inclusions. Forty-four fluid inclusions were investigated in four different pseudosecondary fluid inclusion trails of different ages. The heating runs showed that the volatile-rich fluid inclusions were homogenizing from the liquid and vapor to the liquid phase, between 24 and 31^{o}C (temperature of homogenization = Th).

Figure 16. Isolated fluid inclusions tubes in a secondary fluid inclusion feather of an untreated Mong Hsu ruby with a three phase inclusion (liquid, CO2-rich multivolatile vapor and diaspore). Transmitted light

Melting of CO_2 at –61^oC indicates possible contamination of CO_2 by CH_4, with one or more further components such as N_2 or H_2S, showing that the concentration of CO_2 is greater or equal to 85 mol.% of the volatile part. HF may also be present as a component of the volatile part.

Because of the presence and size of Al-hydroxides as daughter minerals in the fluid inclusions, it was furthermore concluded, that minor contents of H_2O, approximately 5-10 mol. %, were also originally present in the fluids. Thus, in summary, the fluids involved in the formation of Mong Hsu rubies can be described as water-bearing multi-volatile CO_2-rich fluids.

6 FORMATION CONDITIONS

The minerals found in the alluvial deposits with the rubies, namely andalusite, almandine, white mica and staurolite can provide sensitive information concerning the metamorphic conditions in the Mong Hsu region. For the purpose of estimating these formation conditions, the stability field of almandine, andalusite and staurolite was calculated in the system FeO-Al_2O_3-SiO_2-H_2O using a computer programme of Connolly. The mineral reactions that relate to the formation of almandine, staurolite and andalusite occur above 530^oC. The stability field of andalusite limits the possible pressures up to approximately 4.5 kbars. Different micas + quartz are stable assemblages under these P-T conditions. The temperature required for tremolite to form in CO_2-rich conditions within dolomite marbles confirms the above temperature estimations.

Further constraints on the formation conditions of the rubies are obtained from the fluid inclusion analyses. Form the homogenization temperatures of the fluid inclusions, an isochore (Figure 7) was calculated. Other minor components present in the fluids will not considerably alter the position of the isochore. The isochore defines a line in the P and T diagram (Figure 19) which indicates the possible pressures (P) and temperature (T) under which the fluid inclusions were formed. For the estimation of the actual P and T conditions, either P or T must be determined independently. At T between 500 and 550oC, the likely P can be calculated as 2-2.5 kbars.

7 TITANIUM MOBILITY

It has been shown by Peretti et al. that the violet to black zones in the rubies are due to high concentrations of titanium and chromium. Therefore, in determining how these color zones were formed, it is essential to know how these transition metals are transported in the fluid systems during ruby formation.

Hydrothermal fluids in the Earth's crust contain a number of complex-forming ligands (or molecules) which are important for the transportation of metals in fluid. Some of the most important are Cl^-, HO^-, HS^-, HCO_3^-, HSO_4^-, NH_3, F^-. Different metals tend to form ligands with different anions; Mn^{2+}, Fe^{2+}, V^{3+}, Cr^{3+}, Ti^{4+} for example, may preferably form ligands with F^-, Cl^- or OH^-. Variations in temperature and pressure in fluid systems are also important factors. With increasing temperatures and pressures, transition metals will tend to form associated neutral metal- lig- and-complexes rather than charged ionic species in the fluids. Variations in the formation conditions such as P, T or chemical composition of the fluids will influence the type of complexes and their concentrations in the fluids. Depending on the chemical system, the solubility of minerals in such fluids will be different and minerals may precipitate when formation conditions vary. In order to obtain detailed information on the speciation in the fluids, thermodynamic analyses are necessary. However, because of the range of minerals occurring in the system related to the rubies, such calculations would have to be carried out in the chemical system Si- Mg- Ca- Na- K- P- Al- Cr- Ti- V- Fe- B- C- O- H- F- N. With so many components this is very complex and there are not yet enough thermodynamic data to do this accurately. The elements Si to P are found in the inclusions, Al to Fe are found in the ruby, and B to N occur in the fluid system.

The presence of fluorite inclusions in the 'R' growth phase of the rubies shows that F was present in the Mong Hsu solutions. From the analyses of the fluid inclusions, it was deduced that water was present in the fluids. Because there are rutile inclusions in the rubies, the concentrations of Ti in the fluids can be discussed in terms of the solubility of rutile. It is known from experiments that rutile is highly soluble in H_2O-HF fluids due to the formation of Ti-hydroysluoride complexes such as $(Ti(OH)_{2+x}F_{2-X})$. Variations in the solubility of rutile occur with variation in P, T and HF-concentration in the fluids. In the T interval between 500 and 550^{o}C and at P of 2-2.5 kbar, which are the deduced conditions for formation of the Mong Hsu rubies, the solubility of rutile in H_2O-HF-fluids increases strongly with increasing T and HF-concentrations in the fluid with only minor changes caused by variations in P. At very high P up to 30 kbars, the critical factors controlling the solubility of rutile are different but such conditions did not occur in the Mong Hsu area. Other complexes in the system C-O-H-S-Cl-F may also be of importance but their presence cannot yet be proposed on the basis of our present analyses of the inclusions.

8 DISCUSSION

The most characteristic feature of the Mong Hsu rubies is their color zoning which is related to the trace contents of titanium along with small F-concentrations and chromium. The trace element concentrations in Mong Hsu rubies change in a rhythmic pattern during growth and many ruby samples have Ti-rich zones with increasing Cr-concentrations as shown in Figure 10. The pattern of chemical zoning in the Mong Hsu rubies typically shows a strong phase of Cr-depletion (‘I’ zone) followed by an increase in Cr and this is followed by increasingly higher concentrations of Ti (‘V’ zone). At a certain stage of the ruby growth, mostly when the level of Cr is high, the Ti-concentrations in the ruby abruptly change to zero (‘R’ zone). The abrupt change may occur twice in one crystal and is always correlated with a sharp color border between sapphire and ruby. The distinct chemical change (from sapphire to ruby) is accompanied by a crystal habit change. In the different color zones, some of the larger identifiable crystals were found to be fluorite and rutile and some of the submicroscopic minerals are hydrous.

The range of observations concerning inclusions and color zones are interpreted as due to oscillations in the chemical composition of the fluids present during ruby formation. Indication for such variation in the chemical composition of the fluids was also obtained from the analysis of dravite from Mong Hsu. This mineral is characterized by strong oscillations in both chromium and fluorine. Based on the correlations of these elements in the tourmalines, it is concluded that the fluids which were relatively enriched in chromium were also relatively enriched in fluorine. The importance of fluorine in the system is further confirmed by the high concentrations found in the green tremolite associated with the Mong Hsu ruby and dravite.

Fluid inclusions in the Mong Hsu rubies are water-bearing, CO_2-rich and contain CH_4 with possibly N_2, H_2S and HF. Fluorine is known to play a vital role in the complexing of titanium, particularly at the P and T likely during formation of the Mong Hsu rubies, forming complexes such as $(Ti(OH)_{2+x}F_{2-x})$. Thermodynamic studies of the solubility of rutile, at such P and T conditions have shown that concentrations of Ti in the fluids are strongly influenced by variations in temperature and F-content. Based on experimental data, the range of concentration of Ti in the Mong Hsu fluids could be controlled by oscillations in fluorine content or by variations in temperature. However, no evidence for abrupt changes in temperature has yet been found, but indications for variations in the fluorine content are found in other minerals. So it is very possible that F is the controlling factor in the variable concentrations of Ti in the Mong Hsu rubies.

The reason for such strong variations in fluid composition in the Mong Hsu area may be related to the infiltration of fluids from metapelites into dolomites. Fluids which are equilibrated with metapelites may be rich in certain elements such as B, C, H, O, S, N, P, F, Al, Mg, Si, Ca, Na and K, as well as Cr, V and Ti, depending on the degree of metamorphism, the rock type and type of complexing agent present in the fluids. If such external fluids come into contact with dolomites, the fluid will equilibrate with minerals present in the dolomites and hence dramatic changes in the fluids may be expected. It is evident from the data now available from the Mong Hsu area minerals that the chemical conditions of their growth, in particular the compositions of the fluids varied and changed relatively rapidly. Repeated oscillation of Cr and Ti in the rubies as shown in Figure 10 is probably the result of the multiple influx of fluorine-bearing fluids from the metapelitic rocks into the dolomites where they reacted to the different chemical environment by precipitating at various stages hydroxides, hydrous silicates, corundum, fluorite and rutile.

It is thus proposed that F concentration of the metasomatising fluids migrating into the host carbonate rock was a major factor in the development of the color zoning of the Mong Hsu rubies. According to our preliminary simplified mode, relatively high F- and OH-concentrations induced complexing of Ti as well as high Ti-concentrations in the fluids. From such fluids Ti ± Fe and Cr-ions were incorporated in the corundum structure (Ti-rich Cr-rich violet to black colored sapphire = 'V' growth phase). Decreasing F-concentrations, possible by precipitation of fluorite, induced decreasing Ti-concentrations in the fluids (no Ti-ion incorporation in the corundum structure, medium to high Cr-bearing red ruby = 'R' growth phase). A modification of this model may be presented when more detailed data on the primary deposits become available and thermodynamic modeling of complex systems becomes more advanced in the future.