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Inclusions in Rubies from South India

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ABSTRACT

Inclusions are the mineral phases which are in equilibrium with the gemstones that they occur in. Karur rubies exhibit crystal/solid inclusions such as rutile (in crystal and needle form), sapphirine, muscovite, margarite, biotite, apatite and zircon; two-phase inclusions and melt inclusions. Rubies from Madikeri show crystal/solid inclusions of rutile, graphite and zircon; melt inclusions and they also display twinning. Rubies from Channapatna show rutile (in crystal/ solid form) and diaspore inclusions. Channapatna rubies in addition to the above inclusions also exhibit hexagonal growth lines and color zoning, iron staining. Rubies from Karur and Channapatna show three sets of rutile needles exhibiting a six rayed stari.e. asterism. The inclusions in rubies from Channapatna, Madikeri and Karur were identified and confirmed using Laser-Raman spectroscopy.

The melt inclusions in Karur and Channapatna rubies indicate high temperature and pressure of formation. Triangular etch marks and the presence of secondary fluid inclusions point towards the action of metasomatic fluids. Inclusions of spinel, rutile, apatite and zircon are protogenetic. Rutile needles in rubies from Karur and Channapatna, indicate the phenomenon of exsolution.

Keywords: Rubies, inclusions, Laser Raman Spectroscopy.

I. INTRODUCTION

Rubies in India are found in all three geological settings, i.e. in igneous, sedimentary and metamorphic rocks. Rubies in Rajasthan are found to be hosted in gneisses. Those from Madhya Pradesh are hosted in gneisseses and schists. Rubies from Orissa are found as pebbles in river beds and in gneisses (Hughes, 2013). In Andhra Pradesh, rubies are found to be hosted in gneisses, granulites, pegmatites and anorthosites (Sangam et.al, 2013). Rubies in Karnataka are found to be hosted in pegmatites, crystalline limestones, anorthosites, gneisses, schists and granulites and also as pebbles dispersed in soil (Radhakrishna et.al, 1997). Rubies in Tamil Nadu are hosted in paragneisses, granulites and gneisses. Rubies in Kerala are found to be hosted in granulites and gneisses.

Solid inclusions in gemstones are the stable mineral phases which are in equilibrium with the gemstone. Solid inclusions may be of three types, namely, protogenetic, syngenetic and epigenetic. Protogenetic inclusions (preexisting inclusions) are formed before the formation of the host crystal, these inclusions are always minerals. Protogenetic inclusions have slightly rounded edges and lack sharp crystal faces (Kane et.al, 2005).Syngenetic inclusions (contemporaneous inclusions) are formed and 'imprisoned' in the host crystal when it was growing, these may be minerals or fluids (gases and liquids). Epigenetic inclusions (post growth

inclusions) are formed after the host has completedgrowing, anywhere from immediately to millionsof years later.

Inclusions in gemstones indicate how it is formed, its growth conditions and the place of origin. The geological conditions under which the gemstone was formed, can be deciphered from its internal paragenesis (mineral association). Certain inclusions indicate a specific magmatic environment and also where they are formed in the earth. Certain inclusions indicate a metamorphic environment of formation (Kane et.al, 2005).

Rubies from Channapatna exhibit protogenetic, syngenetic and epigenetic inclusions. They display solid/crystal inclusions, two phase inclusions, colour zoning, rhombohedral parting, twinning and iron staining.

Karur rubies also show all three types of inclusions, i.e. protogenetic, syngenetic and epigenetic. They show evidence of melt inclusions, two phase inclusions, solid/crystal inclusions, rhombohedral parting and reaction rim.

Protogenetic and epigenetic inclusions are seen in rubies from Madikeri. They display solid/crystal inclusions, rhombohedral parting, colour zoning and twinning.

The inclusions in the present study were confirmed by their characteristics under the petrological microscope and their host rock petrography, some others were confirmed by Laser Raman Spectroscopy.

II.GEOLOGY

South India is divided into the DharwarCraton, SinghbhumCraton, EasternGhat Mobile Belt, Cuddapah Basin, Palghat – Kaveri Shear Zone and the Southern Granulite terrain (Meert et.al, 2010) (fig 2). The ruby specimen in the present study were collected from Channapatna in the Eastern DharwarCraton(EDC), Madikeri in the Western DharwarCraton (WDC) and Karur in the Southern Granulite Terrain (SGT).

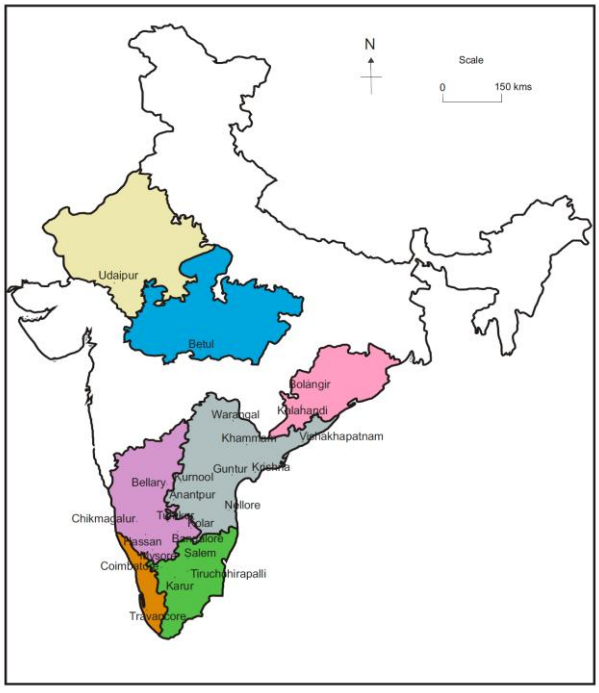

Fig 1: Locations where rubies are mined in India

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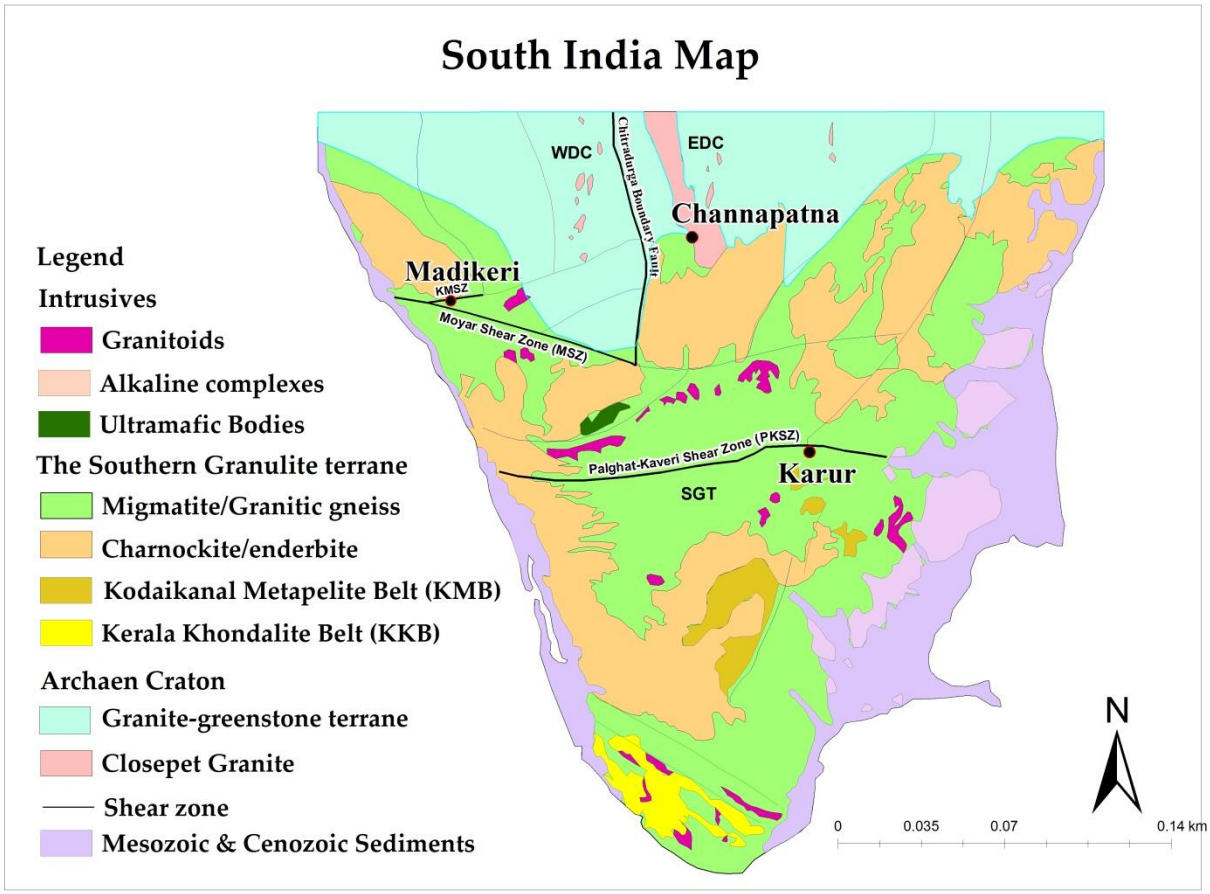

Fig 2: Geological Map of South India

Karur

The rocks of this region have undergone granulite facies metamorphism.

The ruby bearing rocks are ofmetamorphic origin, belong to the Sathyamangalam Group, and are amphibolites, paragneisses and granulites.Sapphirine is also seen as an associated mineral, in the host rock. The hornblende schist shows an assemblage of plagioclase, biotite, hornblende. The cordierite schist shows an assemblage of biotite, cordierite and plagioclase. The other rock exposed is a kyanite schist with an assemblage of kyanite, cordierite and muscovite.The biotite-cordierite-corundum schist shows that the rock has undergone retrograde metamorphism, since the biotite has pleochroic haloes.

Madikeri

The town of Madikeri (Mercara) is located in the Kodagu district of Karnataka state.Madikeri is located on the Western Ghats.

According to Chetty et al (2012), Madikeri lies on the Kasaragod – Mercara Shear Zone (KMSZ). The rocks of this region are Archaean – Proterozoic in age and lie in the WDC. They belong to the Peninsular Gneissic Complex. These rocks exhibit amphibolite to granulite facies metamorphism. The ruby bearing rocks of this

region are all metamorphic and are pyroxene granulites, fuchsite schists, hornblende gneisses and amphibolites. The corundum granulite shows granoblastic texture and minerals like corundum, biotite, muscovite, zircon, rutile and cordierite.The kyanite schist shows blastoporphyritic texture. The rock shows an assemblage of kyanite, muscovite and cordierite.

Channapatna

Channapatna village is on the Bengaluru-Mysuru highway and is accessible by railways also. MCBL passes through Channapatna. Channapatna lies in the EDC. Rubies are found dispersed in red lateritic soil. They are not hosted in any rock, the inclusions in these rubies will help in deciphering the host rock. The Closepet granite exposure is found near Channapatna.

The rocks in Karur are silica deficient, have a high alumina content, have a low iron oxide content and high chromium oxide content and they exhibit the ideal conditions for the formation of the rubies from Karur.The high chromium content in these rocks is due to the presence of fuchsite mica and the low iron content is because cordierite (which is an associated mineral) is formed. The high chromium oxide and the low iron oxide content give the rubies from Karur its blood red colour.

Materials and Methods

The rubies were made into thin sections and then studied under the petrological microscope. Some of the inclusions were identified under the petrological microscope with the help of their form, relief and host rock mineralogy. A few of them were confirmed by Laser Raman Spectroscopy.

Instrumentation

1) The petrological microscope used in this study was of the following specifications: Make- Nikon, Model- Eclipse E200 Pol, Binocular Polarizing Microscope for transmitted light application, using power supply of 220V-240V. The petrological microscope had a camera attachment of the following specifications: Make – Nikon, Model- Digital Sight DS-Fi1, requiring power supply of 12V-18V.

2) Laser Raman Spectroscopy was carried out on the rubies from two places.

a) From IIT Powai Mumbai. The specifications of the instrument were: Make-Thermonicolet, Model-Almega WD Raman, using a 532 nm Argon green laser.

b) From Gemmological Institute of India, Mumbai. The specifications of the instrument were Make-Renishaw, Model- Invia Raman, using 785 nm and 532 nm laser, exposure time 10 secs per sample, magnification 20x, the instrument is peltier cooled, at room temperature, no. of scans- single CCD detector.

Inclusions

Karur

The rubies in Karur are found to be hosted in Metamorphic rocks like amphibolite, hornblende gneiss, hornblende schist and granulite. Karur rubies, have solid inclusions of sapphirine (fig 3), zircon (fig 4, 5, 6 and 7), apatite (fig 8 and 9), green biotite (fig 10, 11), muscovite (fig 12), spinel (fig 13) and rutile (fig 14 and 15).

They also exhibit melt inclusions (fig 16). Other features like lace doilies (fig 17), negative crystals (fig 18), liquid filled tubes (fig 19) are also seen. Some of these rubies exhibit a reaction rim of spinel+sapphirine +cordierite, which is isotropic between crossed polars (fig 21) and blue-green under the microscope (fig 20). Rhombohedral parting (fig 22 and 23) and iron staining (fig 24) is also seen in these rubies. These inclusions were identified under the petrological microscope.

The sapphirine inclusion in ruby is protogenetic, anhedral and blue in colour, and it indicates that the host rock has been metamorphosed and recrystallized (Lin Sutherland et al, 1996). The zircon inclusions are protogenetic, euhedral showing distinct pinacoidal, prismatic and pyramidal faces. One of the zircon inclusion is twinned and the other zircon shows haloes. Presence of zircon indicates that the protolith was of sedimentary origin. Apatite is also protogenetic and subhedral with high relief, presence of this mineral indicates that the protolith was sedimentary. Occurrence of subhedral, syngenetic green biotite as an inclusion indicates that the rock has undergone retrograde metamorphism. Muscovite is syngenetic, subhedral and a metamorphic mineral. Spinel, which is euhedral i.e. octahedral, protogenetic also indicates that the rock has undergone metamorphism. The ubiquitous solid rutile, is protogenetic, brown and anhedral and it crystallizes before ruby in metamorphic environment (Gubelin et al, 2008). The melt inclusion (Bodnar et al, 2006) indicates that the rock has undergone granulite facies metamorphism. The lace doilies are secondary inclusions, and is the reticulated pattern of a liquid filled feather (Gubelin, 2008). These lace doilies are syngenetic.In some of the localities the ruby was surrounded by a reaction rim of sapphirine+spinel+cordierite (Santosh et al, 2006) which was blue under the microscope and isotropic between crossed nicols. This reaction rim is formed due to the partial metamorphism of the host rock. Rhombohedral parting is also seen. Iron staining is also seen in these rubies, which is formed due to the leaching of iron rich fluids, after the formation of the ruby.

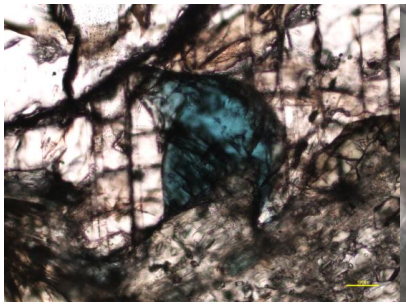

Fig 3:Syngenetic Blue Sapphirine inclusion

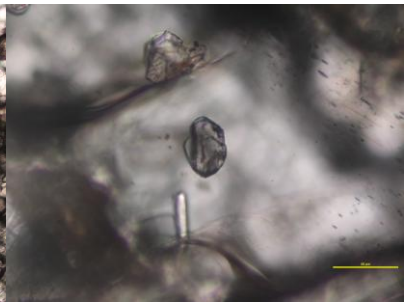

Fig 4: Twinned zircon inclusion

Fig 5: Protogenetic zircon inclusion

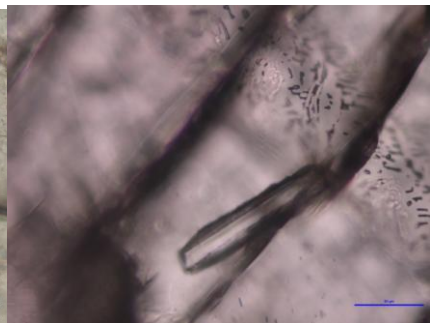

Fig 6: Prismatic zircon inclusion

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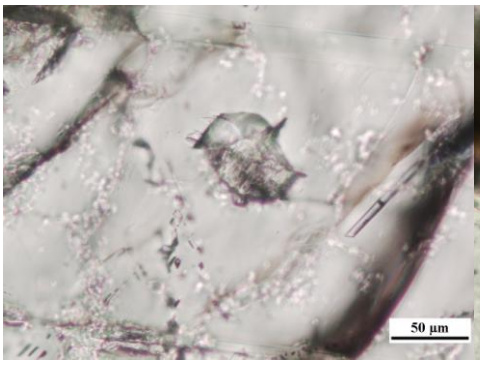

Fig 7: Protogenetic zircon inclusion

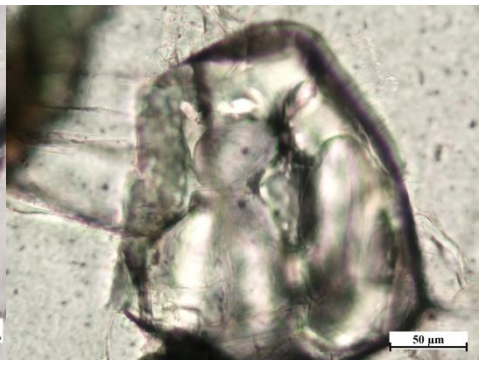

Fig 8: Protogenetic apatite inclusion

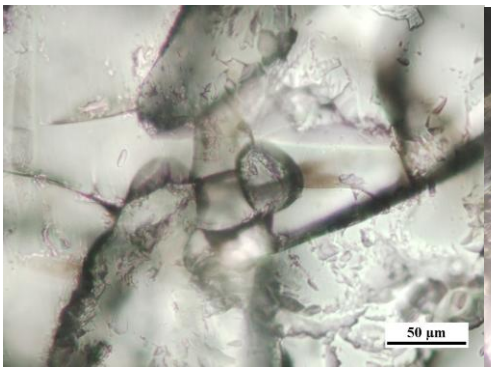

Fig 9: Protogenetic apatite at the center

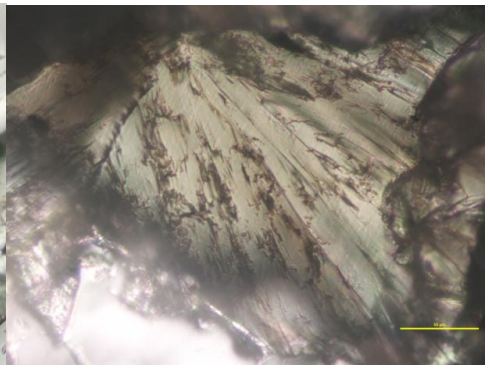

Fig 10: Syngenetic green biotite

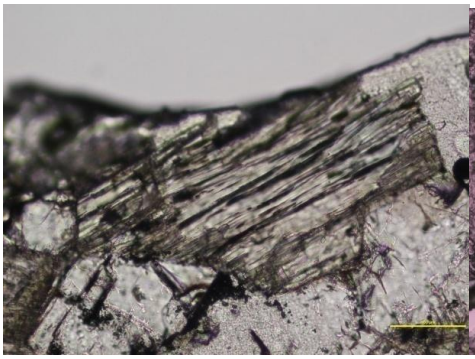

Fig 11: Syngeneticbiotite inclusion

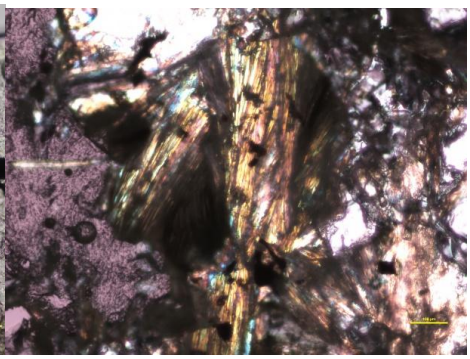

Fig 12: Syngenetic muscovite inclusion

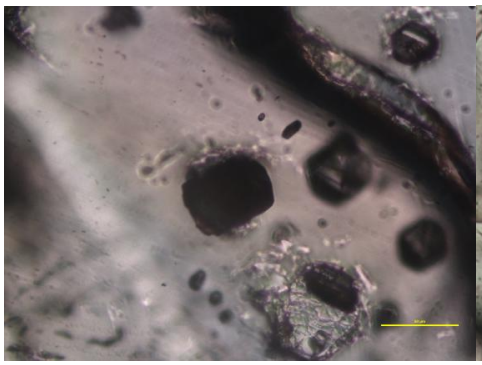

Fig 13: Octahedral protogenetic spinel

Fig 14: Protogenetic rutile

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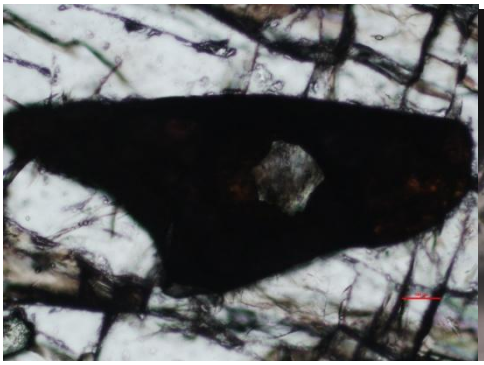

Fig 15: Protogenetic rutile

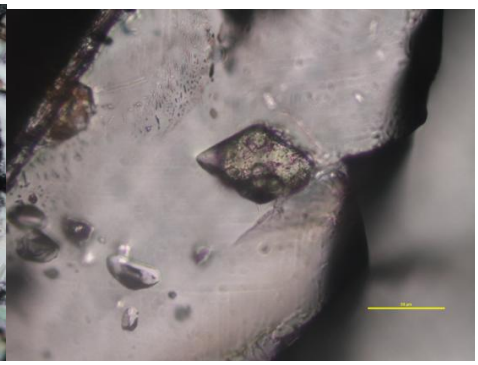

Fig 16: Melt inclusion

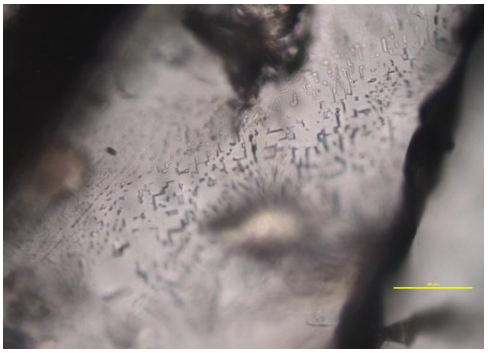

Fig 17: Lace doilies

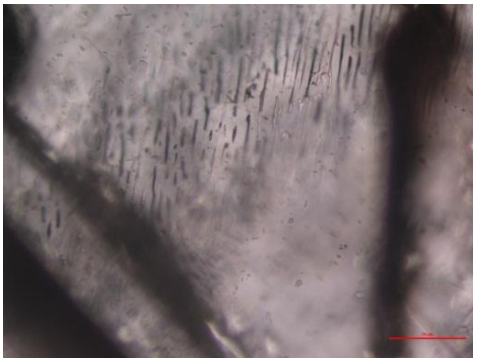

Fig 18: Negative crystals

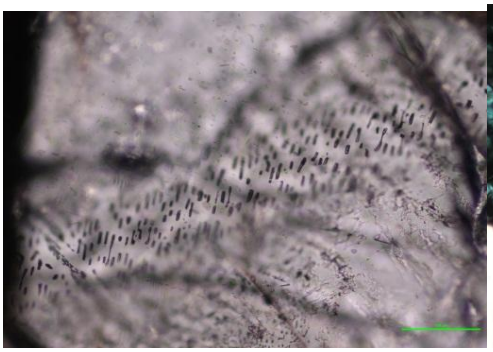

Fig 19: Liquid filled tubes in a feather

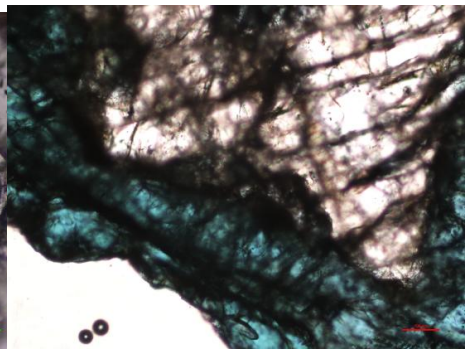

Fig 20: Ruby with blue reaction rim

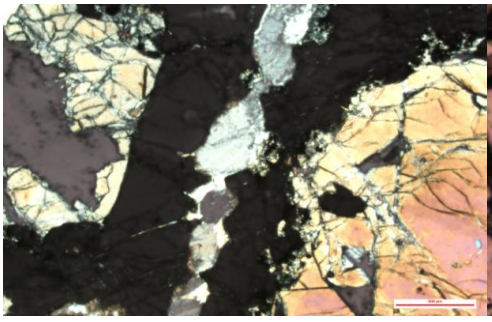

Fig 21: Isotropic reaction rim

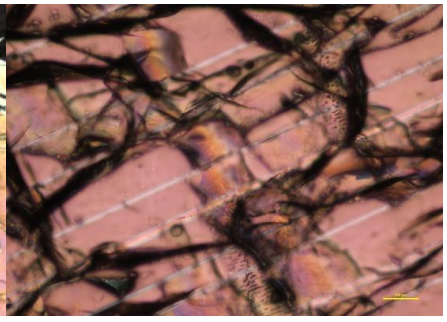

Fig 22: Ruby with rhombohedral parting

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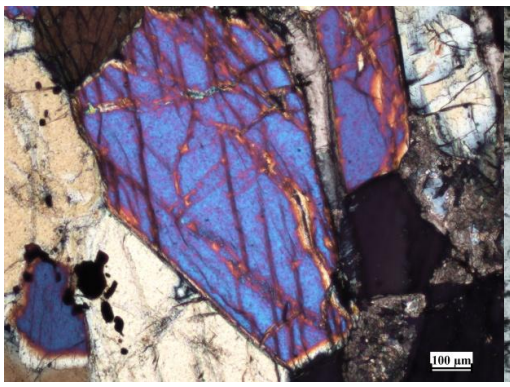


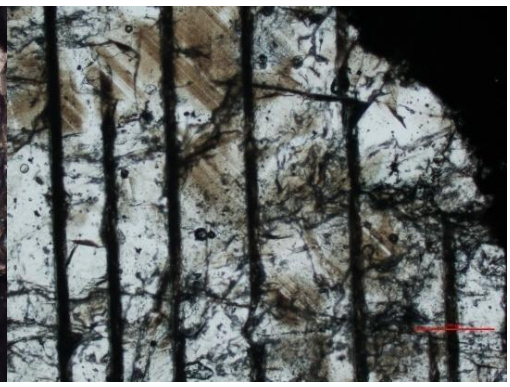
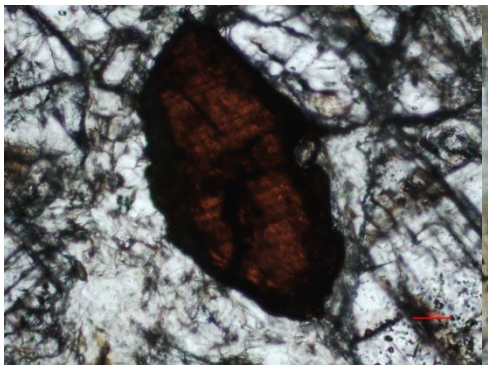


Fig 23: Ruby with rhombohedral parting **Fig 24: Ruby with iron staining**

Madikeri

Rubies from Madikeri are found in Metamorphic rocks like fuchsite-corundum schists, hornblende gneisses and granulites. They exhibit solid rutile (fig 25 and 28), zircon (fig 26 and 28), apatite (fig 28) and ruby inclusions (fig 29). These rubies also display twinning (fig 30).

The rutile inclusion is protogenetic/ syngenetic, subhedral and red brown in colour, and similar to the solid rutile inclusions in Madagascar (Andilamena and Ilakaka) rubies (Gubelin, 2008).These zircons are prismatic, euhedral and colourless to pale yellow in colour. Apatite inclusions show high relief, anhedral form, colourless and protogenetic. Ruby inclusion in ruby, is protogenetic, with hexagonal cross-section, euhedral showing partings. Ruby in host rock, showing twinning at the centre of the photo no.30.. .



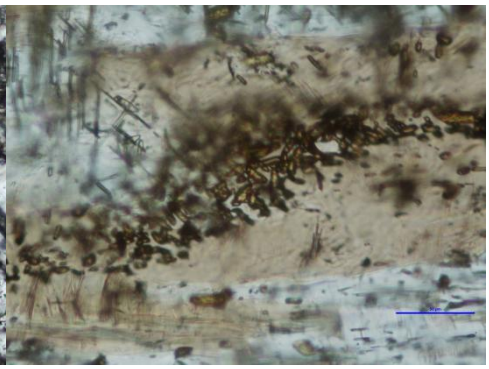
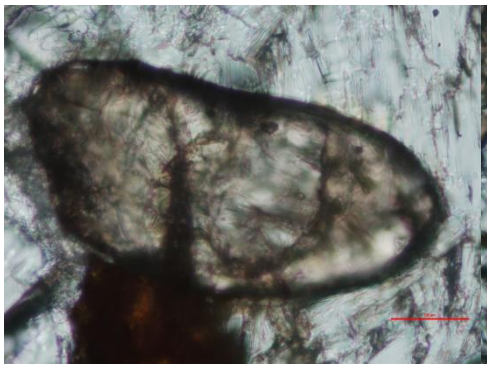


Fig 25: Proto/ syngenetic rutile inclusion **Fig 26: Trail of protogenetic zircons**



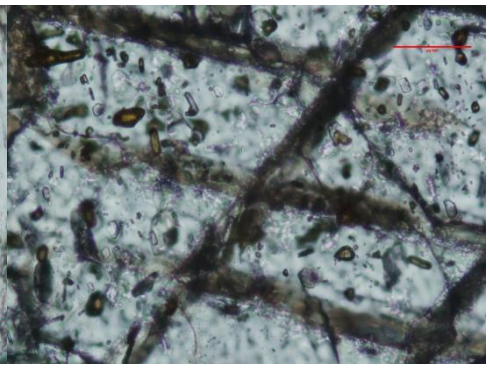


Fig 27: Protogeneticapatite **Fig 28: Zircon and rutile inclusions**

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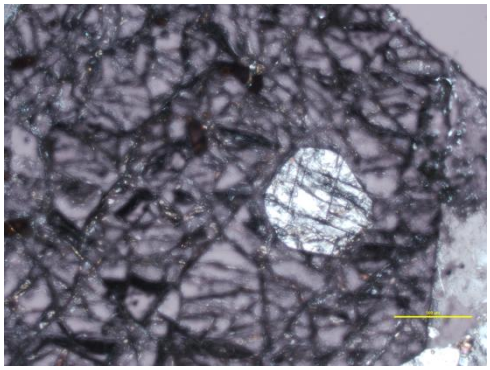

Fig 29: Ruby within ruby

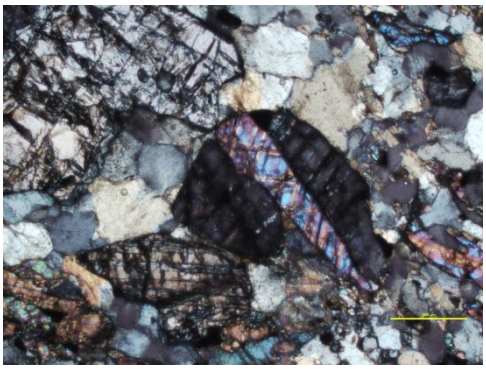

Fig 30: Ruby showing twinning

Channapatna

Rubies from Channapatna are found dispersed in soil, there is no host rock. These rubies show negative crystals (fig 31) and iron staining (fig 32). These rubies also show rutile needles (fig 33) and two phase inclusions (fig 34 and 35). The solid inclusions displayed by these rubies are of monazite (fig 36) and biotite (fig 37).

The negative crystal inclusion is filled with some fluid, from its appearance and the surrounding mineral remnants, the inclusion was of mica before forming a negative crystal. It is epigenetic. The iron staining in displayed by these rubies, may be due to the fact that, they are found dispersed in lateritic soil. The rutile needles exhibited by these rubies are epigenetic and are exsolved after the ruby is formed. Due to these rutile needles arranged in three directions, the rubies display a six rayed star, a phenomenon called asterism. Two phase fluid inclusions are a part of a liquid filled feather and are secondary inclusions. Monazite inclusions are brownish with corroded crystals and rounded contours. These are also found in rubies from Songea, Tanzania (Gubelin, 2008). Biotite is subhedral, brown, with cleavage. Presence of syngenetic mica as an inclusion gives a hint that an intrusion of acidic rock (in this case, granite i.e. Closepet granite) intervened with the gem's formation in its metamorphic parent rock. Rubies from Ambosary, Madagascar also have similar mica inclusions (Gubelin, 2008).

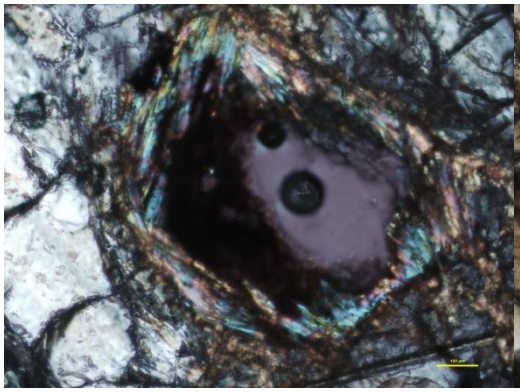

Fig 31: Negative crystal

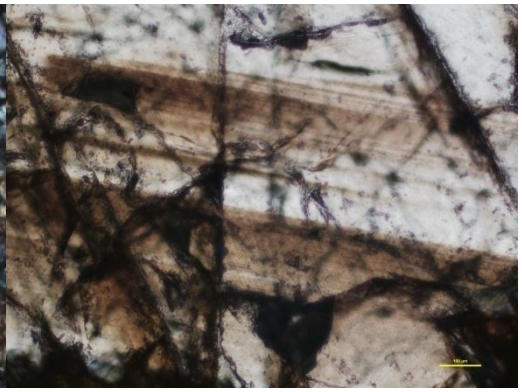

Fig 32: Iron staining

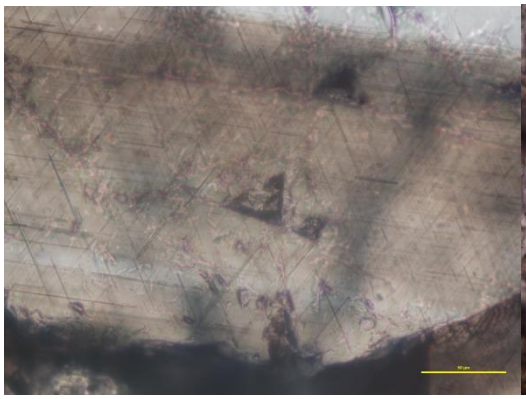

Fig 33:Epigeneticrutile needles in ruby

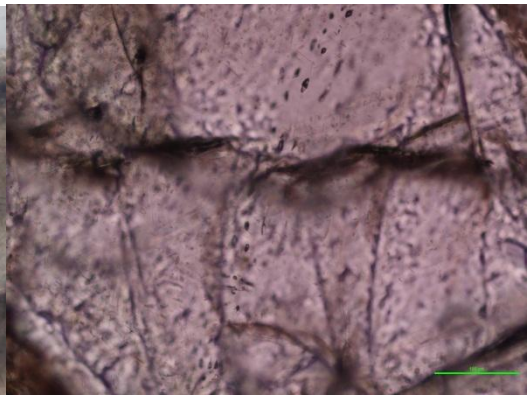

Fig 34: Two phase inclusions

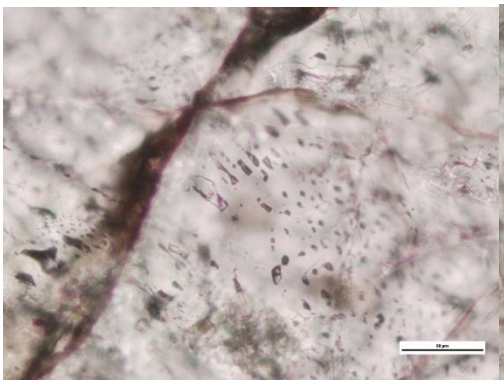

Fig 35: Two phase inclusions

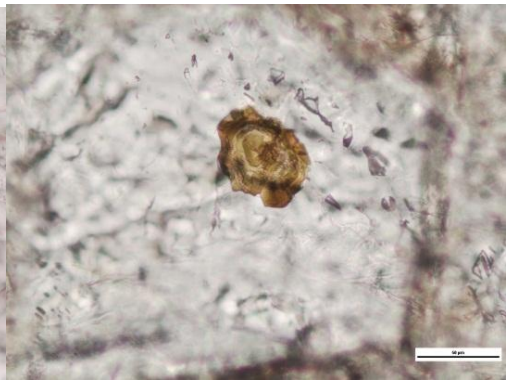

Fig 36: Monazite inclusion

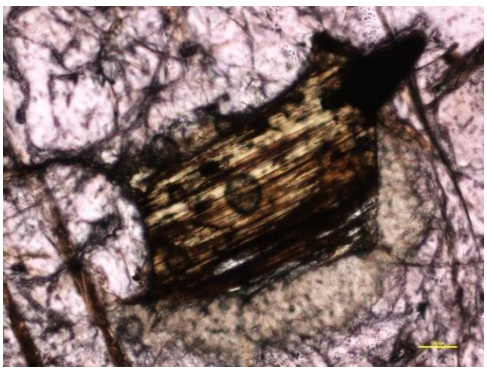

Fig 37: Syngeneticbiotite inclusion

c) Laser Raman Spectroscopy (LRS) – Laser Raman Spectroscopy was done on the inclusions in the rubies from all the three areas.

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Inclusions in rubies from Channapatna

i) Rutile Inclusion (fig 38)

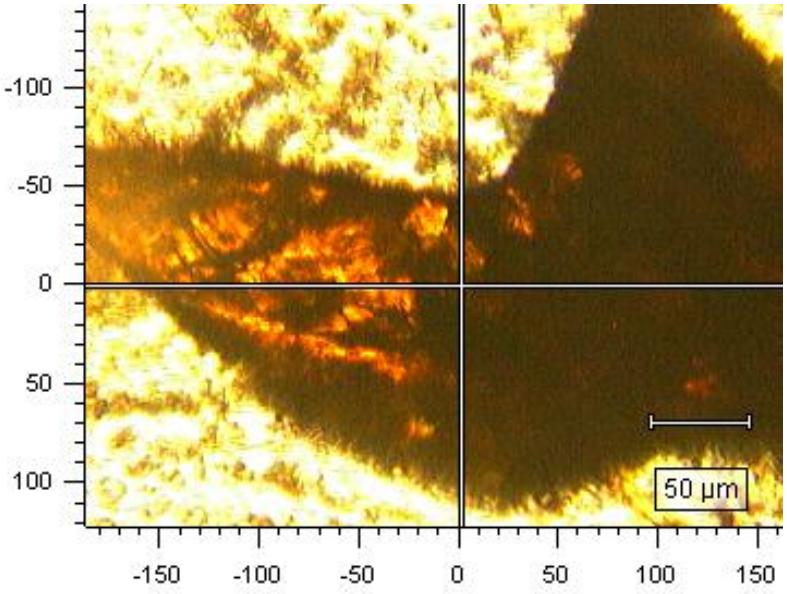
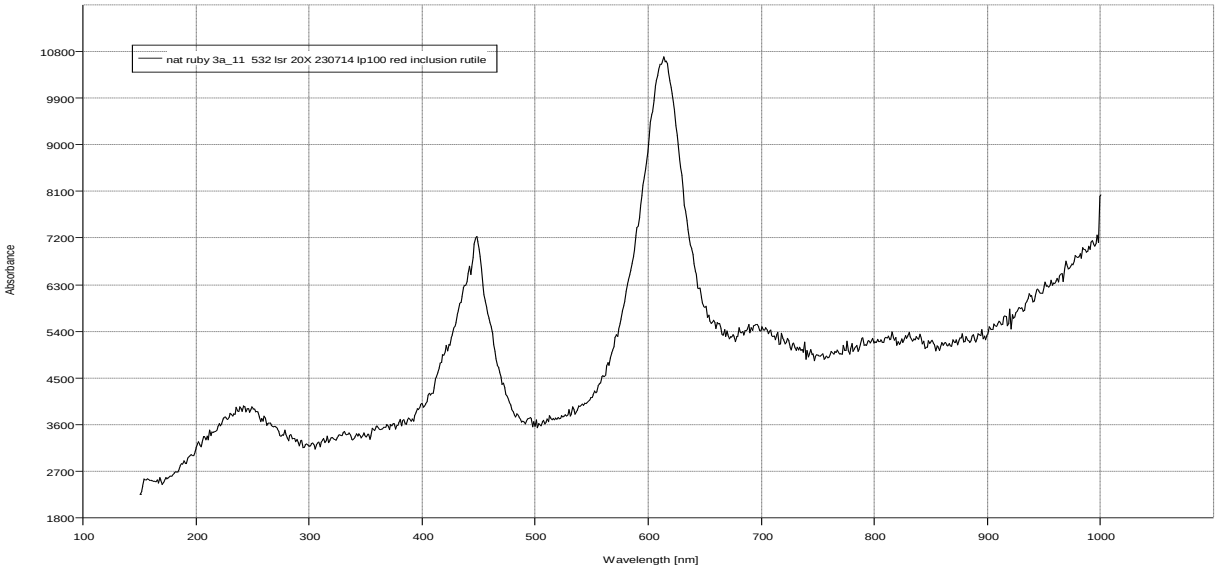


Fig 38: Rutile inclusion



Graph 1: Graph showing peaks for rutile inclusion

Peak values for the rutile inclusion (graph 1) in Channapatna ruby

Spectrum: nat ruby 3a_11 532lsr 20X 230714 lp100 red inclusion rutile

The intensity of the laser used was 532 with laser power of 100

ii) Diaspore inclusion

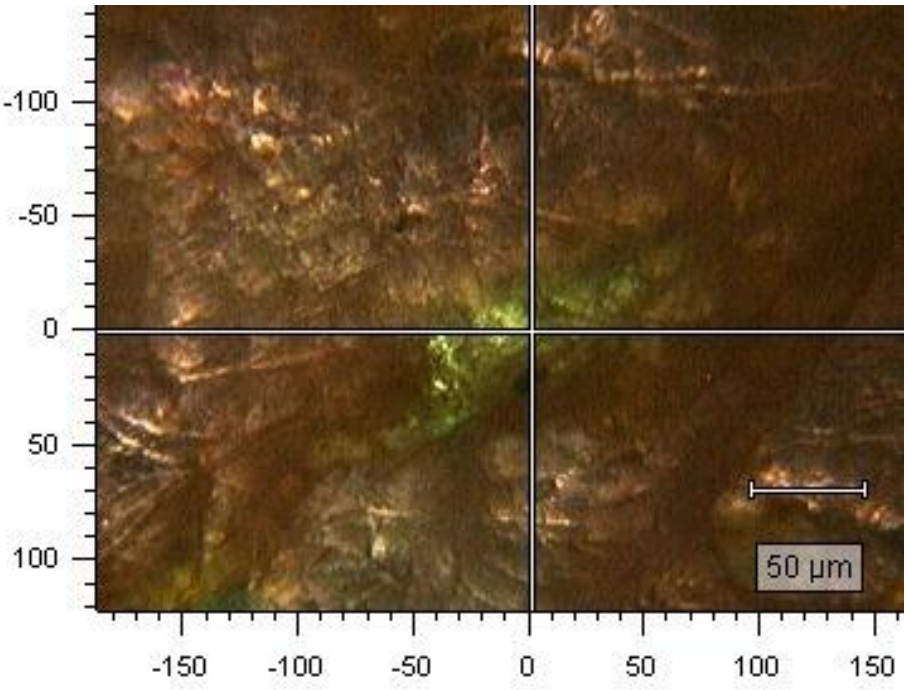
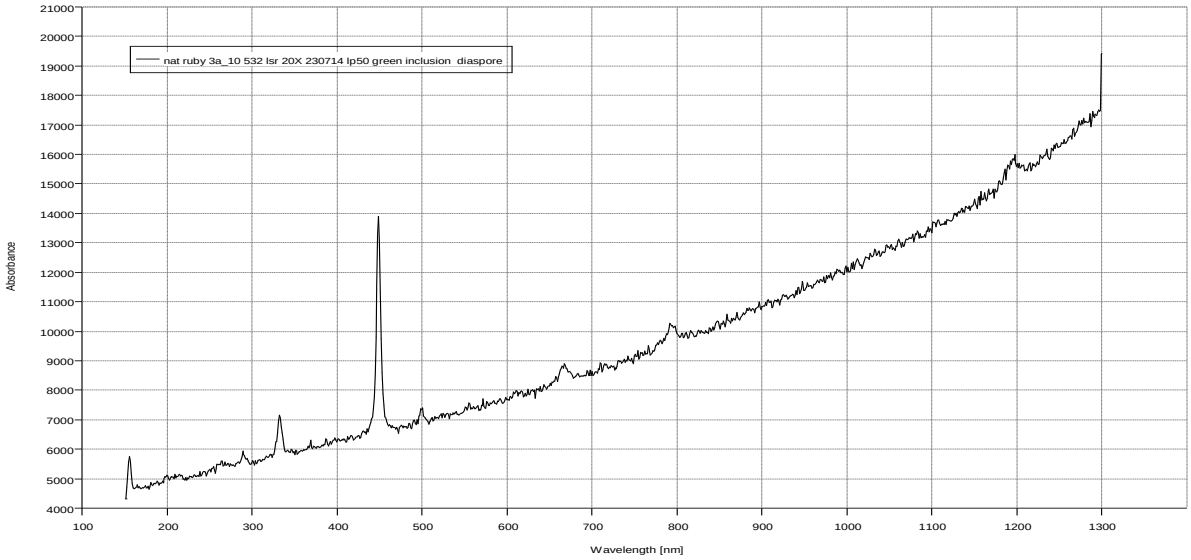


Fig 39: Diaspore inclusion



Graph 2: Graph showing peaks of diaspore inclusion

Peak values for the diaspore inclusion (graph 2) in Channapatna ruby. Presence of diaspore (fig 39) indicates that the metamorphic rock has undergone retrogression.

Spectrum: nat ruby 3a_10 532 lsr 20X 230714 lp50 green inclusion diaspore

The intensity of the laser used was 532 and the laser power was 50.

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Inclusions in rubies from Madikeri

i) Graphite inclusion

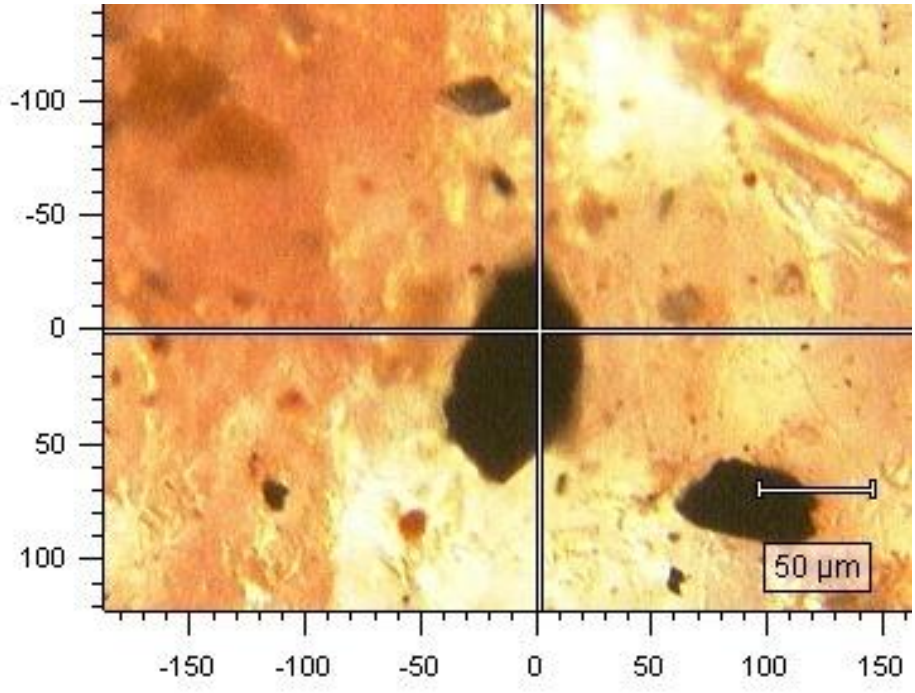
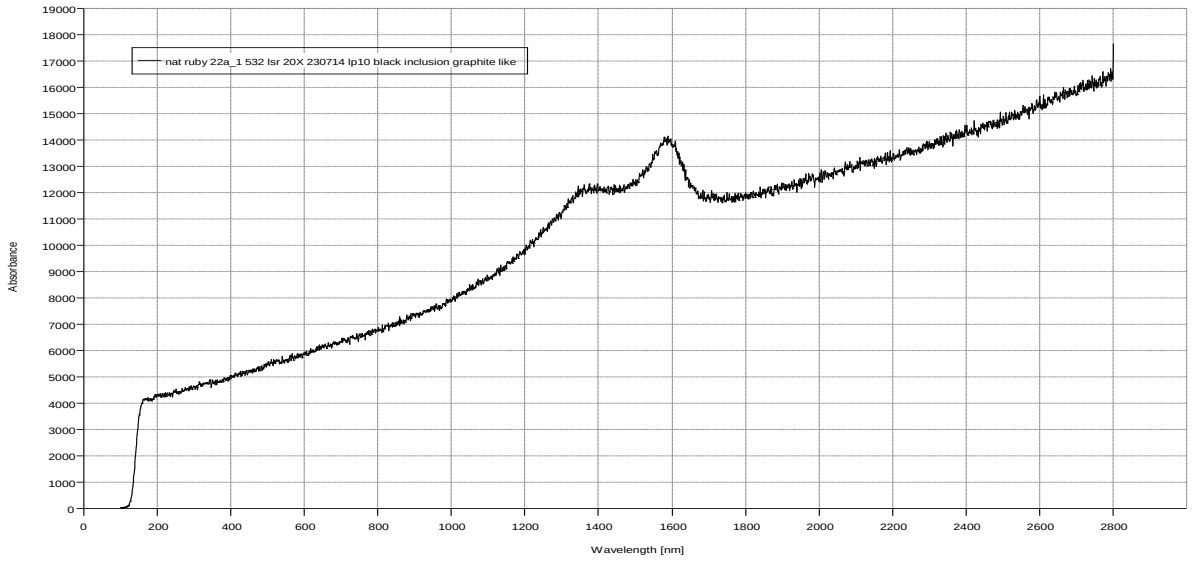


Fig 40: Graphite inclusion



Graph 3: Graph showing peaks of graphite inclusion

Peak values for the graphite inclusion (graph 3) in Madikeri ruby. Presence of graphite (fig 40) as an inclusion indicates origin in metamorphic rocks (Gubelin, 2008).

Spectrum: nat ruby 22a_1 532 lsr 20X 230714 lp10 black inclusion graphite like

The intensity of the laser used was 532 and the laser power was 10.

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ii) Rutile inclusion (fig 41)

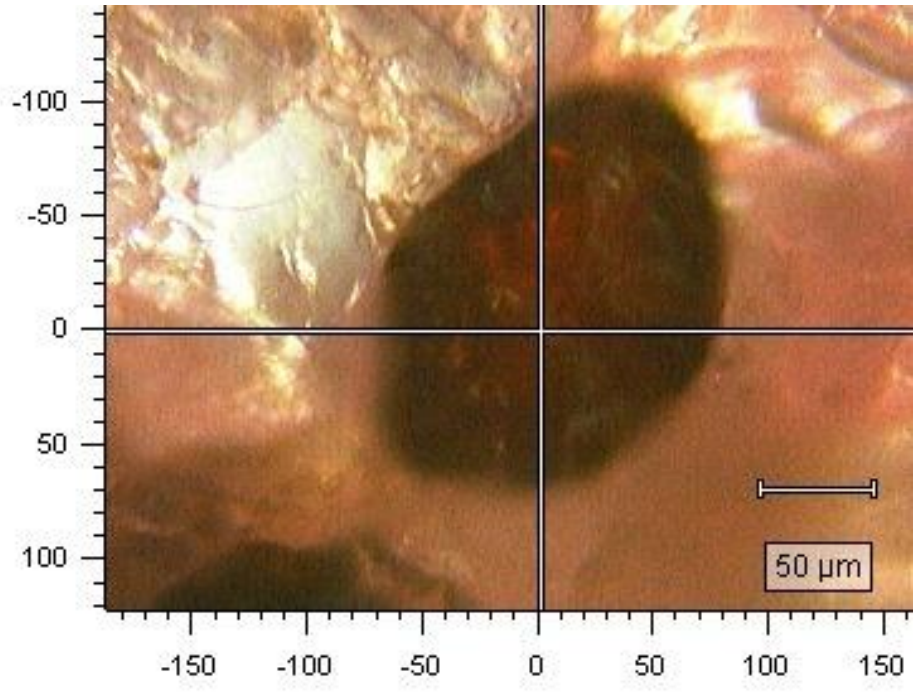
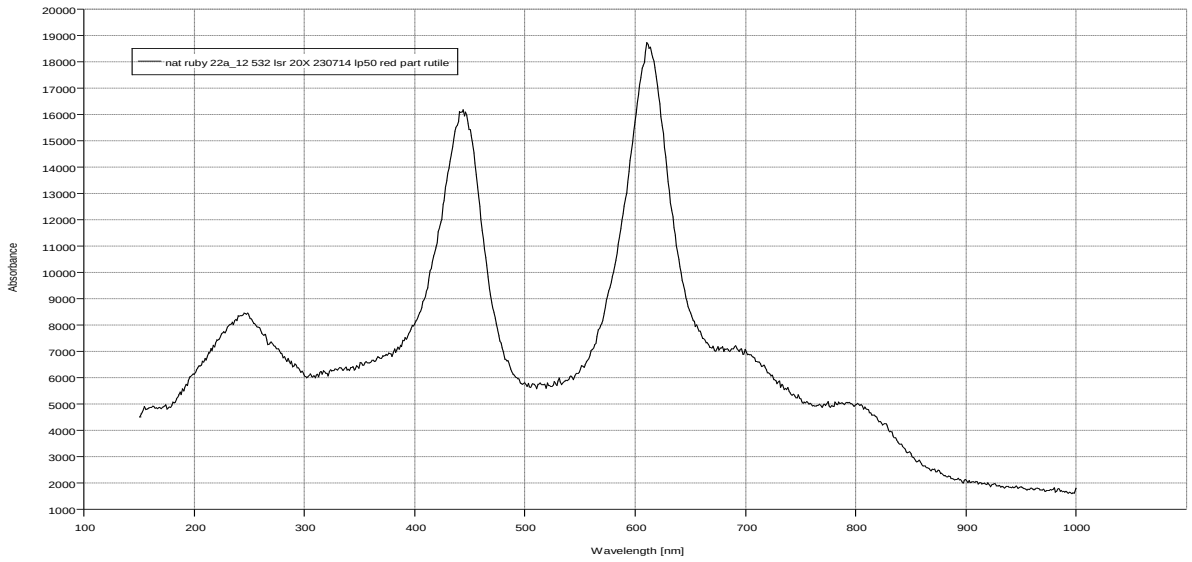


Fig 41: Rutile inclusion



Graph 4:Graph showing peaks of rutile inclusion

Peak values for the rutile inclusion (graph 4) in Madikeri ruby

Spectrum: nat ruby 22a_12 532 lsr 20X 230714 lp50 red part rutile

The intensity of the laser used was 532 and the laser power was 50.

Inclusions in ruby from Karur

i) Sapphirine inclusion

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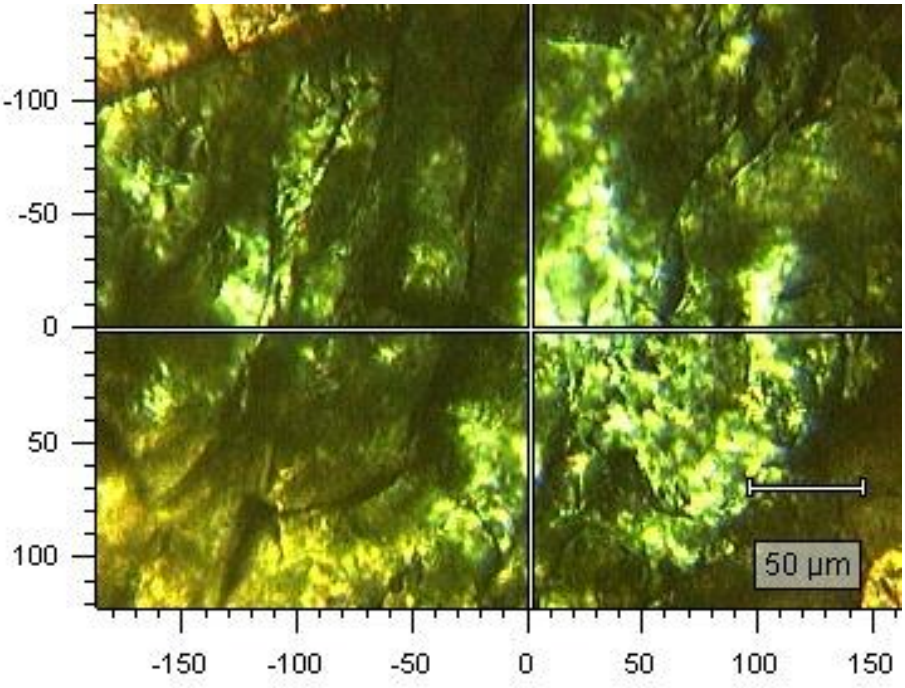
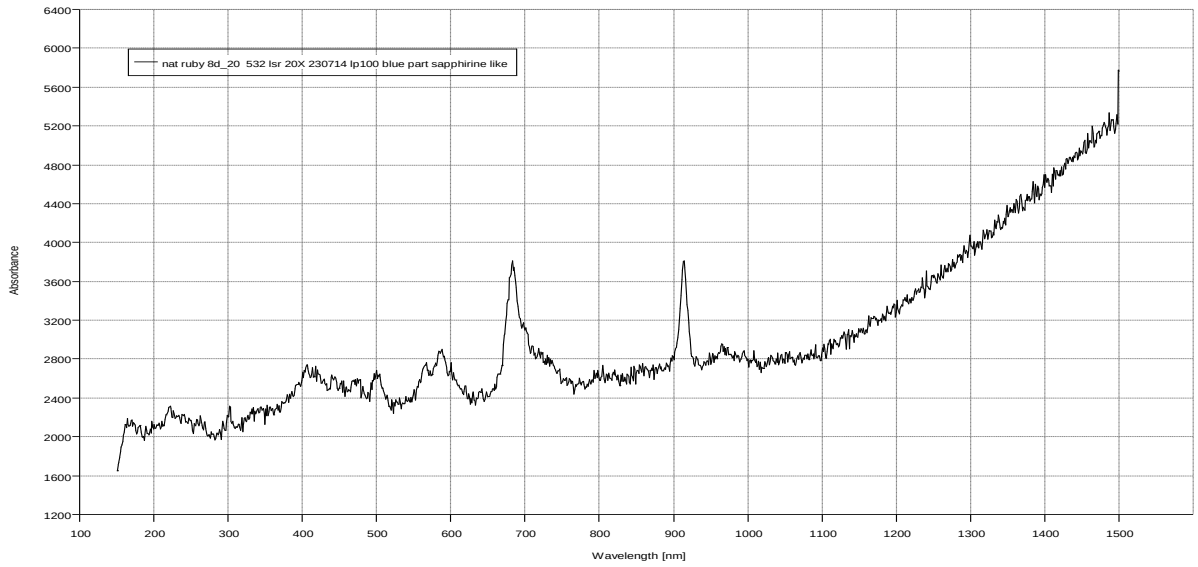


Fig 42: Sapphirine inclusion



Graph 5: Graph showing peaks of sapphirine inclusion

Peak values for the sapphirine inclusion (graph 5) in Karur ruby. Presence of sapphirine (fig 42) as an inclusion indicates a metamorphic parent rock (Gubelin, 2008).

Spectrum: nat ruby 8d_20 532lsr 20X 230714 lp100 blue part sapphirine like

The intensity of the laser used was 532 and the laser power was 100.

ii) Muscovite inclusion

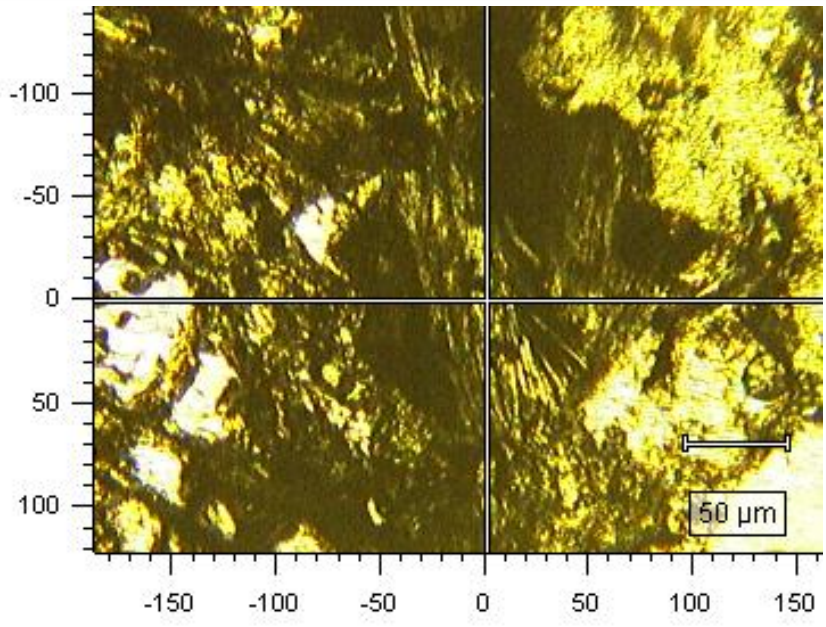
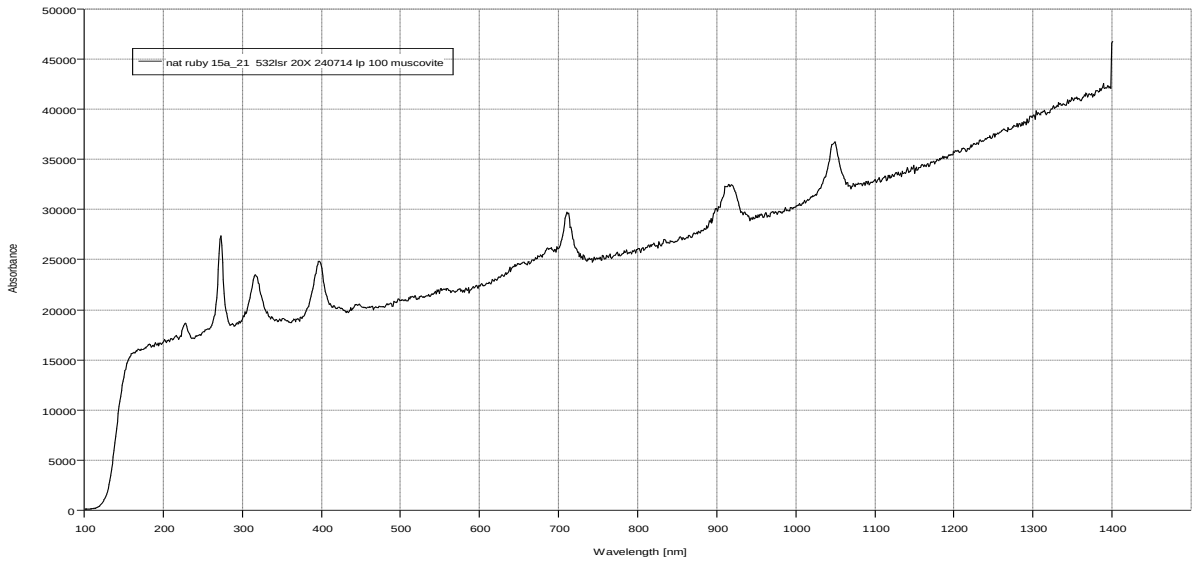


Fig 43: Muscovite inclusion



Graph 6: Peaks of muscovite inclusion in ruby

Peak values for the muscovite inclusion (graph 6) in Karur ruby. Muscovite (fig 43) is indicative of metamorphic parent rock.

Spectrum: nat ruby 15a_21 532lsr 20X 240714 lp 100 muscovite

The intensity of the laser used is 532 and the laser power is 100.

iii) Margarite mica inclusion

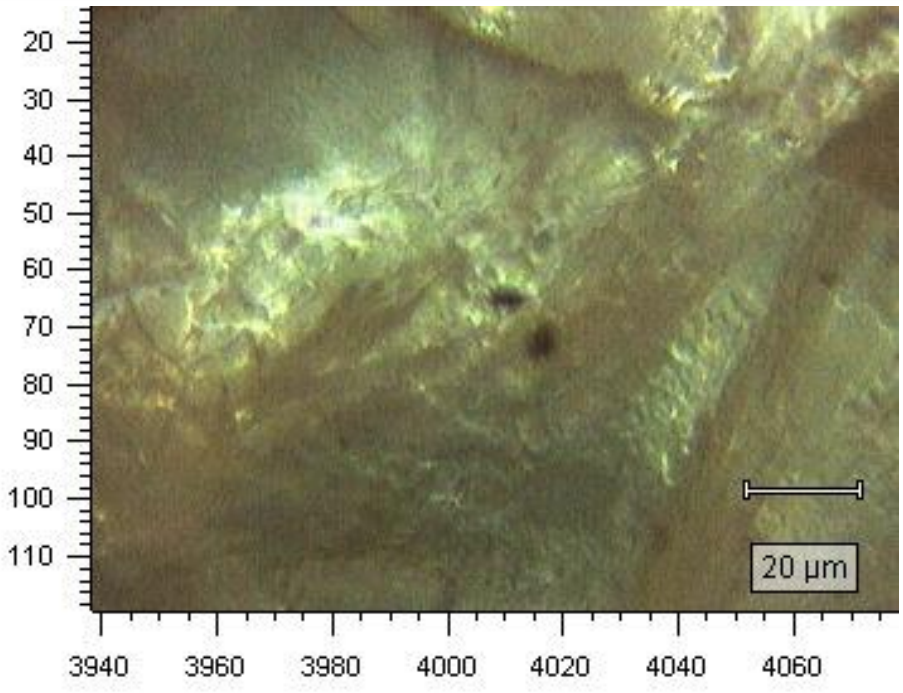
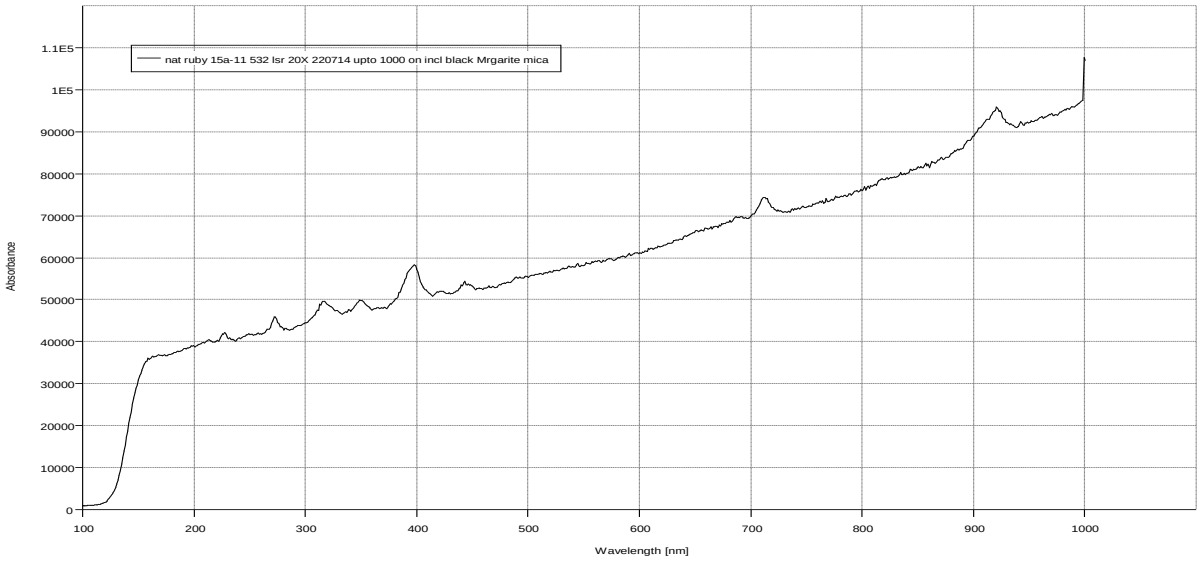


Fig 44: Margarite mica inclusion



Graph 7: Graph of peaks of margarite mica in Karur ruby

Peak values for the margarite mica inclusion (graph 7) in Karur ruby. Presence of margarite mica inclusion (fig 44) indicates that the metamorphic parent rock has undergone retrogression (Gubelin, 2008).

Spectrum: nat ruby 15a-11 532 lsr 20X 220714 upto 1000 on incl black Margarite mica

The intensity of the laser used was 532 and the laser power was 1000.

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iii) Biotite inclusion (fig 45)

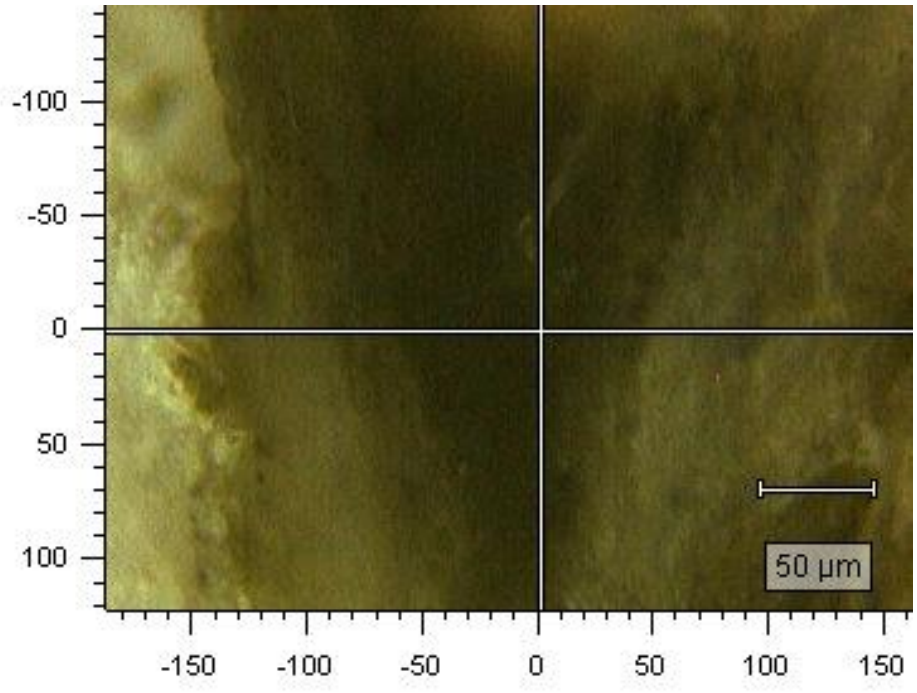
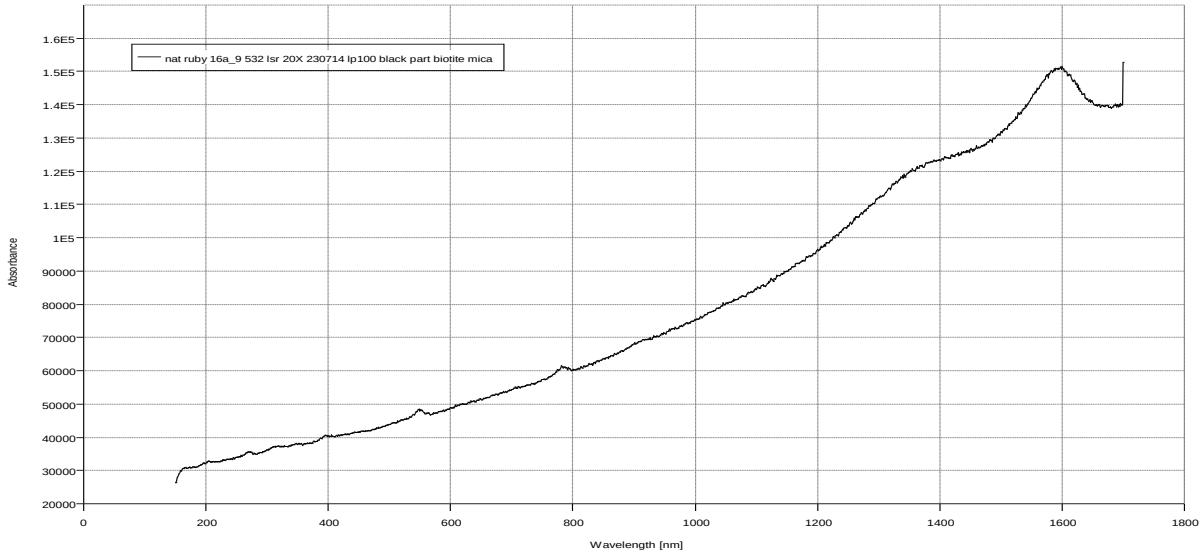


Fig 45: Biotite inclusion



Graph 8: Graph showing peaks of biotite

Peak values for the biotite inclusion (graph 8) in Karur ruby.

Spectrum: nat ruby 16a_9 532 lsr 20X 230714 lp100 black part biotite mica

The intensity of the laser used was 532 and the laser power was 100.

iv) Apatite inclusion (fig 46)

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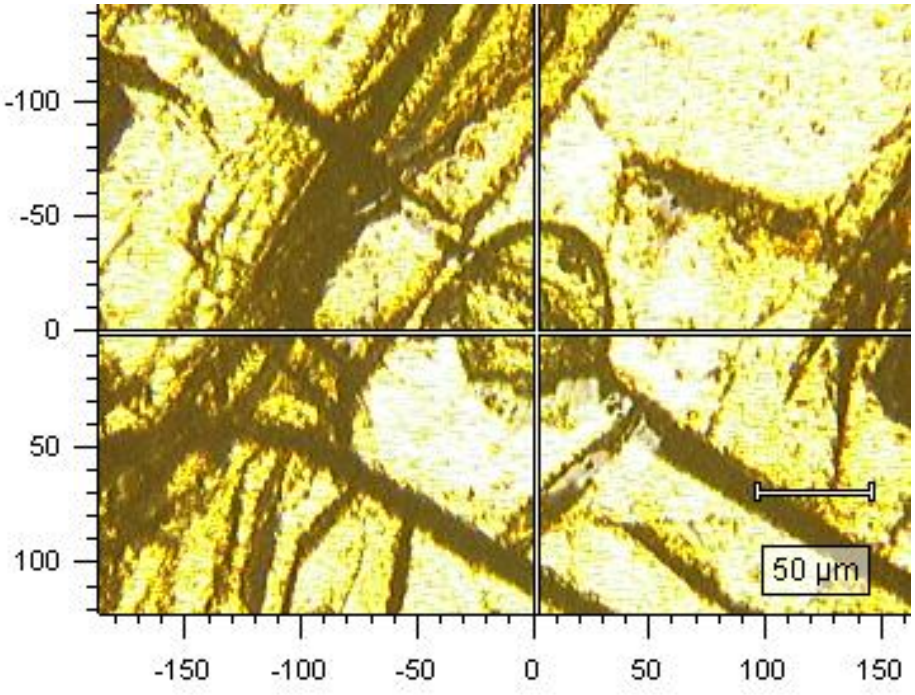
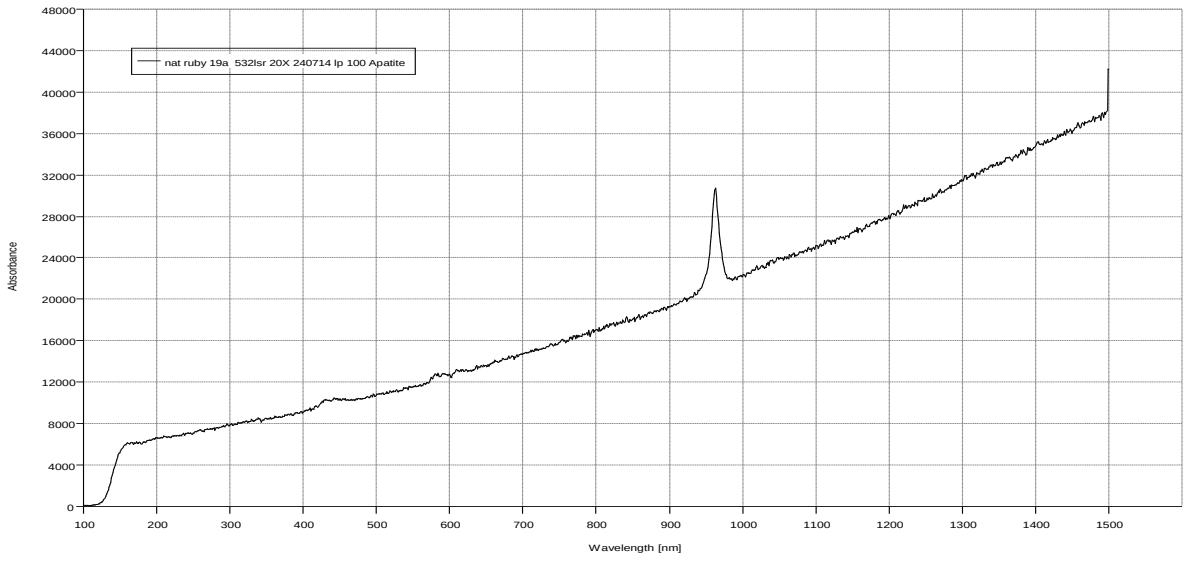


Fig 46: Apatite inclusion



Graph 9: Graph showing peaks of apatite in Karur ruby

Peak values for the apatite inclusion (graph 9) in Karur ruby

Spectrum: nat ruby 19a 532lsr 20X 240714 lp 100 Apatite

The intensity of the laser used was 532 and the laser power was 100.

v) Rutile inclusion (fig 47)

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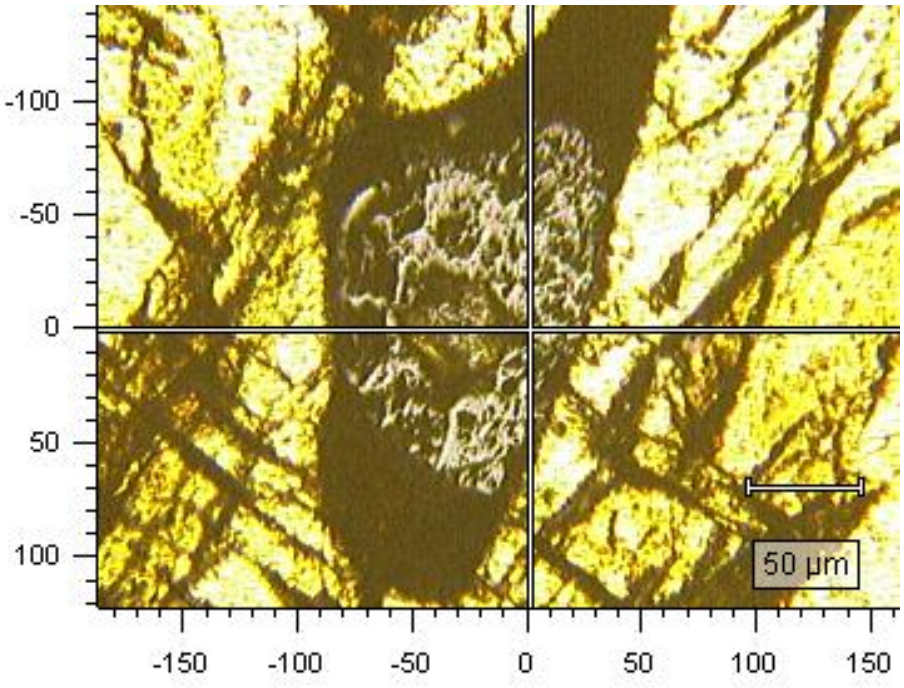
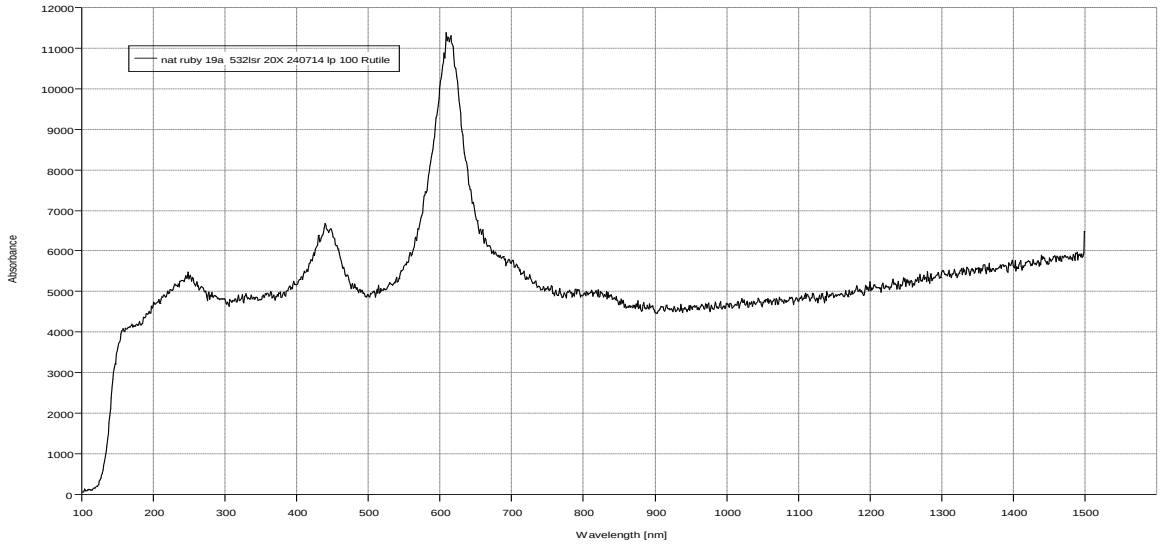


Fig 47: Rutile inclusion



Graph 10: Graph showing peaks of rutile in Karur ruby

Peak values for the rutile inclusion (graph 10) in Karur ruby

Spectrum: nat ruby 19a 532lsr 20X 240714 lp 100 Rutile

The intensity of the laser used was 532 and the laser power was 100.

DISCUSSION AND CONCLUSION

There is a possibility that Karur rubies may have a sedimentary protolith (zircon and apatite inclusions from the sedimentary rocks) and have been metamorphosed and recrystallized. The parent rock of Karur rubies has undergone granulite facies metamorphism and retrograde metamorphism. During the metamorphism fluids were present and the ruby reacted with the parent rock. Thai and Cambodian rubies show similar characteristics.

Madikeri rubies also may have a sedimentary protolith (zircon and apatite inclusions from the sedimentary rocks) and are found in metamorphic rocks. These rubies show inclusions similar to Madagascar and Tanzanian rubies.

Channapatna rubies are found in metamorphic rocks intruded by acidic granite. The parent rock has undergone retrograde metamorphism. These are similar to Tanzanian and Madagascar rubies.

Similarity of rubies from India and Madagascar and Tanzania and also Thailand and Cambodia is an evidence of the continental drift theory and plate tectonics. The continents drifted apart, but since the rubies were from the same environment, they show similar inclusions. All these inclusions are reported for the first time in these rubies.

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