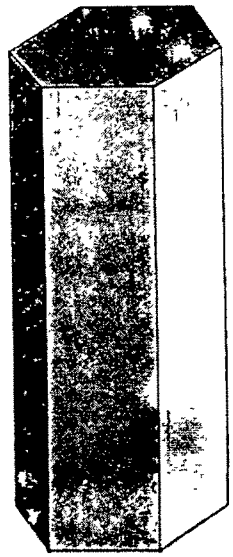

Chapter -1

Introduction

1 - INTRODUCTION

Of nearly 3000 minerals that occur in nature, *beryl* is one of the highly esteemed minerals, because of its beauty and economic utility. A mineral is defined as *a naturally occurring homogenous solid with a definite (but generally not fixed) chemical composition and a highly ordered atomic arrangement. It is usually formed by inorganic processes.* If beryl corresponds to precisely in composition to its chemical formula, $Be_3Al_2Si_6O_{18}$, it would be clear and colourless. Notwithstanding, the nature is benevolent enough to add certain "impurities" in right proportion to transform otherwise uncoloured beryl species to vividly tinted varieties that are sought after by connoisseurs for several millennia The rich velvety green emerald (*Plate 1.1*), delicate and soothing sky blue aquamarine (*Plate 1.2*), dazzling red bixbite and other coveted varieties (*Plates 1.3 & 1.4*) of beryl owe their colour to impurities present in solid solution. Not just the presence of impurity elements matters for colouring, their position in the crystal structure, interaction with neighbouring ions and many other factors play and important role.

The eyes, however, are satisfied with what the rays in visible range interact with beryl. Many other components of the electromagnetic spectrum disclose that beryl as an intriguing mineral for investigation.

Spectroscopic methods in recent times have advanced to a great height, enabling various type of studies for characterising minerals. These studies divulge enormous information such as, the oxidation of ions, their interaction with the surrounding ion, probable site and its symmetry, presence of hydrous species, molecular ions and inorganic radicals.

Plate 1.1 :Emerald from Columbia (from Gems and Crystal, by Anna S. Sofianides and George Harlow)

Plate 1.2 : Aquamarine enclosed by albite (from Gems and Crystal, by Anna S. Sofianides and George Harlow)

Plate 1.3 : Heliodor (from Gems and Crystal, by Anna S. Sofianides and George Harlow)

Plate 1.4 : Green beryl (from Orissa Mining Corporation)

1.1 BERYL AND ITS VARIETIES

The mineral species of *beryl* is classified into several varieties based on its colour : dull opaque, bottle green - *industrial beryl* (non gem quality used for the extraction of beryllium), goshenite (colourless), heliodor (yellow), aquamarine (sky blue), morganite (rose - pink), bixbite (red), green beryl (greened only by iron), emerald (greened by chromium/vanadium).

By and large, beryl is classified into two groups, (i) pegmatite type and (ii) schist type (Beus, 1965; Sinkankas and Read, 1985). Emeralds belong to the latter type while all other beryls occur mainly in granitic pegmatites. Beryllium rich hydrothermal emanations are responsible for the formation of beryls. Largely the metasomatism of these emanations in metabasic chromium bearing schistose rocks produce emeralds.

Of all the varieties, emerald is the most attractive, highly praised and priced variety by connoisseur and common man alike, because of its enchanting velvety green colour unparalled by any other green coloured mineral. Colour of emerald is on account of chromium and sometimes vanadium impurity. Beryl can also be green due to iron impurity. These are not called emerald, but just "green beryl".

Next to emerald it is the *aquamarine* which is a highly favoured beryl in the gem trade Although greenish blue colour or colour of sea water due to which it obtained the name was sought after in earlier days; the sky blue coloured aquamarine is highly esteemed in modern times. The greenish blue colour of aquamarine can be "enhanced" to a more favoured sky blue by "controlled heating". It has been found that colour of many uncoloured, greenish yellow and yellow beryls can also be converted to blue by various enhancement techniques *as aquamarine having blue shade has great demand especially in European market*

Morganite is a rare variety of beryl and bixbite is even rarer - found in only one locality in the world (in rhyollites of Wah Wah Mountains, Utah, USA).

Colour is one of the fascinating aspects of beryl to be studied. Various causes of colour in minerals have been identified for the last four decades. Cause of colour in beryl varieties is of several types. The branch of *Gem Enhancement* has gained importance for the last four decades in which beryl (*Plate 1.5*) is one of extensively worked out gem species (Nassau, 1994).

Mineralogically apart from colour, beryl has many other aspects that are interesting for investigation such as morphology, growth features, its unique 'honey comb' internal structure, and its ability to accommodate various impurities and volatile species. Beryl forms an important mineral to study behavioural characteristics of trapped molecules.

These aspects have been discussed in detail in the present thesis by the author.

1.2 WORLD OCCURRENCE

Beryl is not an uncommon mineral. Its varieties occur in many parts of the world. Brazil, Madagascar and Russia are three of the important countries known for the occurrence of beryl, mainly found in granitic pegmatites. Giant crystals weighing several tons are known to occur in pegmatites.

Of all the emeralds, those from Columbia are considered as the best. They occur in black shales at Chivor and Muzo regions separated by 80 - 100km. These emeralds are deep green in colour and larger stones fetch over one lakh per carat. Brazil produces five times higher amount of emerald that Columbia, nonetheless, as far as quality is concerned these emeralds are inferior. In Russia and Zambia - Zimbabwe (former Rhodesia) emerald occurs in tremolite - actinolite schist . Algeria, Tanzania and South Africa, Australia and

Plate 1.5 : Cut and polished beryls (from Gems and Crystal, by Anna S. Sofianides and George Harlow)

Habatchal in Alps are also known for emerald. In Asia emerald is found in Afghanistan, Pakistan and India.

Beryls of other colour are widely distributed in Brazil (Minas Gerais and gravels of Cascallo), Urals and south central Siberia in Russia, Madagascar, Tanzania, Nigeria, Egypt, Namibia, Zimbabwe, USA, Canada, Afghanistan, Pakistan, China, Sri Lanka and India.

1.3 INDIAN OCCURRENCE

Emerald occurs in small quantity at several places in the Aravalli Mountain range. Ajmer and Kaliguman are two of the important localities (Iyer, 1961). Recently emerald crystals have been reported from grantites-schist contact at Sankari Taluk, Salem district, Tamil Nadu (Panjikar, 1995). There are recent reports of emeralds from Gghuchapali - Antaria in Bolangir district (Mishra and Mohanty, 1995).

Blue aquamarine is rather plentiful in pegmatites of Karur - Kangayam region of Tiruchurapalli district, Tamil Nadu Many places in Salem district are also known for aquamarine. In Karnataka, aquamarine were recovered from Melukote in Hassan district in earlier days (Iyer 1961). Greenish blue aquamarine has been reported form Ooruttamalam and Uzhamalakkal (UNDP report, 1983). Industrial beryls are found in mica mines of Gudur - Nellore in Andhra Pradesh and Hazaribagh and Monghyr ditricts of Bihar. The famous Sunjam sapphire mines (33°25' : 76°25') in Kashmir has yielded several fine crystals of aquamarine along with the world famous sapphires. Goshenite and aquamarine have been recovered at a few places in Aravalli region in Rajasthan (Iyer, 1961).

Aquamarine, heliodor, yellowish - green, bluish - green beryl and goshenite have been reported from several places in Orissa (Mishra and Mohanty, 1995). They occur in

the zoned pegmatites of Charbhati - Beldihi, Bagdhapa - Tabloi and Meghpal - Ranchipa in Sambalpur district, Badmal - Mursundi in Sabarnapur district, Gulchepali - Antaria in Bolangir district; and in the Mahanadi gravels.

In Orissa beryl occurs in zoned pegmatite intruded into Khondalites. The pegmatites are mainly distributed in the districts of Sambalpur, Sabarnapur and Bolangir. Badmal in Sabarnapur district happens to be the central place for the occurrence of beryl bearing pegmatites. Therefore, beryls mined from the surrounding areas are broadly named after Badmal. As many as 200 pegmatites have been traced in Badmal pegmatite zone, many of which contain beryl (Mr. B.P. Mishra, Dy Director, DMG, Bhubaneshwar, personal comm.). Mining from primary source is carried out at a few places in Badmal (*Plates 1.6a & b*). Most of the crystals, however, are collected illegally by the tribals from colluvial and alluvial zones (*Plates 1.7 a & b; 1.8*).

1.4 BERYL SAMPLES UNDER STUDY

The author has concentrated his studies mainly on colourless, blue, blue green, green and yellow beryls from Orissa (*Figure 1.1*). For a comparison he has also taken samples; (i) blue aquamarine from Karur, Tamil Nadu; (ii) greenish blue aquamarine from Melankode (Kerala), (iii) blue - green from Hazirbagh, Bihar, (iv) yellow beryl from Siberia and (v) Brazilian beryls.

For his studies, the author has procured the samples from, (i) gem quality Orissan samples: local tribals and gem merchants from Bhubaneshwar (Mr. R. K. Singh) and Jaipur (M/s Lunawat Gem Corporation), (ii) Karur samples from gem merchants from Kaurur, (iii) Melankode from Dr. M. Santosh, Trivandrum, (iv) Hazaribagh, Bihar from Mr. R.C. Mishra, Patna, (v) Siberian beryl from Prof. P. Musteikis, Vilinus university, Lithuania and

Plate 1.6a : Beryl from primary source at Bagdhapa

Plate 1.6b : Highly weathered pegmatite from Badmal

Plate 1.7a : Sample being collected from scree material at the illegal mining site at Badmal

Plate 1.7b : Beryl from colluvial zone at Meghpal

Plate 1.8 : Author collecting beryl samples along a small stream near Bagdhapa

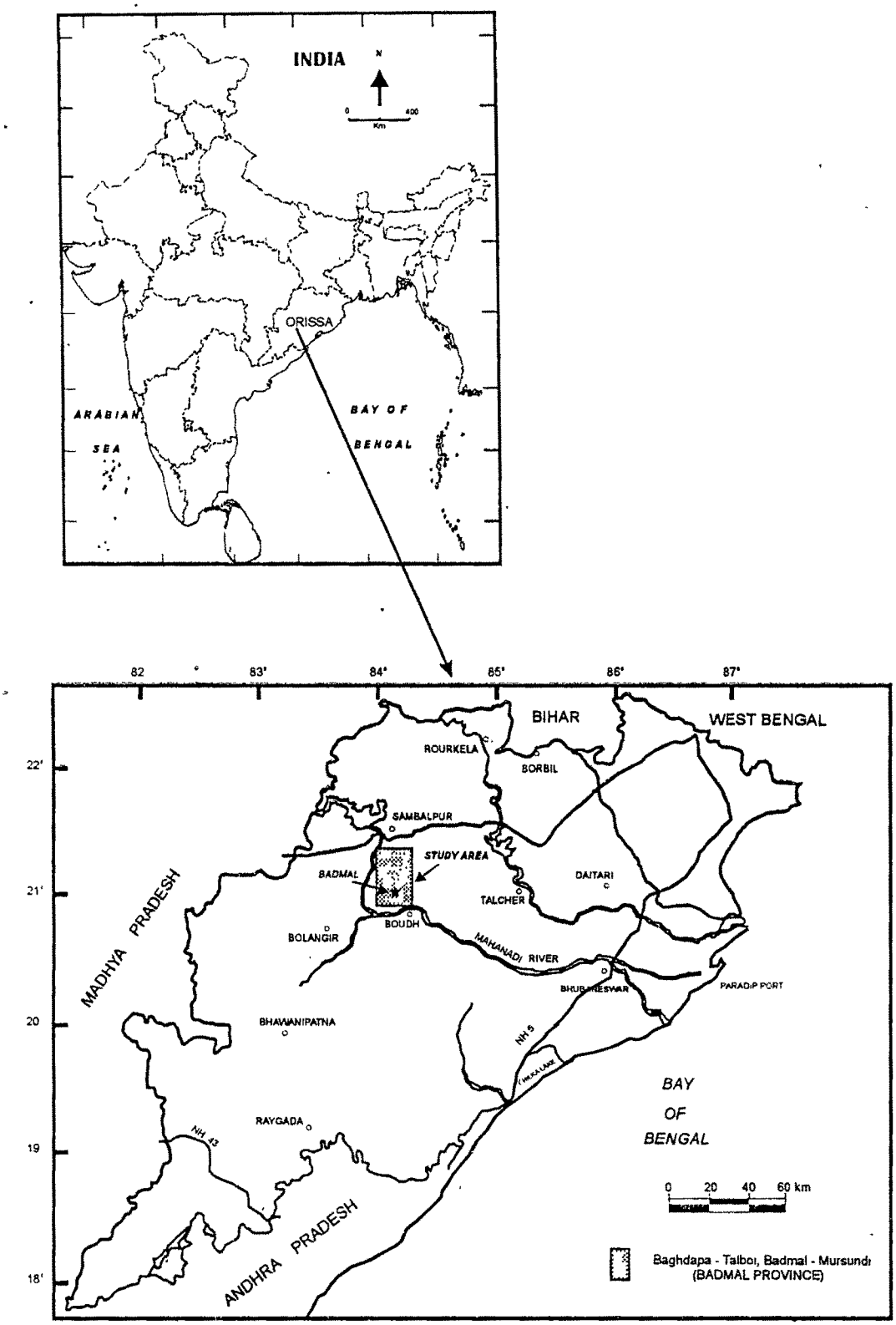

Figure 1.1 : Location map of the study area

(vi)Brazilian samples from M/s Lunwawat Gem Corporation. Although there is report of emerald from Orissa, on detailed study the samples obtained as emerald from Orissa happened to be iron bearing 'green beryl' but not true chromium/vanadium emerald.

1.5 SCOPE OF STUDY

India is one of the countries rich in gem mineral deposits such as diamond, corundum variety and beryls. Although much investigation have been carried out on diamonds and corundum varieties, gem varieties of beryl have not been studied in detail. As mentioned in the *section 1.1.*, beryl is a very interesting mineral for the study of cause of colour, colour enhancement, study of internal structure, impurities and trapped molecules. Moreover, most gem beryls of India happens to be uncoloured or colours that are not desirable in the market. Therefore, the author has taken up beryl samples from the recently discovered deposits of Orissa for his study. The studies have been carried out as given below.

Chemical analysis of beryl samples were carried out using Electron Probe Micro analysis at the Department of Geology, Mysore University. Surface microtopographical studies were carried out to decipher nature of growth using petrological microscope and SEM. Structural details and characterising various channel constituents in beryl was investigated using Fourier Transform Infrared (FT-IR) and Raman spectroscopy at RSIC, IIT, Mumbai. Thermogravimetric and Differential Thermal analysis were attempted on powder samples to understand loss of volatile constituents.

Cause of colour in natural, as well as produced after irradiation and heating were investigated using three spectroscopic techniques ; 1) Electron Spin Resonance (ESR) from RSIC, IIT, Mumbai; 2) Optical absorption spectroscopy from Central Salt and Marine Chemical Research Institute (CSMCRI), Bhavnagar and 3) ^{57}Fe Mossbauer

spectroscopy from IUC - DAEF (Inter University Consortium, Department of Atomic Energy Facility), Indore.

Single crystal and powder X - ray diffraction studies were carried out to deduce the cell parameters (*c, a*) at CSMCRI, Bhavnagar and IUC-DAEF, Indore. Electron beam irradiation of beryl samples were carried out at Isotope Division, BARC, Mumbai and ^{60}Co gamma source radiation at Microbiology Department, M. S. University of Baroda, Vadodara.