MINERALOGY AND GEMMOLOGICAL IMPORTANCE OF SPODUMENE BEARING PEGMATITES AND HOST ROCK OF KUNAR DARA-I-PECH, NORTHESTREN AFGHANSITAN


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## DEPARTMENT (DIATI)

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# DEDICATION

- TO MY BELOVED PARENTS FOR THEIR SUPPORT AND ENCOURAGEMENT THROUGHOUT OUR EDUCATIONAL CAREER AND LIFE.
- TO MY RESPECTED TEACHERS FOR THEIR CONSISTENT COOPERATION AND GUIDANCE
- TO MY DEAREST FRIENDS FOR THEIR OVERWHELMING SUPPORT

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# Abstract

Numerous rare-metal pegmatites are found in the mountainous terrain of the Hindu Kush in northeastern Afghanistan. The igneous rocks bodies around Dara-i-pech, Kunar, NE Afghanistan are studied in terms of their petrography, field features, and Gemological properties. Field relationships and petrographic studies lead to a distinction of the study area into (i) host rocks i.e. Grandiorite, Diorite, Quartz Diorite, Quartz-mica-schist and (ii) pegmatite bodies.

Texturally the rocks are granoblastic at places, however, massive medium to coarse grained and foliated varieties do occur, particularly along the shear zones. Furthermore, the crystals have radiating and interlocking texture medium to coarse grained varieties consists of zoned, saussuritized plagioclase, and perthitic alkali feldspar. The groundmass is predominanted by plag-feldspar, biotite, and quartz, minor to accessory amounts of tourmaline, muscovite, spodumene, chlorite, epidote, garnet, zircon, sphene, and beryl.

Field features and Petrographic studies of pegmatites suggest that these pegmatites are spatially and genetically related to Oligocene-age which represent the youngest of three phases of the Laghman intrusive complex. Some of the unclassified pegmatites are also encountered which haven’t reported before.

From all the tests conducted for Gemological studies and analyzing hand specimens it is concluded that the crystals is Kunzite, Hiddenite, triphane, the gem varieties of Spodumene. Sizeable amount of gem varieties and museum quality crytals of Quartz, triphane and schorl are encountered and can be used for jewelry making and collection purposes. With increasing in lithium demands the studied spodumene pegmatites have the potential both in terms of its extent, grade and can be extracted economically.

# 1 INTRODUCTION

## 1.1 General Statement

Numerous rare-metal pegmatites are found in the mountainous terrain of the Hindu Kush in northeastern Afghanistan. Earlier investigations by Soviet geologists suggested that this area contains the largest concentration of lithium-bearing pegmatites in the world. Granitiod rocks and the associated pegmatites also serve as host rock for a variety of gemstones. A wide range of gems has been reported from the pegmatites and associated quartz-feldspar (hydrothermal) veins in various localities of north-eastern Afghanistan. These include tourmaline, Kunzite, hiddenite, aquamarine (sea blue to inky blue), topaz (colorless, brown, honey color), zoisite-epidote (pink, green), Mn-rich garnet, clear to colored quartz (including amethyst), fluorite, moonstone, sphene, rutile, apatite, zircon, axinite, and many others (Jan and Kazmi, 2005).

The rare-metals include elements such as Li, Be, Nb, Ta, Zr, and Hf (Pollard, 1995) that are commonly concentrated in silicate melts by high degrees of fractional crystallization (Linnen and Cuney, 2005).

Therefore, rare-metal mineralization is generally hosted in highly evolved, peraluminous granites (e.g., Beauvoir in France, Raimbault et al., 1995; Yichun in south China, Yin et al., 1995; Cinovec in the Czech Republic, Breiter et al., 2017), as well as in granitic pegmatites (e.g., Tanco in Canada, Černý and Simpson, 1977; Stilling et al., 2006; Koktokay in northwest China, Wang et al., 2006).

Granitic rocks and the associated pegmatites also serve as host rock for a variety of gemstones. A wide range of gems has been reported from the pegmatites and associated quartz-feldspar (hydrothermal) veins in various localities of nort eastern Afghaistan. These include Kunzite, hiddinite, tourmaline, aquamarine (sea blue to inky blue), topaz (colorless, brown, honey color), zoisite-epidote (pink, green), Mn-rich garnet, clear to colored quartz (including amethyst), sphene, rutile, apatite, zircon, and many others (Rossovskiy and Chmyrev, 1977).

## 1.2 Location of the Study Area

A large body of granitiod rocks and associated pegmatites viens is well exposed in and the surrounding areas of Dara-i-Pech, NE Afghanistan. The Dara-i-Pech (N34058’07.9’’ E070044’00.8’’) is located in the north eastern portion of Kunar Province, along the western border of Pakistan (Fig. 1.1). This area is partly accessible through Chaghasri- Nuristan road. Geologically, the study area is a part of Nuristan complex.

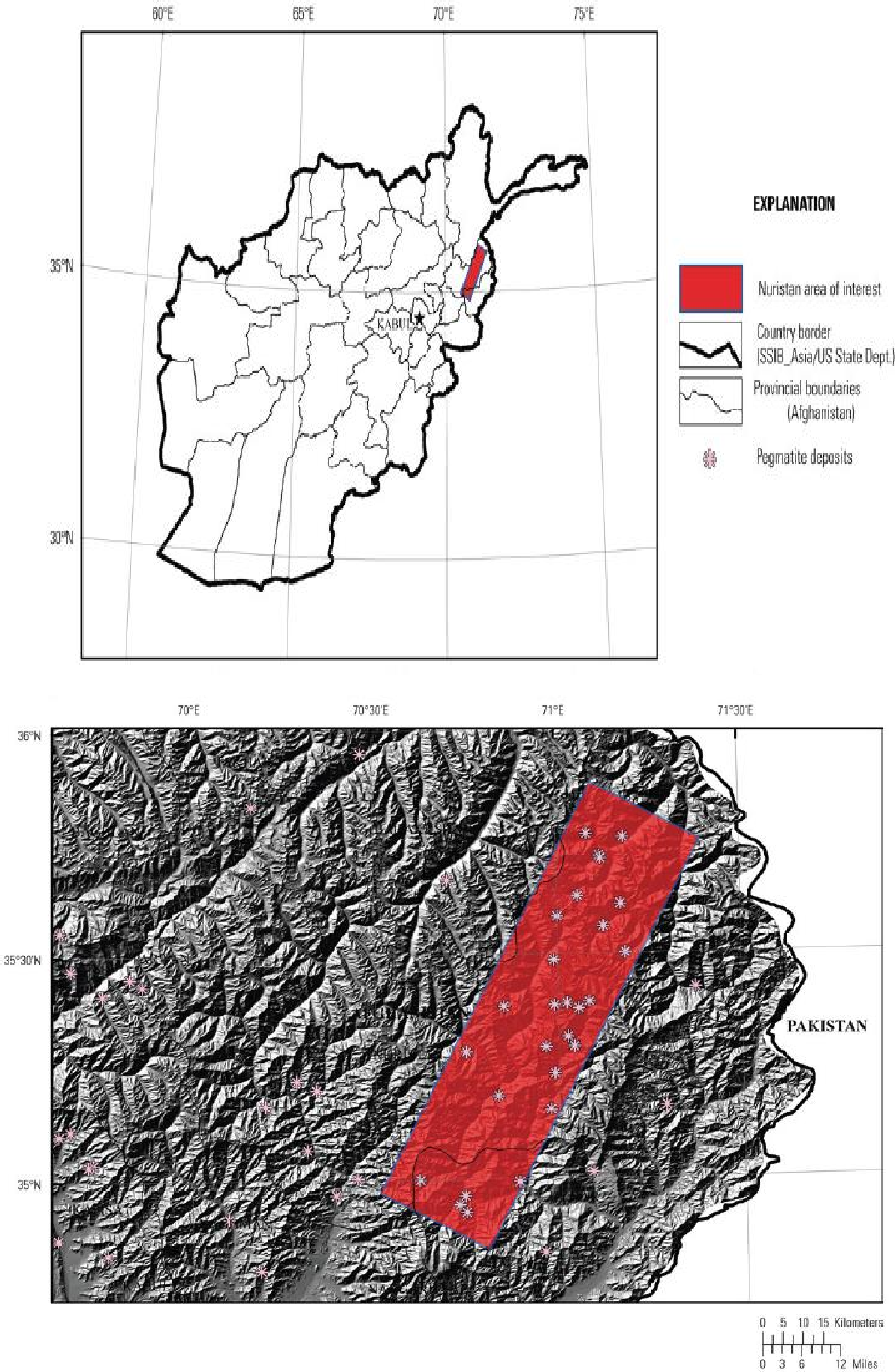



Fig. 1.1. (A) Map of Nuristan area of interest ; (B) Index Map showing the location of the Nuristan rare metal pegmatite. The stars representing the major pegmatites deposits.

## 1.3 Previous work on Nuristan Rare metal pegmatite's

Due to the presence of more than 70% of mountainous areas the country have high potential of natural resource to be present. Pegmatites within the Nuristan rare-metal pegmatite were poorly known to the western world until Soviet geologists began mapping the geology and assessing the mineral resources of northern Afghanistan in the 1960s and 1970s and then by Americans, Germans, Italians, Austrians and also the Afghans have conducted some of the research. Some of the work has been highlighted here,

Pegmatites of Afghanistan's Badakhshan and Nuristan have been known since from ancient time. Precious and semi-precious stones specially Lapis Lazuli and micas have been mined.

Hayden (1911) when for the first time he gave some preliminary information about Afghanistan's pegmaties in the country north eastern region. According to Hayden, these pegmatites are indicative of the Himalayas pegmatite belt rich in quartz, feldspar, muscovite (large crystalline), schorl and barrel.

Famous botanist and Geographer of the former Soviet Union Wilov (1924) was for the first time crossed Nuristan region. He mentioned that this area is rich in Pegmaties viens and granites.

Muhammad Ahsan khan (1934) highlighted beryl bearing veins in Nanglam Kunar dara-i- Pech district.

The group led by Ghulam Ali Khan (1941) start surveying somewhere in Nangrahar pegmaties district and he was successful in finding beryl crystals. In 1948 he discovered the first bery mine in Dara-i-Nor district of Nangrahar Province and studied the basic Geological and mineralogical properties of the pegmatite bodies. Ghulam Khan (1949) reported some of the beryl bearing pegmatites in Dara-i-Pech, Kunar. Based on areal Photographs he made 1:5000 map of the studied area.

Said Hashim mirzad and Ahamd Khan (1960) reported for the first time lithium mineralization in Dara-i-Pech.

M. Nerudny and Schwarkov (1965) identified the Nilaw Pegmatite field. They are reported rare metal pegmatites in Wigal, Paron and Alingar.

Soviet researchers Noviskov, Susan, and Afghan engineers (1976) in Nilaw Kulam pegmatite field conducted and collected systematic sampling and after Geochemical analysis the reported the percentage of Tantalum and Niobium.

Amir Mohammad Musazai Naqibullah Sahak (1988) in the Nuristan pegmatite fields translated and wrote some of the pamphlets in country's Native languages. They also carried out their PhD research in those areas. They are considered the most recent compiled work done by any Afghans. In their thesis they reported the origin and extension of pegmatite belts. It has been identified that Afghanistan's rare metals reserves especially beryllium, lithium, tantalum, niobium, cesium is one of the world leading regarding its grade.

## 1.4 The Present Investigation

### 1.4.1 Scope

The Dara-i-Pech area contains well exposed exposures of granitiod rocks. Most of the other rocks in the region, particularly those in Nuristan zone, have been studied in reasonable detail in the past. The spodumene pegmatites are cited as an example of the albite–spodumene type of rare-element Li class of pegmatites (Černý & Ercit 2005, Černý et al. 2012). The absence of zoning and the dominance of albite and quartz over K-feldspar distinguish these pegmatites. The purpose of this study is to document the mineralogy of spodumene-bearing (ore) and spodumene-free (barren) pegmatites in the Dara-i-Pech and to evaluate the mineralogy in light of recent models for pegmatite petrogenesis (e.g., London 2008, Simmons & Webber 2008). Also to find out the gemological properties of spodumene in reasonable details.

### 1.4.2 Aim and Objectives

The Aim of this research work is to determine the economic potential and gemological properties of the Spodumene bearing Pegmatite vein deposits of the Kunar Dara-i-Pech (District/province), Gul Salak, N/E Afghanistan.
This aim will be achieved through the followings Objectives.

1. To prepare a geological map of the study area using field and petrographic studies.

2. To carry out a detailed petrographic examination of the Kunar Dara-i-Pech Spodumen Pegmatites and associated rocks in order to determine their modal mineralogy, textural behaviors and alterations.

3. Comparison between spodumene free and rich pegmatites.

4. The determination of gemological properties of Spodumene and other associated gems.

## 1.5 Methodology

### 1.5.1 Field Work

Field work were conducted in the surrounding areas of Dara-i-Pech specially Majid kot and Kawargal villages. Twenty representative samples were collected from the area of interest from mine dumps, available outcrop exposures and few were obtained from beneath the mine. Geographic coordinates of each sample were recorded as shown in the (Table.1.1).

All samples were selected on the basis of mineral paragenesis, location with respect to internal zoning Within a pegmatite, mineral clarity, color, and lack of significant clay alteration or organic staining. The largest crystals ('7.2cm) were preferentially sampled for analysis as shown in (Fig. 3.3b). In some of the larger, complex pegmatite's a variety of samples were collected from different locations along the strike of the pegmatite.

Table 1.1. GPS readings of the collected samples from the targeted area.

| Sample No. | GPS Readings | |
|---|---|---|
| | Northing | Easting |
| 1 | N 34*58'07. 9" | E070*44'00.8" |
| 2 | N 34*58'07. 9" | E070*44'00.8" |
| 3 | N 34*58'07. 9" | E070*44'00.8" |

| | | |
|---|---|---|
| 4 | N 34*57'11.3" | E070*43'06.5" |
| 5 | N 34*57'11.3" | E070*43'06.5" |
| 6 | N 34*57'12.3" | E070*43'07.5" |
| 7 | N 34*57'03.1" | E070*43'09.4" |
| 8 | N 34*57'03.1" | E070*43'09.4" |
| 9 | N 34*57'03.1" | E070*43'09.4" |
| 10 | N 34*57'05.1" | E070*43'11.4" |
| 11 | N 34*57'05.1" | E070*43'11.4" |
| 12 | N 34*57'09.1" | E070*43'13.4" |
| 13 | N 34*57'09.1" | E070*43'13.4" |
| 14 | N 34*57'06.4" | E070*43'25.4" |
| 15 | N 34*57'06.4" | E070*43'25.4" |
| 16 | N 34*57'06.4" | E070*43'25.4" |
| 17 | N 34*57'06.4" | E070*43'25.4" |
| 18 | N 34*57'06.4" | E070*43'25.4" |
| 19 | N 34*57'11.3" | E070*43'06.5" |
| 29 | N 34*57'11.3" | E070*43'06.5" |

### 1.5.2 Thin section preparation

Fifteen (15) out of 27 collected samples were cut into thin sections for detailed petrographic studies in the Rock Cutting laboratory of the National Center of Excellence in Geology, University of Peshawar. These thin sections were studied in the Petrography laboratory, Department of Geology, University of Peshawar and in Sedimentology Laboratory, National Center of Excellence in Geology, University of Peshawar, Pakistan.

## 1.6 Problems and limitations during the Research

Due to the ongoing war and unrest I wasn’t able to have access to the areas that have high potential of my interest. The extremist groups have occupied the mentioned territory since very long time. The security threats was very high from the Taliban and also from the government side as there was constant drone attacks conducted by the Afghan army and their allies (NATO). Using the GPS is somehow redline for the extremist but still I managed to take few of the GPS points of the sampling areas and to click some pictures also.

The second problem I would like to mention is the lack of a well-equipped laboratory so that I can have access to the technical machines used for Petrographic, mineralogical, chemical, spectral analysis as well as the age of the rocks to be determined.

Due to the lengthy and almost impossible bureaucracy for carrying out the samples outside the country.

The infrastructure and without proper metaled roads it was impossible to carry out field work in such an extreme conditions (Fig. 1.2 a,b).

Fig. 1.2. Field Photographs: (A,B) Images highlighting the poor infrastructure.

## 1.7 Classification and Origin of Pegmatites

The classification of granitic pegmatites was constantly attempted in the past century, with varying success and applicability. Internal structure, paragenetic relationships, bulk chemical composition, petrogenetic aspects, nature of parent medium, and geochemical features were applied by (e.g., Fersman 1930; Cameron et al. 1949; Jahns 1953, 1955, 1982; Brotzen 1959; Stewart 1963, 1978; Jahns, 1982; Ćerný 1982a). However, all of the attempts were marked by subtle success as by ignoring differences in geological environment. Since the late 1970s a prominent progress were achieved. From earlier works done by Ginsburg and Čern´y two approaches were used for classification. Based on geological location five different classes were identified. These are (abyssal, muscovite, muscovite – rare-element, rare-element, and miarolitic), most of which are subdivided into subclasses with basic different in geochemical (and in part geological) characteristics. These subclasses were in turn divided into types and subtypes with differences in P–T conditions of solidification, expressed in variable assemblages of accessory minerals. Three families are distinguished in the second approach based on petro genetic difference derived by igneous differentiation from plutonic parents. These are NYF family with icreasing accumulation of Nb, Y and F (besides Be, REE, Sc, Ti, Zr, Th and U), fractionated from subaluminous to metaluminous A- and I-type granites. Second peraluminous LCT family marked by prominent accumulation of Li, Cs and Ta (besides Rb, Be, Sn, B, P and F), derived mainly from S-type granites. The third family is the combination of NYF + LCT family of diverse origins.

Table 1.2. Classification of Granitic Pegmatites based on Geological, Paragenetic and Geochemical analysis Ginsburg et al. (1979).

| Class | Sub Class | Type | Sub Type |
|---|---|---|---|
| Abyssal (AB) | AB-HREE, AB-LREE, AB-U, AB-Bbe | | |
| Muscovite (MS) | | | |
| Muscovite-Rare element (MSREL) | MSREL-REE, MSREL-LI | | |
| Rare element (REL) | REL-REE | allanite-monazite, auxenite, | |
| | REL-LI | Beryl | beryl-colombite, beryl-colombite-phosphate |
| | | complex | spodumene, petalite, lepidolite, elbaite, |
| | | Albite-spodumene | |
| Miar0litic (MI) | MI-REE | topaz-beryal | |
| | | gadolinite-fergusonite | |
| | MI-LI | Beryl-topaz | |
| | | MI-spodumene | |
| | | MI-petalite | |
| | | MI-lepidolite | |

Table 1.3. Subdivision of the rare element class of Granitic pegmatites.

| Sub class | Sub type | Geochemical signature | Typical minerals |
|---|---|---|---|
| Complex | Spodumene | Li, Rb, Cs, Be, Ta-Nb, (Sn, P, F; ±B) | spodumene, beryl, colombite, tantalite, (amblygonite, lepidolite, pollucite) |
| | Petalite | Li, Rb, Cs, Be, Ta-Nb, (Sn, P, F; ±B) | petalite, beryl, columbite-tantalite, (amblygonite, lepidolite, pollucite) |

| | | | |
|---|---|---|---|
| | Lepidolite | Li, F, Rb, Cs, Be, Ta-Nb, Sn, P, B | lepidolite, beryl, topaz, microlite, columbite-tantalite, pollucite |
| | Elbaite | Li, B, Rb, Sn, F (Ta, Be, Cs) | tourmaline, hambergite, danburite, datolite, microlite |
| | Amblygonite | Li, Rb, Cs, Ta-Nb, Be,(Sn) | amblygonite, beryl, columbite-tantalite, (Lepidolite, pollucite) |

Geographic symbols: AR: Argentina, AU: Australia, AZ: Arizona, CO: Colorado, CZ: Czech Republic, DRC: Democratic Republic of Congo, NO: Norway, QC: Quebec, SD: South Dakota, SWE: Sweden, TX: Texas, WA: Western Australia.

### 1.7.1 Importance of Pegmatites

Pegmatites are one source for rare metals such as lithium, tantalum, niobium, beryllium, tin, and cesium, which are in demand for their individual properties or properties that they impart to other materials or metals (Kunaz, 1994; Harben and Kužvart, 1996). Although lithium-bearing brines have replaced lithium-bearing pegmatites as the principal source of lithium, current and future demand for lithium may result in a return to mining of lithium-bearing pegmatites. The pegmatites in northeastern Afghanistan are described as the largest concentration of lithium-bearing pegmatites in the world (Rossovskiy and Chmyrev, 1977) and could be considered as the world's recognized future principal source of lithium. Some rare elements, mainly those that support high-technology industry, have an increasing demand due to their variety of uses in new technologies. Among these elements, also known as high-technology metals, Li are in high demand owing to their use in capacitors for wireless technology, in battery applications, and in liquid crystal displays (LCD) and touch-screen displays. This metal can occur in high concentrations in pegmatites.

# 2 REGIONAL AND LOCAL GEOLOGICAL SETTINGS

## 2.1 Tectonic Setting of Afghanistan

Afghanistan is located at the west of Himalayan orogeny with most of the country lies within the Asian Plate where the western end of the Indus suture crop outs in eastern Afghanistan, with Indian Plate rocks lies in the southeast (Treloar and Izatt, 1993). The country has complex and diversified geology, and the ages have been determined as from Archean, Proterozoic and all Phanerozoic Eras.

Afghanistan forms the most stable part of a foreland that projects south from the Eurasian Plate (Ambraseys et al., 2003; DeMets et al., 1990) (Fig. 2.1). West of Afghanistan, the Arabian Plate is subducted northward beneath Eurasian Plate, and east of Afghanistan the Indian Plate does the same. South of Afghanistan, the Arabian and Indian Plates adjoin and both are subducted northward beneath the Eurasian Promontory. The plate boundaries west, south, and east of Afghanistan are hundreds of km wide. They involve the contractional deformation of large parts of the Eurasian Promontory (Kazmi, 1979; Hessami et al., 2003).

The rock units to the north and west of Herat and Central Badakhstan faults i.e. North Afghanistan (also Tadzhik, platform), were part of the Asian Plate since before the PermoTrias (Sengor et al., 1988), while those to the south of this fault system and to the north and west of the Chaman and Konar faults were part of Gondwana that separated from supercontinent before India separation, and during the Cimmeride orogeny accreted to the southern margin of Eurasia (Sengor, 1984; Boulin, 1991).

The zone that marks the boundary between Afghan Block and the Indian Plate, within Afghanistan, is a collage of tectonic units, which includes the East Nuristan island arc; Kabul block; Katawaz basin and the Kabul and Khost ophiolites (Treloar and Izatt, 1993) (Fig. 2.1).

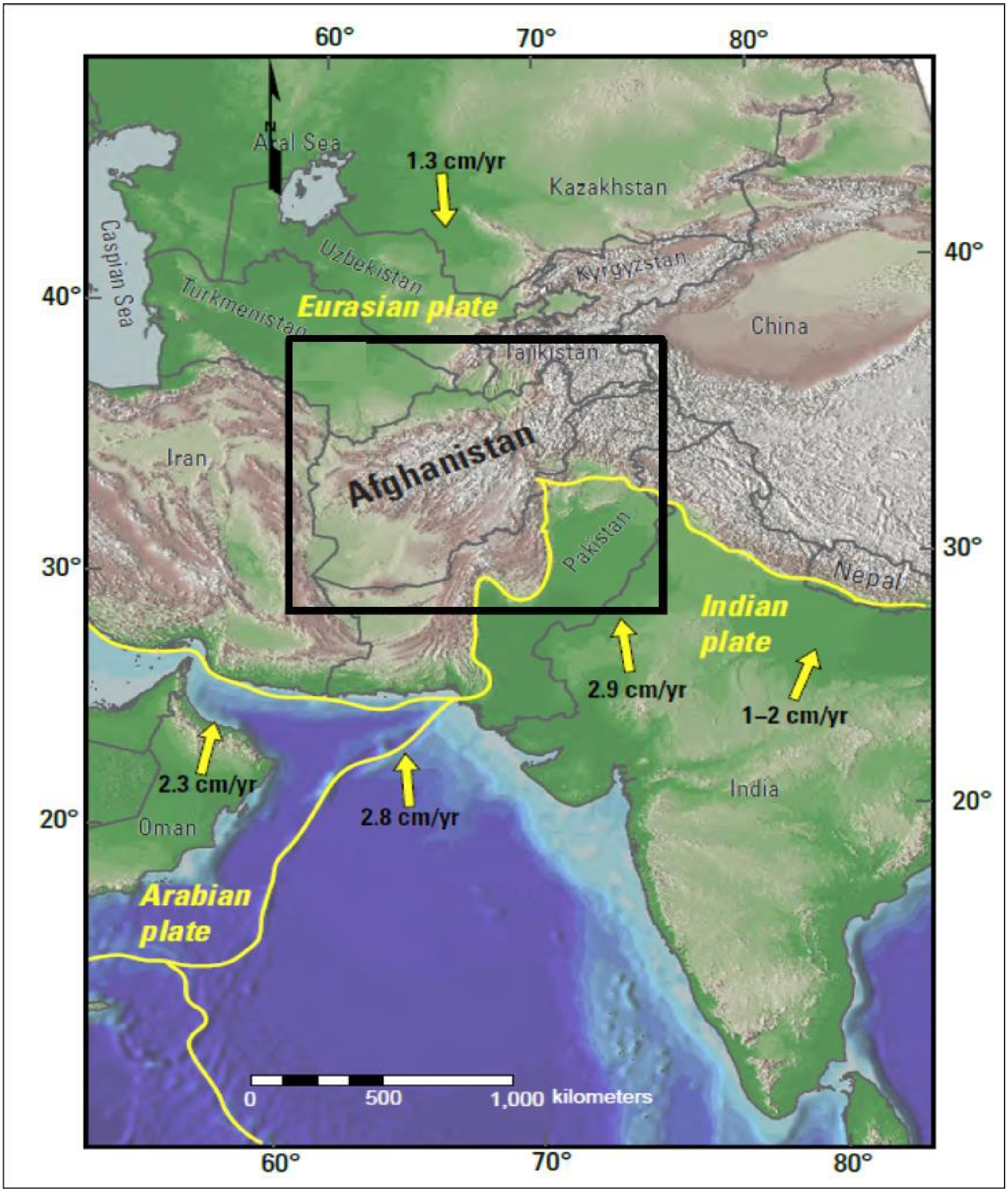



Figure 2.1. Greater Alpine-Himalaya orogenic belt of Asia. Vectors show relative plate motions and velocities between the Indian, Eurasian, and Arabian Plates (plate boundaries shown and labeled in yellow). Plate velocities from Jade (2004), Bird (2003), Vernant et al., 2004 and Sella et al., 2002 by Ruleman et al., 2007.

## 2.2 Geology and Tectonics of Northeastern Nuristan Block

The Nuristan island arc is the western continuation of the Kohistan-Ladakh arc (KLA), having basic to acidic plutons in the Eastern side which intrude a range of basic volcanics and volcaniclastic sediments

(Debon et al. 1987). Dronov, Abdullah, and Chmyriov (2008) described the Nuristan terrane as a region of chiefly amphibolite-grade gneissic and schistose country rock affected by extensive granitization, including widespread injection zones. Zones of cataclasis and retrograde metamorphism are also common. They subdivided the Nuristan series into three parts. The lower part consists of the Nejrab, Chebak, and Kamdesh Formations, the middle part consists of the Waygal Formation, and the upper part consists of the Kamal Formation. The majority of eastern Afghanistan consists of the Nuristan Fault Block composed of Lower Proterozoic metamorphic rocks intruded by a series of Cretaceous-Tertiary biotite-granite and granodioritic intrusions known as the Lagman Complex or Lagman Zone (Abdullah and Chmyriov, 1977).

The rare metal pegmatite veins within the Nurestan-Pamir Median Mass occur in fields with an area ranging from 10 to 800 sq. km: 21 fields of this kind are already known. Dozens, or less commonly hundreds, of the rare-metal pegmatite veins occur within the fields (Benham and Coats, 2007).

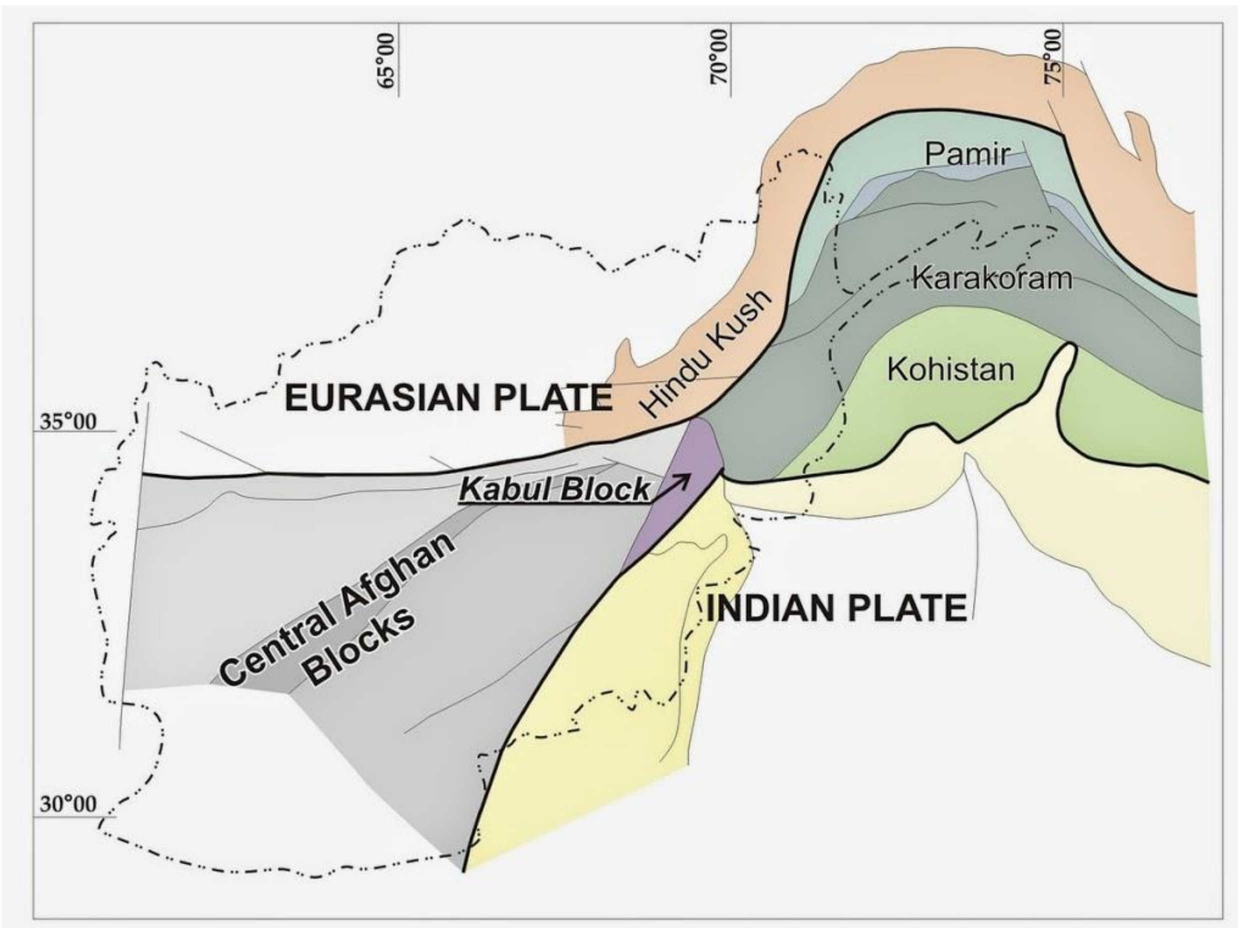



Fig. 2.2. Map of different blocks of Afghanistan (Treloar and Izatt, 1993).

## 2.3 Pegmatite Provinces, Belts, Fields, and Groups in Northeastern Afghanistan

Pegmatite provinces are defined by the total pegmatite fields (or belts) within metallogenic provinces (Černý, 1982a). Pegmatite belts consist of pegmatite fields, which are related to large-scale linear structures such as lineaments, deep faults, or margins of granite plutons (Černý, 1982a). Two major pegmatite belts are associated with the Alingar Pluton. The Nuristan pegmatite belt lies along the eastern flank of the pluton, and the Hindukush belt lies along the western flank (Fig. 2.2). Each belt consists of several pegmatite fields, which, in turn contain one or more named pegmatites and probably numerous unnamed pegmatites.

Pegmatite fields are areas that contain related pegmatites in a common geological-structural environment, and with a common age and igneous source (Černý, 1982a). The Hindukush belt consists of the Mundol, Nilaw-Kolum, Nilaw, Alingar, Samakat, and Sahidan pegmatite fields. The Nuristan pegmatite belt consists of the Iska-Sem, Pacigram, Paran (Jamanak-Pasghushta), Kantiway, Dara-i-Pech, Cawgao, Surkhrud, and Darrah Nur pegmatite fields (Rossovskiy and Nuiskov, 1974b) and extends beyond the northern and southern boundaries of the Nuristan rare-metal pegmatite. The Iska-Sem, Cawgao, Surkhrud, and Darrah Nur pegmatite fields of the Nuristan pegmatite belt also lie outside of the Nuristan pegmatite belt.

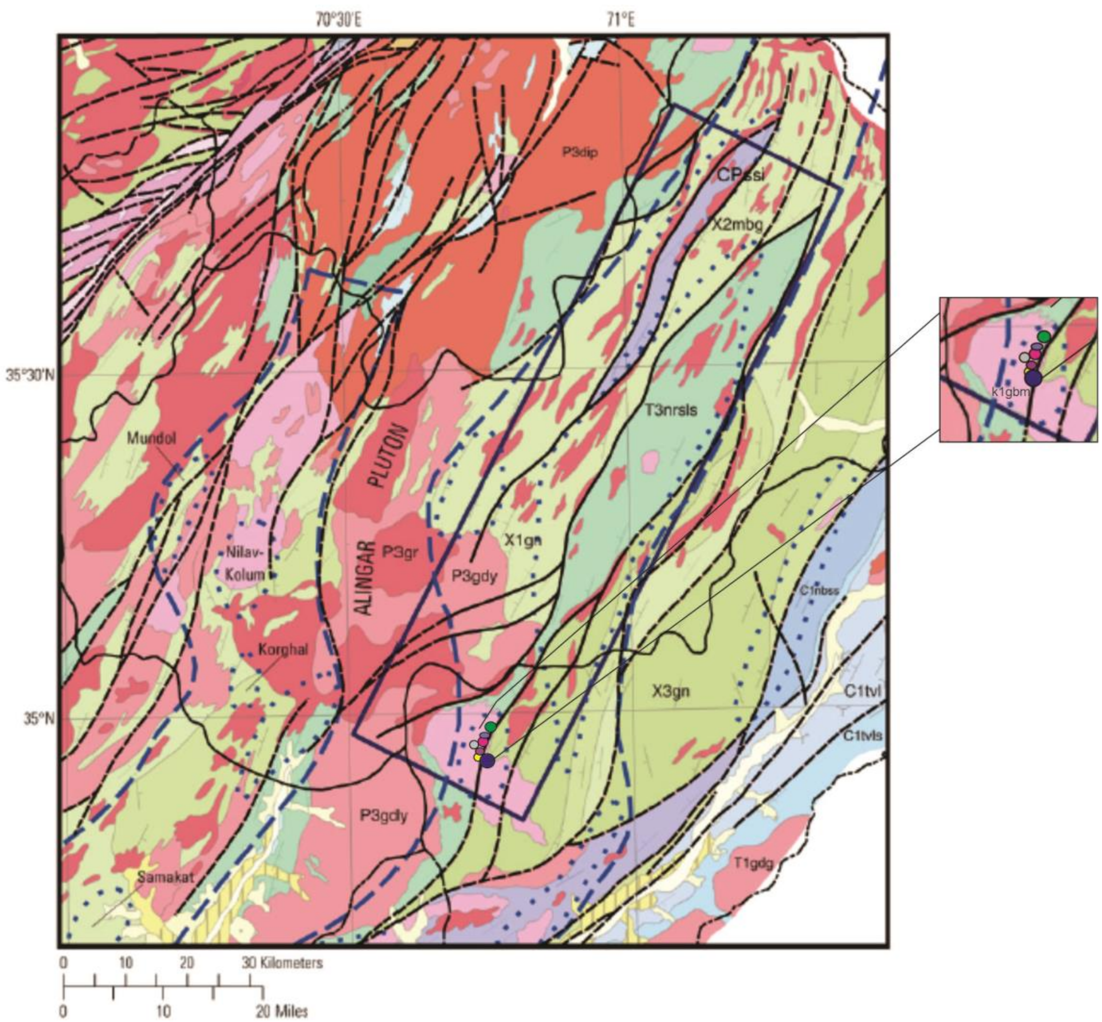
Table 2.1. Pegmatite fields and their reported economic minerals in the Nuristan rare-metal pegmatite area of interest. [Be, beryllium; Cs, cesium; ESCAP, United Nations Economic and Social Commission for Asia and the Pacific; Li, lithium; Nb, niobium; Rb, rubidium; Sn, tin; Ta, tantalum]

| Locality/deposit name | Province | Approximate size (square kilometers) | Commodities | Significant minerals or materials (other than Q, M, F) | Selected references |
|---|---|---|---|---|---|
| | | | | | |
| Paron (Jamanak-Pasgushta) | Nuristan | 1158 | Li, Ta, Nb, Sn, Cs, Rb | columbite, cassiterite, schorl, garnet, beryl | ESCAP, 1995; Abdullah and Chmyriov, 2008 |
| Pacigram (Pachigram) | Nuristan | 221 | Li, Be, Sn, Nb | spodumene, schorl spodumene, tantalite, | ESCAP, 1995; Abdullah and Chmyriov, 2009 |
| Darrahe Pec (Darra-i-Pech) | Kunar | 85 | Be, Nb, Ta, Li, mica | spodumene, beryl, columbite-tantalite, pollucite | ESCAP, 1995; Abdullah and Chmyriov, 2010 |
| Kantiway | Nuristan | 130 | gemstones, Li, quartz | kunzite, spodumene, tourmaline, cassiterite, cleavelandite | ESCAP, 1995; Abdullah and Chmyriov, 2011 |

## 2.4 Geology of the Nuristan Rare metal Pegmatite Province

Numerous pegmatite occurrences are known within the Nuristan Block. These pegmatites vary from minor dikes, sills and pods to large deposits up to several hundred meters long and over 30 meters wide. (Refrence missing). Most of the productive pegmatites have been mined only for the Gem varities of the different minerals. But some contain associated minerals enriched in rare elements. Earlier investigations by Soviet geologists suggested that this area contains the largest concentration of lithium-bearing pegmatites in the world. In addition to lithium, these pegmatites are enriched in other rare metals such as tantalum, niobium, beryllium, tin, and cesium. Gem-quality tourmaline, kunzite, beryl, and optical grade quartz have been mined from some of these pegmatites.

The oldest rocks in the Nuristan rare-metal pegmatite are Early Proterozoic metamorphic rocks that are divided into an Early Part, a Middle Part, and a Late Part (Fig. 2.2).Early Part rocks consist of mica, biotite, biotite-amphibole, garnet-biotite, garnet-sillimanite-biotite, and pyroxene-amphibole gneiss, as well as plagiogneiss, schist, migmatite, quartzite, marble, and amphibolite. Middle Part rocks consist of biotite and garnet-staurolite-biotite gneiss and schist, quartzite, marble, and amphibolite. Late Part rocks consist of biotite and garnet-biotite gneiss and schist, quartzite, marble, and amphibolite. Metamorphic grade of the Proterozoic rocks is either epidote-amphibolite or muscovite-staurolite-schist facies (Rossovskiy and Chmyrev, 1977). Younger lithologies include Carboniferous-Early Permian sandstone, siltstone, shale, and mafic-volcanic rocks and Late Triassic (Noria-Rhaetian) siltstone, sandstone, shale, and conglomerate (Doebrich and Wahl, 2006). Descriptions of the individual pegmatite fields and deposits indicate that the Carboniferous-Early Permian and Late Triassic rocks have been metamorphosed (Abdullah and Chmyriov, 2008, Summaries of Important Areas for Mineral Investment and Production Opportunities of Nonfuel Minerals in Afghanistan).



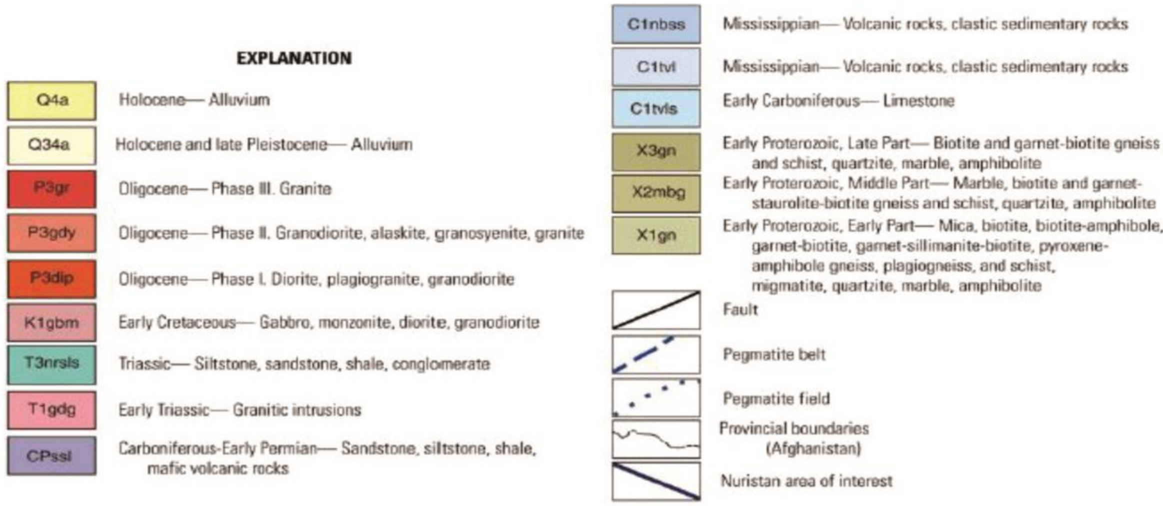



Fig 2.3. Regional geologic map showing the major granitic bodies of the Pagram intrusive complex, faults, and pegmatite belts, fields, and the Nuristan rare-metal pegmatite area of interest. Units (Doebrich and Wahl, 2006)

## 2.5 General Geologic settings of study area

The rare metal pegmatite veins within the Nurestan-pegmatite province occur in fields with an area ranging from 10 to 800 sq. km (Book 2 Mineral Resources of Afghanistan. Dozens, or less commonly hundreds, of the rare-metal pegmatite veins occur within the investigated fields. Two structural types of veins were encountered in the study area: (1) those consisting of tabular, gently-dipping veins normally found in gabbro-diorite massifs, where the veins are mostly confined to the contraction fissures developed in the endocontact zones. (2) Fields of tabular, steeply dipping veins confined to deep-seated fracture zones in quartz-mica schist. The largest veins and veined zones of spodumene pegmatites were encountered in the fields of this type.

## 2.6 Geology and Pegmatites types of the Study Area

The study area “Dara-i-Pech”, Gul Salak, Konar Province, 34°52'30"-34°59'00" N, 70°42'10"-70°45'40"E. Rare metal pegmatites occur within the eastern exocontact of a large intrusion of Oligocene granite, where Proterozoic metamorphics, Lower Triassic shale, and Early Cretaceous gabbro-diorite are exposed (G.K. Eriomenko and L.N. Rossovskiy, 1974). The following types of pegmatite dikes have been found there: (1) plagioclase-microcline with biotite and muscovite, varying in thickness between first few centimeters and 15 m and in length between 800 and 1,000 m, which contain beryl and columbite-tantalite; (2) albitized microcline, ranging in width from 1 to 15 m and in length from 200 to 1,500 m, with beryl and tantalite-columbite (of 100 dikes 12 - 15 are of commercial value); (3) albite, 1 to 15 m wide and 200 to 1,500 m long, which are promising for tantalum; and (4) spodumene-albite, varying in width between 1 and 25 m and in length between 500 and 2,500 m, with spodumene, finely disseminated beryl, and columbite-tantalite. (Book 2, Geology and mineral resources of Afghanistan).

# 3 PETROGRAPHY

## 3.1 General Statement

The modal mineralogy and the textural relationships within a rock are best described with the help of petrographic studies. These include observations of important field features such as the difference in lithology, color, texture through outcrop and hand lens as well as a detailed microscopic examination of rocks. Petrography includes the identification of minerals, their texture and alteration which are critical for understanding the origin and deformation of rocks. A detailed petrographic account of the study area rocks is presented in this chapter.

## 3.2 Field Features

The Darrahe Pech pegmatite field is located on the eastern contact of Alingar Granite Pluton (Abd Ullah volume 2), whose mineralogy, grain size, contacts, and thickness vary from place to place. The study area was divided in to the two fields, Majeed kot and Kwaragal.
Most of the veins in both the fields are gentle dipping almost 30° with no overprints of regional tectonics while some in Kawaragal have steep dips that reaches almost 50° (Fig. 3.1a,b).

Fig 3.1. Field Photographs: (A, B) Gentle and steep dipping pegmatite veins

### 3.2.1 Majeed Kot

In Majeed kot area is consisting of tabular, gently-dipping veins found in gabbro-diorite massifs, where the veins are mostly confined to the contraction fissures developed in the endocontact zones. The veins vary from 3cm to 4 meters width and 200-300 meters in length with gentle to steep dips. (Fig. 3.1a).

The veins have very sharp contact with the host rock and are extremely weathered which can be seen in thin section as well (Fig. 3.2b).
They are composed of Quartz, Feldspar, Tourmaline (schorl, dravite), Micas, petalite, Spodumene (Hidinite, Triphane), Garnets. Most of the pegmatite's is Spodumene free in the mentioned area.
The textural difference is wide spread with some consisting of very coarse megacrystal grains to very fine small grains (Fig. 3.2c) Primary magmatic features i.e. zoning because of the evolved chemistry as the joint expanded, increasing of grain size from side to core were visible (Fig. 3.2a) .

Fig 3.2. Field Photographs: (A) Zoning in Pegmatite; (B) Image of sharp contact with the host; (C) Weathered outcrop in Majeedkot location.

### 3.2.2 Kwarangal

In the Kawargal field, veins are tabular, steeply-dipping and confined to deep-seated fracture zones in quartz-mica schists. The largest veins and veined zones of spodumene pegmatites are encountered in this field (Fig. 3.3f).
The thickness and width have increased enormously with some reaching almost 25meters in width (Fig.3.3c).The grain size are coarse and very rich in tourmaline, Micas, albite and spodumene (Fig. 3.3a).

In some parts the crystal of schorl reaches 11cm (Fig.3.3b) and the spodumene upto 10cm as shown (Fig. 3.3d). Some of the sutured contacts were also seen. In some parts fabric developed due to some local deformation zones (Fig. 3.3e).


Fig 3.3. Field Photographs: (A) Image of very coarse grain size rich in tourmaline, Micas, albite and spodumene; (B) Large crystal of tourmaline (schorl); (C) Huge pegmatite vein; (D) Large crystal of spodumene (triphane); (E) Fabric development in the host rock; (F) Veined zones of spodumene pegmatites with flakes of micas.

## 3.3 Samples and Methods

Thirteen (13) representative samples out of total 27, were cut into thin sections for detailed petrographic studies. Based on detailed field and petrographic observations rocks are divided into two rock types: pegmatite veins and their host rocks (Granodiorite, Diorite, Quartz diorite, Quartz Monzodiortie).

Texturally the rocks are granoblastic at places, however, massive medium to coarse grained and foliated varieties do occur, particularly along the shear zones (Fig. 3.6b). Furthermore, Furthermore, the equigranular medium-grained varieties consists of zoned and saussuritized plagioclase, and perthitic alkali feldspar. The groundmass is predominated by plag-feldspar, biotite, and quartz, minor to accessory amounts of tourmaline, muscovite, garnet, zircon, sphene, and beryl. The modal abundance of these minerals is presented in the (Table 3.1) and the normalized values are plotted on the IUGS classification triangle. Based on the IUGS plot, the studied rocks fall into two categories (Table 3.2).

Table 3.1. Modal Mineralogical composition of Majeed kot and Kawarangal Granitiods.

| Sample No. | Qtz | Plg | Alkf | Bt | Ms | Tur | Clay Min | Sph | Grt | Ore | Epd | chl | spd |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| H1 | 5% | 33% | 5% | 10% | 6% | -1% | 8% | | | 7% | 15% | 10% | 1% |
| H2A | 3% | 50% | 3% | 20% | 2% | 2% | 1% | 3% | 1% | 2% | 3% | 1% | 8% |
| H2B | 15% | 62% | 2% | 10% | 1% | | | 1% | 1% | | 7% | | 1% |
| H3A | 15 | 65 | 4 | 10 | 1 | 1 | | 1 | 1 | | 1% | | |
| H3B | 15 | 50 | 4 | 15 | 1 | 1 | | 1 | 1 | | 2% | | 10% |
| H4 | 40% | 20% | 4% | 25% | | 2% | 1% | 1% | | | 1% | 1 | 5% |
| PED1 | 15% | 55% | 3% | 2% | | 1% | 1% | | 15% | 1% | 2% | 1% | 4% |
| B | 15% | 62% | 2% | 10% | 1% | | | 1% | 1% | | 7% | | 1% |
| E | 3% | 50% | 3% | 17% | 2% | 2% | 1% | 3% | 1% | 2% | 6% | 1% | 6% |
| P3C | 10% | 15% | 1% | 3% | 1% | | | | | | | | 70% |

Abbreviations: Qtz = quartz, Plg = plagioclase, Alkf = Alkali feldspar, Bt = biotite, Ms = muscovite, Tur = Tourmaline, Sph = Sphene, Grt = Garnet, Epd = Epidote, Chl = Chlorite, Spd = Spodumene.

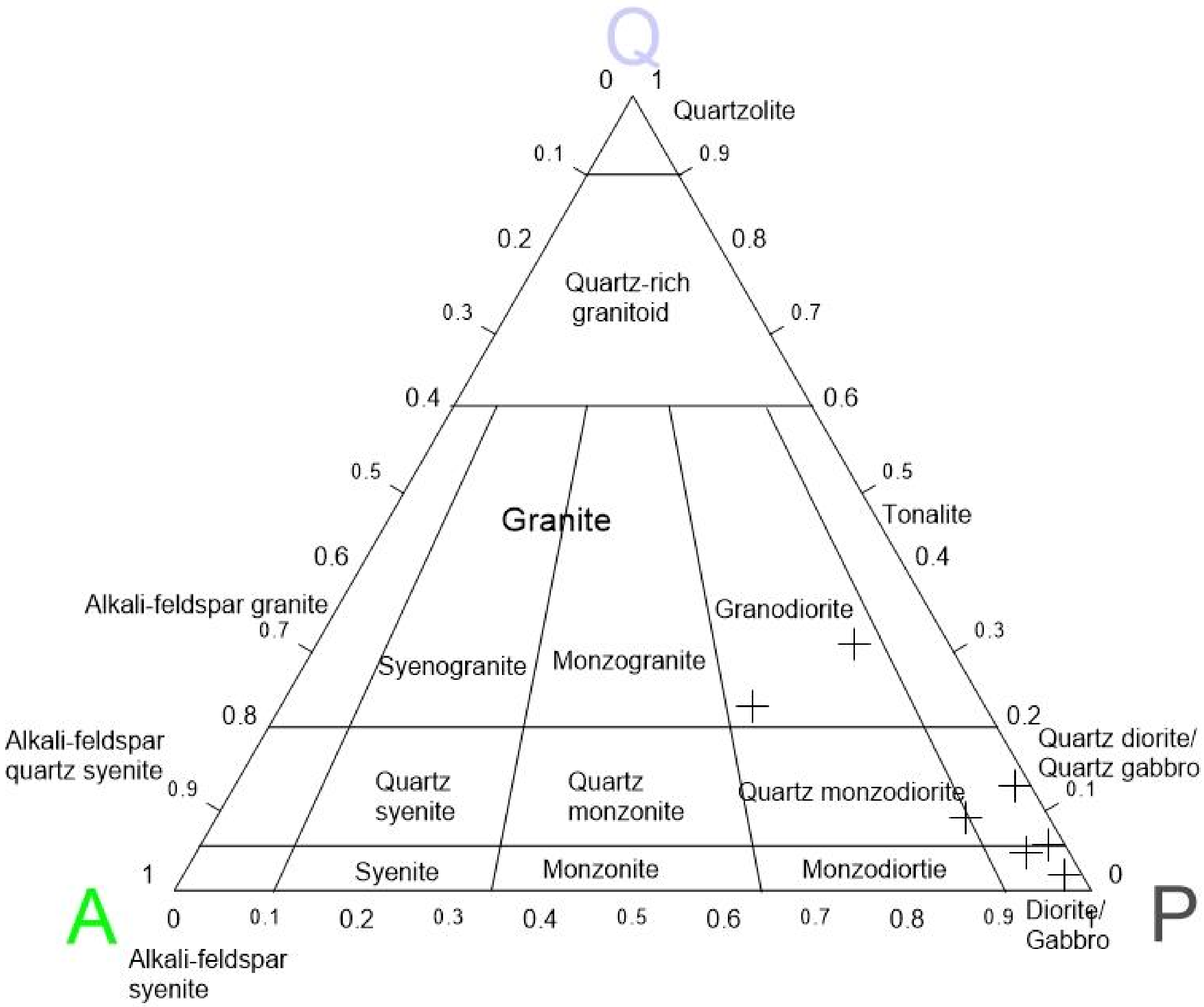



Table 3.2. Classification of the Majeed kot and Kwarangal Granitoids on the basis IUGS triangular plot after Le Maitre (2002), all the studied samples fall in the field of Grandodiorite, Diorite, Quartz Diorite, Quartz monzodiorite.

Symbols: A: Alkali-feldspar, P: Plagioclase, Q: Quartz

### 3.3.1 Granitoids

The host rock essentially consist of plagioclase, quartz, Orthoclase, biotite, tourmaline, garnet with few accessory minerals discussed below,

Compositionally Quartz occurring in most of these rocks shows a wide range of modal proportion (4-20 %). Almost all quartz grains display undulose extinction (Fig. 3.4a). However, some of the studied samples display mortar or flaser texture whereby clustering of unstrained fine-grained quartz separate (Fig. 3.4c) reflects the strain-induced syntectonic recrystallization and is the evidence of shearing and deformation in these rocks. Strain has caused the quartz crystal to deform into domains with slightly different extinction angles (Fig. 3.4b). Typical for quartz, but not feldspars.

Among the Feldspars. Plagioclase feldspar is abundant and dominated the modal mineralogy. The crystals have radiating and interlocking texture in some places making QF domain (Fig. 3.5b). In some parts the plagioclase grains have cloudy appearance because of partial alteration. The alteration products include clay minerals, sericite, muscovite, epidote (Fig. 3.6a) and chlorite (Fig. 312a). hence, the processes of alteration are largely sericitization and saussuritization. Albite and polysynthetic twining are very common (Fig. In some places bite texture due to alkali silica reaction (Fig. 3.5d). Some of the plagioclase phenocrysts are zoned (Fig. 3.5a) .Coronas (reaction rims) and patchy zoning is quite common (Fig. 3.5c). Ateration to fine-grained material typically occurs along fractures, twin planes, or cleavages (Fig. 3.5c).

The orthoclase feldspar is very sparse and show very less percentage overall, ranging from 2 to 6% of the overall model mineralogy. Perthite Exsolution is observed in grains (Fig. 3.5b). While also display the intergrowth of alkali feldspar and quartz in the form of graphic texture (Fig. 3.4b).

Flaky Biotite is very much abundant and comes second after plagioclase in modal mineralogy having radiating (Fig. 3.7a) and interlocking texture (Fig. 3.7d). In some places altered to chlorite and epidote (Fig. 3.12b). Alkali silica reaction showing bite texture (Fig. 3.7e) and iron rich brackish red biotite is very common (Fig. 3.7b).

Tourmaline constitute 10% of modal minerology and ranges from 1514-808µm. The crystals are zoned, have rounded to flaky appearance (Fig. 3.8a), and occur as coarse discrete grains with few as nodules (Fig. 3.8b). These are most probably formed by the injection of residual boron-rich magmatic fluids along fractures in the already crystallized granitoids.

Muscovite is also common especially in those samples showing some fabric development (Fig. 3.6b). Some of the muscovite grains have diffused margins with associated biotite grains which suggest that these muscovite grains might have formed at the expense of biotite (Fig. 3.7f). Such a relationship also suggests topotaxial growth of muscovite over biotite. Topotaxial growth is the conversion of a single crystal into one or more products which have a definite crystallographic orientation with respect to the original crystal (Shannon and Rossi, 1964).

Medium to fine sized euhedral to sub hedral grains of epidote and clinozoisite mostly associated with sericite are also observed in some of the studied samples (Fig. 3.9a). Some epidote grains are distinctly zoned. The zoning is indicated by a marked difference in interference color within individual grains. Such zoned grains have bluish interference color along the margins and yellowish/pinkish interference color in the core, indicating low (-medium) grade prograde metamorphism of these granitic rocks (Fig. 3.9b). The mode of occurrence and association suggest that epidote formed by the alteration of amphibole and plagioclase.

Relatively larger, colorless grains of Garnet also occur in some of the studied samples (Fig. 3.10a). These grains may be magmatic in origin. The grains of garnet are uhedral to sub hedral and ranges from 100 to 700µm. Fracturing is commonly observed (Fig. 3.10b).  Although mostly found in pegmatites and aplitic dykes, magmatic garnet is also reported to occur in felsic to very felsic per-aluminous granitoids (e.g. du Bray, 1988; Kebede et al., 2001). Dahlquist et al. (2007) used such a magmatic garnet as a geothermobarometer.

Trace amounts of sphene occur in some of the studied samples. It is mostly associated with biotite (Fig. 3.11a). It occurs as small discrete grains as well as disperse flexes as thin rims (Fig. 3.11b).

Subhedral to anhedral Amphibole (spodumene) occurs as medium to coarse sized discrete grains displaying strong pleachroic color in cross light (Fig. 3.12a) and partial alteration to chlorite, biotite, epidote and clay minerals. (Fig. 3.12b).

Black ores (isotropic minerals) (Fig. 3.13a,b)is quite common having prominent coarse discrete grains and contributing 10% to modal mineralogy (Fig. 3.13c).

### 3.3.2 Mineralogy of pegmatites

As most of the grain size is very coarse grained so it was quite hard to make a thin sections. So by visual estimation the average composition of the spodumene pegmatites is estimated as: 30% Quartz, 24% Albite, 25% spodumene, Tourmaline 8% K-feldspar, 6% muscovite, Garnets 3%, 4% Beryl and 3% others .

The spodumene-bearing pegmatites are the most common spodumene-bearing rocks in the Kwarangal region (Fig. 3.15b) while that of Majeed kot have less spodumene mineralization (Fig. 3.15a.). Spodumene pegmatites consist of two textural elements: 1) the medium- to coarse-grained pegmatitic fabric composed of quartz, albite, spodumene, tourmaline, and micas (Fig. 3.15b,c,d,) and 2) the altered albite quartz-mica fabric that replaces the medium- to coarse-grained texture. (Fig. 3.16d).

White to light green spodumene forms large, fractured crystals in the spodumene pegmatite. The spodumene content of individual dikes varies from 5 to 35 vol%. Uncommonly, there is slightly more spodumene toward the center of pegmatite dikes .The spodumene grains are generally free of inclusions. Edges of the spodumene crystals are typically sharp. Large crystals of spodumene are generally fractured, and in some cases, completely broken into distinct fragments. Fractures in spodumene crystals are typically healed with the fine-grained albite–quartz fabric or, less commonly, with fine-grained muscovite (Fig. 3.15c). Well-developed Quartz crystals with dimension reaching upto 4 inches (Fig. 3.15a). Fine-grained, bluish to colorless beryl (aquamarine) is commonly associated with spodumene along with garnets in Kwarangal area (Fig. 3.15e).

This rough estimation is based on surface exposures and samples, no drilling, trenching, or underground workings have been carried out. The calculated reserves include only a few of the pegmatite deposit in the previous works. Unevaluated resources are probably much larger. Till now No reserves are available for the gemstone-bearing pegmatites.

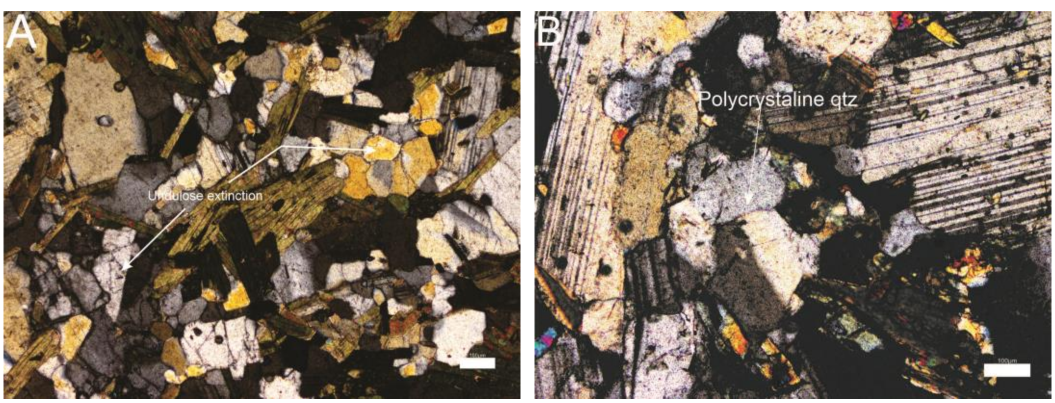



Fig 3.4. Photomicrographs Quartz (XPL): (A) Undolose extinction in Quartz grains; (B) Polycrystalline Quartz grain; (C) Mortar texture in quartz grain.

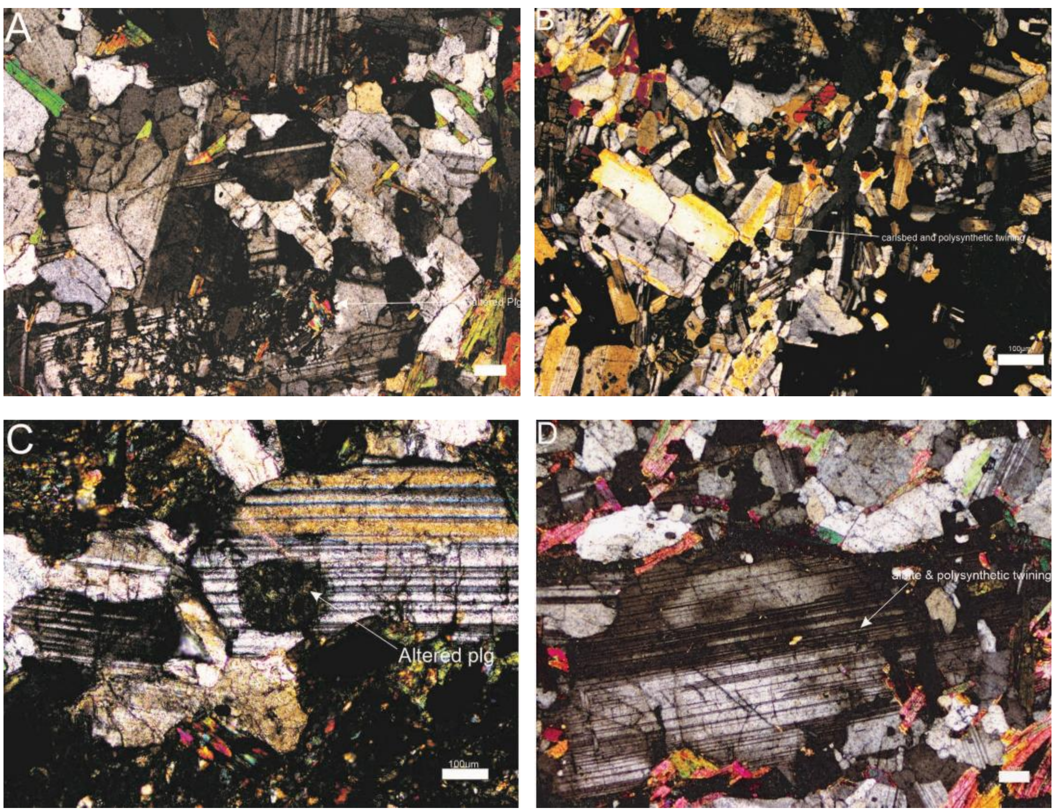



Fig. 3.5. Photomicrographs plg (XPL): (A) Altered Plagioclase grain; (B) Grains showing Carlsbed and Polysynthetic twining; (C) A Phenocryst of Zoned Plagioclase; (D) Albite twining in Plagioclase.

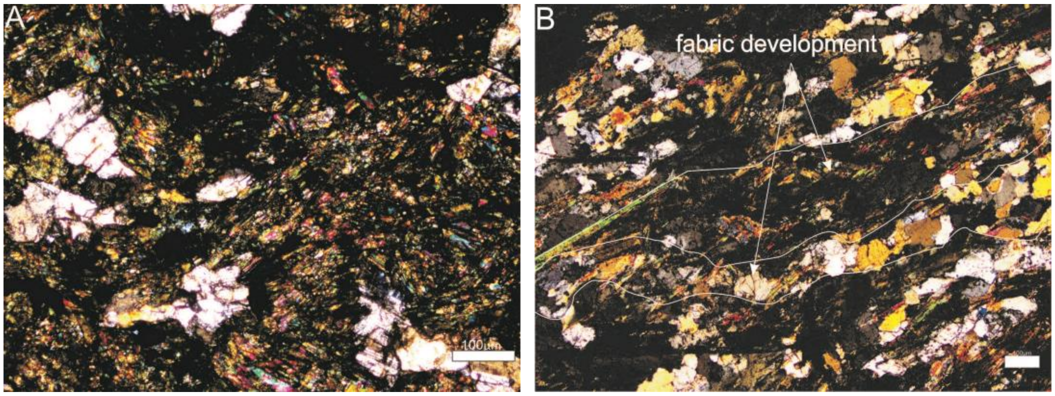



Fig. 3.6. Photomicrographs (XPL): (A) Altered Plagioclase into chlorite, biotite, epidote and Sericite; (B) Fabric development in Quartz Mica-schist.

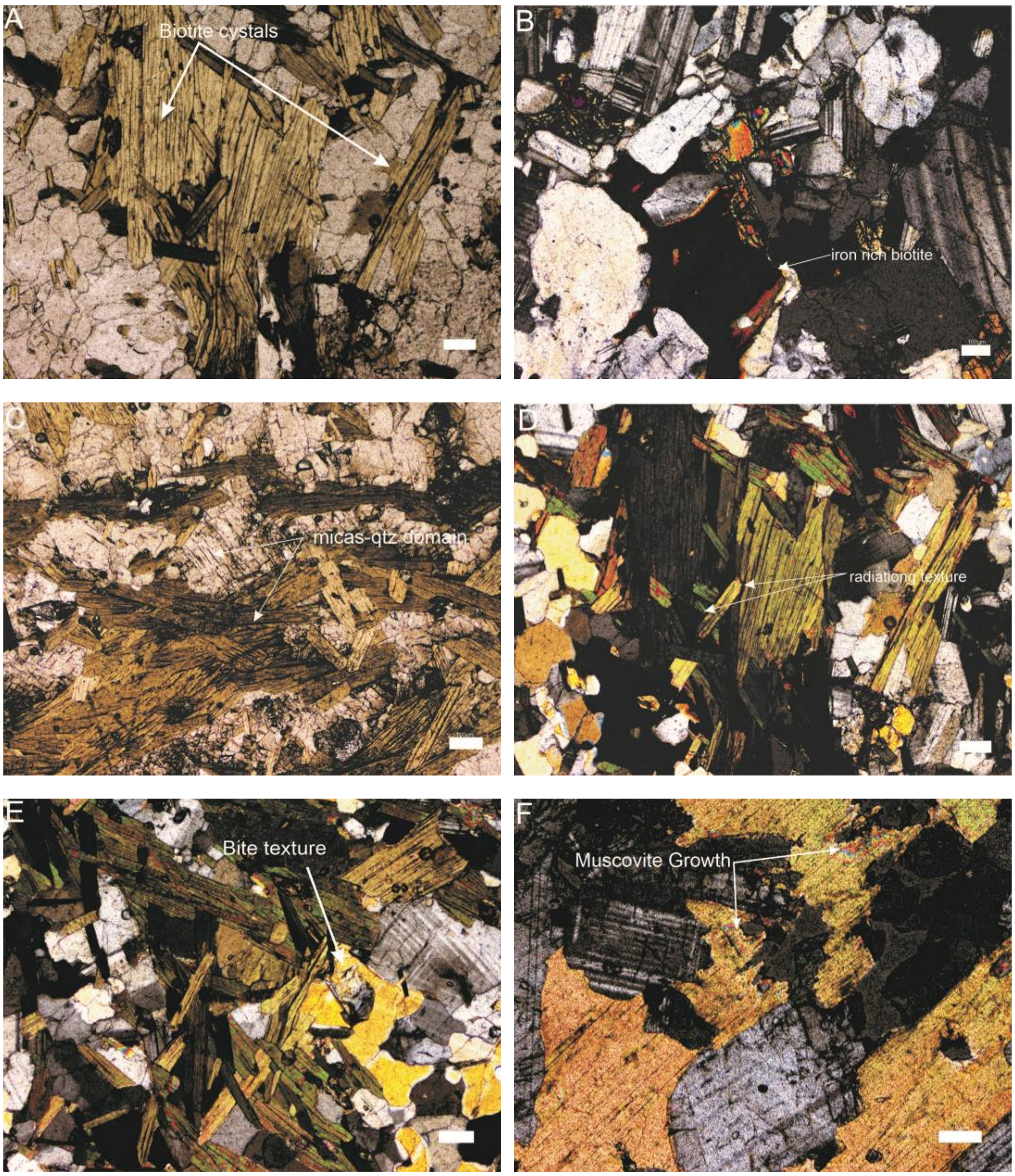



Fig. 3.7. (A) Photomicrograph of Biotite crystal's (PPL) ; (B) Photomicrograph of Iron rich Biotite (XPL) ; (C) Photomicrograph showing Mica-Quartz domain; (D) Radiating texture in biotite (XPL); (E)

Photomicrograph showing bite texture; (F) Photomicrographs showing topotaxial growth of muscovite above biotite.

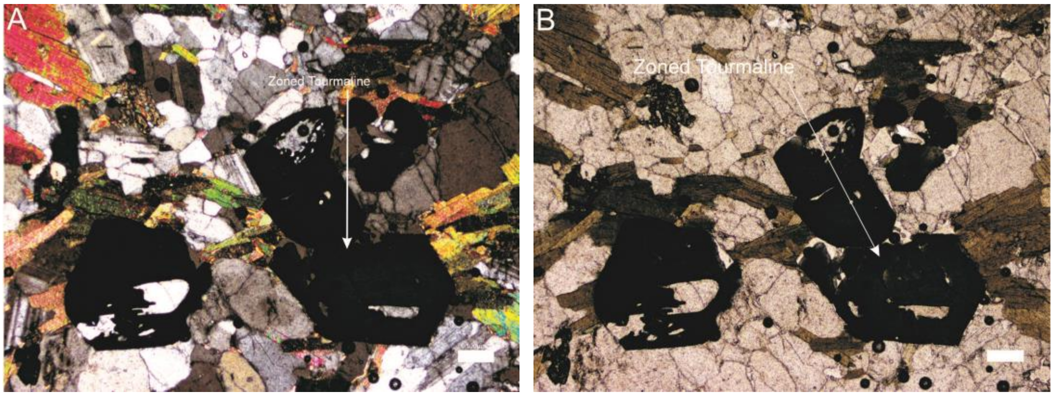



Fig. 3.8. (A), (B) Photomicrograph of Zoned tourmaline crystals in both cross polarized and plain polarized light.

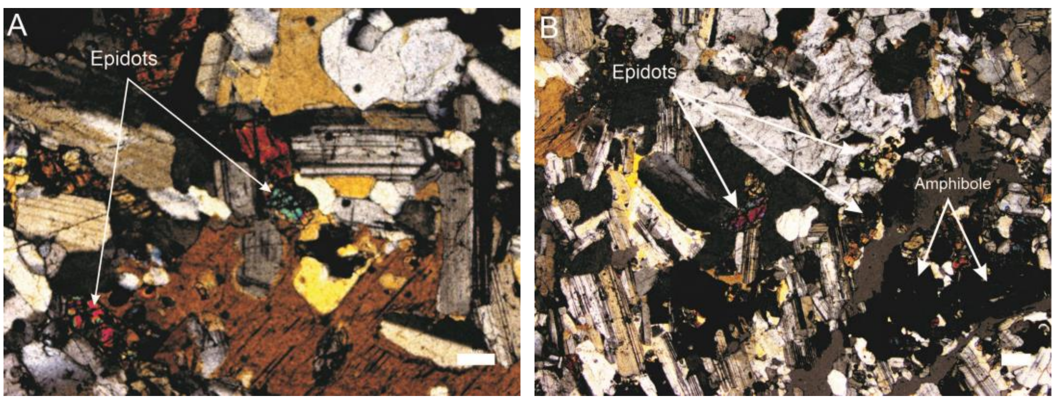



Fig. 3.9. (A) Photomicrograph of Epidote crystal’s (XPL); (B) Small crystals formed by the alteration of biotite, amphibole and  plagioclase (XPL).

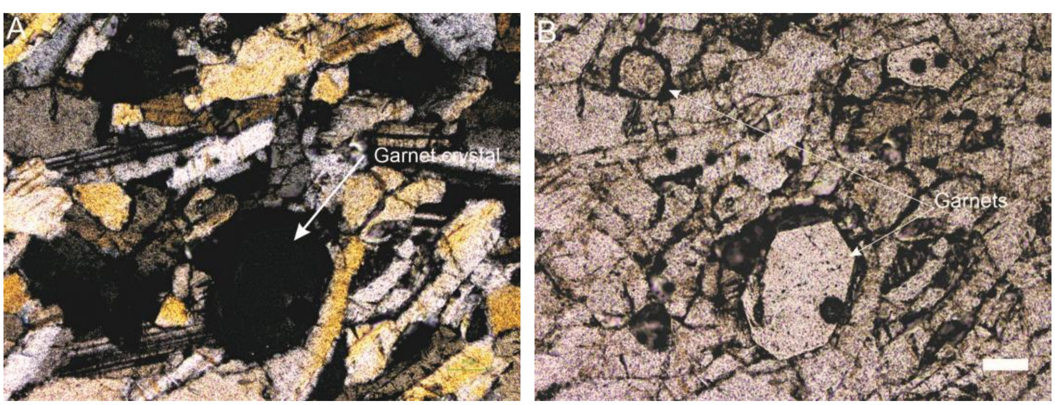



Fig. 3.10. (A), (B) Photomicrograph of Garnet crystal’s in cross polarized and plain polarized light.

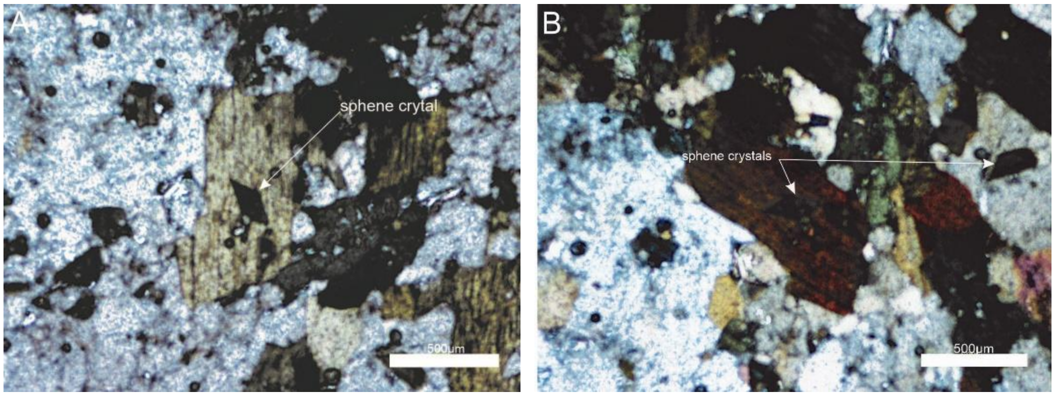



Fig. 3.11. (A) Photomicrograph of Sphene crystal in-between biotite (PPL); (B) Flexes of sphene crystals (XPL).

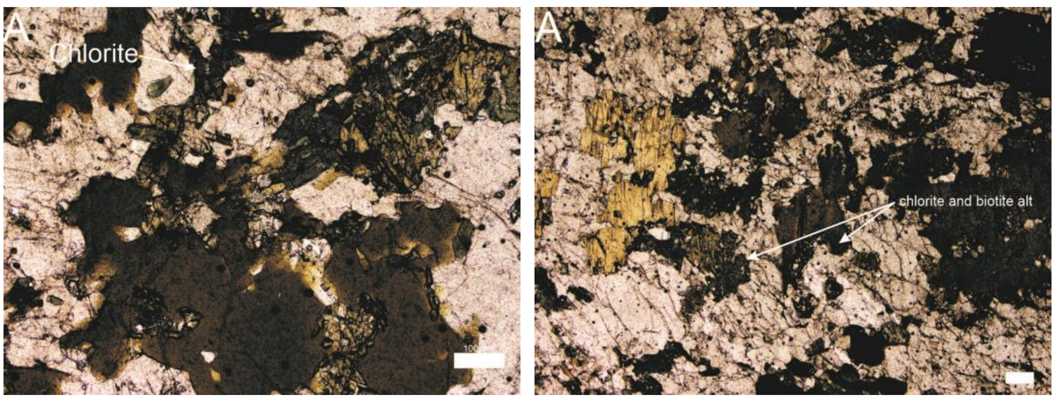



Fig. 3.12. (A) Photomicrograph of Chlorite crystal's (PPL); (B) Photomicrograph showing alteration of plagioclase into Biotite into Chlorite (PPL).

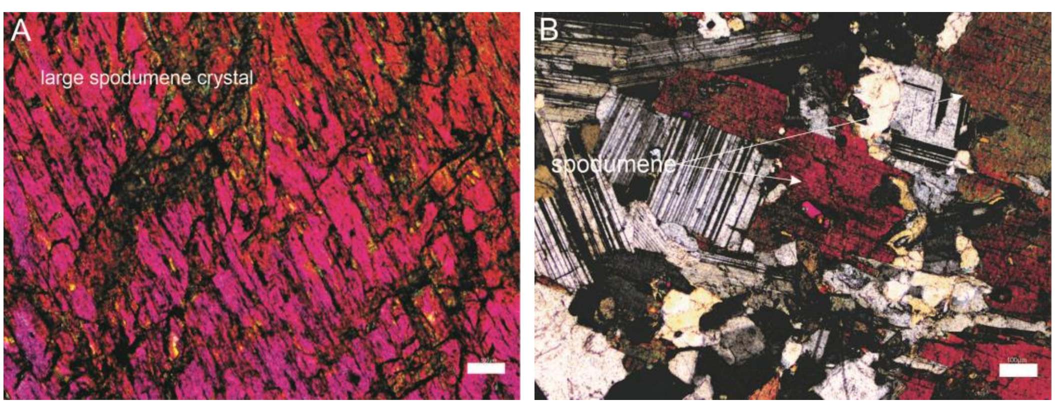



Fig. 3.13. (A) Photomicrograph of large spodumene crystal (XPL); (B) Altered spodumene crytals at the expense of plagioclase (XPL).

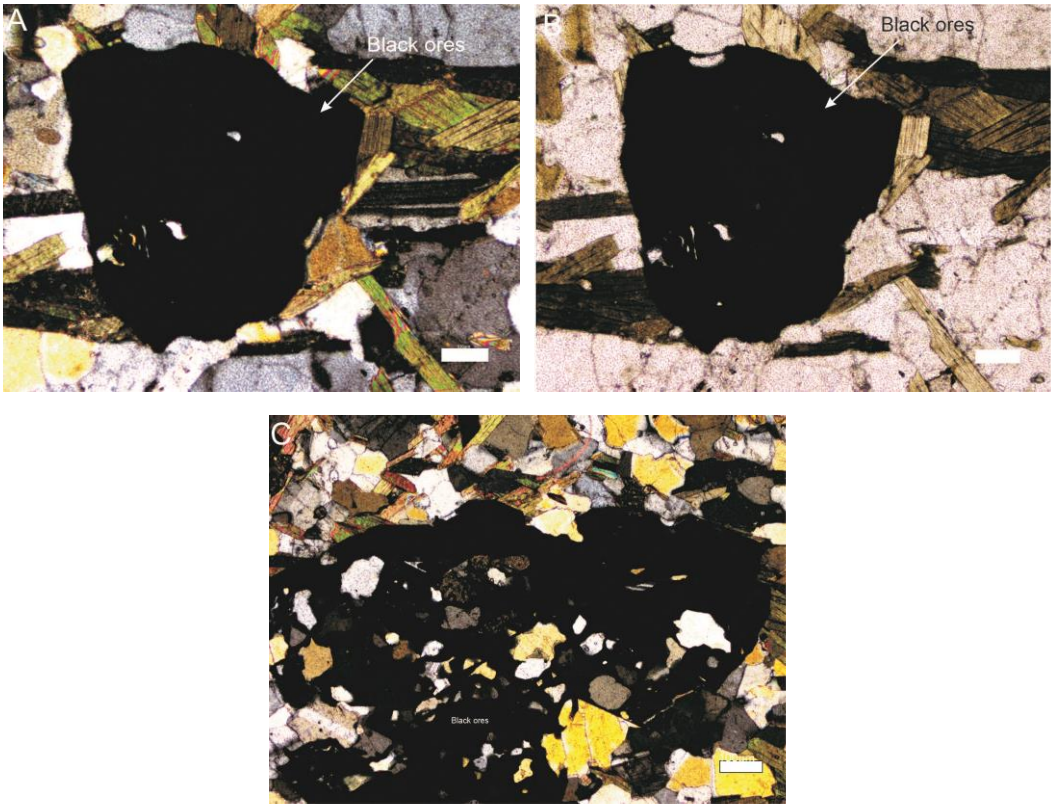



Fig. 3.14. (A), (B) Photomicrograph XPL: of isotropic black ores in both plane polarized and cross polarized light; (C) Photomicrograph of isotropic minerals covering the whole section view (XPL).

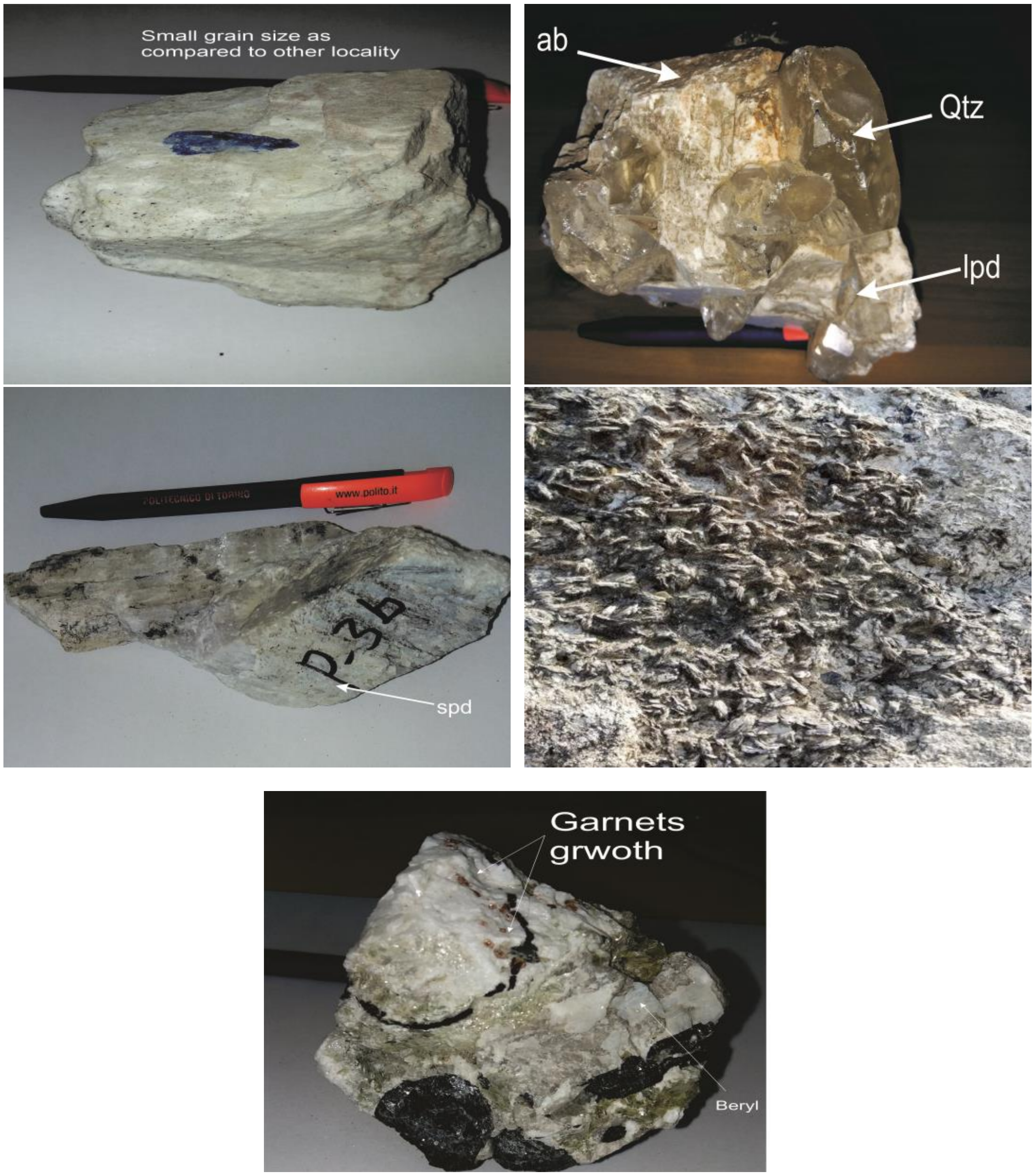



Fig. 3.15. Hand specimens photographs: (A)Fine grained pegmatite in Majeed kot location; (B) Well developed crystals of Quartz and albite; (C) Large spodumene crystal; (D) Micas growth in kawarangal location; (E) Beryl and garnets growth in Kawarangal locality.

# 4 X-RAY DIFFRACTION ANALYSIS

### 4.1. X-Ray Diffraction (XRD) analysis

X-ray diffraction (XRD) is a basic tool in the mineralogical analysis of economic minerals. It is an analytical technique primarily used on a crystalline material to identify its phase and can provide information on unit cell dimensions. It is most widely used for the identification of unknown crystalline materials (e.g. minerals, inorganic compounds). From a small area, XRD measures the intensities of a reflected area and from the results obtained; the atomic-level spacing of the crystal can be calculated. This helps in understanding the crystal structure of the substance. Determination of the degree of crystallization can also be calculated with the help of XRD. Furthermore, XRD also helps in identifying different phases with identical compositions such as the state of atomic order. Due to this versatility, XRD finds a wide range of applications in geology, material science, and environmental science.

### 4.2. Methodology

The X-ray diffractometer consists of three basic elements i) An X-ray tube ii) A sample holder iii) An X-ray detector. X-rays are produced in a cathode ray tube by heating the filament 56 to produce electrons and accelerating them to the target material by applying a voltage. As the sample and detector are rotated, the intensities of diffracted X-rays are recorded. When Bragg's equation is satisfied, it means that the geometry of diffracted X-rays shows constructive interference and peak shows up in the diffractogram. The detector, which is present inside the diffractogram, records that intensity. This intensity is then converted into a count rate, which is displayed and recorded into the monitor. The geometry of the diffractometer is such that the sample rotates the X-rays beam 36 at an angle of θ, whereas X-rays, which are diffracted, rotates an angle of 2 θ. The goniometer rotates the sample and detector.
The sample was ground to powder and then the sample was put in the sample holder of the X-ray diffractometer and a test was conducted on it.

### 4.3. Results

XRD was used to identify different phases associated with the host rock and Pegmatite's veins. The associated minerals which are identified in host rock are Albite, Orthoclase, Microcline, illite and Quartz. While in pegmatites, Oxy-schorl Tourmaline, and Spodumene (Triphane) were identified (Fig.4.1-4).

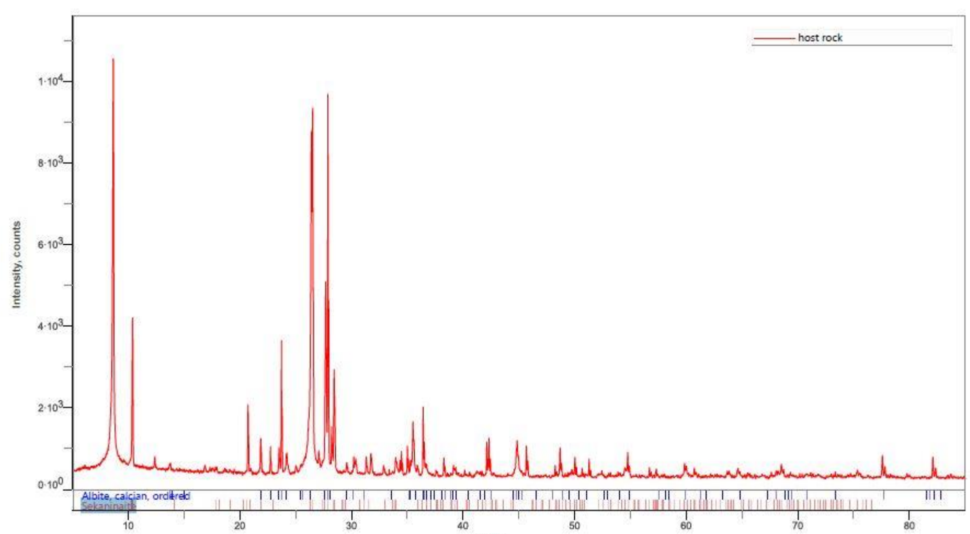



Fig. 4.1. XRD patterns of Host rock (H2A)

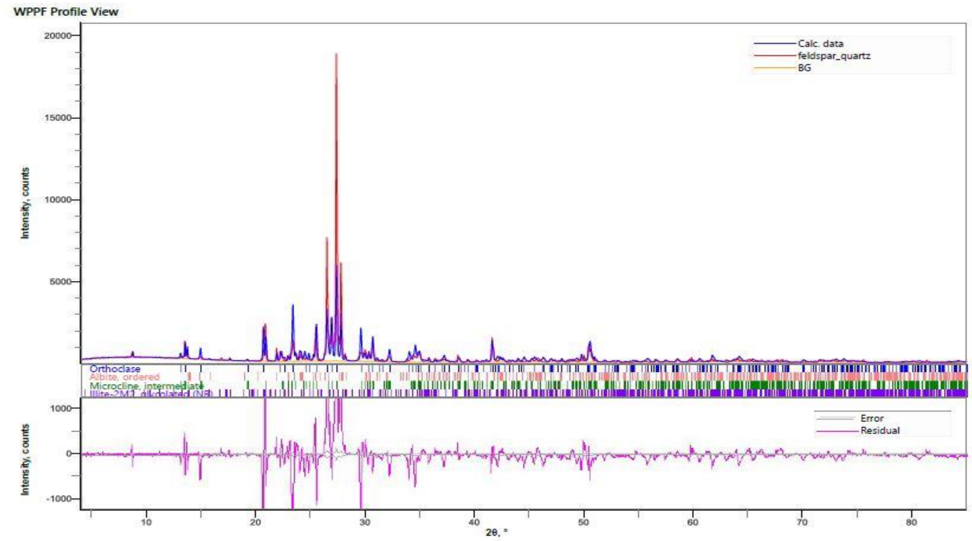


Fig.4.2. XRD patterns of host rock (H3A)

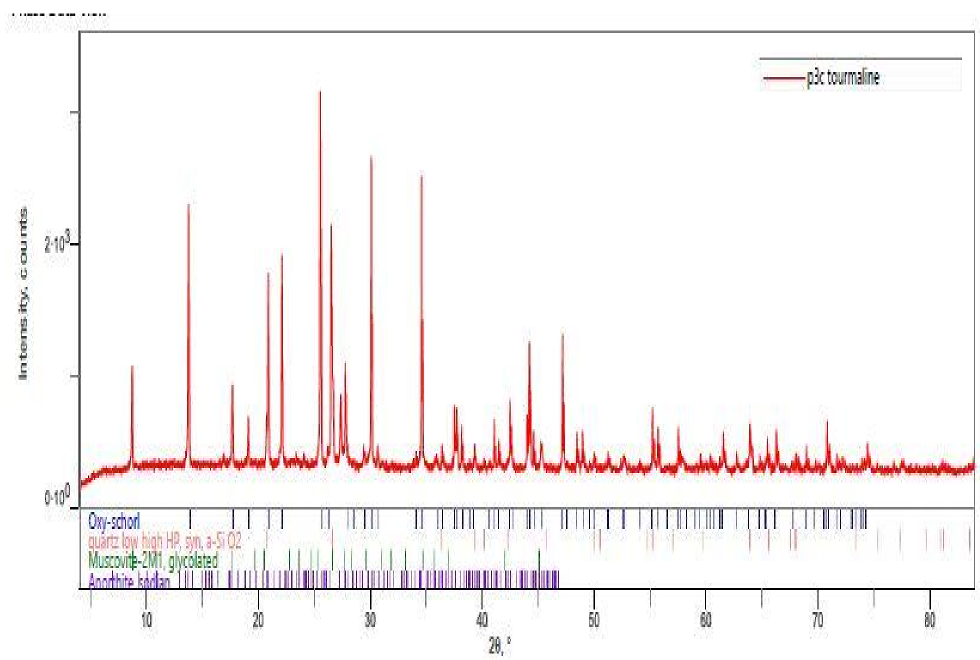


Fig.4.3. XRD Patterns of Pegmatite (P3C)

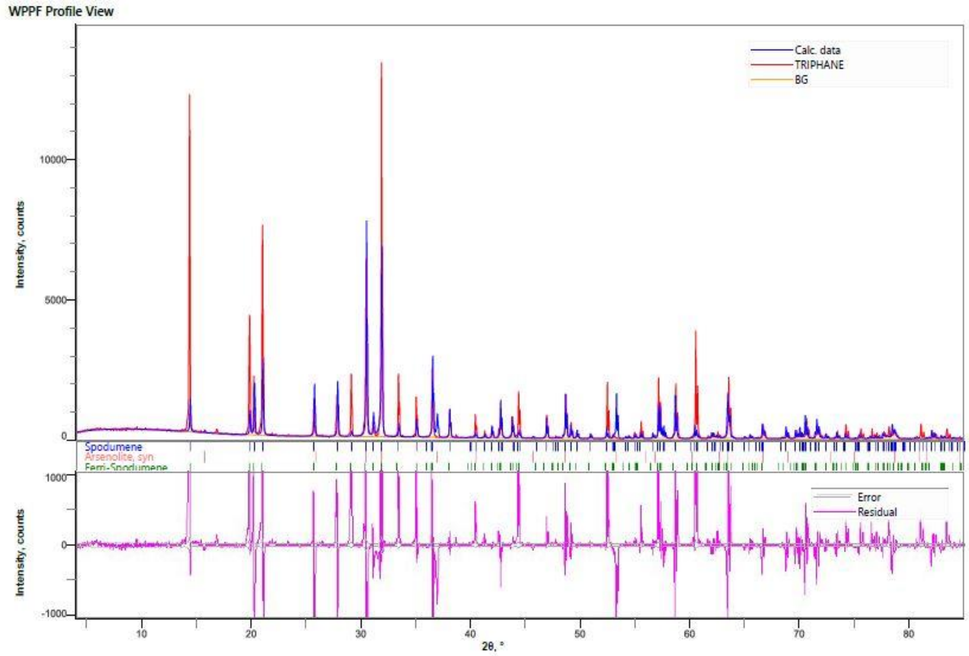



Fig.4.4. XRD Patterns of Pegmatite (P2C)

# 4 GEMOLOGICAL PROPERTIES OF SPODUMENE

## 4.1 General statement

Gemology is the science which deals with the study of the technical aspects of gemstones and gem materials and the use of these aspects for identification purposes (Kiefert et al., 2000). Gemstones are properties, such as pleochroism. The physical property such is "hardness" is defined by the Mohs scale of mineral hardness. Gemstones are timeless treasures of nature, which do not only represent objects of beauty and intrigue but also signify for most valuable commodities on the earth surface. The extraordinary and satiated colors of many gemstones enhance their aesthetic beauty and make them highly valuable. When mankind first picked a stone from the ground for its innate beauty rather than as a tool or weapon, this symbolized an important event in the evolution of gemology.

Gemstones have more tangible properties so it needs detail study to quantify its authenticity and economic value which are mostly based on gemological parameters. Gemology covers a number of aspects of gem material such as basic identification, polishing, fashioning and distinguishing natural samples from treated and synthetic ones.

## 4.2 Methodology

During fieldwork, some spudumene crystals were collected which are analyzed at Gems and Jewelry Centre of Excellence (GJCOE) University of Engineering & Technology, Peshawar for gemological characteristics**.** Five samples of the green Hiddinite, Pink Kunzite and Triphane have been selected and polished its surface for evaluating its gemological properties. Different gemological instruments were used such as Refractometer, Gemological binocular-microscope, Spectroscope, Chelsea-Color Filter, Ultra-Violet light, Hardness pencils, Hydrostatic machine, and loupe. Listed below tests have been carried out for the identification of mineral.

1. Refractive index.
2. Specific Gravity.
3. Hardness.
4. Microscopic Study (Inclusions).
5. Spectrum.
6. Ultra-Violet light.
7. Chelsea Color Filter.

### 4.2.1 Refractive index

The ratio of the velocity of light in a vacuum (c), to its velocity in a specific medium (v).

$n = c/v$

For the determination of refractive index, we used a standard refractometer and R.I fluid (Fig. 5.1 A). The sample's surface is polished for the accurate determination of R.I values and the glass of refractometer is cleaned by a soft cloth. Then put a small drop of R.I fluid (Di-iodomethane) of almost less than 1 mm. The sample is placed on the glass of refractometer by sliding it. Then press the stone gently from the top in order to spread the R.I fluid and to remove the air trapped. The lid of the refractometer is then closed. For determining the readings, observation is taken through the eye-piece of the refractometer. A shadow appears on the scale fitted inside the refractometer which terminates/ends on the value of almost 1.660-1.676 (Fig. 5.1 B). After then the polarizer is rotated, but the shadow fluctuate confirming that it is inisotropic. For precise reading, the sample has been rotated in all directions. The R.I value indicates that the sample is spodumene (Herve Nicolas Lazzarelli, Blue Chart Gem Identification, 2015).


**Fig. 5.1.** (A) Standard Refractometer with R.I fluid (Di-iodomethane);
(B) Termination of the shadow of refractive Index showing the value of 1.660.

### 4.2.2 Specific Gravity

Specific gravity is the ratio of the density of a substance to the density of a reference substance; equivalently, it is the ratio of the mass of a substance to the mass of a reference substance for the same given volume. Apparent specific gravity is the ratio of the weight of a volume of the substance to the weight of an equal volume of the reference substance. The reference substance is nearly always water at its densest (4°C) for liquids; for gases, it is air at room temperature (21°C). In gemology it is actually the ratio of the weight of a substance in air to the difference of its weight in air and water.

S.G = Wt. in air/Wt. in the air - Wt. in water.

For determining specific gravity we use the standard Hydrostatic weighing machine (Fig. 5.2). For determining specific gravity, the sample is placed in the upper pane of the balance for finding its weight in air. Then placed it in the lower spiral pane and noted its weight in water. By putting both the values in the given formula.

S.G = Wt. in air/Wt. in air - Wt. in water.

S.G = 3.18.

Specific Gravity is dimensionless, as it is the ratio of same quantities. After comparing the obtained value with the given standard table, the result matches with serpentine (Herve Nicolas Lazzarelli, Blue Chart Gem Identification, 2015).

Fig. 5.2. Standard Hydrostatic weighing-Machine for measuring specific gravity.

### 4.2.3 Hardness

The resistance of a mineral to scratching is called hardness. Every mineral has its own unique hardness. There is a well-known comparative scale for hardness designed by a German geologist and mineralogist Friedrich Mohs in 1812. On which different minerals are placed according to their specific hardness in which Talc having scale "1" being the softest and Diamond having scale "10" being the hardest mineral.

1. Talc.

2. Gypsum.

3. Calcite.

4. Fluorite.

5. Apatite.

6. Orthoclase/Feldspar.

7. Quartz.

8. Topaz.

9. Corundum.

10. Diamond.

For checking the hardness of sample "hardness pencils" of different hardness from 2 to 9 is used (Fig. 5.3). The hardness pencils are rubbed on sample's surface one by one state at least from 2 to onward. The sample has not been scratched on the pencil having hardness “4”, means that its hardness is above 4. After I found the hardness in the range from 6 – 7. (Herve Nicolas Lazzarelli, Blue Chart Gem Identification, 2015).

Fig. 5.3. Standard hardness pencils ranging from 2 to 9 hardness.

### 4.2.4 Spectrum

The distribution of colors produced when white light is dispersed by a prism or diffraction grating. There is a continuous change in wavelength from red, the longest wavelength, to violet, the shortest. Seven colors are usually distinguished: violet, indigo, blue, green, and yellow, orange, red as shown in Fig. (5.6).

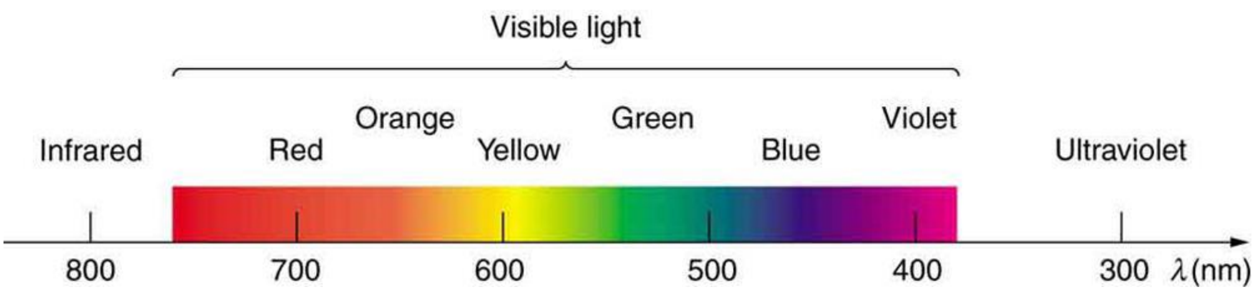



Fig. 5.4. Range of visible portion of light spectrum from red (700nm) to blue (400nm).

Every mineral has its own specific absorption spectrum. The absorption spectrum is basically the vertical black lines and/or bands produced in the rainbow colors due to absorption of a particular wavelength of light. For the determination of spectrum diffraction grating spectroscope is used (Fig. 5.5). The sample is placed on the fiber optic light source and turns on the light source. Then spectroscope is placed above the sample to see its absorption spectrum. There is huge absorption after +/-450 nm. Which shows that it is Kunzite or hiddenite.


Fig. 5.5. Standard diffraction grating spectroscope

The sample is cleaned to remove dust and organic material. Then placed on a black non-reflecting pad. After then LWUV is turned on, the sample gives a weak whitish green glow. Then switched on the SWUV, the sample remains inert. Williamsite is also inert to whitish-green (Herve Nicolas Lazzarelli, Blue Chart Gem Identification, 2015). So this test confirmed that it is Williamsite.

### 4.2.5 Color-Change

The light transmitted by a colored mineral can be analyzed with color filters. In gemology, a Chelsea Color Filter is a dichromatic optical filter used for identifying colored stones/minerals. Standard Chelsea color filter is used for this test (Fig. 5.6).

The sample is placed on a sheet of white paper. Bright tungsten light source is used. Then placed the filter close to the eye. The sample remains inert means no change in color. This test is used for confirmation of Kunzite. While heddinite has changed its color to red/pinkish while some didn't change its color. Which means they are Green Spodumene. (Herve Nicolas Lazzarelli, Blue Chart Gem Identification, 2015). As it is inert to Chelsea color filter so it confirms that it is Kunzite.


Fig. 5.6. Standard Chelsea-Color Filter (C.C.F).

## 4.3 Overall Conclusion

From all these tests it is concluded that the sample is Kunzite, Hiddenite which is the gem variety of Spodumene. The Spodumene of Kwarangal, Dara-i-Pech Kunar, Afghanistan is found in sizeable amount both in gem variety and also for commercial use. Hence, these are economical both in terms of its extent and quality.

# 5 CONCLUSIONS AND RECOMMENDATIONS

## 5.1 Conclusions

The various details regarding field features, petrographic observations, and Gemological properties of rocks from Majeed Kot and Kwarangal area are presented in the previous chapters. These discussions lead to the following conclusions:

1. Field features and Petrographic studies of pegmatites suggest that these pegmatites are spatially and genetically related to Oligocene-age which represent the youngest of three phases of the Laghman intrusive complex.

2. From field features the rocks are generally small, with dimensions on the order of 1 to 5 km. These intrusions are commonly elongated layer-like bodies that are conformable with the strike of the surrounding rocks and are commonly located along major northeasterly striking faults.

3. The structural disposition of the pegmatites in various pegmatite fields is determined by either the host rock lithology or by the structural history of the host rocks, or both. Pegmatites are characterized as (1) steeply dipping veins, (2) flat to gently dipping sills, are developed mainly in gabbroic and diorite bodies. While the steep dipping occur in schist and form linearly elongated zones.

4. In some of the rocks in some cases cut by the faults, and in others, they apparently are guided by the faults and some may cross the faults. This suggests that some fault movement occurred subsequent to formation of these rocks.

5. In the Kwarangal field, veins are tabular, steeply-dipping and confined to deep-seated fracture zones in quartz-mica schists. The thickness and width have increased enormously with some reaching almost 25meters in width.The grain size are coarse and very rich in tourmaline, Micas, albite and spodumene. In some parts the crystal of schorl and Spodumene reaches 11cm in size.

6. Dara-i-Pech Pegmatite field exhibit vertical zonation from relatively barren pegmatites to those enriched in the rare metals.

7. Some of the unclassified pegmatites are also encountered which haven't reported before.

8. From Field features and petrographic studies, The igneous rocks of the Majeed Kot and Kwarangal area are broadly divided into two categories:
    a) Granitoids: These granitoids are predominantly mega-porphyritic; however, fine grained massive and foliated varieties are also present along shear zones. Besides, fine-grained granitic dykes also cut across these rocks at places. Some of the studied samples display mortar texture whereby clustering of unstrained fine-grained quartz separate, reflects the strain-induced syntectonic recrystallization and is the evidence of shearing and deformation in these rocks.
    b) Pegmatite Veins: Most of the veins in both the locations are gentle dipping almost 30° with no overprints of regional tectonics while some in Kwarangal have steep dips that reaches almost 50°. The tabular, gently-dipping veins found in gabbro-diorite massifs, where the veins are mostly confined to the contraction fissures. Primary magmatic features i.e. zoning because of the evolved chemistry as the joint expanded, increasing of grain size from side to core were visible. Steeply dipping veins appear to contain most of the important lithium deposits and occurrences.

9. In both the locations of interest the generalized sequence of pegmatites is 1. barren pegmatites of granitic texture, with magnetite and biotite; 2. barren plagioclase-microcline pegmatites, partly graphic, with biotite and schorl mostly in Majeed Kot. While 3. zoned microcline-albite pegmatites with beryl extensively replaced, with lithium and boron mineralization; 4. relatively homogeneous albite-spodumene pegmatites with minor beryllium, tantalum mineralization; 8. Essentially quartz veins with minor feldspar(s) and one or more of beryl are in Kwarangal locality.

10. From all the tests conducted for Gemological studies and analyzing hand specimens it is concluded that the crystals is Kunzite, Hiddenite, triphane, the gem varieties of Spodumene. Sizeable amount of gem varieties and museum quality crytals of Quartz, triphane and schorl are encountered and can be used for jewelry making.

## 5.2 Recommendations

- The pegmatites in the Dara-i-Pech pegmatite field can be compared to the LCT family of pegmatites, which exhibits an accumulation of lithium, niobium, cesium, and tantalum along with rubidium, beryllium, tin, boron, phosphorous, and fluorine. Maybe derived mainly from peraluminous S-type granites.

- The lithium-rich magmas responsible for the spodumene-bearing rocks of the Dara-i-Pech may be derived by the anatexis of lithium-bearing sedimentary rocks. But more work is needed on the granite to verify the relation.

- Vertical Zonation by Fenogenov and Musazai (1989) are essentially albitic with rare spodumene; small phenocrysts beryl and tantalite-columbite; microcline-albitic with ore, screened beryl, and tantalite-columbite; but there might be some more zonation's of pergmaties.

- As previously reported that the pegmatites are oligoclase-microcline, schorl tourmaline-biotite-muscovite (barren) pegmatite. But my study suggest that the pegmatites are albite-spodomene, schorl tourmaline-biotite-muscovite with beryl.

- The Laghman intrusive complex is separated into three main phases. Phase I rocks of the Laghman intrusive complex include diorite, quartz diorite, granodiorite, tonalite, granosyenite, and plagiogranite (Abdullah and Chmyriov, 2008). As previously said that most of the rare metal pegmatites lies in the third phase but I also encountered in the first phase. More precise work is need to demarcate these phases and their related mineralization.

- Some of the petrographic features, discussed in earlier chapters, indicate that the Dara-i-Pech granitoids have experienced a low (-medium) grade progressive metamorphism. A detailed investigation of intra- and inter-granular variation in the chemical composition of some of the mineral phases, especially epidote and garnet, would help in finding out the sense and conditions of metamorphism.

- Exploration and assessment of these pegmatites for economic concentrations of rare metals may be facilitated by their size and probably excellent exposure in the mountainous terrain. Access to this area is limited due to poor infrastructure.

- Some rare elements, mainly those that support high-technology industry, have an increasing Demand due to their variety of uses in new technologies. Among these elements, also known as High-technology metals, Li are in high demand owing to their use in capacitors for wireless Technology, in battery applications, and in liquid crystal displays (LCD) and touch-screen displays. Li can occur in high concentrations in pegmatites and occasionally form ore deposits. Consequently, data to improve the prospecting criteria for rare metal ores in pegmatites are critical for the localization of undiscovered resources.

- The pegmatites in northeastern Afghanistan are described as the largest concentration of lithium-bearing pegmatites in the world (Rossovskiy and Chmyrev, 1977) and could be considered as the world's recognized future principal source of lithium both in terms of its extent, grade and can be extracted economically.

- The detailed geophysical survey will be helpful in estimating the tonnage data of these deposits and if proved economical, these will raise the socio-economic conditions of the area.

- The geological conditions suggest that pegmatite deposits of Dara-i-Pech, are characterized by a Remarkably expressed Li, Be, Ta and Sn anomaly. The huge spodumene deposits, deposits of tantalum and beryl, in the nearby areas.

- Systematic mining procedures should be applied in order to increase the production. Gemmi crystals of kunzite, hiddenite, tourmaline, and beryl should be properly extracted by advanced techniques which can minimize the chances of breaking. Which in turn can play an important role in Jewelry industry.

- All the mining activities should be carried out under the supervision of onsite mining geologist and engineer, because of the fragile nature of the rocks in the study area.

- Previous zonation made by Fenogenov and Musazai have been started from 1500m above sea level. While during the field work I started collecting samples from 1350 and reached up to 1700m. I found the aforementioned zonation within this altitude. More precise work is needed to find out the exact vertical zonation in Dara-i-Pech pegmatite field.

- Discussions regarding the genesis and evolution of the pegmatites in this part of Afghanistan must wait for more detailed mineralogical and geochemical data.

- Further evaluation of the pegmatites should involve more detailed work on the known pegmatites, as well as for the exploration and documentation of pegmatites which is still undiscovered.

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