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THE PEGMATITIC GEM DEPOSITS OF MOLO (MOMEIK) AND SAKHAN-GYI (MOGOK)

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ABSTRACT

Molo, situated about 32 miles (51 km) northeast of Momeik in Myanmar's Shan State, is a new source of many rare gemstones and minerals including phenakite, petalite, hambergite, Cs-rich morganite and pollucite. At Molo, botryoidal-type tourmalines of various colour, aquamarine, topaz, quartz and Li-mica (lepidolite) also are found. These minerals and gemstones are mainly recovered from the alluvial sediments as well as in pegmatite dykes that are intruded into peridotite country rock (Kyaw Khaing Win, 2003).

The pegmatite deposit at Sakhan-gyi, which is situated about 10 miles (16 km) west of Mogok in the Mandalay Division, has been the main source of aquamarine, goshenite, topaz and quartz. Occasionally, scheelite and cassiterite are also encountered. The dyke is much kaolinized where orthoclase, cleavelandite, microcline, quartz, muscovite, topaz, aquamarine, goshenite and other minerals are found. The pegmatite dyke at Sakhan-gyi is about 15 Ma old and it is found intruding the Kabaing granite (about 16-20 Ma), (Searle and Haq, 1964, Touret 2004 - pers.commun.)

The types of pegmatites and the probable temperatures and pressures of their formation, their physical and optical properties, characteristic features, EDXRF results and selected mineral inclusions found in some of these gems are presented in this paper.

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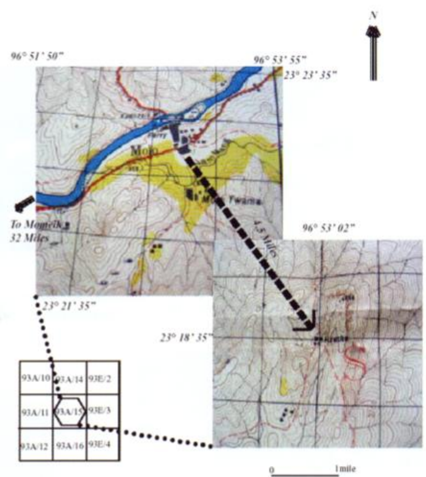
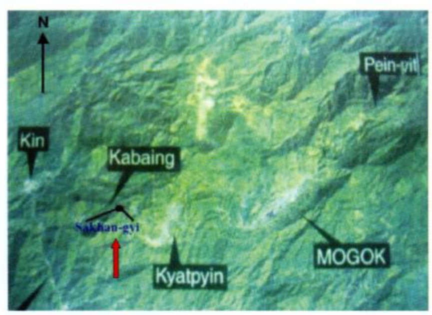


Map 1 Location of the Molo pegmatite deposit.



Map 2 Satellite image of Sakhangyi pegmatite deposit (Source: USGS).

Fig. 1. Cs-rich morganite (pink beryl) in feldspar matrix from Molo (Momeik).

Fig. 2. A 4.43 ct faceted gemstone and a 10.55 ct rough crystal of phenakite from Molo (Momeik).

Fig. 3. A 2.30 ct faceted gemstone and 15.32 ct rough crystal of pollucite from Molo (Momeik).

Fig. 4. Faceted hambergite of 1.65 ct from Molo (Momeik).

Fig. 5. Faceted pinkish brown petalite of 20.90 ct from Molo (Momeik).

Fig. 6. Rough crystal of yellow scheelitel of 120 g from Sakhan-gyi (Mogok).

Fig. 7. Large aquamarine crystal of 20 cm length from Sakhan-gyi (Mogok).

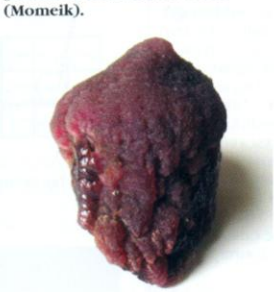


Fig. 8. Large mushroom-shaped crystal of rubellite of 320 g from Molo (Momeik).

Fig. 9. Crystal of green danburite of 133.34 ct from Molo (Momeik).

Fig. 10. A 6.02 ct crystal and 3.52 ct faceted gemstone of yellow fluorapatite from Molo (Momeik).

Introduction

Molo is situated in a remote area about 32 miles (15 km) north-east of Momeik (Map 1). Since 2003, the area has lured local gemmologists and gem traders as it has produced many rare minerals and gemstones, such as tourmaline (mainly botroyidal and mushroom types, which are rare), beryl (aquamarine and Cs-rich morganite), very rare gem quality (the first find in Myanmar) colorless pollucite and hambergite, petalite (colorless, brown and pinkish brown), phenakite (colorless and light yellow), topaz, quartz (rock crystal and citrine), and Li-mica (lepidolite). These minerals and gemstones (Figs 1-6, 8-10) are mined from alluvial deposits as well as from in situ deposits in the pegmatite dykes. These pegmatite dykes are found intruding the peridotite country rock (Kyaw Khaing Win, 2003).

The pegmatite deposit at Sakhan-gyi (Map 2) is located about 10 miles (16 km) west of Mogok. For more than 100 years, Sakhan-gyi has been the main source of aquamarine (Fig. 7), goshenite, topaz, quartz, danburite. Occasionally, gem quality white, yellow and green scheelite, cassiterite, columbite-tantalite, uraninite (Ba Than Haq, 1964), and Li-mica (lepidolite) also are encountered. The pegmatite dykes are much kaolinised and crystals of orthoclase, cleavelandite, microcline, quartz, muscovite, topaz, aquamarine, etc. are found in pegmatite dykes that intrude the Kabaing granite.

The nature of pegmatite

The term *pegmatite* (Fig. 11) was coined in the early 1800s by the French mineralogist Haüy to describe the geometric intergrowth of quartz and feldspar which is now known as graphic granite. Today, the term pegmatite is applied as a textural description of the intruded igneous body. The pegmatite can be recognized by its distinctive textures that consist of a very coarse grain size, variable grain size that usually features an increase in grain size from the margin to its centre, and porphyritic layering.

Pegmatite mineralogy is highly variable, ranging from the simple barren pegmatite composed entirely of alkali feldspar, quartz, muscovite and biotite to the highly fractional mineralized rare-metal pegmatite that may contain more than one hundred mineral species (Cerny, 1991 in Kerkvoort, 1995).

Pegmatites are the source of large sized impressive crystals. A vivid example of the massive size of some pegmatitic minerals is presented by a gigantic 19 feet long beryl crystal and a 47 feet long spodumene crystal that are

Fig. 11. Topaz, quartz, cassiterite and cleavelandite in pegmatite from Sakhan-gyi (Mogok).

associated with microcline-perthite in a pegmatite discovered at Keystone in the Black Hills of South Dakota, USA (Hatch & Wells, 1956). Also, a massive quartz crystal found in a pegmatite in Kazakhstan weighed about 70 tons, while another enormous crystal from Norway weighed 100 tons (Smirnov, 1976). Hundreds of smaller and beautiful crystals are found in numerous pegmatite locations around the world. The pegmatites are also the main source for high-tech metals and minerals, such as rubidium, tantalum, tin, lithium and others (Cerny, 1991 in Kerkvoort, 1995).

Classifications of pegmatites

Numerous classifications of the pegmatite bodies have been proposed based on their form, size, relationship with the associated rocks, chemical composition, texture, internal structure, presumed origin, mode of development and other attributes. Moreover, some geologists have combined some of these features and proposed new classifications based on multiple criteria (Jahns, 1955 in Kerkvoort 1995; also Cerny, 1980 in Kerkvoort 1995). For example:

1. Pegmatite classification based on internal structure.

Heinrich (1956 in Kerkvoort 1995) classified pegmatites into three types, based on their internal structure, as:

1. Simple pegmatites
   This is the most common type of pegmatite that consists only of quartz, feldspar, and mica and has no internal structure.

2. Zoned pegmatite
   This type consists of quartz, feldspar, mica and numerous accessory minerals. These minerals are formed in distinct zones (layers) with crystal size increasing toward the center (or core) of the pegmatite body.

   The zones are configured as concentric layers around a very coarse-grained core forming border, wall, intermediate and core zones. In these pegmatites, gemstones are found either in the core or in intermediate zones.

3. Complex pegmatite.
   This pegmatite is very similar to the zoned pegmatite, but it has undergone extensive alteration. Often, numerous rare gemstones and minerals are found in irregular openings (pockets), which may vary greatly in size and have recorded diameters of up to several metres. These pockets may be found either in the core zone or between the edge of the core and intermediate zone.

2. Pegmatite classification based on petrogenesis and other features.

Ginsburg *et al.* (1974 in Kerkvoort 1995), Cerny (1992 in Kerkvoort 1995) classified pegmatites into four classes, based on the metamorphic environments, depth of formation and petrogenetic criteria. These classes are described in table 1.

Cerny (1991 in Kerkvoort 1995) subdivided the rare element pegmatite into five types of pegmatite: rare-earth, beryl, complex, albite-spodumene and albite. This classification (Table 2, overpage) is often used by many researchers.

Following the model by Cerny, 1991 (in Kerkvoort 1995), and based on field work, the authors classified (Table 3, overpage) the pegmatite deposits at Sakhan-gyi and Molo as follows:

Pegmatite classification based on genetic features

Smirnov (1976) classified the pegmatite deposits into the genetic classes of simple pegmatites, rcrystallized pegmatites, metasomatic replacement pegmatites and desilicated pegmatites, based on their mineral assemblages and intrusive bodies, as follows:

Discussion

Based on their intrusive nature and mineral assemblages, it is evident that the Molo and Sakhan-gyi pegmatites are not contemporary. The Molo pegmatite is found intruding the peridotite country rock (Kyaw Khaing Win, 2003), whereas the Sakhan-gyi pegmatite is found intruding the Kabaing granite which is 16 Ma according to the

CLASS	GENETIC ENVIRONMENT	TYPICAL MINOR ELEMENTS
Abyssal	Migmatitic products of partial melting; in upper amphibolite to granulite facies of Barrovian to Abukuma-type metamorphic facies (4 – 9kb at 700 – 800 °C)	U, REE, Be Nb; barren to poorly mineralized
Muscovite	Generated by partial melting and/or restricted granitoid differentiation; in almandine-amphibolite facies of Winkler (1967) in kyanite bearing. Barrovian-type terranes (5 - 8 kb at 580 – 650 °C)	U, Th, REE, Li, Be, Ti, Nb>Ta; barren to poorly mineralized, source of muscovite and ceramic industry minerals.
Rare-element	Derived by advanced fractionation of fertile granites; in cordierite-amphibolite (to upper green schist) facies of Winkler (1967) in andalusite bearing Abukuma-type terranes (1.5 - 4 kb at 500 - 650°C)	Li, Rb, Cs, Be, Ga, Y, REE, Sn, Ti, U, Th, Nb, Ta; poorly to extremely mineralized, the main source of lithophile rare metal mineralization among all pegmatite categories
Miarolitic	Produced by advanced fractionation of fertile granite; in part overlapping with rare element class environment, in part within parental shallow to sub-volcanic plutons (1.5 - 2 kb)	Be, Y, REE, Ti, U, Th, Zr, Nb>Ta, F; poorly to extensively mineralized, commonly gem bearing, the main source of optical material, gemstones.

Table 1. Classification of granitic pegmatites (modified from Cerny, 1992 in Kerkvoort 1995).

PEGMATITE TYPE (FELDSPAR + MICA ENVIRONMENT)	PEGMATITE SUBTYPE, GEOCHEMICAL SIGNATURE	TYPICAL MINERALS	ECONOMIC POTENTIAL	TYPICAL EXAMPLES
Rare-earth [Kf>plg to ab; bi≥ msc]	Allanite-monazite (L) REE, U, Th (P, Be, Nb > Ta)	allanite, monazite	REE	Ural Mts., Kobe, Japan
	Gadolinite Y, (H) REE, Be, Nb>Ta F(U, Th, Ti, Zr)	gadolinite fergusonite euxenite (topaz, beryl)	Y, REE, U (Be, Nb -Ta)	Norway, Texas Finland, Sweden
Beryl [(Kf>ab; msc>bi)]	Beryl-columbite Be, Nb<>Ta (±Sn, B)	beryl columbite-tantalite	Be	Meyrs Ranch, Colorado, Namibia, Ural Mts. USSR
	beryl - columbite-phosphate Be, Nb <> Ta, P (Li, F, ±Sn, B)	beryl, columbite-tantalite, triphylite, triplite	(Nb -Ta)	Germany Dan Patch Colorado
Complex [(Kf<>ab; msc<>lep)]	Spodumene Li, Rb, Cs, Be, Ta<>Nb (Sn, P, F, ±B)	spodumene beryl tantalite		New Mexico, Hugo, South Dakota White, Picacho Arizona, Manono, Zaire
		(amblygonite)		
		(lepidolite)	Li, Rb, Cs	
		(pollucite)	Be, Ta	Zimbabwe, Sweden, Finland
	Petalite Li, Rb, Cs, Be, Ta>Nb (Sn, Ga, P, F, ±B)	petalite beryl tantalite (amblygonite) (lepidolite) (pollucite)	(Sn, Ga, Hf)	Australia
	Lepidolite F, Li, Rb, Cs, Be Ta>Nb (Sn, P, ±B)	lepidolite topaz microlite (pollucite)	Li, Rb, Cs, (Ta, Be Sn,Ga)	Colorado, New Mexico, California, Mongolia, Australia
	Amblygonite P, F, Li, Rb, Cs Be, Ta>Nb (Sn, ±B)	amblygonite beryl tantalite (lepidolite) (pollucite)	Li, Rb, Cs, Ta, Be (Sn, Ga)	Viitaniemi, Finland, Madagascar, Australia
Albite - Spodunene [ab>Kf; (msc)]	Li (Sn, Be, Ta<>Nb, ±B)	spodumene (cassiterite) (beryl) (tantalite)	Li, Sn (Be,Ta)	Kings Mountain, North Carolina Brazil
Albite [ab>Kf; (msc, lep)]	Ta<>Nb, Be (Li, ±Sn, B)	tantalite beryl (cassiterite)	Ta, (Sn)	Hengshan, China, USSR Tin Dyke, Manitoba

Note: Minerals enclosed in parentheses indicate minor amounts

Table 2. Classification of granitic pegmatities of the rare-element class (Cerny, 1991 in Kerkvoort 1995).

Beryl [Kf > ab; msc > bi]	beryl-columbite Be, Nb, Ta, Sn±F, U, Li	beryl columbite tantalite topaz (cassiterite) (scheelite) (uraninite) (lepidolite)	Be (Nb-Ta, Sn)	Sakhan-gyi JV mine (7/8), SW part of Sakhan-gyi village, Thit-seint-kone
Complex [Kf<>ab; msc<>lep]	petalite Li, Rb, Cs, Be, Nb (Sn, Ga, Bi, Br, As)	petalite pollucite beryl phenakite morganite hambergite lepidolite	(Cs, Li, Rb,Th)	Red Pearl mine, Hka-che village, Molo

Note: Minerals enclosed in parentheses indicate minor amounts

Table 3. Classification of granitic pegmatites of the rare-element class for Molo and Sakhan-gyi.

GEMSTONES	CHEMICAL COMPOSITION	SYSTEM	FROM	COLOR	H	R.I.
Tourmaline	Complex boro-silicate of Al, Mg, Fe, alkalis, metals, etc.	trigonal	prismatic, mushroom, botryoidal	pink, green, purple, brown, orange, black, red and parti-color	7	o - 1.620 ε - 1.640
Petalite	$LiAlSi_4O_{10}$	monoclinic	prismatic anhedral	white or colorless pinkish brown	6	α -1.506 β - 1.510 γ -1.520 α - 1.508 β- 1.515 γ -1.520
Phenakite	$Be_2SiO_2O_4$	trigonal	prismatic	colorless & light, yellow	7.5 - 8	o - 1.654, ε - 1.670
Pollusite	$H_2Cs_4AL_4(SiO_3)_9$	cubic	anhedral	white or colorless	6.5	1.517 to 1.525
Hambergite	$(Be_2(OH)BO_3$	orthorhombic	prismatic	colorless	7.5	α -1.553 to 1.559 γ -1.625 to 1.631
Cs-Morganite	$Be_3Al_2Si_6O_{18}$	hexagonal	prismatic	pink	7.5	o - 1.580, ε - 1.590
Beryl	$Be_3Al_2Si_6O_{18}$	hexagonal	prismatic	blue & greenish blue	7.5	o - 1.570, ε - 1.575
Topaz	$Al_2(F,OH)_2SiO_4$	orthorhombic	prismatic	colorless	8	α-1.610, γ- 1.62
Apatite	$Ca_5(F,Cl,OH)(PO_4)_3$	hexagonal	prismatic	yellow	5	o - 1.645, ε - 1.648
Danburite	$Ca(B_2Si2O_8)$	orthorhombic	prismatic	green	7.5	α- 1.630 γ- 1.636

Table 4. Physical and optical properties of gemstones from the Molo pegmatite deposit.

Beryl (aquamarine)	$Be_3Al_2Si_6O_{18}$	hexagonal	prismatic	blue & greenish blue	7.5	o - 1.570, ε - 1.575
Topaz	$Al_2(F,OH)_2SiO_4$	orthorhombic	prismatic	colorless, orange, brown, light blue	8	α - 1.610, γ - 1.620
Scheelite	$CaWO_4$	tetragonal	prismatic, anhedral	yellow, white & green	5	o - 1.918, ε - 1.934
Cassiterite	SnO_2	tetragonal	prismatic	black (opaque)	6.5	o - 2.003, ε - 2.101
Quartz	SiO_2	trigonal	prismatic	colorless, yellow, brown, purple	7	o - 1.544, ε - 1.553

Table 5. Physical and optical properties of gemstones from the Sakhan-gyi pegmatite deposit.

D.R.	S.G.	Fluorescence LWUV/SWUV	Microscopic Examination
0.018	3.05 - 3.20	weak yellow & mostly inert	fibrous inclusions
0.014	2.419	weak yellow	tube like inclusions
0.012	2.403	inert	tube like inclusions
0.016	2.95	weak yellow	liquid feather, xl & needle-like inclusions
isotropic	2.850 to 2.940	bright yellow & mod.yellowish brown	tube like inclusions
0.072	2.350	inert	solid & tube like inclusions
0.008	2.710	weak reddish-brown	trapiche inclusions
0.005	2.710	inert	liquid feather
0.010	3.560	weak yellow	liquid feather
0.003	3.201	weak	
0.009	3.00	weak	

0.005	2.710	inert	liquid feathers, solid inclusions
0.010	3.560	weak yellow	liquid feather
0.016	6.102	whitish yellow (yellow stone); blue (white & green stones)	solid inclusions
0.071	6.950	inert	
0.009	2.650	inert	solid inclusions, rutile needles, liquid feathers, 2-phase inclusions

radiometric dating (Searle and Haq, 1964; Touret 2004, pers.commun.). The Kabaing granite also is found intruding the ultramafic bodies of Mogok.

Based on model proposed by Cerny (1991 in Kerkvoort 1995), it is suggested that the pegmatites at Molo and Sakhan-gyi were formed between 1.5 to 4 kb in depth at 500 – 650 °C, These data place these pegmatites in the rare-earth class. According to the genetic classification proposed by Smirnov (1976) the pegmatites of Molo and Sakhan-gyi were formed by metasomatic alteration due to hot gaseous-aqueous mineralized solutions which were chemically not in equilibrium with the primary pegmatite-forming mineral mass. Thus, these pegmatites are regarded as metasomatic replacement pegmatites.

Phenakite, petalite, hambergite, Cs-rich morganite and pollucite are very rare minerals found in abundance at Molo. Chemical analyses indicate that these minerals are rich in rare-earth elements and may be of significant economic importance.

The physical and optical properties of gem minerals from the Molo and Sakhan-gyi pegmatites are given in tables 4 and 5.

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