Chapter 23

Gem deposits of Myanmar

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The aim of this chapter is to review the locations, mineralogy and briefly the origins of the major gem deposits in Myanmar. Myanmar is fortunate in containing world-class gem deposits, such as the finest pigeon's-blood-coloured ruby from the Mogok Stone Tract in Mandalay Division, the Mong Hsu ruby deposit in Shan State and imperial coloured jadeite jade from Kachin State (Fig. 23.1). For the purposes of description the gemstone deposits in Myanmar are classified into: (1) primary hard-rock deposits in which the gemstones are hosted in the rocks in which they were crystallized or in their weathered products; and (2) secondary deposits in which the gemstones have been weathered out of their original (primary) host rock, transported and deposited as placer deposits in alluvial sediments.

Examples of the primary-type gems are ruby in marble (Mogok, Mong Hsu and Sagyin), sapphire in syenite pegmatite, syenite and nepheline syenite (Mogok) and jadeite in serpentinized peridotite (Tawmaw). Other precious gemstones from primary deposits include spinel in marble (Mogok), peridot in dunite/peridotite (Mogok), topaz, aquamarine, tourmaline, quartz, etc. in pegmatite (Mogok, Mong Hsu and Momeik) and kyanite in quartzite (Moehnyin).

Rare gemstones are often found in primary gem deposits in the Mogok Stone Tract and include johachidolite and hackmanite from pegmatites, painite from leucogranite and skarn, pollucite, petalite, phenakite, pezzottaite, monazite, danburite, jeremejevite and hambergite from pegmatites in the Momeik area.

Common secondary gemstones include ruby, sapphire, jadeite, diamond, spinel, zircon, aquamarine, tourmaline, topaz and amber. Many rare collector gemstones have been found in secondary gem deposits in Myanmar. Recently a new mineral species named after the first author, Kyawthuite ($Bi^{3+}Sb^{5+}O_4$), was reported from Mogok (Kampf *et al.* 2016).

Geological setting

The geological setting of the gemstone deposits in Myanmar is described with reference to the six major north–south tectono-stratigraphic zones shown in Figure 23.1. These zones also are characterized by the occurrence of economic mineral deposits (Bender 1983; Khin Zaw 1990, 2017; Khin Zaw *et al.* 2015).

From west to east these zones comprise:

Zone 1. Rakhine Coastal Strip, composed of Miocene molasse, extending northwards into the Assam Basin and southwards into the northeastern Indian Ocean.

Zone 2. Indo-Myanmar Ranges, representing an outer-arc or forearc, underlain by Triassic turbidites and dismembered ophiolites in the east and tightly folded turbidites of Cretaceous–Early Eocene age in the west (Clegg 1941; Searle & Ba Than Haq 1964; Bannert *et al.* 2011; Kyi Khin *et al.* 2017). Rocks in this zone dip typically towards the east and strike parallel to the north–south trend of the ranges.

Zone 3. Western Inner–Myanmar Cenozoic Basin, an inter-arc basin or trough containing a thickness of up to 15 km of dominantly Tertiary marine and fluviatile sedimentary rocks.

Zone 4. Central Volcanic Belt (or Line), a magmatic-volcanic arc composed of Pleistocene–Recent volcanoes, Cretaceous granitoid plutons and Miocene volcano-sedimentary rocks, hosting high- and low-sulphidation epithermal Cu ± Au deposits such as at Monywa.

Zone 5. Eastern Inner–Myanmar Tertiary Back-arc Basin or trough. Zones 5 and 6 are separated by the Sagaing Fault, with transcurrent movement commencing in the Miocene and continuing to the present day.

Zone 6. Shan–Tenasserim Massif, also known as the Eastern Highlands Plateau, composed of Palaeozoic and Mesozoic sediments and intrusions. The oldest rocks in this plateau are the Late Cambrian Ngwe Taung and Molohein Groups (Aye Ko Aung 2012), consisting of slightly metamorphosed turbidites, clastic rocks and volcanics. The overlying Palaeozoic rocks include clastic and calcareous sedimentary rocks with minor volcanic rocks and an extensive, mostly Devonian, 'Plateau Limestone' unit.

Khin Zaw (1990) has described the Myanmar granitic rocks in these tectonic zones as occurring in three north–south belts. The Eastern Belt in the far east of Zone 6 are Triassic in age and are a continuation of the Triassic I–S-type granites of northern Thailand (Cobbing *et al.* 1992). U–Pb SHRIMP dates of igneous zircons from the Central Belt (western margin of Zone 6) range in age from Jurassic through Cretaceous to Palaeogene, and zircon dates from the Western Belt (Zones 2 and 3) span the Early Cretaceous–Eocene (Barley *et al.* 2003; Kyaw Linn Oo *et al.* 2015).

Mogok Metamorphic Belt (MMB)

The most important area in terms of Myanmar's gemstone potential for rubies, sapphires and alluvial diamonds is the Mogok Metamorphic Belt (MMB) (Fig. 23.1) (Barley *et al.* 2003; Mitchell *et al.* 2004, 2007, 2012; Searle *et al.* 2007, 2017) at the western margin of Zone 6 (Shan–Tenasserim Massif) and the Jade Mines Belt (Thet Tin Nyunt *et al.* 2017) in Zone 4.

The major gemstone deposits in the Mogok Metamorphic Belt are situated in the 'Mogok Stone Tract' (Iyer 1953; Hughes 1997; Themelis 2008) (Fig. 23.2). The Mogok Stone Tract is a source of world-class rubies, sapphires and other gemstones.

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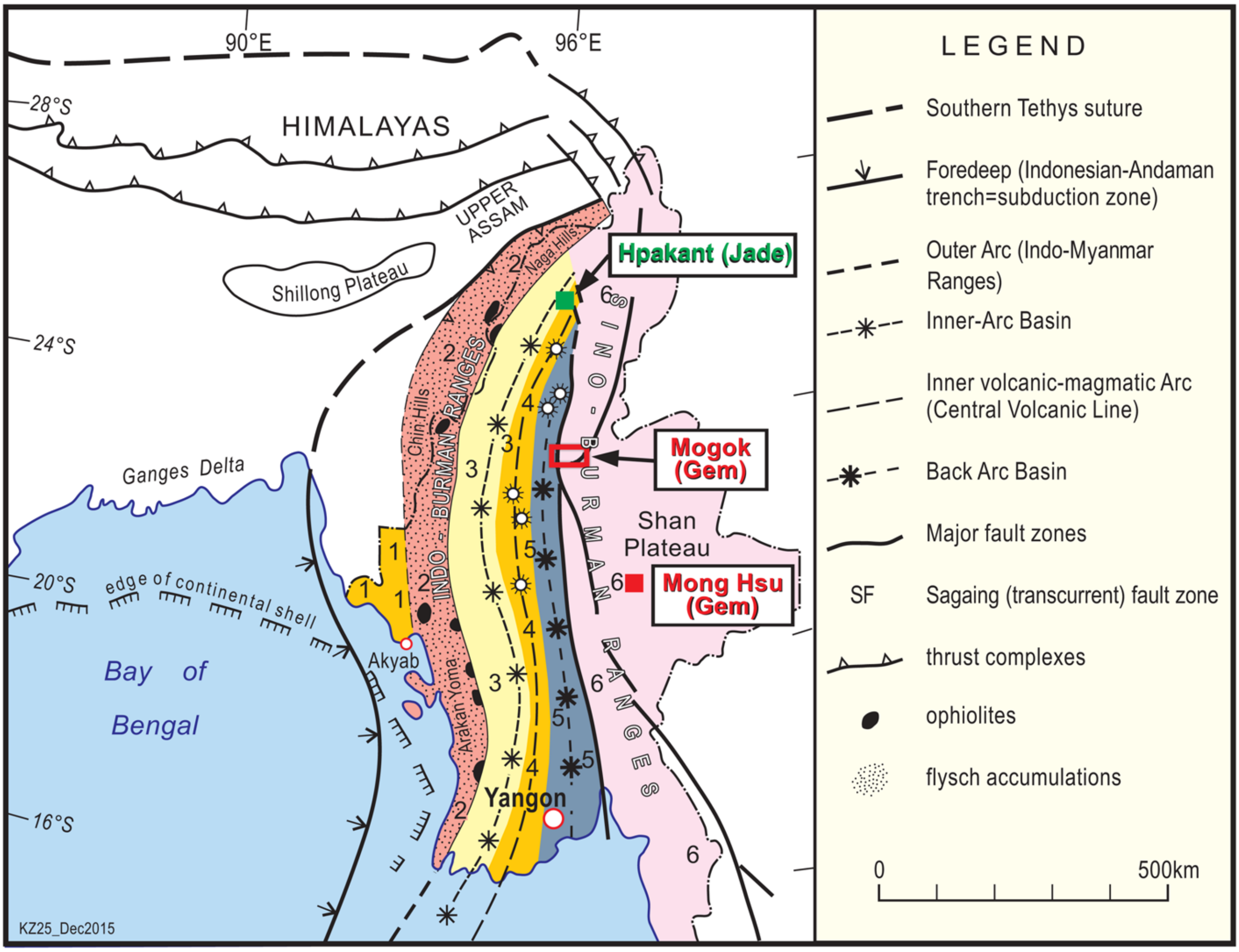


Fig. 23.1. Locations of the Jade Mine, Mogok Stone Tract and Mong Hsu areas and the tectonic zones in Myanmar: 1, the Arakan (Rakhine) coastal strip; 2, Indo-Myanmar Ranges; 3, Western Inner-Myanmar Tertiary Basin; 4, Central Volcanic Belt (Central Volcanic Line); 5, Eastern Inner-Myanmar Tertiary Basin; 6, Shan-Tenasserim Massif (map modified after Bender 1983; Khin Zaw 1989, 1990; Khin Zaw *et al.* 2015). Small white circles represent extinct or dormant Tertiary volcanoes.

Radiometric dating of magmatic and metamorphic rocks in the MMB includes an Ar–Ar biotite age of 15.8 Ma for the Kabaing granitoid and a K–Ar age and Ar–Ar biotite ages on three nearby metamorphic rocks ranging from 15 Ma K–Ar age (Searle & Ba Than Haq 1964) to 16.5–19.5 Ma (Bertrand *et al.* 2001). These dates, along with Ar–Ar phlogopite ages for a ruby-bearing marble of 18.7 Ma and for two ruby-free marbles of 17.1 and 17.9 Ma (Garnier *et al.* 2006, 2008), all appear to be resetting ages due to later tectonic and metamorphic events. U–Pb dating of zircon inclusions in a Mogok ruby gave an age of 31–32 Ma (Khin Zaw *et al.* 2008, 2010, 2012, 2015). Kyaw Thu (2007) dated leucocratic granite intrusions at Mogok using the LA-ICP-MS U–Pb zircon method, yielding ages of 45 and 25 Ma. These age data suggest that the MMB has experienced multiple tectonic magmatic and metamorphic, uplift and exhumation processes, most likely accompanied by metamorphic core complex formation, from as early as the Jurassic to the Recent (Khin Zaw *et al.* 2015).

The Mogok area consists of a series of high-grade metamorphic rocks; the dominant unit is banded gneiss with biotite, garnet, sillimanite and oligoclase, interspersed with quartzite and bands and lenses of marble (Kyaw Thu 2007; Themelis 2008; Yui *et al.* 2008; Khin Zaw *et al.* 2015) (Fig. 23.2). Marbles are mainly calcitic; dolomitic marbles are less common. Some marbles contain ruby; others have spinel, forsterite or diopside, or are phlogopite-graphite marbles (Kammerling *et al.* 1994; Kyaw Thu 2007; Themelis 2008; Yui *et al.* 2008; Khin Zaw *et al.* 2015). Rutile, graphite, calcite, pargasite, zircon, titanite, apatite group, scapolite group and spinel group minerals are all found as inclusions in Mogok rubies (Kammerling *et al.* 1994; Kyaw Thu 2007; Khin Zaw *et al.* 2008, 2010, 2012, 2015; Themelis 2008). The metamorphic rocks are intruded by alkaline igneous rocks (mostly sodic nepheline–syenite and syenite–pegmatite) and leucogranites, and there is also a mafic–ultramafic suite of peridotites, minor dolerites and norites. Biotite granitoids are widely exposed at Kabaing and Thabeikkyin near Mogok and some of the syenite pegmatites contain sapphires (Khin Zaw 1990, 1998; Waltham 1999; Kyaw Thu 2007; Themelis 2008). The Kabaing granitoids and the metasedimentary rocks are commonly intruded by late-stage pegmatites and aplites (Khin Zaw 1998). A summary of modes of occurrence and origin of the precious gemstone deposits of the Mogok Stone Tract has been presented by Maung Thein (2008).

The jadeite mining area or tract is about 1287 km^2 in extent and is located to the west of the Sagaing Fault in Zone 4 (Fig. 23.1) within the Hpakant–Tawmaw area of the Kachin State of northern Myanmar (Figs 23.3 & 23.4).

The eastern part of the area of jadeite deposits is composed mainly of NNE–SSW-trending undifferentiated metamorphic

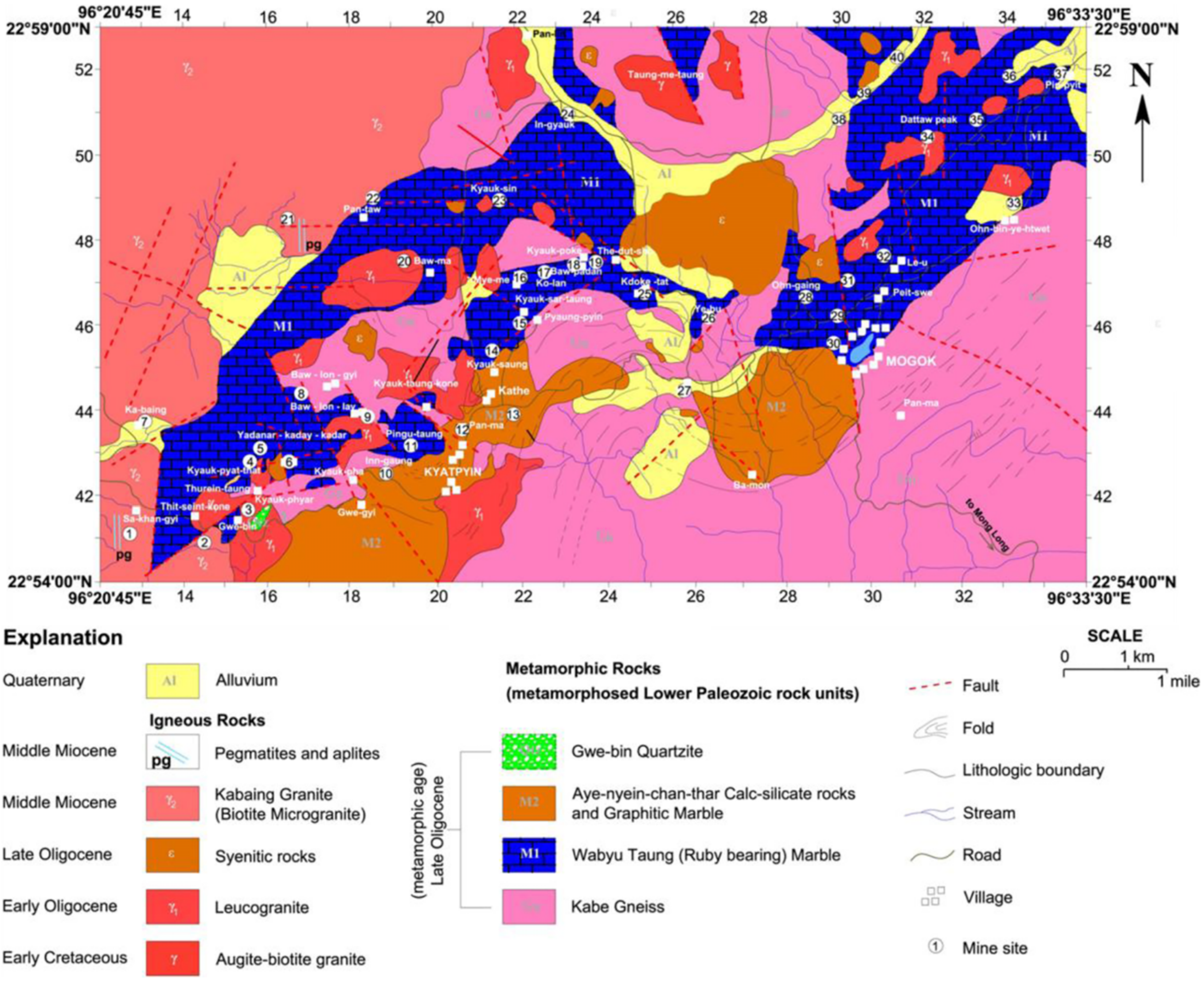


Fig. 23.2. Geological map of the Mogok area (Kyaw Thu 2007; Themelis 2008; Khin Zaw *et al.* 2015). 1, Sa-khan-gyi (Sakangyi); 2, Thit-seint-kone; 3, Kyauk-phyar; 4, Kyauk-pyat-that; 5, Yadanar-kaday-kadar; 6, Lone-sho/Sin-khwa; 7, Ka-baing; 8, Baw-lone-gyi; 9, Baw-lone-lay; 10, Inn-gaung; 11, Pingu-taung; 12, Pan-ma; 13, Tagung-nann-daing; 14, Kathe-Kyauk-saung; 15, Pyaung-pyin; 16, Ko-lan; 17, Baw-padan; 18, Kyauk-poke; 19, Tha-dut-sho; 20, Baw-mar; 21, Pazun-seik; 22, Pan-taw; 23, Kyauk-sin; 24, In-gyauk; 25, Kadoke-tat; 26, Ye-bu/Tha-phan-pin; 27, Min-tada; 28, Ohn-gaing; 29, Lin-yaung-chi; 30, Shwe-pyi-aye; 31, Shwe-daing; 32, Shon-ban; 33, Ohn-bin-ye-htwet; 34, Dattaw; 35, Hta-yan-sho; 36, Pyant-gyi; 37, Pin-pyit; 38, Chaung-gyi; 39, Mana; 40, Kyauk-wa.

rocks, mainly schist and gneiss, with granite intrusions outcropping in the Kumon Range. These units are also exposed in the northeastern part of the Haungpa area and the southern part of the Jade Mines area. Intrusions of gabbro and related rocks are abundant in the middle and eastern parts of the area. Cretaceous *Orbitolina*-bearing limestones occur sparsely in the jadeite mining area. Sedimentary units of the Upper Pegu Group (Miocene) are widespread in the western, middle and eastern parts of the area. Peridotite and serpentinite ultramafic rocks are well exposed in the Jade Mines area NW of Hpakant (Fig. 23.4) and are also present in the southern parts of Haungpa, west of Nalong and NE of Myitkyina (Hla Htay *et al.* 2017).

The origin and time of formation of the jadeite deposits is under debate. Bender (1983) and Hughes *et al.* (2000) suggested that the 'jadeite–albite dykes' described by Chhibber (1934) were unlikely to be intrusions, but were high-pressure metamorphic rocks formed during regional metamorphism. Shi *et al.* (2008) interpreted a SHRIMP U–Pb zircon age of 163 ± 3.3 Ma (Middle Jurassic) as the time of growth of the oceanic crust, which was subsequently hydrothermally altered by serpentinization prior to the formation of the jadeite deposits. A younger U–Pb age of 146.5 ± 3.4 Ma (Early Cretaceous) of zircons in jadeitite was interpreted as the formation age of the jadeites by Shi *et al.* (2008). Yui *et al.* (2013) have queried this interpretation as a misunderstanding of the ages of metamict zircons (incompletely grown crystals), which give spurious ages. Alternatively Yui *et al.* (2013) have proposed that the timing of the jadeite growth was <77 ± 3 Ma.

An important source of secondary jadeite in the Hpakant, Lonkin and Hwehka areas (Fig. 23.4) is Pleistocene fluvial gravels, such as the Uru Boulder Conglomerate.

The second-largest ruby deposit in Myanmar occurs at Loi Hsan Tao Mountain, Mong Hsu area (Fig. 23.5a) and is associated mainly with sedimentary and regional metamorphic rocks. The regionally metamorphosed rocks (probably of Palaeozoic age) include biotite–almandine–staurolite schist, diopside calc-silicate rocks and biotite quartzite interbedded with biotite phyllite and ruby-bearing white marble (Fig. 23.5a, b). Some granitic pegmatites intruded the metamorphic rocks in the area,

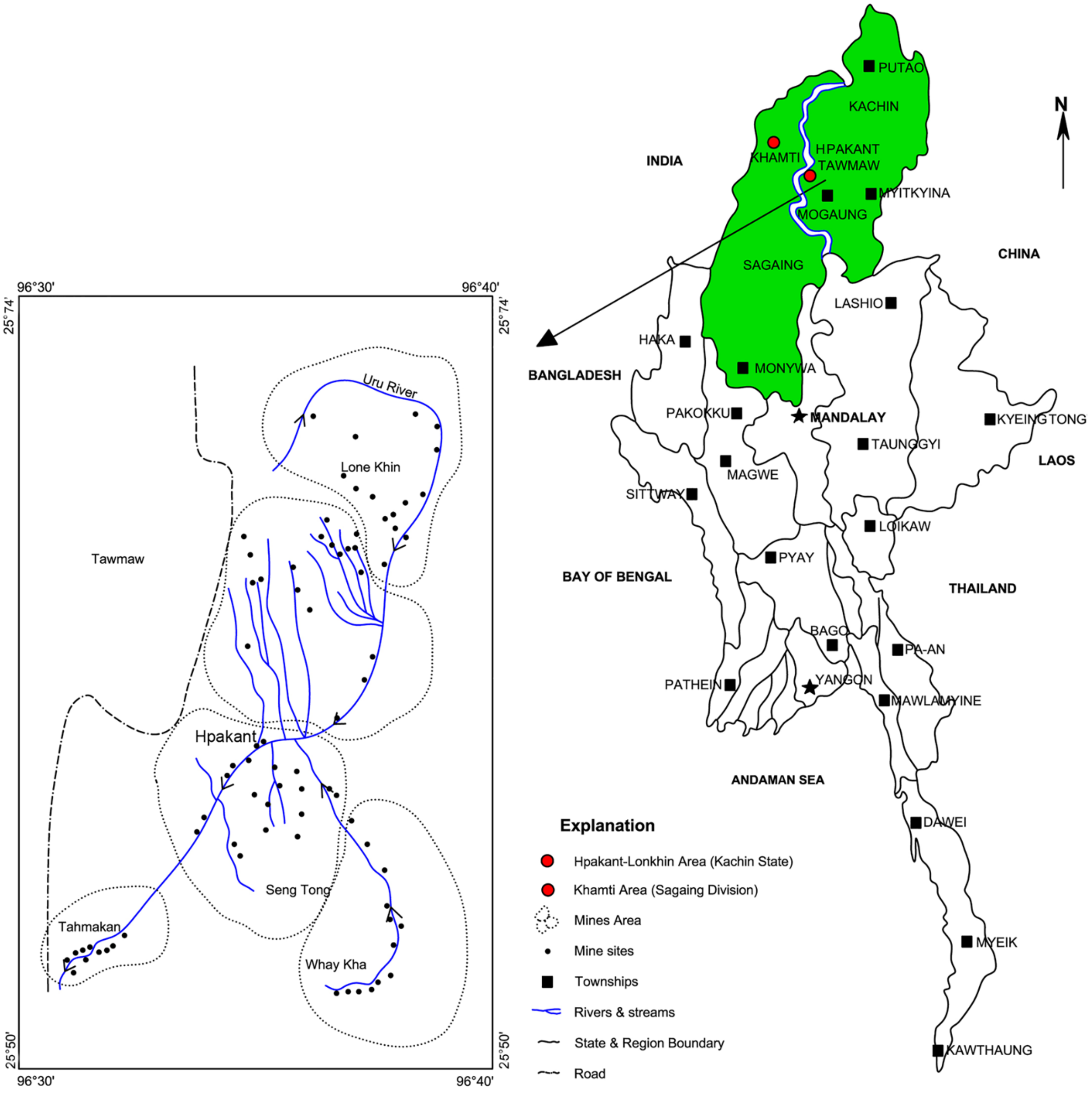


Fig. 23.3. Location map of the jadeite and jade occurrences in Myanmar.

and can be traced into the eastern and southeastern parts as far as Than Lwin River. In addition, massive Plateau Limestone (Devonian?) occupies the northern part of the area and shale, siltstone, minor limestone beds (Silurian) and bedded limestone (Ordovician) are present in the middle and southeastern parts of the Mong Hsu area.

Primary (hard-rock) occurrences of the Myanmar gemstone deposits

Maung Thein (2008) initially reported the modes of occurrence and origin of the precious gemstone deposits in the Mogok Stone Tract, Myanmar (Table 23.1). In this section his descriptions are extended by the authors' own field and laboratory studies and experience of the gem deposits in Myanmar: (1) ruby-bearing bands parallel to foliation, in the marbles locally named 'Ge Gyaw' (Mogok, Mong Hsu, Sagyin); (2) skarn, ruby and sapphire in the contact zones between the marbles and the syenite, nepheline syenite, urtite or leucogranite, locally named 'Kyauk Ohe' (Mogok, Mong Hsu); (3) sapphire segregation within syenite, nepheline–syenite and syenite–pegmatite (Mogok, Thabeikkyin); (4) veins (hydrothermally altered and bearing sapphire) extending from some syenite–pegmatites (Mogok); (5) dyke or sill (bearing jadeite-albite) from altered peridotite and serpentinite (Tawmaw); (6) peridot segregation within dunite and peridotite (Mogok); and (7) pegmatite dykes or veins (bearing topaz, quartz, aquamarine, tourmaline, etc. and some rarer gemstones) intruding metasedimentary rocks and granitoids (Mogok, Momeik, Mong Hsu, Thabeikkyin, Let Pan Hla).

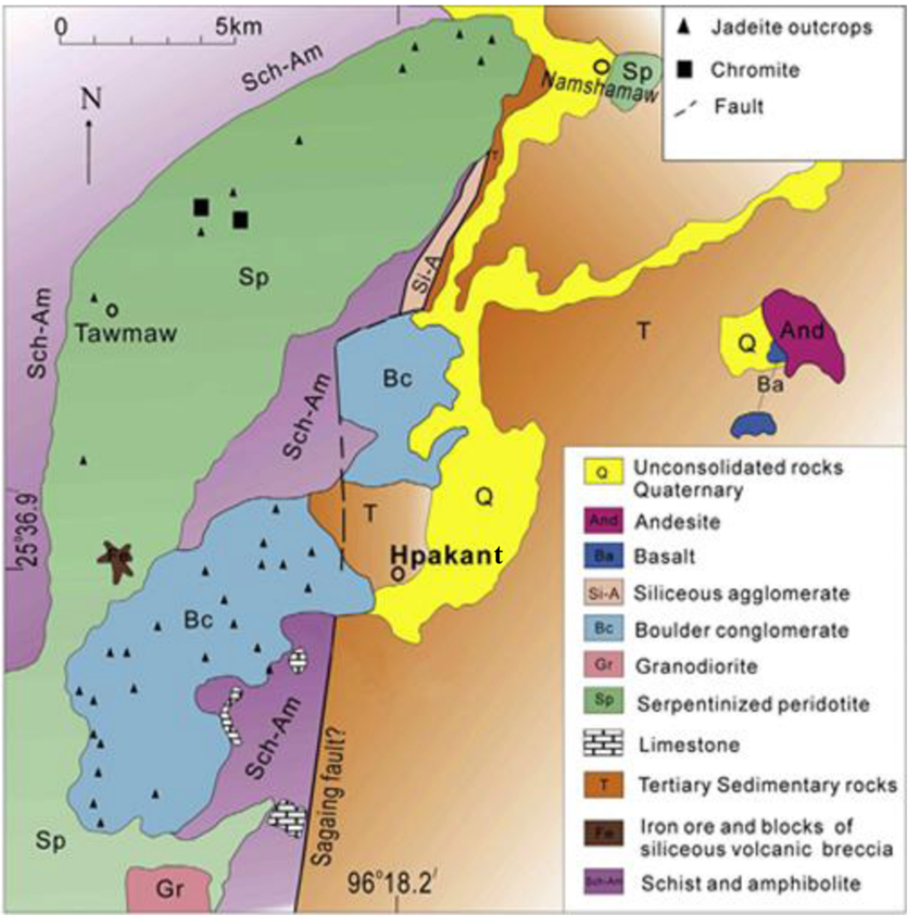


Fig. 23.4. Simplified geological map of the Myanmar jadeite deposit area (modified after Bender 1983; Shi *et al.* 2008).

Gemstone deposits in the Mogok Stone Tract

Primary ruby deposits around Mogok

The Mogok Stone Tract of Myanmar is legendary as the source of the finest high-quality rubies and spinels found in marbles (e.g. Themelis 2008; Fritsch 2014; Pezzotta 2014; Tin Hlaing 2014; Peretti & Falise 2016). The rubies occur usually in thin gemstone-bearing bands, locally known as 'Ge Gyaw', parallel to the foliation in the marble. The marble beds are regionally metamorphosed in the upper amphibolite facies, as indicated by the mineral assemblage of diopside, phlogopite, scapolite and plagioclase. The most important areas of gemstone mining are around Dattaw, Shwetaing, Linyaungchi, Kadoketat, Bawpadan, Kyaukpoke, Kyauksar Taung, Pyaungbyin, Pingu Taung and Bawlonegyi (Figs 23.6–23.9).

The main minerals in the primary ruby bands are calcite, phlogopite, titanate (sphene); pyrite is also common. Other minerals such as sodalite and nepheline, as well as phlogopite, spinel, pargasite and tourmaline, are less common. In the Dattaw area rubies in marble are associated with blue cancrinite or davyne and with less abundant scapolite (intermediate meionite–marialite).

Htar Htar Aung (2000) reported that skarn assemblages in the western mine-site of Pingu Taung rubies are distinctive. Here rubies occur in skarns surrounding a dyke or a small stock. The skarn mineral assemblage includes the plagioclase feldspar, bytownite, commonly altered to scapolite, ruby, muscovite, tourmaline, pyrite and pyrrhotite.

Ruby is also found as pocket-type aggregates locally known as 'Kyauk Oh' in the contact zone between marble and syenite. Typical minerals found in the skarn deposits at Dattaw, Kolan, Bawpadan, Pingu–Taung and Thurein–Taung include scapolite, diopside, sodalite, nepheline, pyrite, phlogopite and datolite or alkali feldspar (moonstone).

Skarns in phlogpite-bearing marble intruded by leucogranite at Wetloo and Thurein–Taung contain overgrowths of ruby on painite, associated with tourmaline (mostly foitite, but less commonly dravite and uvite); scapolite, phlogopite and margarite are the result of skarn reactions, as described by Harlow *et al.* (2006) and Harlow & Bender (2013).

Gem deposits are also found at Pyinlon (Nawarat) at the northeastern extension of the Mogok Metamorphic Belt (MMB), located at 23° 39′ 05″–23° 40′ 50″ N and 97° 20′ 10″–97° 22′ 20″ E, 80 km SW of Namkhan township, northern Shan State. The area is composed mainly of metamorphic rocks such as marble, calc-silicate rock, quartzite and gneiss with intrusive rocks of biotite granite, syenitic rocks, leucogranite and pegmatite. Minor amounts of basalt and ultramafic rock also occur in this area. Although the Pyinlon gem deposits are presently depleted, one of the famous rubies from Myanmar known as Nawarat Tharaphu Ruby (5.25 carats) faceted from 9.70 carats rough stone was found from the Pyinlon gem deposit in 1990. Ruby is mainly formed in the breccia zone of the metamorphic rocks and biotite granite. The associated minerals of ruby-bearing breccias are spinel, tourmaline, garnet, phlogopite, muscovite, margarite, talc, graphite, zircon, rutile, anatase, sphene and pyrite (Nyunt Htay 2010). Sapphires are also found in the contact zone of marble and syenite rocks as well as in the syenitic pegmatite.

Ruby is also found in secondary deposits ('byone') at Nanyaseik (25° 37′ 11″ N, 96° 35′ 00″ E), Mogaung township, Myitkyina district in Kachin state. Most of the secondary mines are depleted however, because of the shallow depth of the gem-bearing gravel beds. The area is composed mainly of marble, garnet biotite gneiss and biotite granite intrusives (Chhibber 1934). The associated gems minerals of the ruby are sapphire, spinel, almandine garnet, tourmaline, zircon, diopside, topaz, quartz and rare gemstone-quality pink painite.

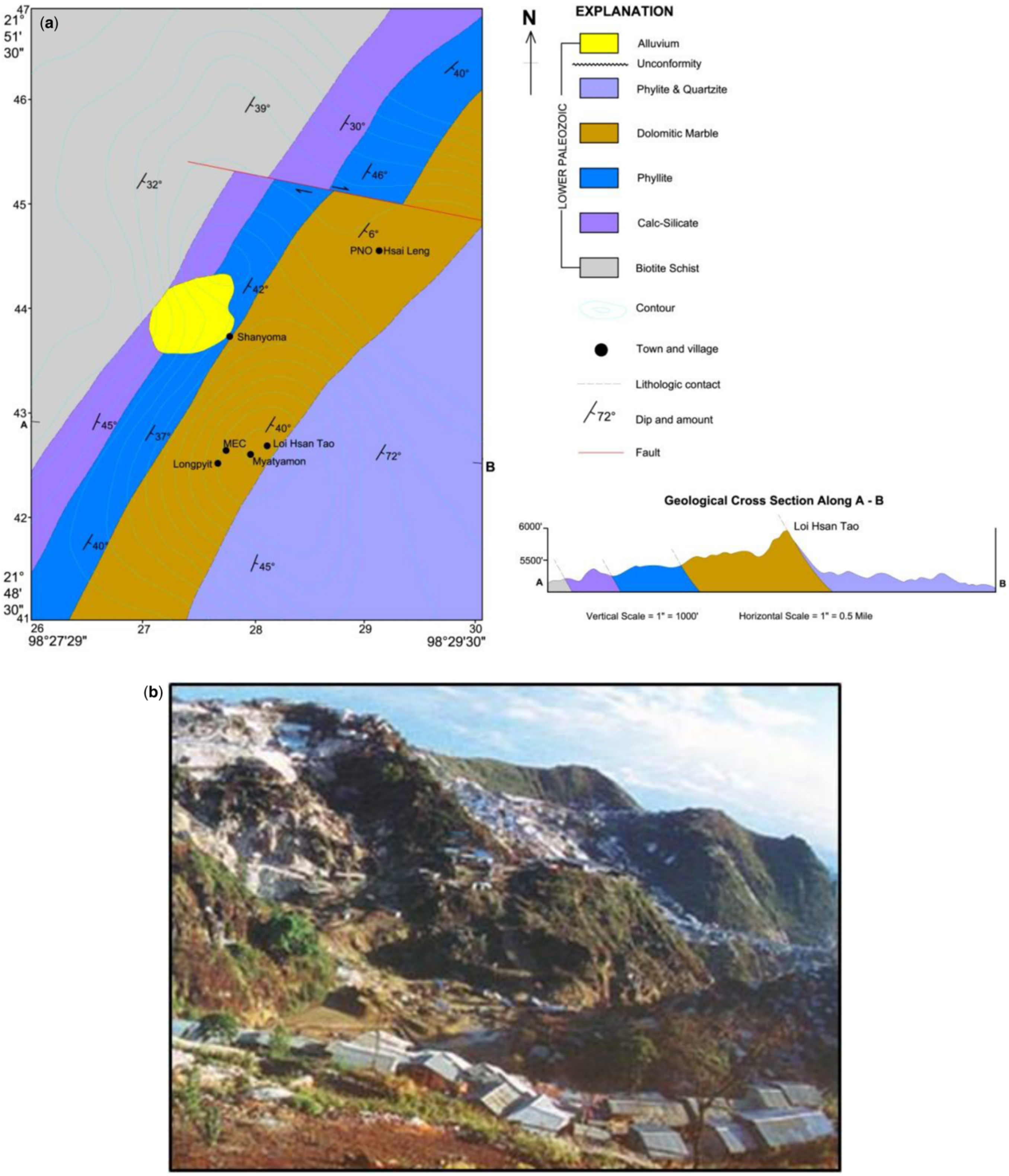


Fig. 23.5. (**a**) Geological map of of the Loi Hsan Tao area, Mong Hsu (modified after Than Than Nu 2003); and (**b**) panoramic view of primary ruby mining in Loi Saung Htauk Hill, Mong Hsu area, northern Shan State.

Characteristics of Mogok rubies

The distinctive features of Mogok rubies are their 'fine pigeon's blood' colour, which resembles the colour of the bright red ring in the iris of the eye of a pigeon. In practice, the colours of Mogok rubies range from light pinkish-red to deep red, with orange to violet saturations. The characteristic crystal form of Mogok rubies is a short prism; however, long hexagonal prisms with pinacoids, combinations of prisms, rhombohedrons and pinacoids are also common. Raised triangular growth marks on basal pinacoids may be present. Examples of Mogok rubies are shown in Figure 23.10.

Two types of inclusions are common in Mogok rubies: (1) 'silk', composed of very fine, usually as three sets, short rutile needles intersecting at 60° angles; and (2) single rutile needles, as intergrown twinned crystals, with a characteristic re-entrant

Table 23.1 *List of gem minerals recorded from the Mogok Stone Tract and other regions, Myanmar*

No.	Gems species	Crystal system	Composition	Varities & colour
1	Amber	Amorphous	Hydrocarbon	Yellow, yellowish green, red, reddish brown to brown
2	Amphibole	Monoclinic	$Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$	(a) Actinolite: green to dark green; (b) hornblende: brownish-yellow
		Monoclinic	$NaCa_2(Mg,Fe)_5Si_7AlO_{22}(OH)_2$	(c) Edenite: light yellow to greenish-yellow
		Monoclinic	$NaCa_2(Mg,Fe)_4Al(Si_6Al_2)O_{22}(OH)_2$	(d) Pargasite: brownish-green, green
3	Anatase	Tetragonal	TiO_2	Inky blue
4	Andalusite	Orthorhombic	Al_2SiO_5	(a) Andalusite: yellowish-green, brownish-green, reddish-brown; (b) chiastolite: greyish to black cross on pinkish or whitish
5	Apatite	Hexagonal	$Ca_5(PO_4)_3F$	Blue, yellow, green, purple
6	Axinite	Triclinic	$Ca_2(Mn,Fe,Mg)Al_2(BO_3OH)(SiO_3)_4$	Dark green, reddish brown
7	Baddeleyite	Monoclinic	$ZrO_2.HfO$	Yellowish brown, black
8	Beryl	Hexagonal	$Be_3Al_2Si_6O_{18}$	(a) Aquamarine: light greenish-blue to deep-sea blue; (b) goshenite: colourless, white; (c) morganite: light pink to pink
9	Calcite	Trigonal	$CaCO_3$	White, blue, yellow, greenish
10	Cassiterite	Tetragonal	SnO_3	Light yellow, white, black
11	Chondrodite	Monoclinic	$(Mg,Fe)5(SiO_4)_2(F,OH)_2$	Orangy yellow
12	Chrysoberyl	Orthorhombic	$BeAl_2O_4$	Colourless, yellow, greenish yellow; (a) alexandrite: light bluish-green to green; (b) cat's eye chrysoberyl
13	Coral	Trigonal	$CaCO_3$	White, pink, orangy pink, black
14	Corundum	Trigonal	Al_2O_3	(a) Ruby: red; (b) sapphire: blue, white, pink, yellow, orange, green, purple, black; (c) padparadscha: orangy pink to pinkish orange; (d) star ruby and star sapphires; (e) trapiche ruby and sapphires
15	Danburite	Orthorhombic	$CaB_2(SiO_4)_2$	White, light yellow to yellow, greenish yellow, green
16	Diamond	Cubic	C	White to tinted white, yellow, yellowish brown to brown
17	Diaspore	Orthorhombic	AlO(OH)	Whitish, purplish, purplish pink, purple
18	Diopside	Orthorhombic	$CaMg(SiO_3)_2$	White, light yellowish green to dark green: (a) cat's eye diopside; (b) 4-arys star diopside
19	Dumortierite	Orthorhombic	$Al_7(BO_3)(SiO_4)_3O_3$	Pinkish purple to violet, greenish
20	Ekanite	Tetragonal	$Ca_2ThSi_8O_{20}$	Green to dark green; radioactive
21	Enstatite	Orthorhombic	$(Mg,Fe)_2Si_2O_6$	Yellowish green to brownish green; (a) bronzite; (b) cat's eye enstatite
22	Epidote	Monoclinic	$Ca_2(Fe,Al)_3(SiO_4)_3(OH)$	Yellowish-green to dark green
23	Euclase	Monoclinic	$BeAlSiO_4(OH)$	Colourless, light blue
24	Feldspar			(1) Alkali feldspar
		Monoclinic	$KAlSi_3O_8$	(a) Orthoclase: white, light yellow, light green; (b) adularia moonstone: white with blue, white and golden sheen
		Triclinic	$KAlSi_3O_8$	(c) microcline (amazonite): bluish-green to green
				(2) Plagioclase feldspar
		Triclinic	$NaAlSi_3O_8$	(a) Albite: white, light greenish; (b) albite moonstone: white body colour with blue and white sheen
		Triclinic	$Na,Ca(Al,Si)AlSi_2O_8$	(c) Labradorite: greyish, bluish body colour with play of colour
25	Fibrolite (Sillimanite)	Orthorhombic	Al_2SiO_5	Greyish-blue, yellowish-green
26	Forsterite	Orthorhombic	$MgSiO_4$	White, light yellow
27	Fluorite	Cubic	CaF_2	Purple, bluish-purple, green, light pink, white, colour changed
28	Garnet	Cubic	$Fe_3Al_2(SiO_4)_3$	(a) Almandine: red to purplish red
		Cubic	$(Mg,Fe)_3Al_2(SiO_4)_3$	(b) Rhodolite: purplish-red
		Cubic	$Mn_3Al_2(SiO_4)_3$	(c) Spessartite: yellowish-orange to reddish orange
		Cubic	$Ca_3Al_2(SiO_4)_3$	(d) Grossular: white, yellow, light pink, green
		Cubic	$Ca_3Al_2(SiO_4)_3.(OH)$	(e) Hydrogrossular: yellowish-green to green
		Cubic	$Ca_3Al_2(SiO_4)_3$	(f) Hessonite: brownish-yellow, four-rays star
29	Hambergite	Orthorhombic	$Be_2BO_3(OH,F)$	Colourless
30	Hematite	Trigonal	Fe_2O_3	Silver greyish to black
31	Herderite	Orthorhombic	$CaBe(PO_4)F$	Light green to green
32	Hibonite	Hexagonal	$(Ca,Ce)(Al,Ti,Mg)_{12}O_{19}$	Brownish yellow, orangy-yellow
33	Idocrase (Vesuvianite)	Tetragonal	Complex Ca, Al silicate	Brownish-yellow, yellowish-green
34	Iolite (Cordierite)	Orthorhombic	$Mg_2Al_4Si_5O_{18}$	Yellowish-blue, blue
35	Jadeite Jade	Monoclinic	$NaAlSi_2O_8$	White, shade of green to bright green, lavander, yellow, bluish, pink, red, black
36	Jeremejevite	Hexagonal	$Al_6B_5O_{15}(F,OH)_3$	Colourless, light yellow to yellow
37	Johachidolite	Orthorhombic	$CaAlB_3O_7$	Light yellow to yellow, yellowish-orange, white, greenish-yellow
38	Kornerupine	Orthorhombic	Mg, Al, Fe Boro Silicate	Yellowish-green to emerald green, brownish-green to brown

(*Continued*)

Table 23.1 *Continued*

No.	Gems species	Crystal system	Composition	Varities & colour
39	Kyanite	Triclinic	Al_2SiO_5	White, blue, greenish blue
40	Kyawthuite	Monoclinic	$BiSbO_4$	Orange
41	Lapis-Lazuli	Cubic	Na, Ca, Al silicate with S	Violitish-blue to dark blue
42	Lazulite	Monoclinic	$MgA_{l2}(PO_4)_2(OH)_2$	Bluish green
43	Malachite	Monoclinic	$Cu_2(CO_3)(OH)_2$	Opaque green (banded)
44	Marcasite	Orthorhombic	FeS_2	Tin-white, light bronze yellow
45	Maw Sit Sit	Monoclinic	Chromium-rich rock	Mottled green with black and white
46	Monazite	Monoclinic	$(Ce,La,Nd,Th)PO_4$	Reddish-brown
47	Montebrasite-Amblygonite	Triclinic	$(Li,Na)Al(PO)_4$ (F,OH)	Light green to green, greenish-yellow
48	Nephrite	Monoclinic	Hydrous Ca,Mg,Fe Silicate	White, various shade of green, brownish, yellowish-green, black
49	Painite	Hexagonal	$CaZrBAl_9O1_8$	Greenish-brown, dark red, brownish-red
50	Periclase	Cubic	MgO	Yellowish-orange
51	Peridot	Orthorhombic	$(Mg,Fe)_2SiO_4$	Yellowish-green to olive green
52	Petalite	Monoclinic	$LiAlSi_4O_{10}$	Colourless, yellowish-brown, greenish-brown
53	Pezzottaite	Trigonal	$Cs(Be_2Li)Al_2(SiO_3)_6$	Pink to reddish-pink
54	Phenakite	Trigonal	Be_2SiO_4	Colourless, light yellow
55	Pollucite	Cubic	$(Cs,Na)(AlSi_2)O_6$. H_2O	White
56	Poudretteite	Hexagonal	$KNa_2B_3Si_{12}O_{30}$	White, light pink, purplish-pink
57	Pyrite	Cubic	FeS_2	Brass yellow
58	Quartz	Trigonal	SiO_2	(1) Crystalline quartz: (a) rock crystal: colourless, white; (b) amethyst: light purple to reddish-purple; (c) citrine: pale yellow to brownish-yellow; (d) smoky quartz: smoky brown; (e) rose quartz: light pink to pink; (f) milky quartz: milky white (2) Cryptocrystalline quartz: (a) chalcedony: various colours; (b) chrysoprase: bright apple green; (c) jasper: red, brownish red; (d) aventurine quartz: green
59	Rhodochrosite	Trigonal	$MnCO_3$	Light pink to pink
60	Rutile	Tetragonal	TiO_2	Brownish-red, orange-red with metallic coated
61	Scapolite	Tetragonal	Group of complex silicate	Colourless, pink, purple, blue yellow, orangy-pink
62	Scheelite	Tetragonal	$CaWO_4$	White, orangy-yellow, green
63	Serendebite	Triclinic	$Ca_2(Mg,Al)_6(Si,Al,B)_6O_{20}$	Dark greenish-blue
64	Serpentine	Massive	Hydrated and silicated of Mg	(a) Serpentine: light green to green; (b) bowenite: green to dark green
65	Sinhalite	Orthorhombic	$MgAlBO_4$	Pale yellow to yellow, brownish-yellow
66	Sodalite	Cubic	$Na_8Al_6Si_6O_{24}Cl_2$	(a) Sodalite: light blue to soda blue; (b) hackmanite: pinkish purple, purple, colour changed
67	Sphalerite	Cubic	(Zn,Fe)S	Brownish-yellow, reddish
68	Sphene	Monoclinic	$CaTiSiO_5$	Orangy-yellow, brownish-yellow, yellow
69	Spinel	Cubic	$MgAl_2O_4$	Various colour
70	Taaffeite	Hexagonal	$Mg_3Al_8BeO_{16}$	Whitish, light mauve, light pink, greyish
71	Thorite	Tetragonal	$(Th,U)SiO_4$	Orange, green, dark green Radioactive
72	Topaz	Orthorhombic	$Al_2(F,OH)_2SiO_4$	Colourless, light brownish-yellow, yellow, orangy yellow
73	Tourmaline	Trigonal	Na, Li, Al borosilicate	(a) Elbaite: pink, reddish-pink, purplish-pink, green, yellow, white, purple
		Trigonal	Na, Mg, Al, Fe borosilicate	(b) Dravite: light to dark brown, yellowish-brown
		Trigonal	Na, Fe, Al borosilicate	(c) Schorl: black, dark reddish
74	Wadeite	Hexagonal	$K_2ZrSi_3O_9$	Yellowish-green
75	Zircon	Tetragonal	$ZrSiO_4$	Yellow, brownish-yellow, green, orangy red, red, brown

angle. Additional mineral inclusions in Mogok rubies are calcite, spinel, zircon, apatite, titanite (sphene), corundum, mica, graphite, boehmite and garnet. Giuliani *et al.* (2015) recently described fluid inclusions in Mogok rubies with trapped melts of the salts CO_2–H_2S–S_8 and Na–K–Ca–CO_3–SO_4–NO_3–Cl–F and other inclusions, and daughter phases such as native sulphur, diaspore, boehmite, dawsonite, shortite, nitrates, chlorides, fluorite, barite, calcite, dolomite, pyrite, rutile and apatite. Giuliani *et al.* (2015) interpreted the fluid inclusions in the Mogok rubies they studied as indicating that the molten salts in impure dolomitic marbles were derived from the amphibolite facies regional metamorphism of evaporitic sediments. These molten salts acted as solvents for the mobilization of Al, V and Cr in the sediments during metamorphism, forming complexes with Cl^- and F^- anions.

Primary sapphire deposits of Mogok

The genesis and origin of the sapphires found in Mogok are very complex, and not fully understood. Some geologists (e.g. Kyaw Thu 2007) postulate that the sapphires at Mogok were derived from a syenitic parental magma, and subsequently from desilicified granitic melts (granite) by reaction with marbles. This process was often enhanced by post-magmatic metasomatic fluids, as evidenced from the liquid-gaseous inclusions

Fig. 23.6. The ruby mine at Dattaw Taung, Mogok. White-coloured materials are the tailings of ruby-bearing marble in middle part of photo and the washing plant (base of photo) is used for processing of secondary ruby deposits (eluvial and alluvial) found downstream. Photograph by Kyaw Thu.

found in the sapphires. Under certain circumstances sapphires are found in or around skarns in marble at their contacts with syenite, nepheline syenite or urtite bodies. Sapphire crystals formed in late-stage hydrothermal segregations within the syenite, nepheline syenite and in veins derived from syenite pegmatite. Blue sapphires may be found in aluminium-rich syenites containing the correct ratio of chromophoric impurities of iron and titanium. Yellow, orange yellow, orange, purple and other coloured sapphires are also found in Mogok. These colours are mainly due to iron associating with other chromophoric impurities, and to structural defects in the crystal lattice of sapphire. Typical mines for primary sapphire occur in Mogok, Ondan, Baw Mar, Laythar, Lesu-konzan and Thurein–Taung. Primary sapphires are also recovered from alkali syenite pegmatite and nepheline syenite at Kyargaung and Kyauktagar, and at Yenya-oo in the Thabeikkyin area (Khin Ma Phyu 2009) (Fig. 23.11).

Characteristics of Mogok sapphires

Colours in Mogok sapphires range from near colourless to deep blue, greenish-yellow to violet. Short or long hexagonal prism/pyramids with basal pinacoids and hexagonal bi-pyramids with basal pinacoids are common crystal forms. A massive habit with a rhombohedral parting is also commonly present in primary deposits. Examples of Mogok sapphires are shown in Figure 23.12. Most of the sapphires at On-dan, Thurein–Taung and Lay–Thar are embedded in a white albitic matrix. Sapphires found in alkali syenite–pegmatites from On-Dan are sometimes of a gigantic size, up to 25–30 cm in length (Thuzar Aung 2003).

Mogok sapphires typically have different suites of inclusions compared with the rubies. This can be attributed to the different modes of origin of ruby and sapphire. Mogok sapphires contain dense clouds of rutile silk and, occasionally, fine star-sapphires in various shades of blue have been recovered. Crystal inclusions are less common, but fluid inclusions are far more abundant in blue sapphires than in rubies. Crystal inclusions in Mogok sapphires are apatite, brookite, dolomite, fergusonite, monazite, mica, pyrrhotite (rare), rutile, spinel and zircon minerals (Gubelin 1953, 1973). Under the microscope Baw Mar sapphires are relatively clear, but contain multiple twins of? boehmite needles at twin intersections. In addition, stress tension fissures, needles and platelets of rutile, K-feldspar and mica inclusions are occasionally present. Baw Mar sapphires have a relatively high iron, low gallium and very low titanium contents, their Ga/Mg ratios vary over 0.6–17, their UV–VIS–NIR spectra display intense iron-related absorptions, and bands mainly composed of boehmite and mica are present in the FTIR absorption spectra (Hpone-Phyo Kan-Nyunt *et al.* 2013). Typically the colour of Mogok sapphires is exceptionally even and homogeneous, banding and sharp zoning are lacking and the presence of rhombohedral glide twinning is distinctive. These features can be used to distinguish Mogok sapphires from other sources of sapphire in the world.

Trace-element characteristics of Mogok rubies and sapphires

Rubies and sapphires are both corundum (Al_2O_3) gemstones, coloured by transition elements within the alumina crystal lattice. Cr^{3+} gives the red colour in rubies and Fe^{2+}, Fe^{3+} and Ti^{4+} ionic interactions colour sapphires. The minor ion V^{3+} introduces slate to purple colours and colour change effects in some sapphires, but its role in colouring rubies remains enigmatic. In previous studies the trace elements commonly

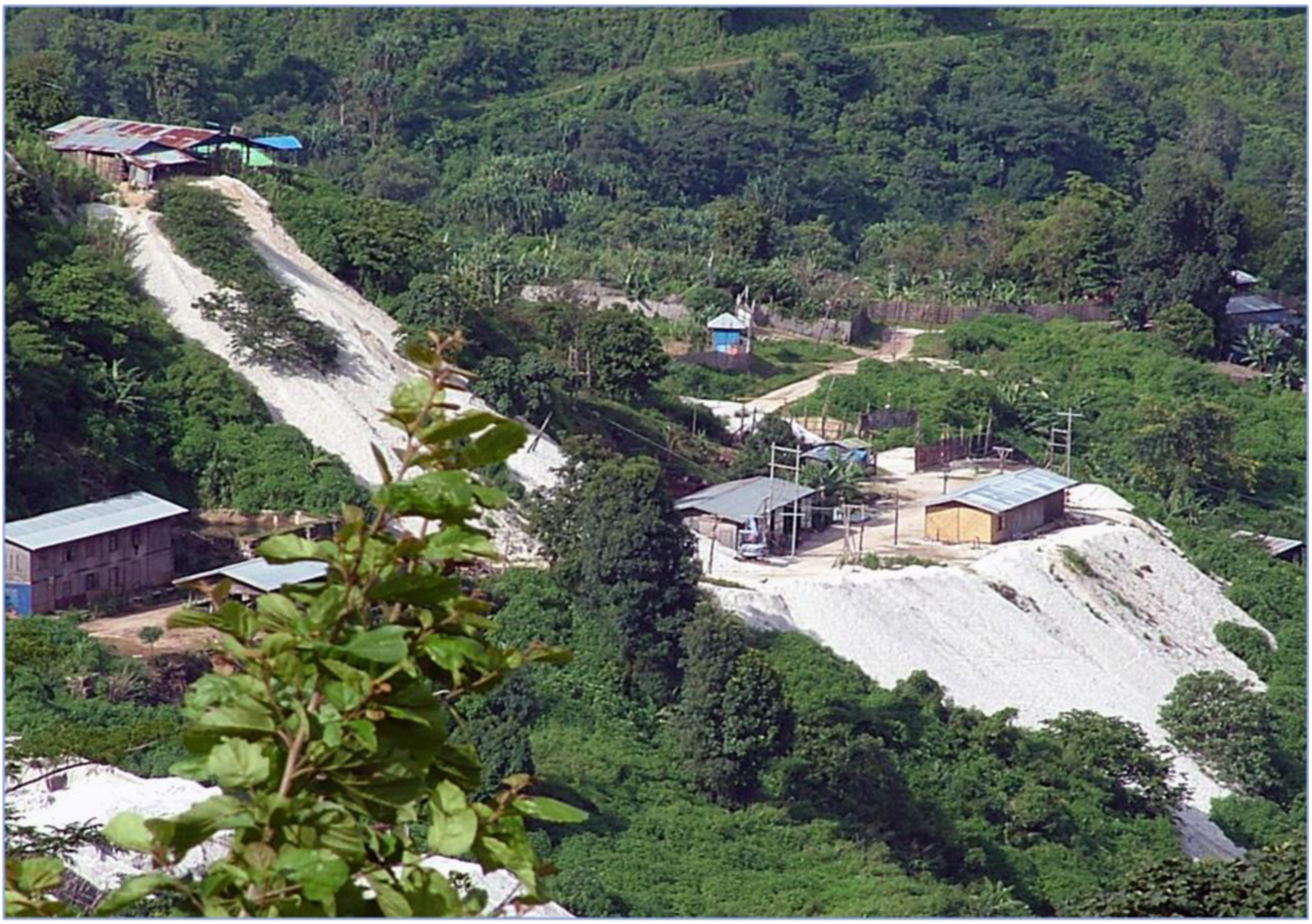


Fig. 23.7. Panoramic view of the primary ruby mines of Baw Padan area showing the white marble tailings. Photograph by Kyaw Thu.

reported in Mogok rubies and sapphires were Cr, Fe, V, Ti and Ga. Precise LA-ICP-MS analysis of rubies and sapphires from Mogok placer and *in situ* deposits has revealed that V can exceed 5000 ppm, giving V/Cr, V/Fe and V/Ti ratios up to 26, 78 and 97 respectively (Khin Zaw *et al.* 2010, 2012, 2015; Sutherland *et al.* 2014). These analyses demonstrate that geochemical studies of ruby suites can reveal new data relevant to their gemmology, the grading of gemstones, their exploration and their genesis. Vanadium can clearly have an important role in finger-printing rubies through comparison of V/Cr ratio variations between ruby deposits and in model studies of the genesis of rubies.

Ruby deposits in the Mong Hsu area

The Mong Hsu area is located about 225 km east of Mandalay in northern Shan State (Fig. 23.1). Rubies were first discovered in alluvial placer deposits in river terraces in this area in 1990 (Tin Hlaing 1991, 1993, 1999). In 1997 the primary source of the alluvial rubies was found in Loi Hsan Tao Mountain (1741 m) SE of Mong Hsu town (Figs 23.13 & 23.14). In the Loi Hsan Tao Mountain deposit, rubies occur in NE–SW-striking Palaeozoic metasediments consisting of schists, phyllites, marbles and calc-silicate rocks. The ruby deposits occur in a 305 m thick white dolomitic marble which dips SE and is sandwiched between two beds of phyllite. This marble band is well exposed along-strike over a lateral distance of *c.* 5 km.

Thin ruby-bearing veins occur within the white marble bed, composed of fine-grained sugary granoblastic calcite and dolomite with or without recrystallized calcite veins. Associated minerals are white to green tremolite, white wollastonite, white to pale green muscovite, brucite, grossularite, chlorite, a green (Cr-rich) tourmaline (uvite), purple fluorite, rutile and pyrite. Rubies are usually found in the softer parts of the marble where weak planes or fissures carry green chlorite group minerals, muscovite, Cr-rich uvite and veins of medium to coarse well-formed crystals of calcite. Fissures and foliation planes are the most important locations for rubies and aggregates of ruby crystals are often concentrated at fissure intersections, so that large quantities of ruby (in tonnes) may be found in a small area. Than Than Nu (2003) suggested that the Mong Hsu rubies have a hydrothermal metamorphic origin on the basis of their associated minerals, mode of occurrence, distinctive colour zoning, rarity of solid inclusions and very common fluid inclusions.

Characteristics of the Mong Hsu rubies

Mong Hsu rubies usually have a barrel-shaped crystal habit. Hexagonal dipyramids terminated by basal pinacoids are also common, and a rhombohedral habit is occasionally found. The colour of the Mong Hsu rubies is different from that of Mogok rubies, being mostly deep red with a distinct blue to violet-coloured zoning. Mineral inclusions are rare, but healing cracks with fluid feather inclusions are very common. Chemical analysis of trace elements in Mong Hsu rubies indicates the presence of Cr, Ti, V, Ga and Fe in descending order of concentration. Manganese is present in higher concentrations than in other rubies (Smith & Surdez 1994). Garnier *et al*. (2002) reported Mong Hsu rubies have high Cr content and distinct from those of rubies and sapphires hosted in basalt from

Fig. 23.8. (**a**) Entrance of tunnel used for underground mining in Mogok Pride Gems Co. Ltd (State Joint Venture mine) at Baw Padan–Kyauk Poke area; (**b**) view of tunnel for transportation of rocks by trolley and drain for underground waters beneath trolley way; (**c**) vertical shaft about 122 m from surface of tunnel in photo (a); (**d**) entrance of adit by timber ladder; the addit is supported by timber between two marble beds, about 195 m from surface to deepest level in a primary ruby mine (local name 'Ge' twin') at Kyauk Saung Joint-Venture mine; (**e**) entrance to underground mine of primary ruby deposit at Dattaw Taung (State Joint Venture mine); and (**f**) two miners take a trolley containing ruby-bearing marbles from a level at about 390 m out of the main shaft lift in the Ruby Dragon mine (State Joint Venture mine), Baw Padan area. Photographs by Kyaw Thu.

other SE Asia regions. Giuliani *et al.* (2015) studied the fluid inclusions in Mong Hsu rubies and found a CO_2–H_2S–COS–S_8 fluid system with daughter phases including dolomite, dawsonite, boehmite, diaspore, rutile and native sulphur.

Peridot deposits

The most-prized gem-quality peridots are large, exceeding 50 carats, from the historic deposit in the Mogok Stone Tract of Myanmar. The important peridot mines at Mogok are in the Pyaung–Gaung (Fig. 23.15), Htin–Shu Taung and Bernard areas. These major deposits within peridotites produce large mineral fragments and well-formed crystals of which pocket-sized crystals, up to 10 cm in size, are called 'Kyauk Ohe'. In addition, some peridots are found in placer deposits in these areas. Peridot is a gem variety of forsterite (Mg_2SiO_4), which occurs in solid solution with Fe_2SiO_4 to form the major constituents of the olivine group of minerals, $(Mg,Fe,Ni,Mn)_2SiO_4$. It has orthorhombic crystal symmetry, a hardness of 7, imperfect cleavages in two directions of {010} and {100}, a specific gravity between 3.22 and 3.29, and refractive indices between 1.635 and 1.690. The colour varies from grass-green to yellow-green and brownish-green; green shades are generally attributed to

Fig. 23.9. (**a**) Drilling a hole in marble prior to blasting in the Dattaw Taung ruby mine; (**b**) miners waiting for the trolley from the vertical main shaft in the Ruby Dragon mine, Baw Padan; (**c**) crushing plant for ruby-bearing marbles in Htay Paing Co. Ltd (State Joint Venture mine) at Baw Lone Gyi; (**d**) first-stage sorting of large-sized rubies in marble blocks from the marble fragments; (**e**) second-stage sorting of small-sized rubies in crushed marble; the crushed marble is washed and passed through a vibrating jig between the first and second stages of washing and sorting in Htay Paing Co. Ltd (State Joint-Venture mine) at Baw Lone Gyi; and (**f**) miners sort rubies from marble fragments on a conveyor belt in the Ruby Dragon mine, Baw Padan. Photographs by Kyaw Thu.

ferric iron (Fe^{3+}) due to oxidation of the ferrous iron (Fe^{2+}) constituent. The mineralogical and textural characteristics of the peridots are illustrated in Figures 23.16 and 23.17.

Host rocks of peridot are peridotites of ultramafic igneous origin, composed largely of olivine. Three types of peridotite are common: dunite with >90% olivine; harzburgite with >40% olivine and orthopyroxene ((Mg, Fe) SiO_3), and <5% of clinopyroxene (Ca (Mg, Fe) Si_2O_6); and lherzolite with abundant olivine (>40%) and orthopyroxene and clinopyroxene generally >5%. Chromite is a minor constituent in these peridotites.

Peridot mining operations in the Mogok area have exposed several narrow bodies of partially serpentinized peridotite,

Fig. 23.10. (**a**) Ruby crystal in marble matrix from Dattaw Taung, Mogok (3.5 × 2.5 × 3.0 cm) (photograph by Kyaw Thu); (**b**) Big MaMa ruby in matrix from Baw Padan–Kyauk Poke area, Mogok (*c.* 10 000 carats) (photograph from Pala Int.); (**c**) SLORC ruby (490 carats) from Dattaw Taung, Mogok (photograph from MGE); (**d**, **e**, **f**) Mong Hsu 'rough' ruby crystals (0.7 × 0.3 × 1.0 cm and 2.0 × 1.0 × 2.5 cm) and cabochon with blue core (1.0 × 0.8 × 0.5 cm) (photograph by Kyaw Thu); and (**g**) ruby in nepheline matrix from Kyauk Pyat That area, Mogok (0.8 × 1.4 × 4.0 cm) (photograph by Kyaw Thu).

Fig. 23.11. (**a**) Small-scale mining camp using a vertical shaft and tunnel (1.2 × 1.2 m wide shaft, locally named 'Lay Bin') in the search for primary sapphire deposits; (**b**) entrance of a Lay Bin, with miners raising a basket filled with rock and soil from underground using a wood-framed rope windlass; (**c**) a Lay Bin underground tunnel dug to exploit a primary sapphire deposit; (**d**) sapphire-bearing syenitic pegmatite pocket surrounded by biotite mica in the Baw Mar mine; and (**e**) sapphire-bearing syenitic pegmatite fragments from the Baw Mar mine. Photographs by Kyaw Thu.

Fig. 23.12. (**a**) Gem-quality sapphire crystal (hexagonal bipyramid form) (2.0 × 1.8 × 4 cm); (**b**) large rough sapphires from the Baw Mar mine (7.0 × 10.0 × 4.0 cm); (**c**) gem-quality rough sapphires from the Baw Mar mine (6.0 × 7.0 × 3.5 mm average); (**d**) selected top-quality rough sapphires from Baw Mar mine (6.5 × 7.0 × 4.0 mm average); (**e**) rough sapphires from the Baw Mar mine (11 × 9 × 4 mm average); and (**f**) faceted fine-quality blue sapphire of 8.05 carats from the Baw Mar mine (16.0 × 12.0 × 4.5 mm). Photographs by Kyaw Thu.

Fig. 23.13. Entrance to adit at the primary hard-rock Mong Hsu ruby mine operated by the Ruby Dragon Co. Ltd at Loi Saung Htauk Hill, northern Shan State. Photograph courtesy of the Ruby Dragon Co. Ltd.

aligned along minor faults and connecting to the major east–west-trending Momeik Fault which bounds the northern side of the Mogok area. A subhorizontal tunnel has been dug into an ultramafic rock body at the currently active Pyaung–Gaung Mine. Here the peridotites exhibit planar layering resulting from shear deformation at depth, cross-cut by younger fractures in several directions. The surfaces of these fractures are coated with a mixture of talc and microscopic carbonate minerals, probably calcite and dolomite (Fig. 23.16a). Another conspicuous feature is veins or fractures filled with coarsely crystallized brown enstatite (some crystals are >10 cm in length). According to miners, these veins are useful in prospecting for peridot as they typically lead to pockets of peridot (Fig. 23.16b). Another vein mineral is brown phlogopite, which is also useful for targeting the peridot pockets.

The ultramafic rocks at Pyaung–Gaung are harzburgite and dunite. The harzburgite consists of comminuted olivine (Fo_{92-93}), orthopyroxene (En_{92-93}), Cr-bearing magnetite ($Mgt_{61}Pcm_{18}Cm_{10}Sp_{9}$) and minor phlogopite, with lizardite serpentine coating all grain boundaries. The dunite consists of olivine (Fo_{92-93}) and spinel ($Mgt_{65-70}Cm_{20-22}Pcm_{8}Sp_{4}$) with an intergranular coating of lizardite. Both rock types are cut by shear zones with the surfaces coated by shiny (soapy) lizardite, and veins of magnetite-rich spinel or snow-flake talc with or without lizardite. Ol–Opx–Spinel thermometry of Mogok peridotite–dunite yielded an equilibration temperature of

Fig. 23.14. Photo showing miners washing and sorting rubies in marble fragments from barren marble at a ruby mine in the Mong Hsu area, northern Shan State. Photograph courtesy of the Ruby Dragon Co. Ltd.

Fig. 23.15. Entrance to an underground mine at Pyaung-gaung showing the weathered outcrop of partially serpentinized peridotite. The rust coloration indicates that there is still olivine in the peridotite that has not been completely altered to serpentinite. Photograph by Kyaw Thu.

730 ± 40°C (Girnis *et al.* 1999) and a pressure of 20 kbar or less (Harlow & Kyaw Thu 2014). This hartzburgite–dunite has been uplifted along the Momeik Fault. The low spinel component in both harzburgite and dunite, containing abundant chromite (Cm: $FeCr_2O_3$), and the high magnetite (Mgt: $Fe^{2+}Fe^{3+}_2O_4$) content suggest re-equilibration, probably by reaction with fluids in the mantle. Finally, the presence of talc and lizardite serpentine in the fractures indicates the late addition of water at much lower temperatures (probably <300°C), probably in the upper crust and related to fault movement.

Peridot compositions from cavities are very homogeneous ($Fo_{92–93}$ with NiO = 0.4–0.5 wt%). In addition to the white material filling the interstices of the peridot pockets adjacent to the cavity walls, there are whitish inclusions in the basal segments of peridot crystals (Fig. 23.16). A combination of X-ray diffraction and electron microprobe analysis shows that the white material around the peridot crystals in the pocket assemblages consists of a mixture of very fine-grained cryptocrystalline carbonate minerals (calcite, dolomite and pyroaurite) and lizardite serpentine. Plates of lizardite can be observed in the white zone, which suggests crystallization in a cavity filled by liquid and gas at a later stage and at a much lower temperature, prior to the infilling of the fine-grained carbonate and serpentine. The white inclusions in peridot crystals generally consist of a spray of serpentine (probably antigorite), magnetite and brucite ($Mg(OH)_2$) crystals, and open spaces. Some inclusions are bounded by a zone of olivine, somewhat higher in iron content (Mg# = 0.943 v. 0.924), which suggests re-equilibration between Mg-rich antigorite in the inclusion (Mg# = *c.* 0.975) and host olivine at $T < 600$°C (Evans 2010). The white inclusions in peridot can be interpreted as the result

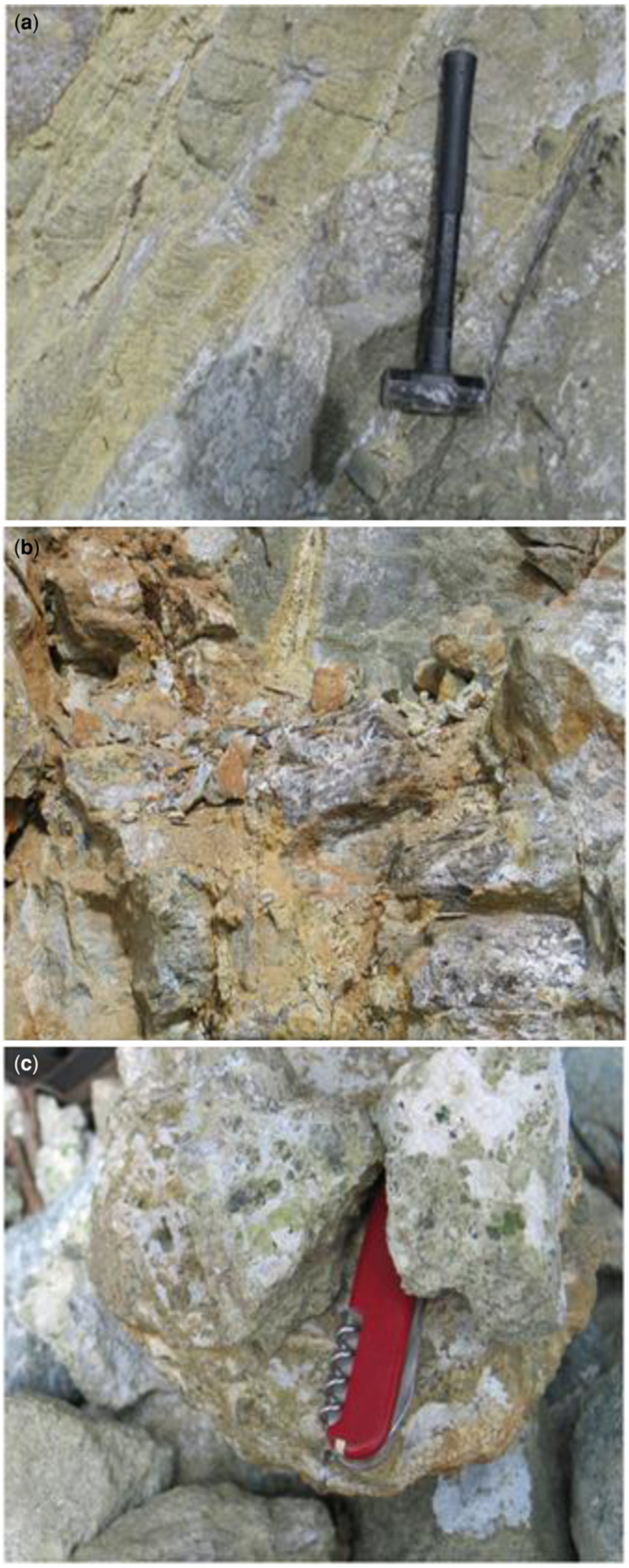


Fig. 23.16. (**a**) Close-up of partially serpentinized peridotite (yellow-green) outcrop showing a subhorizontal planar shear feature, cut by fractures exposing surfaces partially coated with a mixture of talc and serpentine (white and brown); (**b**) close-up of outcrop exposing a large vein of brown enstatite coated by talc and carbonate, running upper left to lower right through this chaotic exposure; the image is *c.* 1 m across; and (**c**) sample of a portion of a pocket showing peridot crystals (green) in white pocket filling (a mix of calcite, pyroaurite-Mg6(Fe^3+)2CO_3(OH)16.4H_2O), talc, and lizardite serpentine) and grey serpentinized host rock of the pocket. Photographs by George E. Harlow and Kyaw Thu.

Fig. 23.17. (**a**) Large gem-quality olive-green-coloured peridot crystal (1280 carats) from Pyaung-gaung in the Mogok Stone Tract; (**b**) faced peridot crystal (150 carats); (**c**) rough peridots weighing 1508 carats in total displayed at a Gem Emporium (2.0 × 3.0 × 4.5 cm to 3.0 × 3.5 × 4.0 cm average); and (**d**) faceted peridot (65 carats) from Pyaung-gaung, Mogok (3.0 × 3.5 × 2.0 cm). Photographs by Kyaw Thu.

of the reaction: forsterite + H_2O = antigorite + brucite. The peridot formation at Pyaung-Gaung is therefore the result of a hydrous fluid dissolving olivine and precipitating the mineral within cavities. The cavities were probably produced by deformation that uplifted the fault slices of peridotite, and are similar in origin to those in the Sapat, Pakistan and Zabargad bodies (Harlow & Kyaw Thu 2014; Harlow *et al.* 2014).

Jadeite deposits

The world-famous jadeite deposits of Myanmar occur as both primary and secondary occurrences (Nyan Thin 2002; Thet Tin Nyunt *et al.* 2017). Primary occurrences occur along the western margin of the serpentinized peridotite body of the Jade Mines area in Kachin State. Secondary deposit jadeite mines (locally called 'maw') are economically more favourable than primary deposits and occur along the Uru Chaung, typically around Kansi in the north (Figs 23.3 & 23.4) at Lonkin, Mawsisa, Hpakant, Tamkhan, Haungpa and Hwehka (Fig. 23.18) in the south.

Primary jadeite deposits

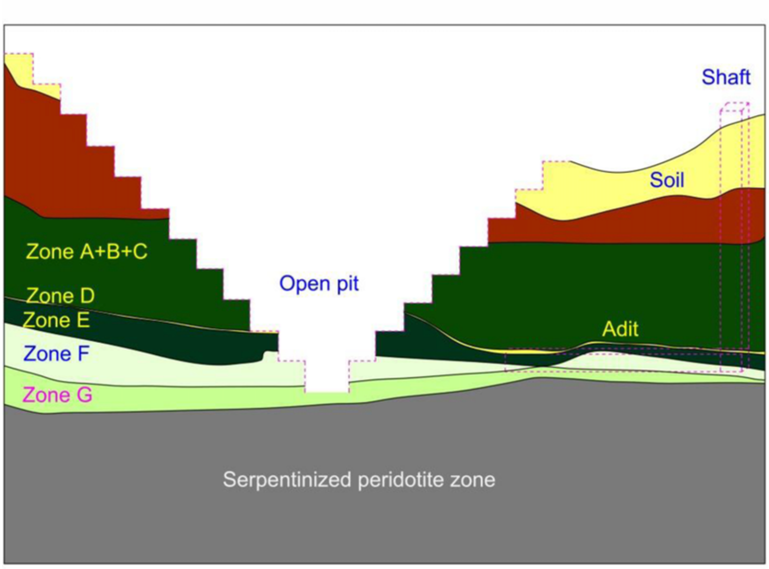
Primary jadeite deposits occur as veins and dykes, 1.5–5 m wide and 5–100 m, long cross-cutting serpentinized peridotite host rocks in the Hpakant–Tawmaw area. The jadeite veins generally have almost NE–SW trends, swinging to the NNE–SSW, or are nearly vertical with a north–south strike. The boundary between serpentinized peridotite bodies and jadeite veins is formed of metasomatic amphibolite, consisting of six types of sodic to sodic-calcic amphiboles: eckermannite, magnesio-katophorite, nyboite, glaucophane, richterite and winchite (Shi *et al.* 2003, 2008, 2014). A cross-section of a primary jadeite deposit, showing the zones of mineralization around jadeite veins and dykes and their types at the Meinkyin worksite in the Tawmaw area, are shown in Figures 23.19 and 23.20. As a result of several stages of later deformation, fragments of the boundary zone are also found intermingled with blocks of jadeite that often have a preferred orientation.

Secondary jadeite deposits

Secondary occurrences of jadeite are widely distributed in the Jade Tract; the main workings are in the Pleistocene Uru Boulder Conglomerate unit, occurring along the Uru Chaung in the Lonekhin, Mawsisa and Hpakant to Mamon areas. Vertical sections of the Uru Boulder Conglomerate are variable in thickness up to a few metres, and are covered by a soil overburden of varying thickness (Fig. 23.21). Local names for pebble- and cobble-sized jadeite-bearing layers which underlie the soil overburden are 'Kyatthwe Gyaw' and 'Kaday Gyaw', respectively. The boulder-sized, jadeite-bearing conglomerate layer is known locally as 'Kyauk Gyaw'. Under the Kyauk Gyaw is a sandy layer containing high-quality jadeite boulders. The bedrock underlying the Uru Boulder Conglomerate is known locally as 'Phar Kyauk', and is serpentinized peridotite. 'Imperial quality' jadeites are mostly found in the secondary deposits associated with the Uru Boulder Conglomerate unit in this area (Fig. 23.21).

Detailed mineralogy and mineral species of Myanmar jades are documented by Nyan Thin (2002) and Thet Tin Nyunt

Fig. 23.18. Excavation in the Uru Boulder Conglomerate (thickness *c.* 300 m) and mining of jadeite in a secondary jadeite deposit at Kanpwint Oo mine, near Hwehka. Photograph courtesy of Khaing Nyein Htay.



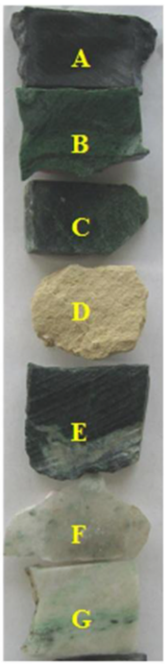


Fig. 23.19. Generalized cross-section of the primary jadeite vein and associated mineralized veins in the open pit mine at Meinkyin, Tawmaw area (modified after Khaing Nyein Htay 2010). Altered serpentinite (Zone A), kosmochlor- and chromite-rich zone (Zone B), actinolite-rich amphibolite (Zone C), talc–chlorite schist (Zone D), hornblende-rich amphibolite (Zone E), albite zone (Zone F) and jadeite zone (Zone G).

Fig. 23.20. Varieties of jadeite jades in a primary jadeitite 'dyke' (approximate total weight *c.* 3000 tonnes) in the Tawmaw area: (**a**) lavender jade; (**b**) pea-green jade; (**c**) white jade (locally called Pain Oo Thar); (**d**) black jade. Photographs courtesy of Khaing Nyein Htay.

et al. (2017). The colours of the different varieties of jadeite jades found in jadeite dykes in the Tawmaw area vary from lavender, green, white to black. Individual boulders of jadeite can weigh as much as 30 tons and imperial green-coloured jadeite jades are highly prized (Figs 23.20 & 23.22).

Diamond deposits

In Myanmar, alluvial diamonds with no obvious source have been found in the Momeik area in the northern part of Myanmar and in the Theindaw area in the south. A few diamonds have also been recovered from gravels in the east of the Taungoo–Htantabin area, Than Lwin River (east of Mong Hsu), Nant Yar Seik area and Nant Phyu (Ta Naing area) in the northern part of the country.

Diamonds are potentially important precious gemstones and industrial stones in Myanmar, but little is known about their occurrences. The first discovery of a diamond (5 carat in weight) in 1959 found by local people from the Momeik township of the northern Shan State was reported in the 'Guardian' newspaper. The stone was purchased by a gem dealer in Mogok. In 1961,

Fig. 23.21. Jadeite-bearing gravel in the Uru Boulder Conglomerate Unit and overburden soil exposed by open cut mining at the Kyaing International Mine, Mawsisa. Photograph courtesy of Khaing Nyein Htay.

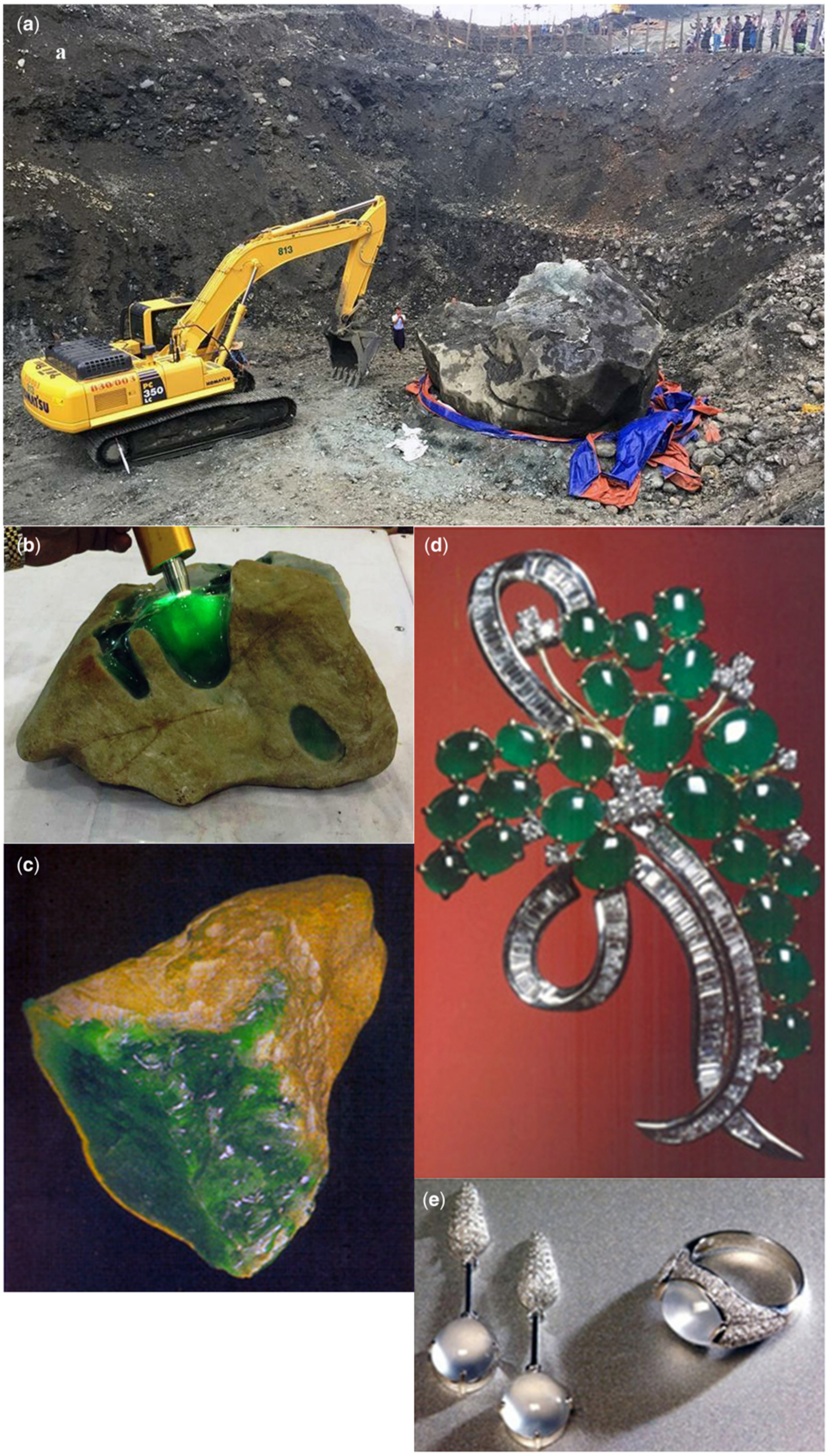


Fig. 23.22. (**a**) Large jadeite jade boulder (approximately 174 600 kg; 5.79 × 4.57 × 4.26 m) from the Malingyaung maw mined by Yadanar Taung Tan Co. in October 2016 (photograph courtesy of Yadanar Taung Tan Co.); (**b**) superb imperial-quality green jadeite jade rough 16.50 kg (reserved price €4.5 million) displayed at 52nd Myanmar Gem Emporium in 2015 (photograph by Kyaw Thu); (**c**) rough imperial green jadeite jade displayed at the Gem Museum, Nay Pyi Taw (4.7 kg; 17.78 × 12.7 × 7.62 cm); (**d**) imperial green cabochon (polished) jadeite jades and diamonds in a brooch (8.0 × 6.0 to 10.0 × 8.0 mm); and (**e**) imperial white jadeite jade (locally named water jade) (11.0 × 9.0 mm) with diamonds in ring and earrings from local jewellery shop (photographs by Kyaw Thu).

U Soe Win and party discovered two diamonds (*c.* 2 carats and 0.3 carat) in the Kyeindaw area at Momeik. According to official records, over 300 diamonds weighing approximately 200 carats have been found in the Momeik area. The largest was 7 carats and the medium size is 0.35 carats.

Five small diamonds were discovered in 1980 by local people panning for gold in the Myatsaw Nyi Naung area, 10 km SE of Taungoo–Htantabin in the Bago Region. Between 1987 and 1988 the Geological Survey of Myanmar found three small diamonds in this area. Occasionally a few diamonds are found during alluvial gold mining by local artisanal miners.

In July 1985 alluvial diamonds were found in alluvial tin deposits at the Theindaw Mine 90 km east of Myeik in the Taninthayi region, southernmost Myanmar, near the Thai border. The Theindaw diamonds are mainly of gem quality and, according to official sources, up to 1995 a total of over 3000 diamonds weighing more than 2000 carats had been recovered.

The largest diamond found was 10.13 carats and the median weight of stones was 0.35 carats.

Three small diamonds were recovered in the Kyaukme Taung–Shwechaung area of Dawei township in 1987, which is about 150 km north of the Theindaw Mine.

Momeik area

The Momeik area lies in the northeastern part of the Mogok Metamorphic Belt (MMB) and the northwestern part of the Eastern Highlands. A geological map of the Kyeindaw–Mohauk area in Momeik Township is shown in Figure 23.23. The rocks in this area consist of migmatites and paragneisses including biotite gneiss, garnet-–biotite gneiss, garnet–sillimanite gneiss, scapolite gneiss, marble, biotite granulite, calc-silicate granulite, quartzite and also younger granites. Olivine basalts are also present to the west of Kin Chaung, near the margin of Mohauk valley, 15 km NW of Momeik and Mogok.

Diamondiferous gravel beds are exposed in an area about 2 km north of Mohauk village and nearly 6 km NW of Kyeindaw village, which is 1.5 km NE of Mogok (Anon 1993a). Diamonds are found in the basal gravels, which are poorly

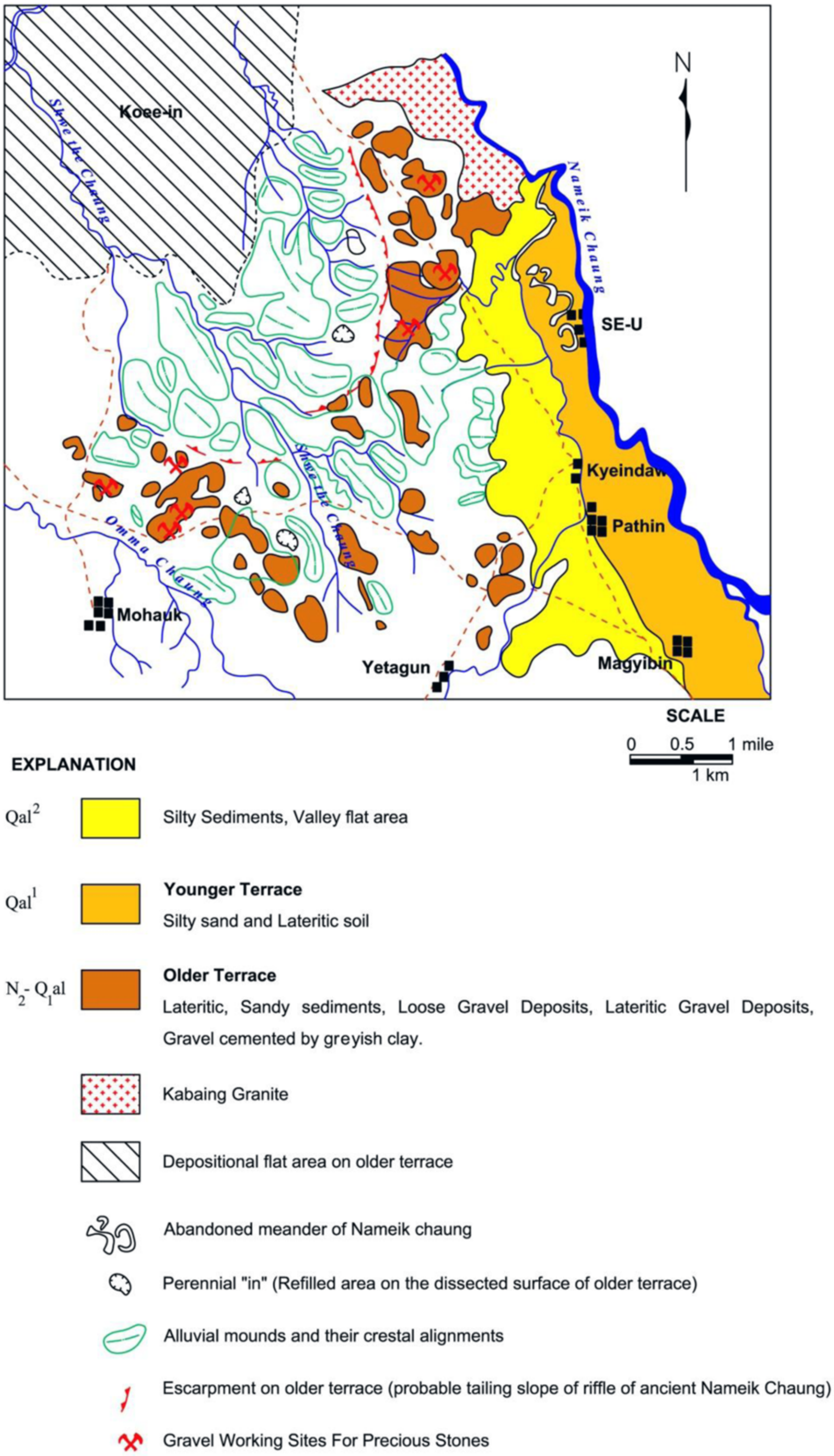


Fig. 23.23. Geological map of Kyeindaw-Mohauk area, Momeik townships, northern Myanmar (modified after Maung Thin & Party 1973).

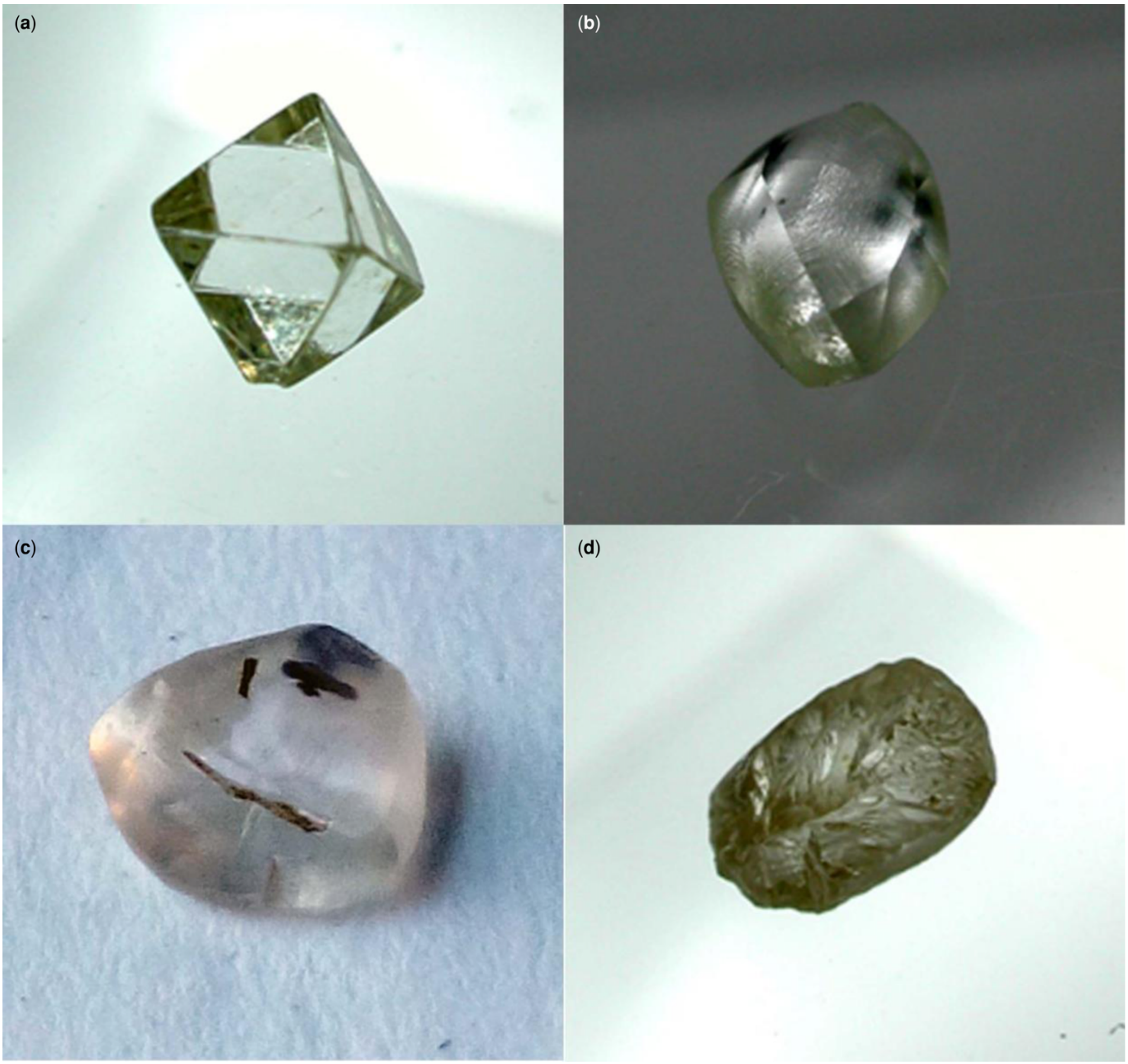


Fig. 23.24. (**a–c**) Rough diamond crystals with different forms (0.590, 0.346, 0.56 carat) from Kyeindaw and Mohauk village, Momeik area; (**d**) 0.28 carat rough diamond crystal from Nanyarzeik, Kachin State. Photographs by Kyaw Thu.

sorted and composed of subrounded to rounded pebbles of vein quartz, quartzites, schistose quartzites, micaceous schists, jasper, black shale, volcanic tuffs, brecciated quartz–tourmaline rocks, slaty rocks and well-rounded pebbles of grey-coloured silicified rocks. These gravel beds contain not only diamonds, but also small quantities of rubies, sapphires and placer gold (Fig. 23.23). The colour of diamonds from Momeik varies from very light brown to dark brown, and very pale yellow to straw yellow. The most common forms are dodecahedra, including rounded, flat, elongated and composite shapes, sometimes composite stones and macle (twinned crystal) (Fig. 23.24).

Taungoo east area

The Taungoo east area is underlain by Mergui Group metasediments consisting of phyllites, schists, conglomerates and sandstones. These rocks have been intruded by biotite granite, muscovite granite and possibly by ultramafic sills. The Mergui metasediments are thought to be Carboniferous–Permian in age, and the granites to be Mesozoic. Small ultramafic bodies are found in the southeastern part of the area. Quaternary high-level terrace gravels occur near Myat Saw Nyi Naung, 10 km SE of Taungoo. The terraces are aligned north–south where most of the alluvial gold workings are found. Small diamonds were found by local people panning for gold from gold-bearing gravels in this area, consisting of pebbly mudstone, granite, coloured chert, sandstone, quartzite, phyllite and vein quartz.

Theindaw area

The Theindaw diamond area (Fig. 2.25) is approximately 4 km north of Theindaw village and about 96 km east of Myeik (Anon 1993b). The Theindaw–Kawmapyin Tertiary basin of the Taninthayi region is composed mainly of sandstone, clayey soil, sandy soil, grit and conglomerate. Carboniferous–Permian sediments of the Mergui Group occur in a younging-upwards sequence of five units: quartzite; quartz-bearing feldspathic sandstone; pebbly sandstone; laminated sandstone; and siliceous mudstone. The Theindaw Basin lies between two parallel

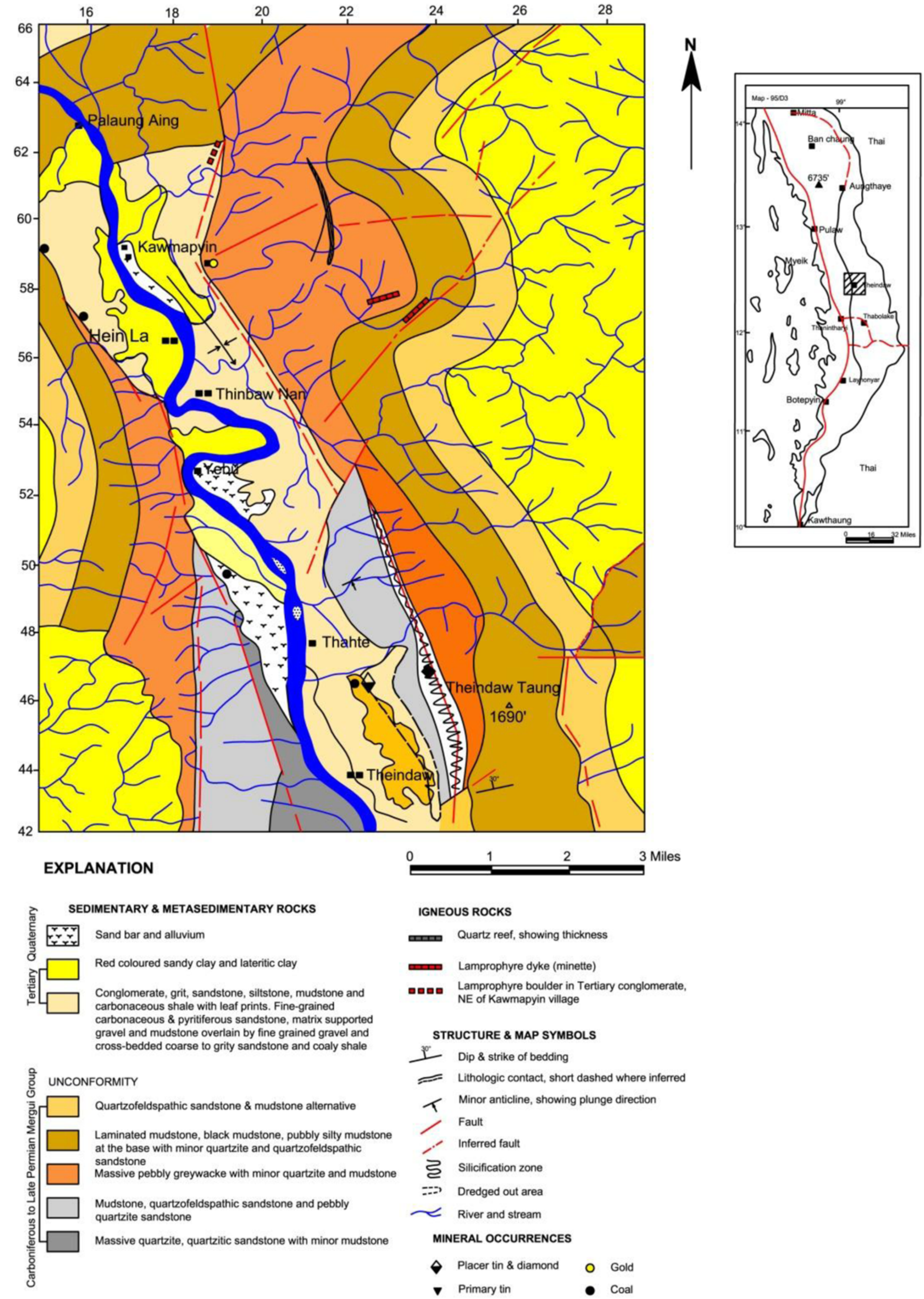


Fig. 23.25. Geological map of diamond workings in the Theindaw area, Tanintharyi Region (modified after Nyunt Htay & Party 1986).

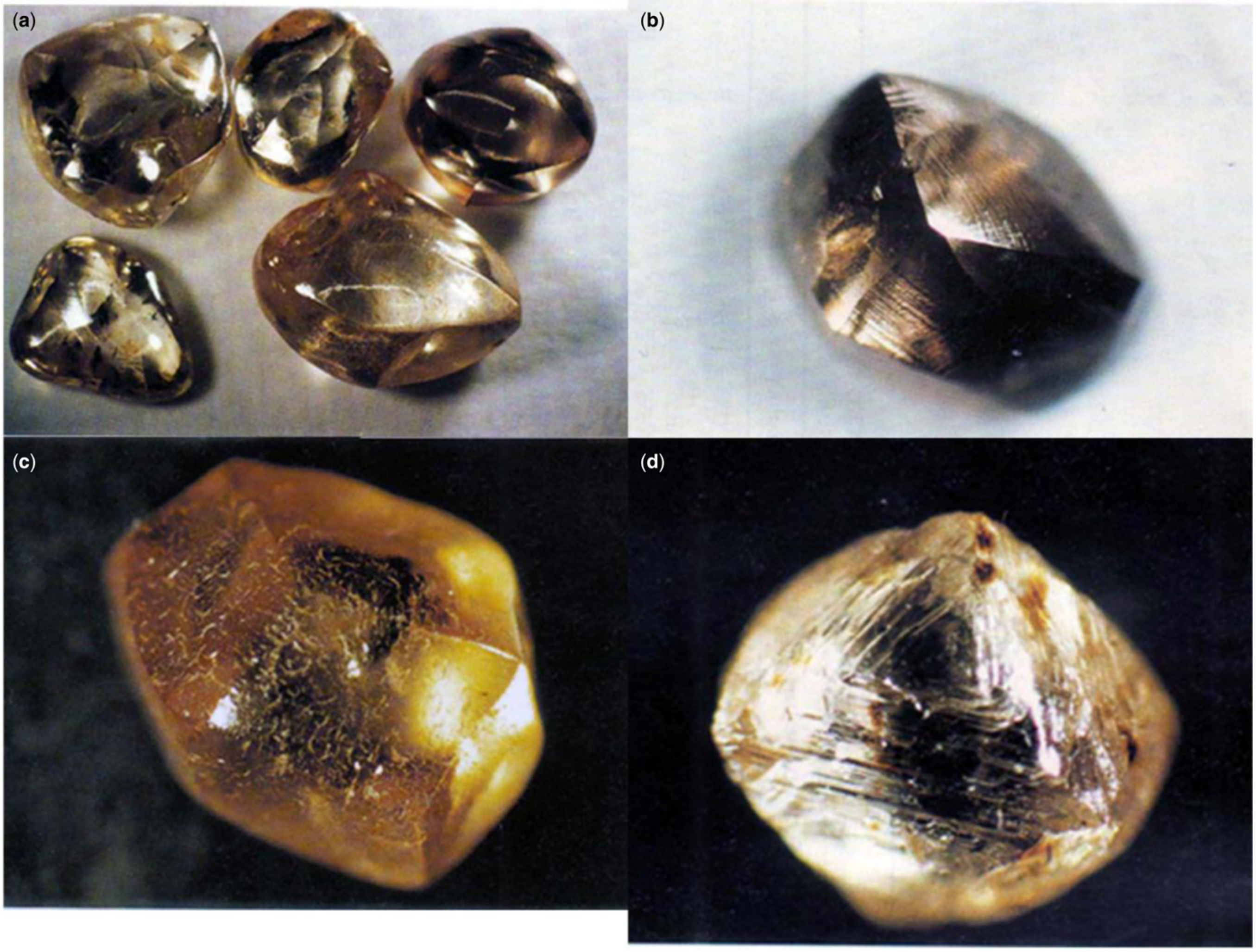


Fig. 23.26. (**a–d**) Rough diamond crystals (0.25–0.50 carat) from placer deposits in the Theindaw area. Photographs courtesy of Nyunt Htay.

faults and has an anticlinal structure with a northeasterly plunge. The only outcrop of igneous rock is exposed in Yebu Stream, 2 km east of Thinbawnan village, which is approximately 100 km east of Myeik (Fig. 23.25). Theindaw diamonds are mostly dodecahedra, with some tetrahexahedra of which half are rounded, broken fragments; octahedrons, aggregates and macle (twinned crystals) of diamond are also found. Coloured diamonds vary from white, greyish, yellowish and brownish shades to reddish brown (Fig. 23.26).

Similarities between the Momeik and Theindaw diamonds suggest that they are derived from similar sources. The occurrence of diamonds in headless placers within a relatively young geological environment, as is especially the case for Theindaw, could suggest a non-traditional (i.e. not kimberlitic or lamproitic) primary source for the diamonds. However, the birefringence and CL studies show that most of these diamonds originally grew as octahedra, as do most diamonds from kimberlitic and lamproitic sources (Bulanova 1995). Their present rounded forms, which truncate the internal zoning, reflect resorption of the diamonds after growth. By analogy with studies of kimberlitic and lamproitic diamonds, their resorption, as well as the abundant etch features, is interpreted as the result of dissolution processes occurring during the entrainment and transport of the diamonds in an alkaline magma. This magmatic rock or rocks represents the primary source of the Myanmar diamonds (Tin Tin Win *et al.* 2001). However, the very highly polished surfaces seen on many stones, the abundance of strongly deformed brown stones, the very high degree of resorption and the common occurrence of blue-yellow oscillatory CL zoning appear to be a more characteristic feature of diamond suites from lamproites rather than of those from kimberlites (Hall & Smith 1984). The abundance of stones with abrasion, breakage and brown radiation damage spots suggests that most of these Myanmar diamonds have a long history of transport in sedimentary and alluvial environments (Fig. 23.27).

Gemstone deposits in pegmatites

Pegmatites are widely distributed in Myanmar (Khin Zaw 1998). Prominent pegmatite-hosted gemstone deposits are found mainly in the Sakangyi and Pan-Taw areas of the Mogok Stone Tract, at Molo NE of Momeik, at Panta-Hoe SE of Mogok and at Let Pan Hla between Mogok and Mandalay. Smaller pegmatite-hosted gem deposits are found in Mogok, Mong Hsu and in many other parts of Myanmar. The mineralogy of the gem-bearing pegmatites includes quartz, feldspar, topaz, aquamarine, rubellite and other rare collector gemstones (Hla Kyi & Kyaw Thu 2004, 2006; Hla Kyi *et al.* 2005) (Figs 23.28 & 2.29).

Pegmatites can contain very large crystals, such as the 6 m long beryl crystal and 15 m long spodumene crystal associated with microcline–perthite in a pegmatite discovered at Keystone in the Black Hills of South Dakota, USA (Hatch *et al.* 1961).

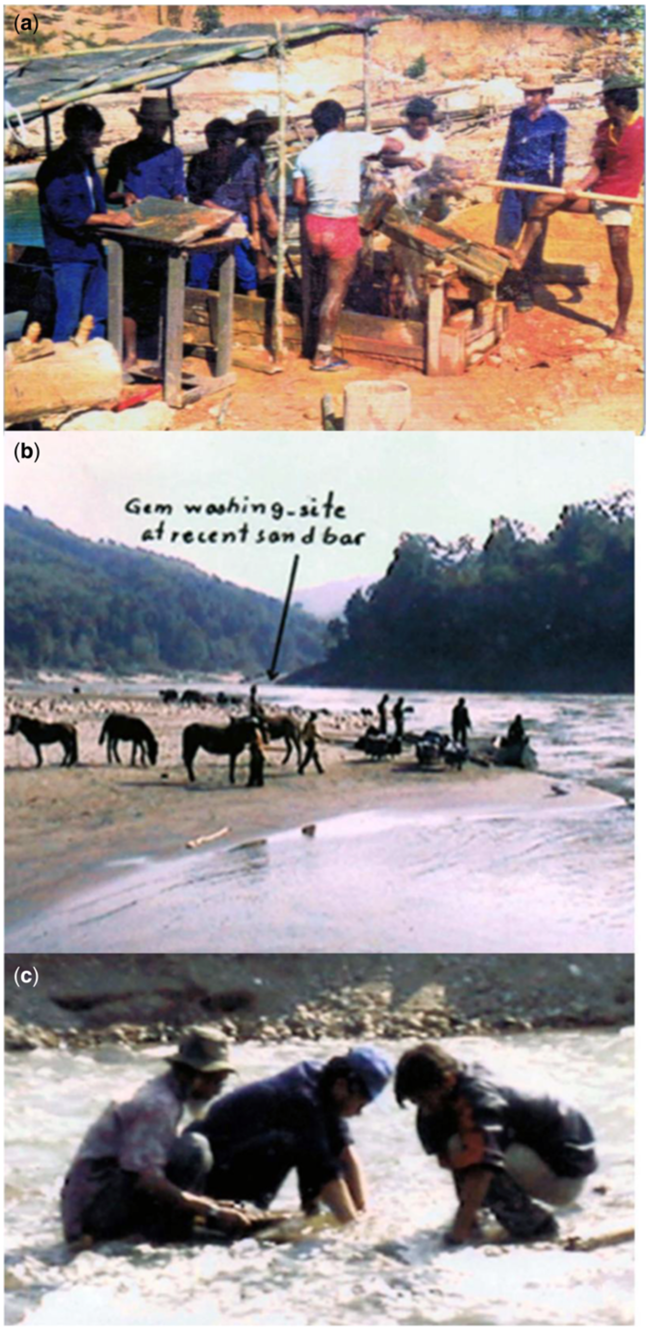


Fig. 23.27. (**a**) Washing and sorting of diamond-bearing gravel at the Theindaw mine; (**b**) washing site for diamonds, panned from river sands on a sand bar in the Than Lwin River, northern Shan State; and (**c**) panning for gold and diamonds at Nan Phyu. Photographs courtesy of Nyunt Htay.

Pegmatite minerals can also be very heavy, such as the 70 000 kg quartz crystal in a Kazakhstan pegmatite and a 100 000 kg quartz crystal from Norway (Smirnov 1976). Pegmatites are a major source of high-tech metals and minerals such as rubidium, tantalum, tin, lithium and other rare metals (Cerny 1991). The minerals of the pegmatite deposits in Myanmar are comparable with those found in other regions.

The pegmatite deposit at Sakangyi is located about 16 km west of Mogok and for more than 100 years has been a major source of aquamarine, goshenite, topaz, large quartz crystals, danburite and fluorite. Occasionally gem-quality zircon, scheelite, hessonite, herderite, cassiterite, columbite–tantalite, uraninite and lepidolite are also encountered. Pegmatite dykes may be up to 30 m wide and are strongly kaolinized. Crystals of orthoclase, cleavelandite, microcline, quartz, muscovite, topaz, aquamarine, herderite, etc. are found in pegmatite dykes that intruded the Kabaing Granite. Pegmatite dykes at Sakangyi are dated at *c.* 16 Ma (Middle Miocene) (Searle & Ba Than Haq 1964), and the Kabaing Granite was emplaced at *c.* 15.8 ± 1.1 Ma (Middle Miocene) (Bertrand *et al.* 2001).

The Pan-Taw pegmatite deposit is situated about 14.4 km NW of Mogok in the southern part of Kyauk-Sin. Since 2004 this area has attracted artisanal miners and gem traders as it has produced gems such as topaz (colourless, yellow, sherry colour), aquamarine, goshenite, quartz (amethyst, rock crystal, citrine, smoky), rhodochrosite, colour-change fluorite, microcline, cleavelandite, muscovite, cassiterite, etc.

The Molo pegmatite is situated NE of Momeik, northern Shan State. This pegmatite intruded into peridotites and is the source of distinctive mushroom-shaped rubellite, prismatic-shaped rubellite, and the rare gemstones petalite, pollucite, hambergite, phenakite, danburite, beryl, morganite, orthoclase and quartz (Hla Kyi *et al.* 2005).

The Panta-Hoe pegmatite is located in the southeastern part of the Mogok Stone Tract between Mogok and Momeik, and has produced mainly rubellite and the rare gemstones jeremejevite and danburite. The Let Pan Hla pegmatite occurs at Pyin Gyi Taung, east of Let Pan Hla village, and has produced prismatic-shaped striking pink-coloured tourmaline, green tourmaline, purple apatite and beryl.

Classifications of pegmatites

Numerous classifications of pegmatites 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. According to the multiple criteria pegmatite classification of Cerny (1991), pegmatites at Mogok fall into three types on the basis of their internal structures: simple pegmatites; zoned pegmatites; and complex pegmatites (Kyaw Thu 2007). Simple pegmatite is the most common type of pegmatite; it is composed of quartz, feldspar and micas and has no internal structure. Zoned pegmatites consist of quartz, feldspar and mica with numerous accessory minerals. These minerals form distinct zones (layers) with the sizes of the crystals increasing towards the centre (or core) of the pegmatite body. The zones occur as concentric layers around a very coarse-grained core, forming border, wall, intermediate and core zones. In zoned pegmatites, gemstones are found mostly either in the core or in intermediate zones. Complex pegmatites are very similar to the zoned pegmatites, but have undergone extensive alteration. Often rare gems and minerals are found in irregular openings (vugs) which may vary greatly in size; diameters of up to several metres have been recorded. These pockets may be found either in the core zone or between the edge of the core and the intermediate zone of the complex pegmatites.

Origin of the pegmatites

Based on their intrusive nature and mineral assemblages the Sakangyi and Pan-Taw pegmatites appear to be contemporaneous, but the Molo, Panta Hoe and Let Pan Hla pegmatites are of a different rare-element class of granitic pegmatite according to their mineral assemblages (Hla Kyi *et al.* 2005). The Sakangyi pegmatite intrudes the Kabaing Granite, which has an Ar–Ar biotite age of 15.8 ± 1.1 Ma (Middle Miocene; Bertrand *et al.* 2001) and a U–Pb zircon age of *c.* 17 Ma (Gardiner *et al.* 2016). The Molo pegmatite intrudes a peridotite (Hla Kyi *et al.* 2005) and the Kabaing Granite intrudes the ultramafic bodies of Mogok; however, the exact age of the Molo pegmatite has yet to be determined.

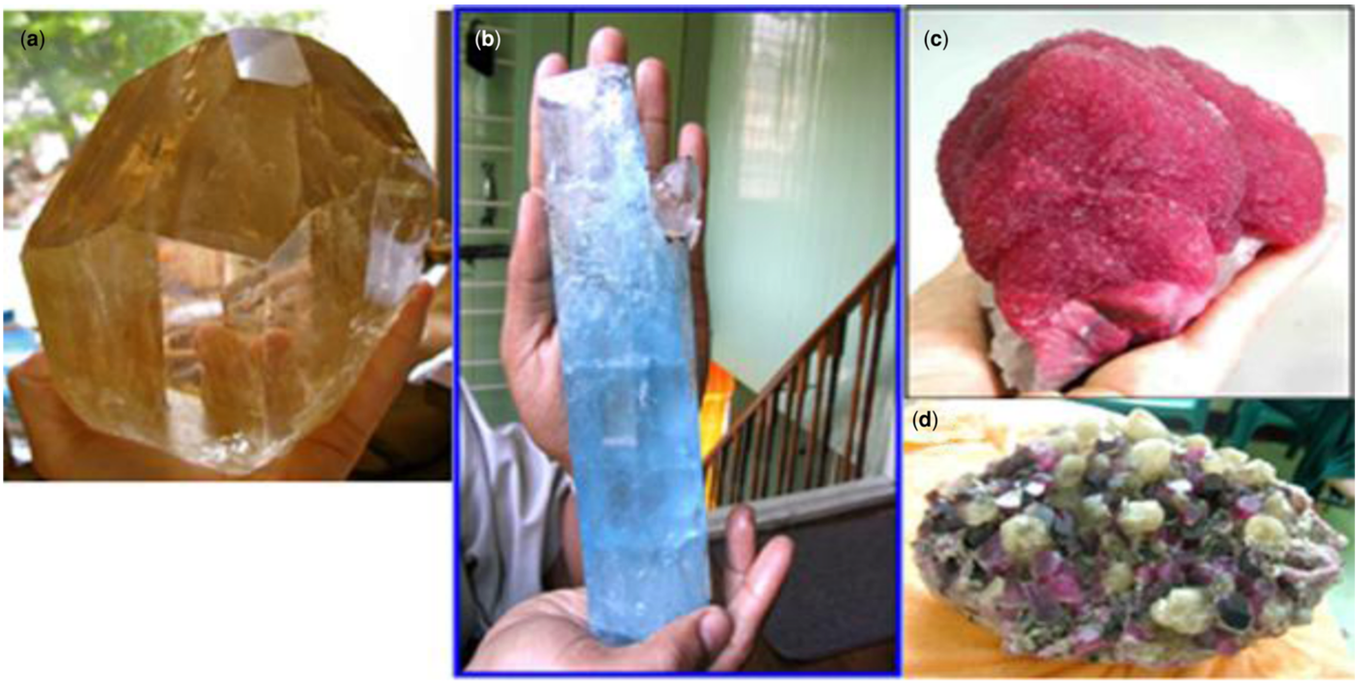


Fig. 23.28. Examples of pegmatitic gems and minerals including topaz, aquamarine, mushroom-shaped rubellite and prismatic-shaped rubellite in apegmatite matrix from the Mogok, Molo and Let Pan Hla areas: (**a**) topaz from Sakhangyi, Mogok (photograph courtesy of Federico Barlocher); (**b**) aquamarine from Sakhangyi, Mogok; (**c**) mushroom-shaped rubellite from Molo, Momeik; and (**d**) prismatic-shaped rubellite, quartz, feldspar and mica in pegmatite matrix from Let Pan Hla, north of Mandalay area (3.85 × 3.0 × 1.5 cm). Photographs by Kyaw Thu.

According to the classification of Cerny (1991), the pegmatites in the Sakangyi and Pan-Taw areas were formed at depths of 1.5–4 km at temperatures of 500–600°C. However, Khin Zaw (1998) studied the fluid inclusions of the quartz, topaz and beryl from the Sakangyi pegmatite, and found that the inclusions equilibrated in the temperature range 230–410°C. Fluid inclusion homogenization data also indicated that the Sakangyi pegmatites have very narrow temperature ranges of homogenization. These data place these pegmatites in the rare-element class (beryl type). Following the genetic classification proposed by Smirnov (1976), the pegmatites of Sakangyi and Pan-Taw were formed by metasomatic alteration due to hot gaseous–aqueous mineralized solutions, which were not chemically in equilibrium with the primary pegmatite-forming

Fig. 23.29. Examples of rare collector gemstones from Myanmar: (**a**) poudretteite crystal (19.5 × 17.4 × 15.3 mm); (**b**) painite crystal (6.0 × 5.2 × 10 mm); (**c**) faceted phenakite (15.0 × 10. × 5.0 mm) and crystals (18.0 × 12.0 × 10.0 mm); (**d**) faceted dumortierite crystals (4.0–10.0 × 3.0–3.1 × 2.0–2.5 mm); (**e**) faceted hambergite (8.0 × 6.0 × 3.5 mm); (**f**) hibbonite crystal (5.6 × 5.5 × 4.7 mm); (**g**) jeremejevite crystal (6.0 × 5.0 × 25 mm); (**h**) faceted johachidolite (15.0 × 12.0 × 6.0 mm); (**i**) faceted taaffeite (14.0 × 12.0 × 4.5 mm); (**j**) faceted poudretteite (11.0 × 9.0 × 5.0 mm); (**k**) faceted monazite (10.0 × 8.0 × 4.5 mm); (**l**) faceted painite (11.0 × 9.0 × 4.0 mm); (**m**) cabochon colour-change hackmanite (15.0 × 12.0 × 4.0 mm); (**n**) faceted petalite (12.0 × 10.0 × 6.0 mm); (**o**) faceted sinhalite (16.0 × 13.0 × 6.5 mm). Photographs by Kyaw Thu.

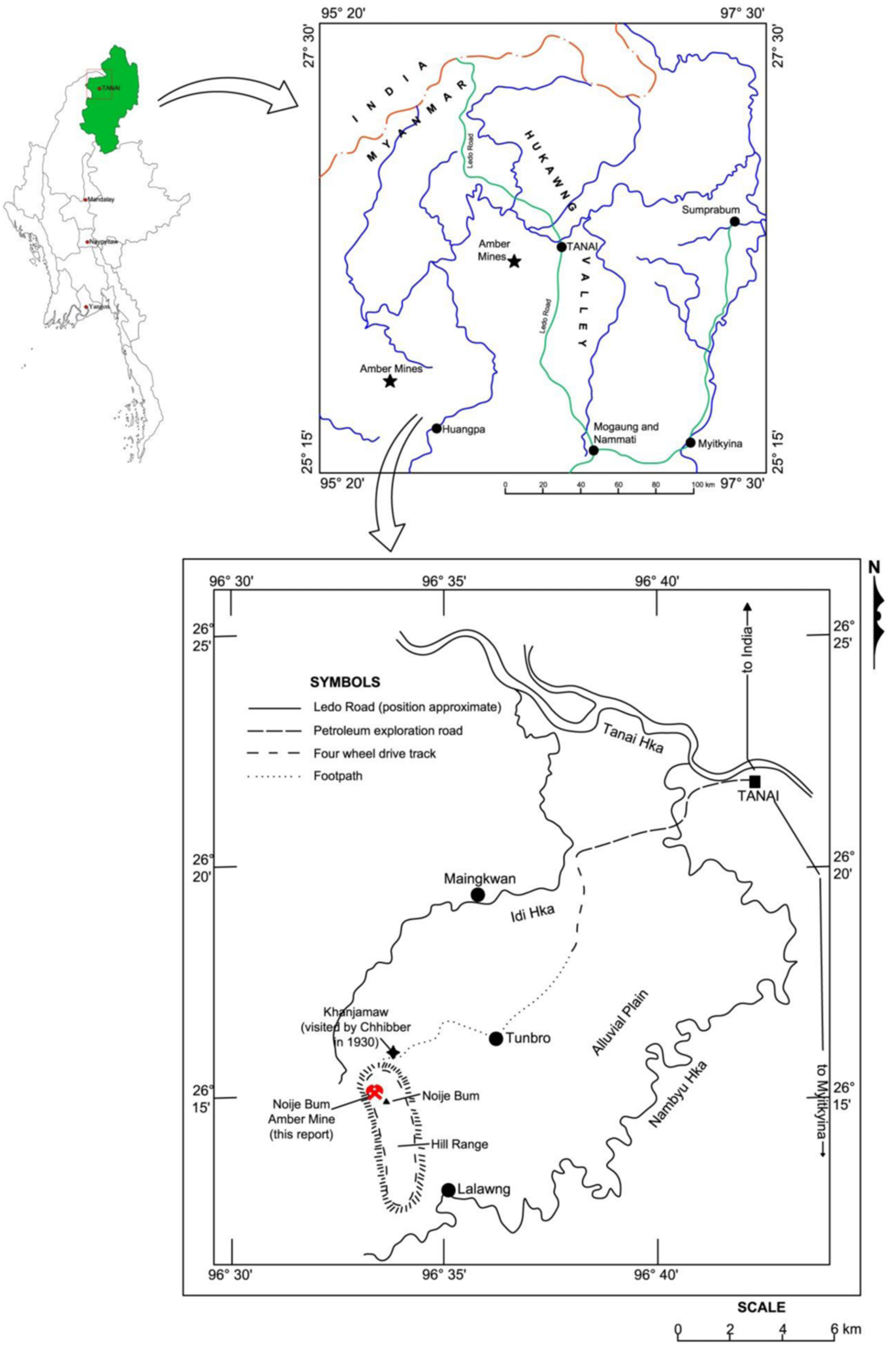


Fig. 23.30. Location map of amber deposits at Tanai, Hu Hukawng Valley, Kachin State, Myanmar. Modified after Grimaldi *et al.* (2002) and Cruickshank & Ko Ko (2003).

mineral body. These pegmatites are therefore regarded as being of metasomatic replacement origin. Cassiterite, scheelite, colour-changed fluorite, Nb-rich rutile, herderite and rhodochrosite are rare minerals found in the Sakangyi and Pan-Taw bodies. Chemical analyses indicate that these minerals are rich in rare earth elements; this may be of economic importance in the future.

Amber deposits

Amber found in Myanmar, known as 'burmite', has been exploited since the first century AD and carved decorative burmite gemstones and jewellery have been produced in China for at least a millennium. The most important amber occurrences are located in the Hukawng Valley, Kachin State of northern Myanmar near Mainkwan and Shingban villages (*c.* 26° 16′ N; 96° 35′ E) (Figs 23.30 & 23.31). Amber is produced currently from the area known as Noije Bum, which was first documented as a source of amber in 1836 (Cruickshank & Ko Ko 2003; Shi *et al.* 2012). Burmite is popular in the gem markets and, since 2010, about 300 000 people from around the country have come to live in the 'amber tract' and undertake private mining and marketing in the areas known locally as Aung-par-hmaw, Myauk-hlwe- kyaw-hmaw, Zee-phyu-kone-hmaw and Nyaung-pin-kone-hmaw.

Fig. 23.31. (**a**) Panoramic view of underground mine sites (Lay-bin twins) in Aung-Par Hmaw, Noije Bum area, Hukawng Valley, SW of Tanai, Kachin state; (**b**) tunnel in an underground amber mine about 76 m from surface; (**c**) miners displaying amber they have found in an underground mine; (**d**) amber pieces in blue-greyish, fine-grained clastic sedimentary rock matrix, showing their orientation parallel to lamination; (**e**) large amber (11 kg) from Aung-Par Hmaw; and (**f**) rough amber from the Noije Bum area (4.0 × 3.0 × 2.0 to 12.0 × 10.0 × 5.0 cm). Photographs courtesy of Aung Min and Jan Jan.

Amber deposits in northern Myanmar are located near Nam Sakhaw stream, 90 km SW of Hukawng Valley and SE from Kham Tee, Sagaing Division. It was known in colonial times and amber was mined between 1948 and 1961. Recently this amber deposit has become famous for a variety of burmite known as 'Kham Tee' amber.

Several studies on insects and other fossils trapped in burmites are available (e.g. Shi *et al.* 2012) which describe scorpion, gastropod shells, gecko, flower and leaf fossils (Fig. 23.32). Shi *et al.* (2012) discuss ion microprobe U–Pb dating of zircons extracted from burmites, and found the ages to fall in a very narrow range of 102–108 Ma for overgrowths on Group-I zircons. Group-II zircons have the rhythmic internal zones typical of magmatic zircons, were inferred to be derived from clasts of volcanic rock and yielded a concordia $^{206}Pb/^{238}U$ age of 98.79 ± 0.62 Ma. Shi *et al.* (2012)

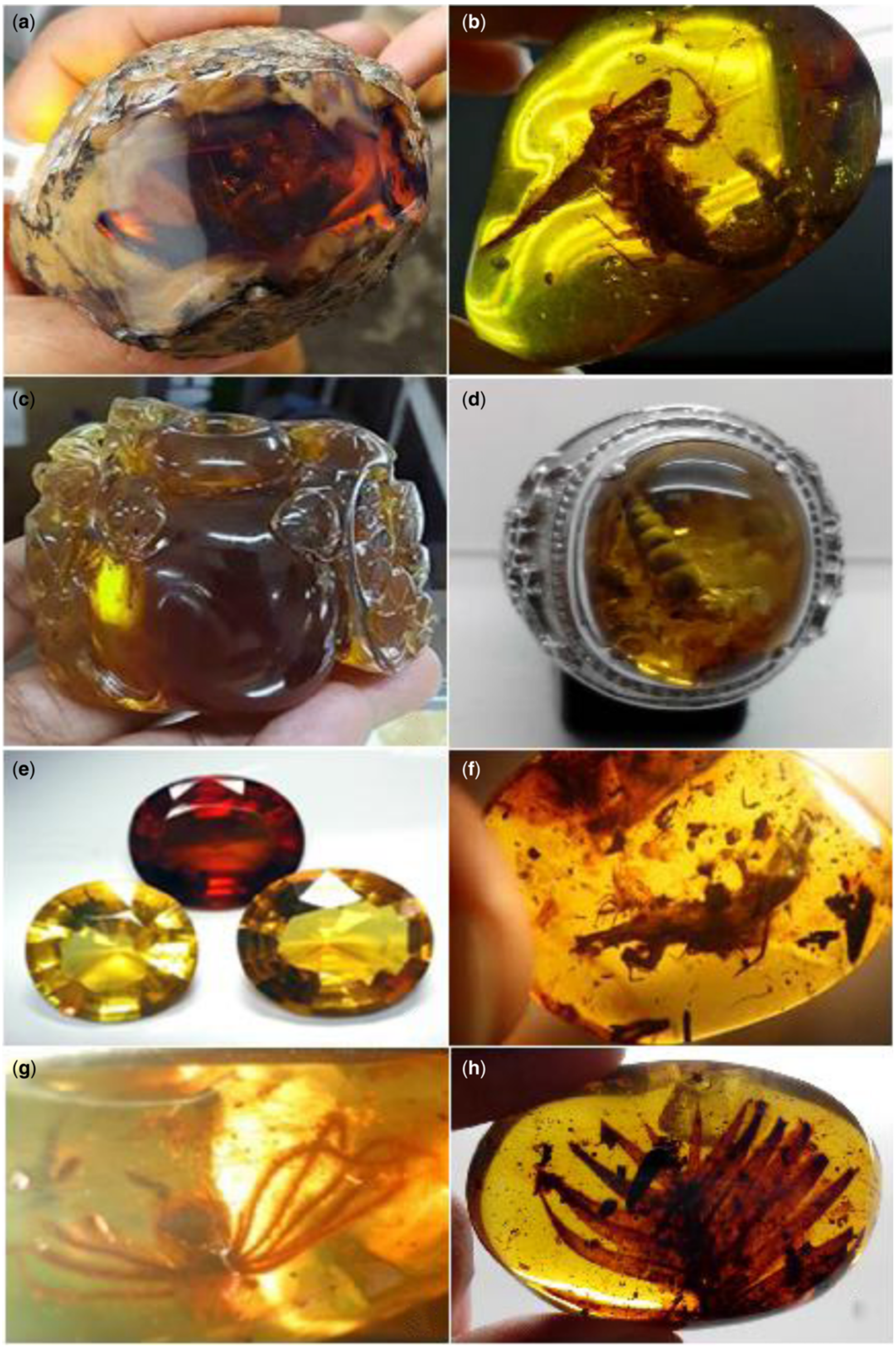


Fig. 23.32. (**a**) Rough orange-red burmite (350 g); (**b**) scorpion in amber (6 × 4 × 2.5 cm); (**c**) example of carved amber; (**d**) gastropod shell in amber (1.5 × 1.3 cm); (**e**) faceted ambers (3 × 2.5 × 2 cm); (**f**) gecko in amber (7 × 5 × 3 cm); (**g**) flower in amber (3.5 × 3 × 1.5 cm); and (**h**) leaf fronds in amber (7 × 5 × 3 cm). Photographs by Kyaw Thu.

considered that the 1 m thickness of the burmite-bearing sediments was deposited in a nearshore-marine environment, and that there was a volcanic eruption nearby at *c.* 98.79 ± 0.62 Ma (earliest Cenomanian) which can be used as an age limit for the formation of the burmites. Recently Lida Xing *et al.* (2016) discovered two exceptionally preserved or mummified precocial bird wings in the mid-Cretaceous Burmese amber. They reported that the studied specimens come from the Angbamo site, Tanai township, Myitkyina district, Kachin state.

A new amber area has been found at Hti Lin in the Gangaw district, Magway state, Central Myanmar, about 750 km south of Tanai (Tay Thye Sun *et al.* 2015), located at 21° 41′ 44.6″ N, 94° 5′ 47″ E. The strata in the Hti Lin amber area is regarded as equivalents to the Paunggyi Formation by Tay Thye Sun *et al.* (2015) and is composed of reddish-brown mudstone and amber-bearing shales 30–40 cm in thickness, with coal-bearing layers, greenish fine- to medium-grained calcareous sandstone, gritty sandstone with quartz pebbles and conglomerate. Occasionally broken sub-bituminous coal is found, together with ball-like pyrite and broken white calcite blocks. At one site sulphur fumes, derived from two small, active sulphurous vents, may indicate the burning of buried coal seams. The beds strike nearly north–south and dip east (*c.* 330/50 NE). The age of the Paunggyi Formation was considered to be Cretaceous by the Geological Survey of Myanmar, and therefore similar in age to the Hukawng valley amber localities.

At Hti Lin, miners usually look for traces of a thin coal layer and follow it until they find amber in shale bedding planes. The colour of Hti Lin amber ranges from white, yellow, yellowish-brown to dark brown, and some are reddish-brown. The amber can be transparent to opaque. Refractive index ranges over 1.54–1.55 and specific gravity (SG) over 1.03–1.05. Slightly higher specific gravities are attributed to the presence of pyrite inclusions in the amber. Under the microscope, dark brown, flattened, gas bubble droplets are present in ambers, and flow marks in amber grains form reflective thin film inclusions which shine under oblique fibre optic lighting. Inclusions of unidentifiable (probably organic) debris are present, but no fossil insects have been found so far. Older flow marks in amber grains are sometimes broken up by a second generation of flow marks, and inclusions of pyrite and masses of reflective thin film inclusions are present. Hti Lin amber tends to fluoresce in a very strong chalky blue colour with white veins under long wavelengths, and a weak chalky blue under shortwave ultraviolet light (Tay Thye Sun *et al.* 2015).

Conclusions

Myanmar has some unique gems and gem deposits and is renowned for the quality of its gems, particularly the highly valuable pigeon's blood rubies, sapphires and imperial jades. Other gem minerals such as diamond, spinel, peridot, aquamarine, garnet, tourmaline, topaz, amber and rare gemstones also fetch high prices. The annual production of valuable and less-precious gems are marketed and sold at the government's annual gem emporium, attended by dealers from many countries.

Most of the rubies and sapphires are found in the Mogok Stone Tract, which was formed during the evolution of the Mogok Metamorphic Belt. The host rocks consist of metamorphosed ?Lower Palaeozoic rock units, probably metamorphosed during the Late Oligocene, ultramafic and mafic rocks (Jurassic?), leucogranite (Early Oligocene), syenitic rocks (Late Oligocene), the Kabaing Granite (Middle Miocene) and pegmatites and aplites (Middle Miocene). Marbles, syenitic rocks, ultramafic rocks and pegmatites are especially important host rocks for the precious gemstones found in the Mogok area.

In the Mong Hsu ruby deposit the host Lower Palaeozoic metasediments are exposed along the Loi Hsan Tao Ridge, 18 km SE of Mong Hsu town, and include garnet–biotite–staurolite schist, calc-silicate rock, biotite quartzite, biotite phyllite and ruby-bearing dolomitic marble with isolated granitic pegmatite intrusions. The ruby occurs in weak planes or fissures, in a white fine-grained sugary dolomitic marble associated with tremolite, wollastonite, muscovite, brucite, grossular, chlorite, chrome-bearing tourmaline, fluorite, rutile and pyrite.

Imperial jadeite jade from the Lonkin–Hpakant area, about 150 km SW of Myitkyina, ranges in colour from emerald green (chromite-bearing) and apple green (ferruginous) to lavender blue (manganiferous) types. It is extracted from primary deposits and also Tertiary–Recent fluviatile gravel sheets. The primary occurrences are composed of jadeite–albite dykes or sills in peridotites and serpentinites, and are pre-Tertiary in age. The largest body at Tawmaw is 30–40 m long. The shallow-dipping occurrence from top to bottom consists of serpentinized peridotite, light green chloritic schist, silicified serpentinite, amphibolites, amphibolite–albitite rocks and lenticular albitite with jadeite intercalations up to 2 m thick. A large percentage of the jade is extracted from fluviatile gravels.

Other gemstones are recovered from different host rocks in many parts of Myanmar such as peridot from peridotite–dunite rocks in Pyaung-Gaung north of Mogok, spinel from marble in Mogok, and typical pegmatitic gems from granitic pegmatites and syenitic pegmatites in the Mogok, Mong Hsu and Momeik areas.

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