CHAPTER II

GENERAL GEOLOGY AND GEM DEPOSIT IN TANZANIA

2.1 Location

Tanzania is located in the eastern part of Africa between latitude 1° S - 11° 45' S and longitude 29° 20' E - 40° 35' E occupying an area of 945,166 km^2. The capital is Dar Es Salaam which is a seashore city located in the east. Tanzania has the connecting boundaries with several neighbor countries including Kenya and Uganda in the north, New Congo, Rwanda and Burundi in the west, and Zambia, Malawi and Mozambique in the south. In addition, there are 3 lakes, Lake Victoria, Lake Tanganyika and Lake Nyasa occupying parts of these borders in the north, west and south of the country, respectively, whereas eastern region opens to the Indian Sea. Songea corundum deposits are located in the southern part of the country, in Mbinga district of Ruvuma area. Songea corundums are therefore named after mining area where is close to the city Ruvuma at latitude 10 °41' S and longitude 35 ° 35' E (Figure 2.1). Most Africa corundums in the market are actually from this area.

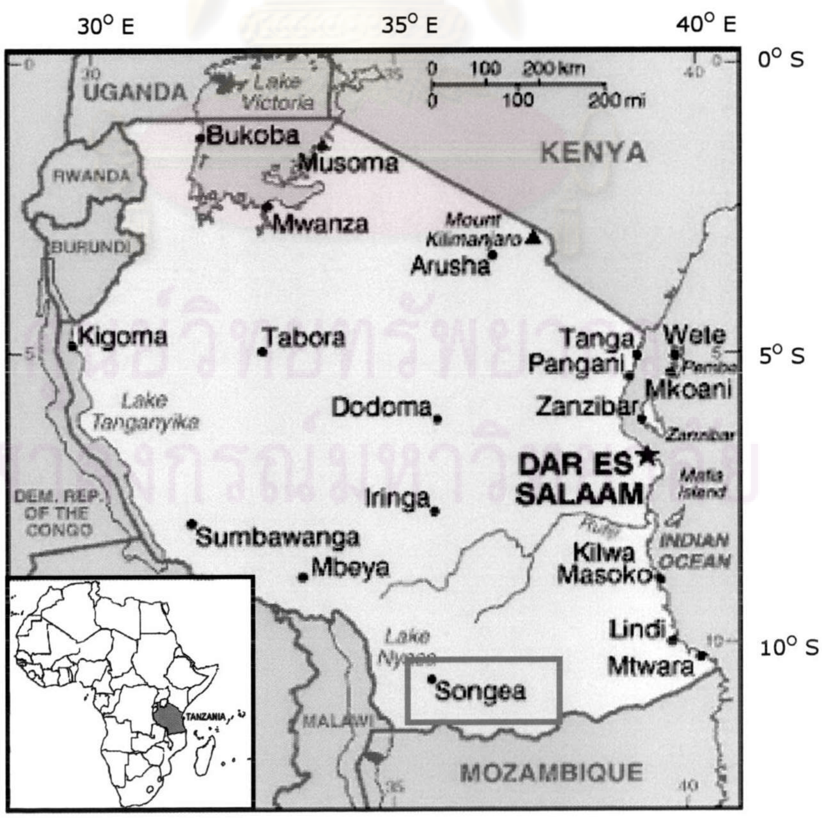


Figure 2.1 Map of Tanzania showing locations of capital city Dar Es Salaam and Songea gem deposits located in the south of the country (www.surgeonsforafrica.org).

2.2 General geology

Geology of Tanzania is significantly occupied by Mozambique Orogenic Belt (Figure 2.2), which it appears to have originated around 650 million years ago during the Pan-African event (Tenczer et al., 2004). Apart from Tanzania, Mozambique Belt influences also many parts of East African countries (i.e. Ethiopia, Mozambique, Kenya, Malawi, Somaliland and Saudi Arabia) as well as Madagascar, Eastern Antarctica, India and Sri Lanka (Kinnaird and Jackson, 2000) (Figure 2.2). Its ancient geometry may have width of about 250-325 km and approximate length of 5,000 km (Hauzenberger et al., 2004).

Mozambique belt in Tanzania is mainly composed of geological terranes combining between Archaean and accreted Proterozoic rocks; Ubendian and Usagaran belts distribute towards east and west, respectively (Figure 2.3a) (Kinnaird and Jackson, 2000), they seem to have been reworking during the period of Pan-Africa event. The Mozambique crystallization within two age domains is at 2.5-2.7 Ga and 1.8-2.0 Ga, where the latter ages represent the formation of the Usagaran complex units which is the location of Songea area.

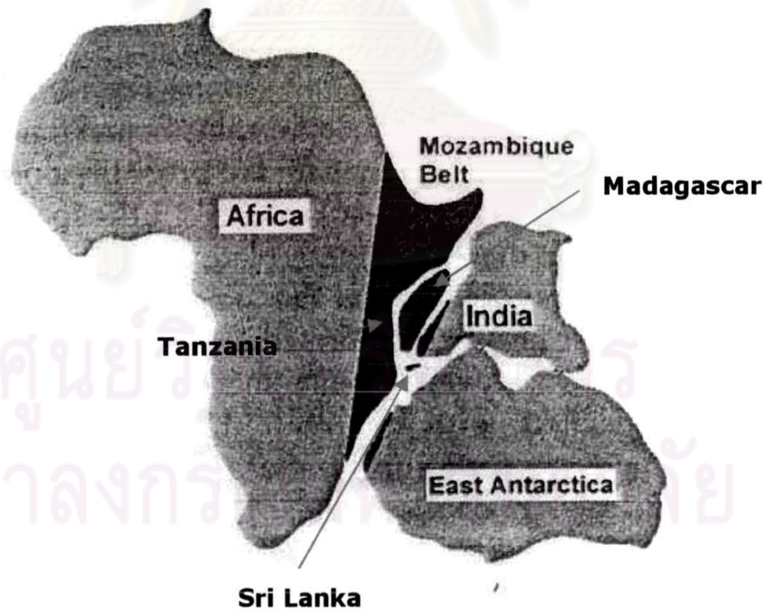


Figure 2.2 Model of the initial Mozambique Orogenic belt before spreading; it included whole parts of Madagascar and Sri Lanka, and some parts of East Africa, India and East Antarctica (Kinnaird and Jackson 2000).

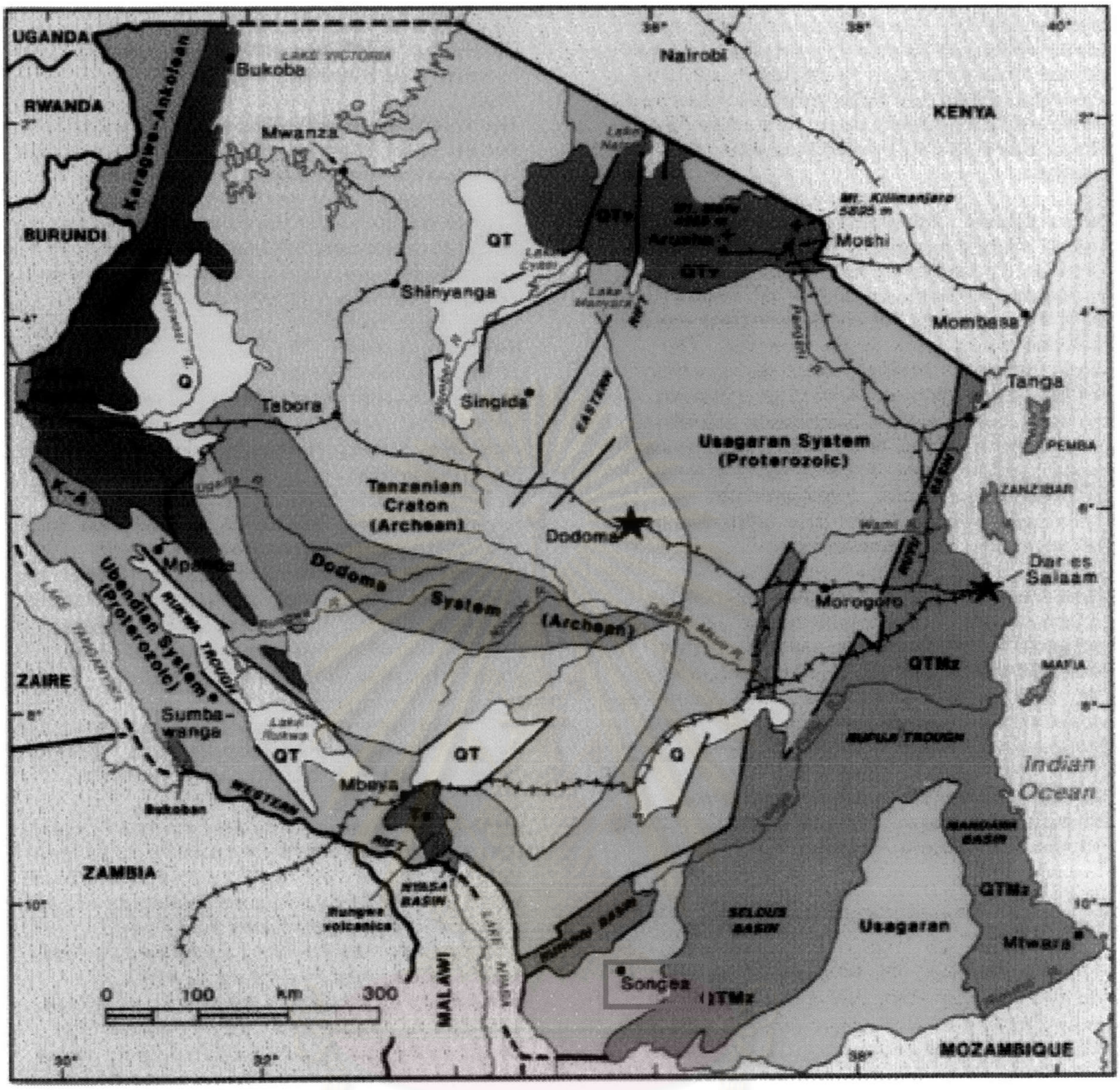
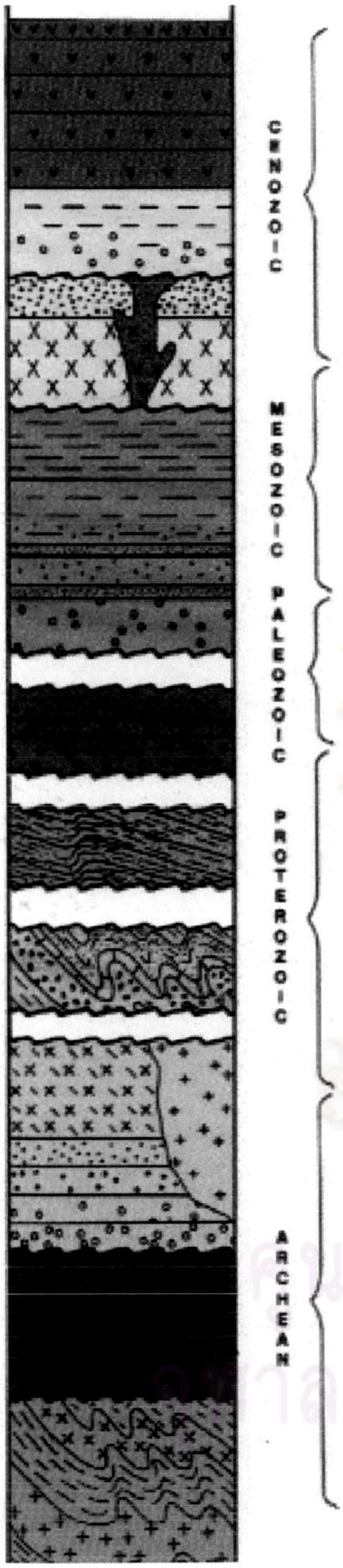


Figure 2.3a Geologic map of Tanzania (http://tanzania.sgu.se/IMAGES/TANZ_3.GIF).



Cenozoic volcanics
Miocene to modern alkali and sub-alkali extrusive and shallow intrusive rocks related to rifting. Restricted to North-Central Tanzania and the north end of Lake Nyasa.

Cenozoic sedimentary rocks
Marine and continental sedimentary rocks of coastal plain and inland basins.

Mesozoic-Cenozoic alkali intrusives
Carbonatites, kimberlites, and related rocks occurring in small bodies across Tanzania. Locally of extrusive origin.

Upper Mesozoic sedimentary rocks
Jurassic and Cretaceous shales, sandstones, carbonates, and evaporates of the coastal basins.

Karroo System
Clastic sedimentary rocks, entirely of continental origin in the south locally marine in north. Late Permian to Jurassic.

Bukoban System
Sandstone, conglomerate, arkose, dolomite, amydaloidal basalts. Not metamorphosed, sub-horizontal. Confined to western Tanzania.

Karagwe-Ankolean System
Weakly-metamorphosed schists, phyllites, argillites, quartzites. Confined to extreme northwest Tanzania

Usagaran and Ubendian Systems
Highly-metamorphosed gneisses, mainly of felsic composition. Includes local marbles. Ubendian in western Tanzania, Usagaran in east.

Granite-Gneiss terrane
Foliated and unfoliated granitic rocks associated with the Archaean units. In part Proterozoic, in part re-mobilized Archaean.

Kavirondian
Mainly coarse clastic molasses sediments, weakly metamorphosed. Overlies Nyanzian, confined to Lake Victoria region.

Nyanzian System
"Greenstone" sequence of mafic volcanics, lesser felsic volcanics, banded iron formation, fine-grained clastic sediments, weakly metamorphosed. Confined to Lake Victory region.

Dodoman System
Sedimentary and lesser igneous rocks, highly metamorphosed and migmatized. Confined to central Tanzania.

Figure 2.3b Stratigraphic column (http://tanzania.sgu.se).

Geologic map of Tanzania (Figures 2.3a and 2.3b) reveals that the Archaean craton is surrounded by younger rock formations which appear to have been undertaken polymetamorphism related to Mozambique Orogenic Belt. These metamorphic rocks have been grouped, based on stratigraphic information and distribution, into three systems. Usagaran and Ubendian systems are recognized as Proterozoic rocks that are located along east-south and west-south boundaries, respectively; besides, northwestern part of the Archaean craton is connected to the Mesoproterozoic Karagwe-Angolean system. In addition, continentally derived sediments of post Mesoproterozoic partly cover the area along with magmatism in several times.

According to geologic map of Tanzania (Figure 2.3a) and the stratigraphic column (Figure 2.3b) rock units can be grouped based on chronological sequence, i.e. Archaean, Proterozoic, Paleozoic, Mesozoic and Cenozoic. Their petrographic descriptions are present below.

Archaean: The Tanzania craton (>2.5 Ga) can be separated into two main parts. The first part, consisting of granite, granodiorite, granitic gneisses and migmatites associated with high grade metamorphic rocks (Manya and Moboko, 2003), is located in central Tanzania. The second part comprises granite-greenstone association exposed on the north and north east of the country. Most of granitic rocks are younger than the greenstones; however, a few phases may be older. In addition, the Archaean Tanzania craton has been mapped and subdivided into Dodoman systems, Nyanzian system, Kavirondian system and granite gneiss terrane.

Dodoman System appears to be the olderest group among the others. The Dodoman is mainly characterized by sedimentary origin and wildly occurs over the southern part of the craton. It contains a few mineral deposits with commercial interest. The east-west stretching Dodoman schist belt is dominated by pelitic schist, gneiss, quartzite and amphibolite.

Nyanzian System, or greenstones, is approximately 2.7 Ga; it consists mainly of mafic volcanic rocks and associated sedimentary rocks including banded iron formation, cherts, shale and conglomerate. A compositional change from mafic to felsic volcanics is observed upwards along the sequence. The associated sediments significantly form as greenstone belts in the central craton. The Nyanzian greenstones are parts of major economic concern, because they hold most of the Tanzania's gold deposits.

Rocks can be divided into Lower and Upper Series on the basis of recognizable upward transition from mafic to felsic lavas, with minor tuffs and interbedded sediments. The lower series consist of initial basalt, andesite and dacite pillow lavas. Sediments include banded iron formation (BIF), recrystallized cherts, some shale and conglomerate. The upper series are characterized by assemblage of felsic lavas, tuffs, ferruginous cherts, BIF and subordinate meta-pelites. These greenstones generally appear to have been metamorphosed to greenschist facies and folded with steeply dipping axial planes.

Kavirondian System occurs in the northernmost Tanzania. Rocks in this system consist mainly of conglomerates, coarse arkosic and feldspathic sandstones and quartzites. They are found resting unconformably on the Nyanzian rocks.

Granite Gneiss Terrane occurred surrounding the greenstones; however, age relations are still confusing. Some age dating data clearly indicate Proterozoic, whereas some data reveal significantly Archean.

Proterozoic: Two main systems (i.e. Ubendian and Usagaran) have been recognized within Proterozoic basement. Ubendian system is significantly found in the western Tanzania, whereas Usagaran system is mainly situated in the east of the country. Although both systems are similarly high-grade metamorphic terrane, they are slightly different in petrogenetic details.

Ubendian System, Lower Proterozoic to Archaean mobile belt, bounds the Archean craton on southwestern side. It includes a variety of medium- to high-grade metamorphic rocks that originated from sedimentary and igneous rocks. They are mainly characterized by metamorphic gneisses and schists, migmatites, amphibolites and granitoid intrusions. The most dominant lithology is gneiss associated with minor mafic and ultramafic intrusives. Metamorphism is significantly classified as amphibolite and granulite facies (5-8 kbar and $550^{\circ}C-700^{\circ}C$, 12-13 kbar and $750^{\circ}C-800^{\circ}C$) but it is rarely found reaching granulite facies (Sommer et al., 2003). The high pressure granulite facies are composed dominantly of clinopyroxene and garnet. Plagioclase, quartz, rutile, ilmenite and hematite are common accessory minerals (Muhongo et al., 2002).

The belt can be subdivided into a number of highly deformed tectonic terranes, which were accreted along the margin of the craton between 1.8-2.0 Ga ago (Hauzenberger et al., 2004). Remnants of an early Paleoproterozoic granulite facies metamorphism were recorded within the belt and likely related to the Usagaran orogeny. Late Paleoproterozoic granitoid rocks intruded along the boundaries between the Tanzania cratonic blocks and the Ubendian shear belt.

Usagaran System occurs in the south and east of the Archean craton, including Songea area. Rocks in this belt appear to have been undertaken metamorphism, magmatism, folding and faulting, especially affected by crustal movement. They comprise mainly medium- to high-grade metamorphic gneisses and schists, granulites, quartzites, marbles and amphibolites. However, the Neoproterozoic-Paleozoic Pan-African deformation and granulite facies metamorphism obliterated most of the older structures and metamorphic signatures. Granulite covering most of Usagaran areas contains mineral group originated under pressure range of 12-13 kbar and high temperature range of about 750°C-800°C (Sommer et al., 2003). Although P-T constraints of about 800°C and 11-15 kbar are similarly recognized in most terrains (Hauzenberger et al., 2004) with metamorphism age of 625-640 Ma, which is considered from metamorphic zircon from high pressure high temperature (metapelites and granitoid orthogenesis) (Moeller et al., 2000; Bauernhofer et al., 2003; Kroner et al., 2003; Sommer et al., 2003), some small local differences especially in pressure still occur. In addition, these granulite gneisses are potential sources of gem deposits in Tanzania, particularly in the eastern region of the country, such as Loliondo, Longido, Loibor Serrit, Pare Mountains, Usambara Mountains, Handeni, Magubike, Nguru Mountains, Wami River, Uluguru Mountains, Ifakara, Furua, Nachingwea, Tunduru and Songea (Muhongo et al., 1999; Simonet, 2000) (see Figure 2.5). It should be notified that corundum samples under this study were collected from Songea deposits, which are situated in these geological terranes.

Granulites formations related to crustal movement are important events, because mineral occurrences in this area are closely affected by high pressure and temperature obtained from these geological events. Not only new minerals occurred under re-equilibrated P-T conditions, some elements (i.e. chromophores, chromium and vanadium) could be removed from the original mineral assemblages. This diffusion process may cause uneven colors, pheochroism and color change in corundum (Dirlam et al., 1992).

Karagwe-Ankolean System, Kibaran Belt, is classed as Mesoproterozoic rock unit that covers mainly in the northwestern part of the country and extends to the west of Lake Victoria. It is evidentally younger than the Ubendian and Usagaran. Sedimentary features of the Karagwe-Ankolean rocks reflect shallow-water deposition; they are composed of argillites, phyllites, low-grade sericite schist and quartzites. Granites intruded partly into the rock system and consequently yielded tin and tungsten mineralization.

Bukoban System, sedimentary and volcanic rocks, occurs in western Tanzania. The Bukoban may span in Proterozoic-Paleozoic boundary; these rocks were deformed without significant metamorphism. They include sandstones, quartzites, shales, red beds, dolomitic limestone, cherts etc. The Bukoban occurs only in the northwestern quarter of Tanzania. One of the main formations, the Bukoba Sandstone, appears to be Mesoproterozoic age instead of Neoproterozoic. This rock unit is situtated in the eastern outer zone of the Kibaran orogenic belt.

Palaeozoic: Only the Karoo Supergroup is recorded as Palaeozoic; it consists of Permo-Triassic continental sediments deposited in a major extensional rift system that have developed during the break up circumstance of the Gondwana continent. Rifting and sedimentation began in the Upper Carboniferous and continued throughout the Permo-Triassic and Lower Jurassic. The basins could accumulate about 10 km thickness of sediments. These basins occurred widely along coastal area and extended southwards. They usually formed east-northeast trending in the south and southwest, whereas north-south trending basins are more common in the north coastal region. The sedimentary sequence is mainly made by coarse sandstone, shale and siltstone with coal seam. Coal-bearing beds of Late Permian to Jurassic sedimentary rocks lies unconformably upon the Precambrian basement; that is present in all basins except areas along the coast. The Karoo rocks are potential sources of oil and gas.

Mesozoic: Upper Mesozoic sedimentary rocks have occurred only along the coastal basins. After Karoo rifting, marine transgressions into the rift basins started in the Middle Jurassic. The coastal basins consequently evolved as a subsiding passive continental margin. During late Jurassic to early Cretaceous, accumulation of thick continental deltaic deposits were taken place. A major marine transgression started in late Cretaceous; that led to deposition of platform carbonates. The Mesozoic sedimentary sequence, which includes limestone, sandstone, shale, marl and local evaporates (i.e. gypsum, anhydrite and salt), is a potential host for hydrocarbon occurrences. The most significant resources are is the Songo gas field and the Mnazi Bay gas field (www.africanonline.co.tz).

Cenozoic: sedimentary rocks appear to be related to development of the East African Rift System, which consists of eastern and western branch. The East African Rift system is well recorded in the north, but it becomes less defined southwards. It consists of series of grabens often associated with volcanism. The volcanic province in northern Tanzania is the youngest phenomena related to the eastern branch of rift system. Volcanic activity (8 Ma), which began after mid-Tertiary faulting event, produced large volumes of alkaline volcanism. The actual rift valley in northern Tanzania was a result of another major faulting period at 1.2 Ma, which was associated with eruptions of nephelinite, phonolite and the famous carbonatite lavas in Oldoinyo Lengai (the only carbonatite volcano of the world).

The Western Rift is composed of series of deep troughs containing thick Pliocene-Quaternary deposits; they are partly occupied by Nyasa, Rukwa and Tanganyika lakes (Figure 2.3a). The rift has been sedimentary basin during Cenozoic time. The coastal basins contain marine sediments with several kilometers thick. The volcanic activity in the western rift system is restricted to the Rungwe volcanic province in Mbeya area.

In East Africa, as elsewhere, rifting is accompanied by volcanic activity and hot springs. There are two such areas in Tanzania; the Kilimanjaro region in northwest and a small area of volcanics in the Rungwe area (Figure 2.3a) in southeast. In both areas, rocks are characterized by intermediate to mafic alkalic extrusives, with local intrusives. Intrusions of diamond-bearing kimberlites were crucial volcanic event, although, they occupy a small area. Some kimberlites are younger than 50 million years old.

2.3 Gem Deposits and Mining

Tanzania has great potential and variation of mineral resources, which include gold, base metals, industrial and construction minerals (Dreschler, 2001) as well as a wide variety of gemstones. The relationships between gem deposits and Africa geology are found closely within Archaean cratons and Pan Africa orogeny. The Archaean craton contains mostly gem-bearing pegmatites; they are sources of emerald and non gem-quality beryl, tourmaline and corundum (Taupitz, 1995). The Pan Africa orogeny exposed wildly along Africa continent (Figure 2.4), especially in the east. Granulite complex in the Pan Africa orogeny (as shown partly in Figure 2.5) have been expected as potential gem deposits (Keller 1992) (e.g. ruby, sapphire, emerald, garnet, alexandrite, tanzanite, tourmaline etc).

A: Distribution of Archean cratons

B: Pan Africa orogeny

C: thick, younger cover

1: pegmatites with non gem-quality beryl and tourmaline

1a: gem-bearing pegmatites

2: emerald occurrences

3: non gem-quality corundum occurrences

3a: ruby and sapphire deposits

Figure 2.4 Map showing distribution of gem deposits and general geology of Africa (Taupitz, 1995).

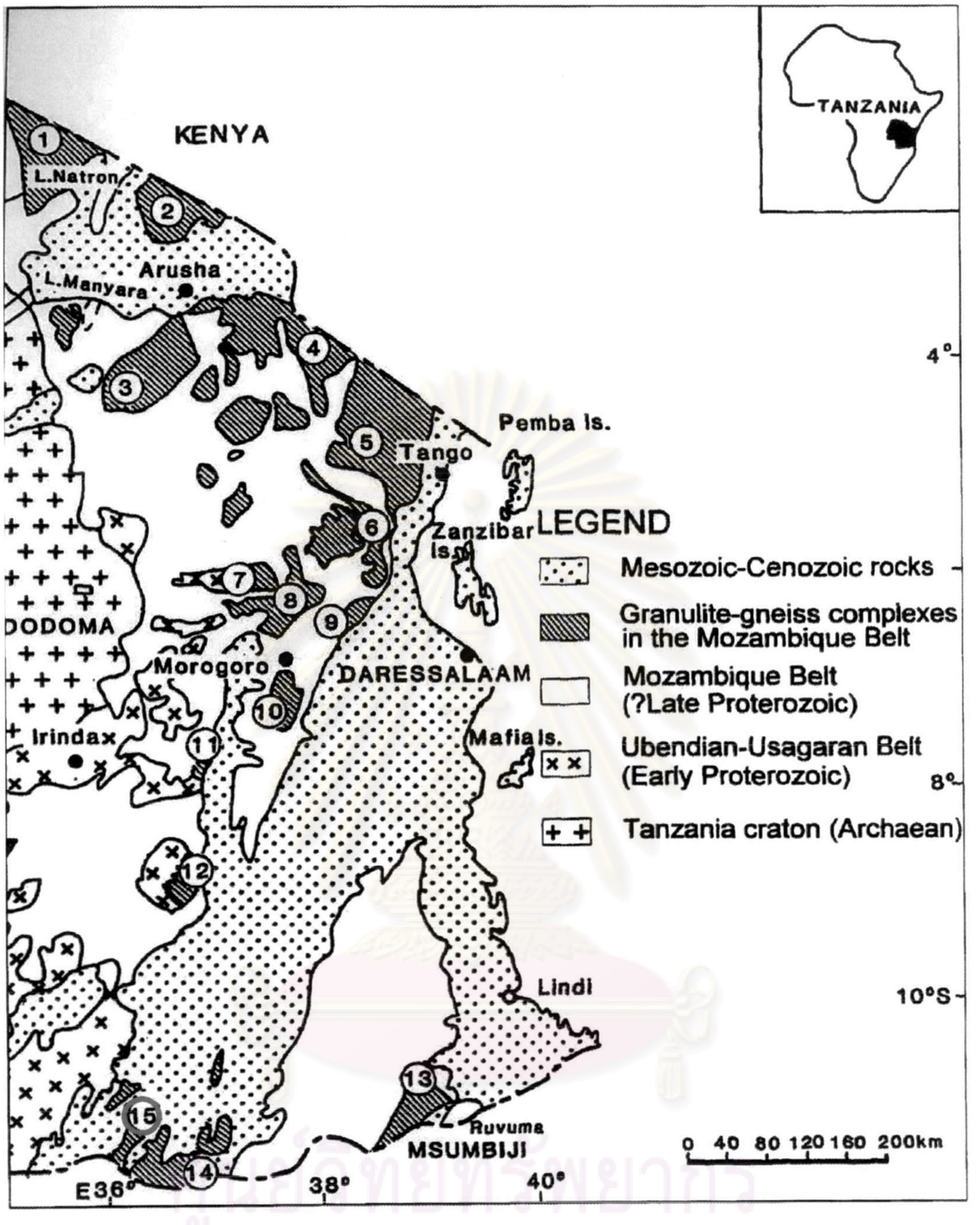


Figure 2.5 Geologic map displays discontinuous granulite-gneiss structure in Mozambique Belt in the Eastern part of Tanzania; they are grouped as parts of Usagaran System and potential area of gem deposits, including 1) Loliondo; 2) Longido; 3) Loibor Serrit; 4) Pare Mountains; 5) Usambara Mountains; 6) Handeni; 7) Magubike; 8) Nguru Mountains; 9) Wami River; 10) Uluguru Mountains; 11) Ifakara; 12) Furua; 13) Nachingwea; 14) Tunduru; **15) Songea** (Muhongo et al., 1999).

Many gem mines in Tanzania are operated in different areas, especially in the eastern part of the country, in which gem potential sources, particularly related to the Mozambique belt, occur extensively. Gem mines (e.g. ruby and tanzanite) were initially operated in the northeast (Figure 2.6); however, many gem deposits are now discovered in many parts of the country (i.e. ruby, sapphire, tanzanite, tsavorite garnet, tourmaline, emerald, aquamarine, alexandrite, amethyst, scapolite, iolite, spinel, apatite, rhodolite-almandite garnets, Malaya garnet (spessartine), chrysoberyl and zircon) (Dreschler, 2001).

Songea deposit was named after small town where is close to the mining area. Geologic environment contains various sites of high-grade mineralization easily workable with simple tools. Various small scale mining claims have been staked along the river beds in the area, where the Muhuwesi and Mtetesi Rivers are converge. Gem gravels are hand picked from the ground just by closely observing, no machinery been used (Dirlam et al., 1992). Amounts of alluvial gems would be produced up to 20-30 kilograms per month (Kammerling et al., 1995). Corundum, spinel (blue to dark blue, violet and black), garnet (grossular, hessonite, tsavorite, pyrope-almandine and spessartite garnet), chrysoberyl (yellow, green and brown chrysoberyl), kyanite and violet scapolite have been discovered in this deposit. In addition gold and diamond are also found (Kammerling et al., 1995). Corundums from this area are worthy characterized by fancy sapphires varying from pink, orange, violet-burgundy, green-magenta, grey, brown, and yellow to colorless.

Large scale mining in Tanzania is reported from areas of Mwadui and Umba Valley (Dirlam et al., 1992). Mwadui (Williamson diamond mine; Figure 2.7) is the biggest kimberlite pipe in the world, around 1,000 meters in diameters. Its age is approximate 2.04 billion years while surrounding areas are about 2.5 billion years (Keller, 1992). Gem deposits along Umba Valley are both primary and secondary deposits. Primary deposit shows accumulation in host rock, whereas secondary deposit is weathered sediments that were transported into river bed. Gem material is also mined from alluvial gravels; dredgers use shovel to get alluvial gravels from river bed and then wash in the river. Machinery is used for mining operation in some areas of Umba deposit (Figure 2.8).

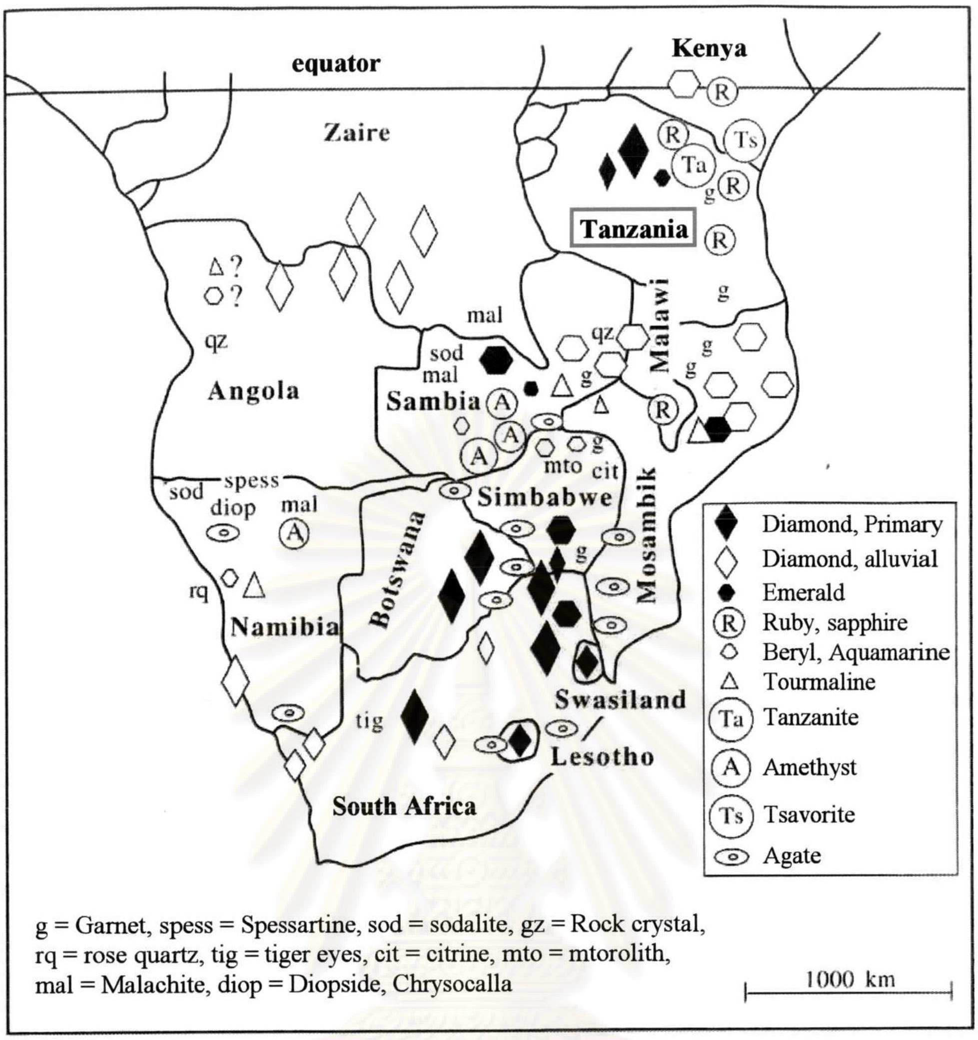


Figure 2.6 Map of mineral mining in Africa. (modifed from Taupitz, 1995).

Figure 2.7 WILLIAMSON diamond mine, Mwadui area is the biggest kimberlite pipe, 1,000 meters in diameters, with age of about 2.04 billion years (Keller, 1992; http://www.lapinliitto.fi/fem2003/foster .pdf).

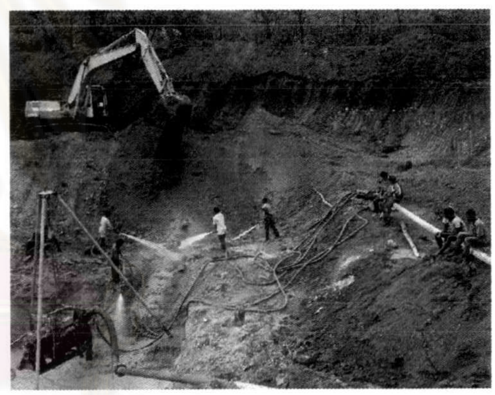


Figure 2.8 (Left) Miners use shovel to collect gravels from river bed, sieve and watch for corundum along Umba River. (Right) Machinery is used to support mining at Umba River Valley (Dirlam et al. 1992).