Ruby and garnet gemstone deposits in southeast Kenya: their genesis and recommendations for exploration

R. M. Key
British Geological Survey, Edinburgh, Scotland
J. O. Ochieng
Mines and Geological Survey Department, Nairobi, Kenya

SYNOPSIS
Commercial ruby and green grossular garnet deposits in East Africa are mined directly from bedrock. Consequently exploration programmes for new deposits have to be based on a sound knowledge of the geological controls on the growth of these two minerals.

Rubies in, or immediately adjacent to, chromiferous ultramafic bodies in the Mozambique Orogenic Belt formed in areas where the regional metamorphism attained granulite facies conditions. Green garnets are also confined to these areas of high metamorphic grade as disseminations in vanadiferous graphitic schist and gneiss associated with marble. The superb body colours which makes the rubies and garnets so valuable are due to high contents of chromium and vanadium respectively, derived from their host-rocks during metamorphism.

The host-rocks are themselves ideal targets for direct and indirect prospecting methods. Exploration programmes should be based on the use of satellite imagery, geological mapping, soil and stream geochemistry, and airborne or land geophysical methods.

Current exploitation of gemstones, especially the coloured corundums (sapphires and ruby) and the various varieties of coloured garnet, has established East Africa as a major new gemstone province. In this arid area there is only local secondary dispersion of the mineralization: gemstones are mined directly from bedrock after initial eluvial extraction. Therefore the scientific search for new deposits has to be based on a sound knowledge of the geological controls on the growth of each type of gemstone.

As such the nature of the host rock has to be known as well as the geological- and especially metamorphic-conditions that were necessary for gemstone formation. However, it is relevant to prospecting programmes to note that the first discovery of gem-quality sapphires in SE Kenya, announced in the Annual Report for 1936 of the Geological Survey of Kenya, was from soils and gravel. These were locally derived from the corundum-bearing wall rock of an ultramafic intrusion.

Gem-quality ruby and garnet in East Africa formed during regional metamorphism within the Mozambique Orogenic Belt. An understanding of the controls on mineral growth is needed in order to effectively plan exploration programmes for new gemstone deposits. Four controls are apparent:

1. Host rock lithology: gemstone varieties are confined to specific lithologies or to specific lithological associations such as the altered contacts of intrusive bodies.
2. Stratigraphy: host lithologies often occur within lithostratigraphic units which are mappable.
3. Metamorphism: each gemstone variety formed within a narrow range of physical conditions (pressure, temperature, activity of CO₂ and H₂O fluid phases) during regional metamorphism.
4. Chemistry: the body colours of ruby and the garnets are due to the presence of traces of certain transition group elements, especially chromium and vanadium, in the mineral matrix. Of equal importance is the absence of other transition group elements which can spoil the body colour, especially iron, traces of which can produce ugly brown tints in ruby considerably depreciating their value.

REGIONAL GEOLOGY
The late Precambrian (Neoproterozoic) meridional Mozambique Orogenic Belt underlies much of East Africa between Ethiopia and Mozambique. It developed as a result of Neoproterozoic collision between a western continental plate (Tanzanian Craton) and an eastern "Kibaran" plate. Shelf sediments and oceanic volcanics were laid down during an initial extensional phase and subsequently disrupted by major folding and associated ductile shearing and thrusting. This collision-related deformation resulted in tectonic interfingering of different lithologies and lithostratigraphic units. Regional metamorphism at amphibolite to granulite facies, as well as crustal melt igneous intrusion, accompanied deformation.

At the end of the Precambrian, meridional transpressive shearing and folding was again accompanied by regional metamorphism (greenschist
to amphibolite facies) with crustal melt igneous intrusion.

Regional uplift throughout Cambrian times accompanied orogenic cooling. Recent reviews of the Mozambique Orogenic Belt are given by Cahen and others, El Gaby and Greiling, Shackleton, and Key and others.

Metamorphic and igneous rocks of the Mozambique Orogenic Belt underlie most of Kenya although exposure is confined to a central north-south belt. To the east, these rocks are covered by various Phanerozoic sedimentary strata. The extensive volcano-sedimentary sequences of the East Africa Rift System mantles much of west and north Kenya (Fig. 1).

CONTROLS ON RUBY CORUNDUM FORMATION IN SE KENYA

Rubies were first located in SE Kenya, in the Taita Hills area during 1973 by two American geologists, John Saul and Elliot Miller. These deposits at Mangari are now known to be amongst the World’s richest so that East Africa may become the future centre of World ruby mining.

Lithological and stratigraphic control

According to Pohl and Horkel the bedrock corundum deposits of SE Kenya are of four types:

1. Desilicated plumbatitic pegmatites in ultramafic bodies.
2. Desilication zones at the contacts of the ultramafics and metasedimentary country rocks.
3. In aluminous metasediments (not economically important).
4. In marbles, associated with red spinel (not economically important).

The lithological control on the economic ruby deposits is clearly the ultramafic intrusives, of which recent mapping has shown there are two main suites. Early sheets tectonically interleaved with metasediments (Fig. 2) are regarded as slices of ophiolite complex which pre-date two regional metamorphisms. Later discordant ultramafics emplaced into already metamorphosed rocks, pre-date the second regional metamorphism. At Mangari, the chemistry of the ultramafic hosts to the ruby mineralization indicates that they were derived from continental crust (J. Saul, pers. comm.). However, these ultramafic intrusions pre-dated the main regional metamorphism and probably belong to the early ultramafic suite. In Northern Kenya (at Baragoi), corundum (sapphire) deposits occur close to ultramafics which are definitely parts of disrupted ophiolite complexes.

Similar corundum deposits in central Kenya (west of the Samburu Game Reserve) have, however, formed by desilication processes associated with an ultramafic stock belonging to the younger ultramafic suite, indicating that corundum formation is independent of the age of the ultramafic intrusions.

In SE Kenya ultramafics are poorly exposed except in hilly country (Fig. 2). The Mangari ultramafics are not naturally exposed and are consequently not shown on the original geological map produced by the Kenyan Geological Survey. The high calcium and magnesium contents of the ultramafics means that they commonly have a cover of calcrite (kankar) as well as the ubiquitous sandy soil.

There is no stratigraphic control on ruby growth. In SE Kenya the rubies, marginal to the ultramafics, form in metasediments assigned to the Kurase Group. In central Kenya, the marginal corundum deposits occur in a desilicated diorite, and in northern Kenya they occur in various lithologies of the Siambu Complex which is a volcano-sedimentary unit.

Metamorphic control

Regional metamorphism in SE Kenya within the Mozambique Orogenic Belt reached amphibolite or granulite facies. The peak temperature of the progressive metamorphism exceeded 550°C and possibly 750°C. Arneth and others deduced from carbon isotope analysis of graphitic metasediments that the metamorphism took place between 550°C and 650°C. Studies of the grossular garnet (tsavorite) deposits at Mgama Ridge (Fig. 2 and next section) have established that the peak metamorphic temperature was greater than 650°C. In a study specific to the ruby-bearing mineral assemblages at Mangari, Key and Ochieng found that the metamorphism reached temperatures in excess of about 650°C. This was based on two-feldspar geothermometry. The presence of kyanite as the Al2SiO5 polymorph in these mineral assemblages indicates that pressures must have exceeded 7 Kbars in this temperature range. Similar PT conditions have been suggested for the development of the corundum deposits further south in Tanzania.

At Mangari, rubies occur in assemblages of the following minerals: tourmaline, plagioclase (albite to labradorite), K feldspar, muscovite, phlogopite, margarite-paragonite and kyanite (some secondary sillimanite) with accessory amounts of graphite, xenotime, zircon, rutile, pyrite, spinel, amethyst, and arsenopyrite. Ruby exhibits marginal marginate alteration and there is some sericite after feldspar. The absence of a fluid phase of the rocks possibly prevented retrogression during cooling after the granulite facies metamorphism. Local replacement of kyanite by sillimanite indicates that the cooling was not isobaric but took place as pressure dropped.

Chemical control

Corundum is allochromatically coloured (ie. coloured by impurities) by traces of transition group elements. The red colour of rubies is due to the presence of chromium. Rubies from SE Kenya have splendid red body colours which rival those of the best stones from SE Asia. Rubies from Mangari contain 0.39 to 0.96% by weight of Cr2O3 compared with a maximum of 0.32% Cr2O3 in Nepal rubies. Significantly the FeO values for the Mangari rubies are very low at less than 0.017% by weight. The presence of TiO2 in the ruby crystal matrix can also...