RUBY IN DIAMOND

By Henry O. A. Meyer and Edward Gübelin

The first substantiated identification of corundum (var. ruby) occurring as an inclusion in natural diamond is presented. The ruby is assigned to the eclogitic suite of inclusions in diamond, and the implications of its occurrence are discussed in relation to the genesis of "eclogitic" diamonds. It is concluded that diamond crystallizes from a melt over a long period of time with possible fluctuations in ambient temperature and geochemical environment.

Inclusions in gemstones can be fascinating for scientist and layman alike. Scientifically, they aid in deciphering the genesis of the mineral; gemologically, they are often distinctive and aid in identifying the host stone (Gübelin, 1953, 1974).

In 1645, John Evelyn, a diarist, reported seeing a "faire Rubie" inside a diamond that belonged to a Venetian nobleman (DeBeer, 1955). This identification, although historically interesting as one of the first recorded observations of a mineral included in a gemstone, has usually been considered incorrect. Harris (1968) suggested that the inclusion to which Evelyn referred was probably a garnet, since garnets have now long been recognized as inclusions in diamonds (see Futergendler, 1950, and Futergendler and Frank-Kamentsky, 1961). Early in 1967, Meyer (1967) used the electron microprobe to obtain the first chemical analyses of mineral inclusions in diamond and discovered that two chemically distinct types of garnet were present. One type consists primarily of magnesium- and chromium-rich, calcium-poor pyropes; whereas the second type is calcium and iron rich, and has virtually no chromium. This latter group of garnets is made up of almandine pyropes; its members are orange-red, whereas the chromium-rich garnets (*chrome-pyropes**, Meyer, 1968) of the first group are claret colored. Similar results were obtained by later studies (e.g., Sobolev and Lavrent'yev, 1969; Prinz et al., 1975; Meyer and Svisero, 1975).

**Asterisk denotes terms defined in the glossary included with this article.*

It was also observed during the early microprobe analyses conducted by Meyer and Boyd (1968, 1969, 1972), and described by Sobolev (1974) and by Prinz et al. (1975), that not only did the garnets comprise two distinct groups, but most inclusions in diamond could be assigned to one of two suites as well: the *ultramafic** or the *eclogitic**. The members of these suites are listed in table 1. Reviews of the minerals in these suites are to be found in Meyer and Tsai (1976), Gübelin et al. (1978), and Harris and Gurney (1979). It should be noted that ruby does not appear on either list of inclusions in table 1.

RUBY INCLUSION IN DIAMOND

During endeavors to find diamonds with unusual, colored mineral inclusions, one of the authors received two diamonds of unknown origin with red crystal inclusions that, on the basis of previous knowledge, were first tentatively identified as chrome-pyrope garnets with a low Cr_2O_3 content. However, the difference in hue between the two inclusions, one of which was claret red while the other was a typical "ruby" red, was so great that additional research was pursued.

The claret-red inclusion, which we freed from its host diamond by breaking the latter, proved on analysis to be a chrome-rich pyrope garnet indeed. However, analysis with the electron microprobe showed that the other inclusion, which was exposed at the surface of one crown face of the 0.06-ct. brilliant-cut diamond (see figure 1), showed

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TABLE 1. Minerals of the ultramafic and eclogitic inclusion suites.

Suite	Mineral	Chemical composition[a]
Ultramafic	Olivine	$(Mg,Fe)_2SiO_4$
	Enstatite	$(Mg,Fe)_2Si_2O_6$
	Diopside	$(Ca,Mg,Fe)_2Si_2O_6$
	Cr-pyrope garnet	$(Mg,Fe,Ca)_3(Al,Cr)_2Si_3O_{12}$
	Mg-chromite	$(Mg,Fe)_1(Cr,Al)_2O_4$
	Mg-ilmenite	$(Fe,Mg)_1TiO_3$
	Phlogopite	$K_2(Mg,Fe)_6Si_6Al_2O_{20}(OH)_4$
	Sulfides	Fe_7S_8; $CuFeS_2$; $(Fe,Ni)_9S_8$
Eclogitic	Almandine-pyrope garnet	$(Fe,Mg,Ca)_3Al_2Si_3O_{12}$
	"Omphacitic" clinopyroxene	$(Ca,Mg,Fe,Na)_1(Si,Al)_2O_6$
	Coesite	High-pressure form of SiO_2, quartz
	Rutile	TiO_2
	Kyanite	Al_2SiO_5
	Fe-chromite	$(Fe,Mg)_1(Cr,Al)_2O_4$
	Biotite	$K_2(Fe,Mg)_6(Al,Ti)_2Si_6Al_2O_{20}(OH)_4$
	Sulfides	Fe_7S_8; $CuFeS_2$; $(Fe,Ni)_9S_8$

[a]*The order of the elements indicates the order of importance. Thus, in olivine, Mg is more important than Fe.*

that it was in fact corundum (var. ruby). The analytical data for this inclusion, together with the data for a gem ruby from Burma, are presented in table 2.

Single-crystal X-ray diffraction studies further substantiated this identification of ruby as an inclusion in diamond. The diffraction pattern of the inclusion was identical to that of a reference ruby or corundum. Cell dimensions were a_0 = 4.76 Å, C_0 = 13.22 Å, compared to 4.758 Å and 12.991 Å, respectively, for a synthetic corundum.

From the X-ray photographs it was observed that the crystal orientation of the ruby did not line up precisely with that of the host diamond as it would in an epitaxial relationship. However, several crystallographic zones in the diamond were

GLOSSARY OF SPECIAL TERMS

Chrome-pyrope
A garnet that is composed mostly of pyrope ($Mg_3Al_2Si_3O_{12}$) in which some of the Al is replaced by Cr. The end member with no Al and all Cr ($Mg_3Cr_2Si_3O_{12}$) is referred to as knorringite.

Eclogite
A rock consisting predominantly of two minerals: a reddish iron-magnesium-calcium garnet and a pale green sodium-calcium rich pyroxene referred to as omphacite. Eclogites are believed to occur at depths in the earth, but they are not as common as the ultramafic rocks.

Grospydite
A rock consisting of the minerals grossular garnet, pyroxene, and disthene (kyanite).

Ultramafic
A term used to describe minerals that have a low silica content but are usually rich in magnesium, iron, and possibly alumina. Rocks in which these minerals occur (ultramafic rocks) are thought to be common in the upper mantle of the earth, i.e., deeper than 35 km. Peridotite, consisting of about 90% olivine, is a good example of an ultramafic rock.

Xenolith
A fragment of rock that is foreign to its host rock. Thus, in kimberlite one often finds fragments of rocks from the deeper parts of the earth that are chemically and mineralogically unrelated to kimberlite and were incorporated into the host kimberlite during its ascent from a depth of about 150 km.

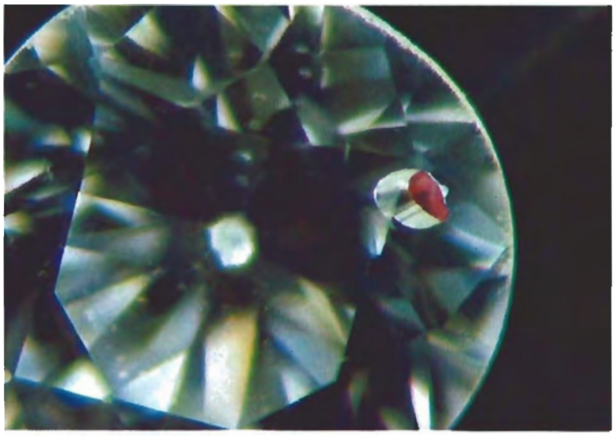

Figure 1. Ruby crystal included in a 0.06-ct. brilliant-cut diamond.

close to those of the inclusion, and possibly at the high temperatures and pressure in which the ruby-diamond couple formed, the crystallographic orientation of the two minerals was better. The inclusion is somewhat elongated and has rounded faces; the elongation may be subparallel to the c-crystallographic direction.

The small size of the ruby inclusion and the fact that it is partly contained in its host stone made determination of the ultraviolet fluorescence and absorption spectrum difficult. Nevertheless, in spite of the yellowish fluorescence displayed by the host diamond, a faint reddish fluorescence was obvious from the inclusion. Furthermore, a very faint absorption line was perceived at 6600 Å, and a slightly stronger one at 6935 Å. Admittedly, the absorption data are subject to some error, but they are compatible with the microprobe and X-ray determinations that the inclusion is a ruby.

DISCUSSION

This is the first substantiated identification of corundum (var. ruby) as an inclusion in natural diamond. The occurrence of this mineral as an inclusion is not unexpected, since both ruby and sapphire have been reported in South African kimberlite (Harger, 1911), and corundum-bearing eclogite and *grospydite* xenoliths** have been found in kimberlites in Siberia and Africa (Sobolev, 1964; Sobolev and Kuznetsova, 1965; Rickwood et al., 1968). More recently, Sobolev (1974) reported a diamond-bearing corundum eclogite from the Mir kimberlite pipe. Curiously, the corundum in this Mir eclogite is bluish, whereas that in non-diamondiferous eclogite from the Obnazhennaya kimberlite is violet-pink. The pinkish color is due to the presence of chromium, as is the case of the corundum inclusion reported here (table 2).

We have, therefore, assigned this ruby to the eclogitic suite of mineral inclusions in diamond. Interestingly, it is usual for the inclusions in the ultramafic group to show enrichment in chromium; this ruby is the first member of the eclogitic suite to have this feature. The fact that ruby has not previously been recognized in diamond is probably a consequence of its rarity as an inclusion. Evidence for this rarity is perhaps indicated by the rareness with which corundum eclogites occur in kimberlite.

If we confine the discussion to diamonds for which genesis is associated with the chemical environment in which eclogites are formed, the following conclusions are suggested.

First, the generally monomineralic nature of the inclusions, their lack of impurities and chemical zoning, and their smallness (usually less than 400 μm) suggest that the diamonds crystallized from a melt.

Second, the similarity in chemical composition of garnet and pyroxene inclusions with those of the host eclogite in which the diamond is embedded (Sobolev et al., 1972) suggests growth equivalent in time at least to that of the major mineral phases (garnet and pyroxene) in the eclogite.

Third, the zonal stratigraphy revealed by etching diamond, as well as the marked variation in

TABLE 2. Analysis of corundum (var. ruby) inclusion in diamond compared to a ruby from Burma.

Oxide	% present in the inclusion in diamond	% present in the Burmese ruby
SiO_2	0.29	0.18
TiO_2	0.09	0.00
Al_2O_3	97.4	99.3
Cr_2O_3	1.30	0.96
FeO	0.22	0.00
MgO	0.13	0.02
CaO	0.02	0.02
MnO	0.02	0.04
NiO	0.01	0.01
Na_2O	0.04	0.00
K_2O	0.00	0.01
Total	99.5	100.5

chemistry and morphology of diamond, suggest that throughout its growth period diamond has been subjected to fluctuating geochemical conditions or to changes in pressure and temperature. A combination of temperature and chemical variations is most likely.

Finally, the presence of ruby, kyanite, coesite, rutile, and other relatively rare or minor minerals as inclusions in diamond is evidence that the "eclogitic diamonds" must have formed in a variety of geochemically distinct, but similar, environments. For example, coesite-bearing diamonds (and coesite eclogites) obviously formed in a relatively silica saturated environment compared to the alumina-rich environment that would give rise to corundum eclogites (or ruby-bearing diamonds).

Much information has been obtained during the last several years regarding the chemical characteristics of inclusions in diamond. Unfortunately, much more information is lacking due to the minute nature of the inclusions and the reluctance with which they and the host diamond give up their secrets. Science will never really know whether Evelyn saw a ruby or a garnet in the Venetian nobleman's diamond; it will remain, like diamond, an enigma.

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