THE CHANTHABURI-TRAT GEM FIELD, THAILAND

By Peter C. Keller

***With** the recent drastic decline in production from the classic ruby mines of Burma, Thailand has become the world's major source of gem ruby. The majority of the ruby production, as well as some significant sapphire production, comes from the provinces of Chanthaburi and Trat in southeastern Thailand. This article reviews the geology of these alluvial deposits and describes the wide range of methods used to mine the corundum. Gemologically, the Thai rubies are distinguished by their violet overtone, inhibited fluorescence, and characteristic inclusions. Also discussed is the heat treatment of corundum to enhance color, which has become a major industry in Chanthaburi. The newest product, "golden" sapphire, is examined, including the apparent stability of the color produced and clues to the detection of the heat treatment.*

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Thailand has been a world supplier of gem ruby and sapphire since the latter part of the 19th century, although the deposits were not thought to be as important as those of neighboring Burma. In 1963, however, the Burmese deposits were nationalized, and supplies of fine gems from these mines declined rapidly. The fact that so little is produced in Burma today has catapulted the Thai deposits into importance. An estimated 70% of the world's high-quality gem rubies come from Thailand. Of these, 85% to 90% come from the Chanthaburi-Trat district alone (Aranyakanon and Vichit, 1979). While the overall quality of these rubies is not as high as those found in Burma, exceptional stones are seen (figure 1).

The gem deposits of the Chanthaburi-Trat (formerly Krat) area are entirely alluvial, having eroded out of deeply weathered basalt flows. The region can, however, be divided into two mining districts based on the type of corundum produced. The first lies to the west, near the town of Chanthaburi (figure 2) and in the Chanthaburi Province. It includes the famous Khao Ploi Waen and Bang Kha Cha mining areas, known for their production of blue, blue-green, and yellow sapphires as well as black star sapphires. The second district, approximately 45 km to the east of Chanthaburi, in Trat Province, is the currently very active Bo Rai/Bo Waen mining area known for its significant production of ruby. In fact, Bo Rai/Bo Waen, together with the Pailin area 27 km to the northeast in Kampuchea (formerly Cambodia), comprises the most important ruby-producing area in the world today. Occasionally, green sapphires and color-change sapphires occur in this district as well.

In 1980, an estimated 39.4 million carats of ruby and sapphire were mined in the Chanthaburi-Trat area by an estimated work force of 20,000 miners (Stamm, 1981). It is difficult to translate this production figure into official export figures because the latter do not include tourist purchases that do not have to be declared at customs or smuggled material. In addition, the tremendous amount

Figure 1. Two fine Thai rubies, 3.41 and 3.04 ct. Photo courtesy of Jack Abraham, Precious Gem Resources, Inc., New York, NY.

of corundum from elsewhere, particularly Sri Lanka and Australia, that is brought to Thailand for heat treatment and thus sold in the gem markets of Bangkok undoubtedly has a major effect on any export statistics. The actual production and export figures are probably much greater than those estimated by the Department of Customs and the Department of Business Economics. It is very significant, however, that these figures have more than doubled since 1973 (Stamm, 1981).

Considering the importance of the Thai deposits, surprisingly little has been written about them. Bauer (1904) provides one of the best early descriptions and includes a detailed map of the deposits. Most of the relatively recent work done by the Geological Survey of Thailand has been published in Thai journals which are, for the most part, difficult to obtain in the United States. An excellent general study of the gem deposits of Thailand was done by Aranyakanon and Vichit (1979). This report included details on the Chanthaburi-Trat area. Charaljavanaphet (1951) did one of the earliest geological reports on the Bo Rai area. One of the most important geological studies of the corundum-related basalts in Thailand was by Vichit et al. (1978). Berrangé and Jobbins (1976) did a superbly detailed study of the gem deposits at Pailin, Cambodia, in which they included many references to the deposits in the Chanthaburi-Trat area. A summary of this work was recently published by Jobbins and Berrangé (1981). There have also been several articles by visitors to the area, most notably Moreau (1976), Chang (1969), and Pavitt (1973, 1976).

None of these papers, however, has put all the aspects of geology, mining methods, production, and gemological characteristics together into a single, comprehensive report. The purpose of this article is to fill this void, as well as to present an update on current activities in the Chanthaburi-Trat area, including the heat treatment of corundum, based on observations made by the author on a visit to the area in June 1982.

LOCATION AND ACCESS

The Chanthaburi-Trat mining district is located in southeast Thailand, approximately 330 km east-southeast of the capital city of Bangkok. The district extends from approximately 102°00′ to 103°00′ west longitude and 12°00′ north latitude to 13°00′ north latitude. The district is contiguous with the very productive Pailin ruby and sapphire gem field, 27 km northeast of Bo Rai in Kampuchea (Cambodia).

Access to Chanthaburi is quite easy now compared to the late 19th century, when, according to Bauer (1904), a 20-hour journey by steamer from Bangkok was required. The new highway has shortened the trip from Bangkok to Chanthaburi to three hours. Bo Rai is about an additional 45 km from Chanthaburi eastward via highway no. 3157. Currently, there are more than 20 active mining operations in the district, ranging from hand operations to highly mechanized ones.

HISTORY

Gem mining in the Chanthaburi-Trat area was first reported at Khao Ploi Waen, also known as "Pagoda Hill" or the "Hill of Gems," in 1850. Khao Ploi Waen is about 8 km southwest of Chanthaburi, near the village of Bang Kha Cha. In 1850, the Shans and Burmese were mining sapphires here (Pavitt, 1973). According to Bauer (1904), a missionary report dated 1859 stated that it was possible to collect a handful of rubies from the "Hill of Gems" in half an hour. Interestingly, the pagoda that Bauer cites still stands.

Bauer (1904) described the state of the ruby and sapphire deposits in the Trat Province (then known as Krat) in the 1870s and 1880s. He divided the district into two groups, roughly 50 km apart: Bo Nawang, an area of about 40 square kilometers; and Bo Channa, 50 km to the northeast and a little over one square kilometer in extent. Bauer noted that the mines at Bo Nawang were small, typically pits one meter deep, and sunk in coarse yellow-brown sand overlying a bed of clay. The rubies occurred at the base of the sand unit in a layer 15–25 cm thick. These mines have been worked since about 1875.

In 1895, an English company, The Sapphires and Rubies of Siam, Ltd., obtained the rights to mine in what was then Siam. This company was an extension of E. W. Streeter, a famous London jeweler with a Burmese gem-mining operation known as Burma Ruby Mines Ltd. The company was not successful in the Chanthaburi-Trat area (Bauer, 1904).

At Bo Channa, the mines were vertical shafts extending to a depth of 7 to 8 m until they reached a gem gravel 15–60 cm thick. The Bo Channa mines have been worked since about 1885. Both Bo Channa and Bo Nawang were worked by the Burmese. Bauer estimated that about 1250 miners worked the two areas at the time.

Since the introduction of the Siam Mining Act in 1919, all gem mining has been limited to Thai nationals. Today, about 2,000 people mine in the Khao Ploi Waen-Bang Kha Cha area, and at least 20,000 people work between Bo Rai, Bo Waen, Nong Bon, and the deposits at Pailin in Kampuchea. Interviews at Bo Rai revealed that at least 1,000 miners from the area cross into Kampuchea every day.

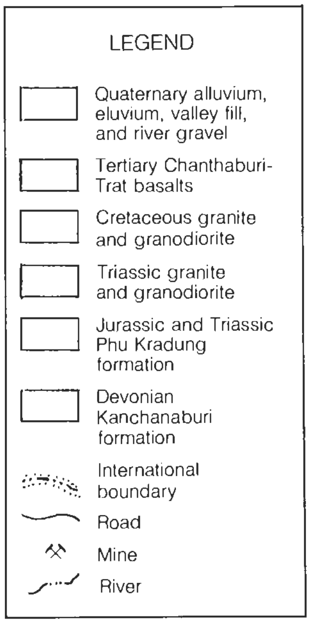
GEOLOGY

Because of the deep chemical weathering and subsequent rapid erosion that is typically associated with tropical climates, the corundum deposits of the Chanthaburi-Trat district occur exclusively in alluvial, eluvial, or residual lateritic soil deposits derived from underlying basalt flows. The gems have long been thought to have been derived from these basalts, although reports of in-situ occurrences are rare (Vichit et al., 1978).

While the precise age of the basalts has not yet been determined, they are thought to be relatively young; estimates range from Tertiary to Pleistocene (Leon Silver, personal communication, 1982). According to Jobbins and Berrangé (1981), the closely related Pailin basalts have been radiometrically determined to be 1.4 to 2.14 million years old. This places the basalts in Upper Pliocene to Lower Pleistocene age. They have been informally designated the Chanthaburi-Trat basalts by Vichit et al. (1978). These flows unconformably overlie the Devonian-age Kanchanaburi formation, which consists of phyllites and quartzites, and the Jurassic/Triassic Phu Kradung volcanic siltstones, sandstones, and conglomerates (Javanaphet, 1969). These units are undoubtedly comparable to the Devonian-age O Smoet formation and Triassic-age Tadeth Group that Berrangé and Jobbins (1976) discuss in their comprehensive study of the Pailin gem field. Other noteworthy geologic units in the region include granites and granodiorites of possible Cretaceous age and the Triassic-age Khao Sa-Bab granite which outcrops just east of Chanthaburi (again, see figure 2).

Outcrops of the Chanthaburi-Trat basalt are rare. The only notable outcrops are at Khao Ploi Waen and Khao Wao. At Khao Ploi Waen, the unit occurs as a dark, fine-grained to glassy vesicular basalt; the hill itself is thought to be a volcanic plug and is possibly a source for the gem-bearing basalt flows in the area (Taylor and Buravas, 1951). The plug at Khao Ploi Waen yields blue, green, and yellow sapphires as well as black star sapphires. Rubies are rare at this locality.

Invariably, the gem deposits are associated with basalt flows or at least remnant flows. The flow at Chanthaburi is only about 35 square kilometers. The basalts in the Bo Rai area are much more extensive. As expected, the basalt flows parallel to the gem deposits, trending in a north-south direction. The flow in the Bo Rai area is about 27 km by 4 km. This roughly delineates the Bo Rai mining district, which Vichit et al. (1978) estimate to consist of about 23 gem localities. Bo Rai produces ruby almost exclusively.



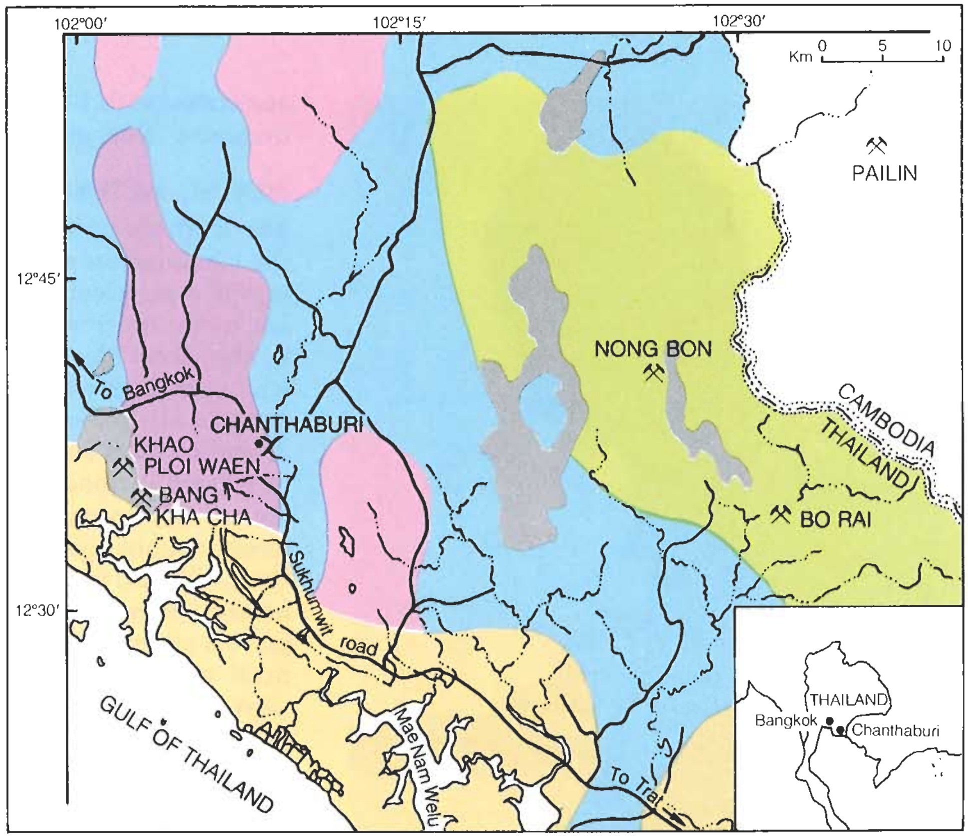


Figure 2. Geologic sketchmap of the Chanthaburi-Trat area, showing major ruby and sapphire mines. Modified from Vichit et al. (1978) and Javanaphet (1969).

From a petrographic point of view, the Chanthaburi-Trat basalts are fine-grained, olivine-bearing alkaline basalts; they have been called "basanitoids" by Vichit et al. (1978) and "basanites" by Berrangé and Jobbins (1976). These basalts locally contain spinel-rich lherzolite nodules, which may, in fact, be the ultimate source for the corundum. Lherzolite nodules are thought to form in the upper mantle of the earth, at depths of about 50 km, and may be unrelated to the magmas that brought them to the surface. The basalts contain augite, pyrope garnet, calcic plagioclase, zircon, spinel, and magnetite. The magnetite has been reported as megacrysts up to 6 cm in diameter. Spinel, which along with olivine and enstatite is typical of lherzolite, is locally abundant but rarely of gem quality.

The structural and historical geology of the Chanthaburi-Trat area is essentially identical to that outlined by Jobbins and Berrangé (1981) for the Pailin area of what is now Kampuchea, which could easily be considered part of the Chanthaburi-Trat district. Jobbins and Berrangé note that during the Himalayan orogeny of early to middle Tertiary times, the region, which is largely underlain by Jurassic-Triassic sandstones and Devonian phyllites, was uplifted and intruded by granites and granodiorites as represented by the Khao Sa-Bob granite. During the final stages of this orogenic episode, the area was also intruded by basaltic dikes which spilled onto the earth's surface in the form of extensive basaltic lava flows. Some volcanic features, such as the volcanic plug now exposed as a remnant at Khao Ploi Waen, were also formed at this time. Since this period of mountain building and volcanic activity, the area has been geologically quiet and the surface has been exposed to intense weathering and erosion as a consequence of the harsh tropical climate. Deep residual soil horizons formed over the basalts which, locally, have been eroded and redeposited to form the secondary gem deposits of the region. Because corundum is durable and heavy, it is an ideal mineral for concentration in these alluvial or eluvial deposits.

The gem deposits in the Chanthaburi-Trat area vary greatly in thickness, depending on the topography of the area and the bedrock. In the Chanthaburi area, sapphires are found on the surface at Khao Ploi Waen, and at a depth of 3–8 m in the area adjoining the hill and at Bang Kha Cha. In the relatively flat Bo Rai area, the gem gravel is at a depth of at least 4–10 m and varies in thickness from 0.3 m to 1 m. At Bo Rai, the ruby is

Figure 3. Primitive washing of gem gravels at Chanthaburi-Trat area.

associated with black spinel, olivine, and, in rare instances, blue, green, or color-change sapphires.

MINING METHODS

The methods used to mine ruby and sapphire in the Chanthaburi area reflect all levels of technological sophistication, from the simple rattan basket to the most advanced bulldozer. The mining in the Khao Ploi Waen area is typical of Thailand's most primitive extraction methods. Independent miners lease land from the local owners. A vertical shaft about 1 m in diameter is then dug to a depth of about 10 m, where the gem gravels are usually intersected. No ladder is used; the miner simply digs footholes into the side of the shaft. The soil is lifted to the surface using a large bamboo crane and rattan baskets. When the gem gravels are encountered, they are washed in artificial pools and sorted by hand in round rattan sieves (figure 3). According to Pavitt (1973), about 2,000 people work using these simple methods in the Khao Ploi Waen area alone.

Just to the south of Khao Ploi Waen, at Bang Kha Cha, which is famous for its black star sapphires and blue and green sapphires, a different style of mining is found. Here, the sapphires are recovered from the muddy tidal flats of the Gulf of Siam, which is located about 5 km to the south. The gem miners take boats out into the flats at low tide and fill them with the gem-bearing mud. They then take the mud to shore where it is washed with the standard rattan sieves. There are more sophisticated operations at Bang Kha Cha,

Figure 4. At Bo Rai, gem gravels are washed by high-pressure water cannons and transported up a pipe (seen to the right in photo) to a long sluice.

but the most technologically advanced mining can be seen at Bo Rai, the ruby mines located on the border of Kampuchea, where claims are generally about 1620 meters square, and the landscape is dotted with bulldozers and sophisticated washing equipment.

Large-scale mechanized mining was formally banned in Thailand in 1980 in response to pressure from farmers who claimed that the mining was destroying the topsoil. Even so, the majority of the ruby mining operations observed during the author's recent visit to Bo Rai used bulldozers to remove the overburden and high-pressure water cannons to wash the gem gravel that is then pumped into sluices from which the ruby is recovered (figures 4 and 5). According to Stamm (1981), "special" permits that allow mechanized mining are issued for 2500 baht (US$125) per month. In addition to the bulldozers and water cannons, the latest mechanical treatment includes a jig or "willoughby" table washer to concentrate the corundum at the end of the long sluice (figure 6). It is interesting to note that most of these so-called new mining methods at Bo Rai have been borrowed from the basic principles of alluvial tin mining used at Phukat, on the southern extension of Thailand.

Not all of the ruby mining in the Bo Rai area is mechanized; here, too, some is done by "pitminers" using only the traditional rattan sieve. These pitminers may work in small groups or on a few square meters of leased land. They commonly pay the government or landowner about 500 baht (US$25) per month and are permitted to keep what they recover. Other small miners search the already-worked tailings of the large, mechanized operations (figure 7). Usually these small miners are successful enough to support themselves and their families. The author noted several of them sorting and selling their ruby production in front of their homes (figure 8).

CHARACTERISTICS OF THAI RUBY AND SAPPHIRE

The rubies taken from the basalt fields of southeastern Thailand can generally be distinguished by their color and unique inclusions from those derived from the crystalline limestone terrain of Burma or from the graphite gneisses of East Africa. Gübelin (1940, 1971) has done detailed studies of inclusions that he found to be typical of Thai rubies. He observed the most common inclusions to be subhexagonal to rounded opaque metallic grains of pyrrhotite ($Fe_{1-x}S$); yellowish hexagonal platelets of apatite, $Ca_5(PO_4)_3(OH,F,Cl)$; and reddish brown almandite garnets, $Fe_3Al_2(SiO_4)_3$. These inclusions were commonly surrounded by circular feathers (figure 9) and characteristic polysynthetic twinning planes (figure 10).

A parcel of over 500 rough rubies obtained by the author from mines in the Bo Rai area were examined for characteristic inclusions and any other distinguishing features. The parcel consisted of well-rounded fragments, generally under 5 mm, which exhibited color variations from

Figure 5. After the gem gravels exit the pipe, they are run over a long sluice. The heavier corundum concentrate collects in a jig at the end.

Figure 6. A jig or "willoughby" table washer, a device borrowed from the Phukat tin mines on the southern extension of Thailand, is very effective at concentrating ruby.

strongly violet to a classic "pigeon blood" red. Grains over a centimeter were rare. The refractive index (1.766–1.774) and specific gravity (3.97–4.05) of ruby do not differ with locality. The high iron content of the Thai rubies does influence their behavior when exposed to ultraviolet radiation, in that their fluorescence is inhibited significantly. The parcel examined exhibited the very weak fluorescence that would be expected for Thai rubies.

By far the most common inclusion in the parcel of rubies studied was subhedral to anhedral pyrrhotite (figure 11). These pyrrhotite inclusions were commonly altered to a black submetallic material (figure 12) that X-ray diffraction analysis by Chuck Fryer of GIA revealed to be goethite, FeO(OH). It is not surprising to see pyrrhotite inclusions in rubies from a basaltic terrain, since basalts are unusually high in iron. Furthermore, according to Carmichael et al. (1974), pyrrhotite appears to be the dominant primary sulfide in basaltic rocks.

In all the samples studied, no inclusions of almandite garnet or rutile were observed. Yellowish anhedral hexagonal platelets of translucent apatite were noted, although these were considered quite rare. A high percentage of the stones studied were totally free of diagnostic mineral inclusions, however; the most characteristic features in these stones were secondary stains of iron oxide that appeared in almost all fractures (again, see figure 11). Given the iron-rich nature of the presumed host basalt, as discussed above, this abundance of iron is to be expected. Typically, the brownish to purplish overtones of the rubies, and their weak fluorescence when exposed to short-wave ultraviolet and X-radiation, has been attributed to the characteristically high concentrations of iron found in the Thai rubies.

Sapphires recovered from the Khao Ploi Waen and Bang Kha Cha areas outside of Chanthaburi are quite different morphologically from the formless Bo Rai rubies. These sapphires show signs of transport, in that they occur as well-rounded hexagonal prisms. I would suggest, however, that the sapphires have not traveled as far

Figure 7. Independent miners often work the tailings of the more sophisticated operations in hopes of recovering any overlooked ruby. This photo was taken at Bo Rai.

Figure 8. Independent miners sorting rough rubies at Bo Rai. Note the bottle of "ruby oil," essentially a coloring agent, which is sometimes used to temporarily enhance the appearance of the gem rough.

as the rubies, which rarely exhibit any of their original hexagonal morphology. The sapphires are generally green, blue, yellow, or black—the black commonly exhibiting asterism. They range in diameter from less than a millimeter up to 10 cm. The average size observed was 3–6 mm. Large, hexagonal blue-green sapphire specimens up to 1720 ct have been reported from the Bang Kha Cha area (Pavitt, 1973). No gem-quality stones of this size have ever been reported, however.

HEAT TREATING "GOLDEN" SAPPHIRES

It is almost impossible to discuss the increased availability of fine ruby and sapphire from Chan-

Figure 9. Typical inclusions in Thai ruby are these circular features surrounding pyrrhotite. Magnified 60×. Photo by John Koivula.

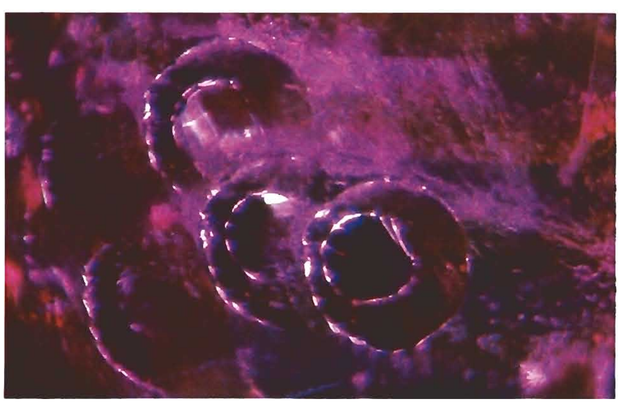


Figure 10. Polysynthetic twinning, here observed under crossed polarizers, is commonly seen in Thai rubies. Magnified 25×. Photo by John Koivula.

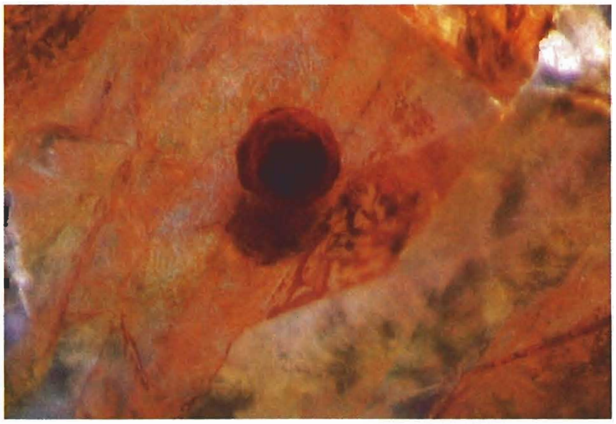


Figure 11. Typical subhedral inclusions of semialtered pyrrhotite in a Bo Rai ruby. Note the characteristic iron stains also. Magnified 50×. Photo by John Koivula.

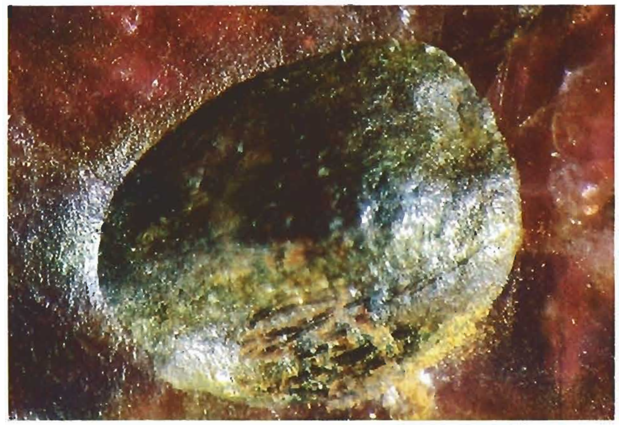


Figure 12. Large goethite inclusion found in an alteration product of pyrrhotite. Magnified 50×. Photo by John Koivula.

thaburi without considering as well the now-common use of heat treatment in that area. The heat treatment of corundum has developed into a major industry in Thailand, primarily in Bangkok and Chanthaburi. Estimates of the number of heat-treatment facilities run from the hundreds to the thousands. These facilities treat not only the local production, but large quantities of material from Sri Lanka, Australia, Kampuchea, and Burma as well. Nassau (1981) and Crowningshield and Nassau (1981) examined the technical aspects of heat treatment and its detection in ruby and sapphire in quite some detail. They limited themselves to those questions relating to enhancing asterism or improving the color of ruby and blue sapphire, however. Abraham (1982) discussed some of the practical aspects of this growing industry in Bangkok, but again limited his article to the commercially important blue sapphires, rubies, and sapphires exhibiting asterism.

On a recent visit to Chanthaburi, the author had the opportunity to interview Mr. Sammuang Koewvan and Mr. Jonk Chinudompong, two of the leading treaters. They were very cooperative and helpful, and essentially confirmed what Abraham (1982) presented in his recent article. The author was, however, especially interested in the relatively large amount of high-quality brownish to orangy yellow—referred to here as golden—sapphire that they were generating, largely from Sri Lankan rough (figure 13). (While significant quantities of blue sapphires have been heat treated for at least the last 10 to 15 years, and rubies for the last three to five years, the heat treatment of golden sapphires on a large scale appears to be relatively new.) To date, very little has appeared in the literature concerning these stones. Crowningshield (1982) reported that light yellow stones were produced by heat treating colorless sapphire seven or eight years ago, but that these were subject to fading. These stones were not the same as the orangy yellow ones observed in this study, which definitely did not fade on prolonged exposure (over several months) to light.

There was a great deal of concern on the part of the gem dealers in Thailand about these sapphires because such a golden color may also be produced by irradiation, and the irradiated stones have been found to fade rapidly when exposed to heat or ultraviolet radiation. Because of this concern, dealers routinely place a suspect stone under a flame for one minute. If the stone has been irradiated, it will fade. If, however, the sapphire has been heat treated, it will temporarily darken and, upon cooling, return to its golden color. (In a recent personal communication, Robert Crowningshield noted that the GIA Gem Trade Lab in New York prefers to place a suspect stone in sunlight for approximately four hours, since natural yellow sapphires from Sri Lanka may temporarily fade at a fairly low temperature.) In a paper by Lehmann and Harder (1970), it was pointed out that the yellow color in sapphire was generally due to trivalent iron impurities. There were, however, some yellow sapphires that owed their color to "irradiation color centers." The authors noted that these sapphires "bleach completely within a few days even in the dark."

The actual heat-treatment process for these golden sapphires appears to be quite simple. Most of the sapphires treated are colorless stones from Sri Lanka. These sapphires are typically very clean and free from the "silk" or rutile that provides the

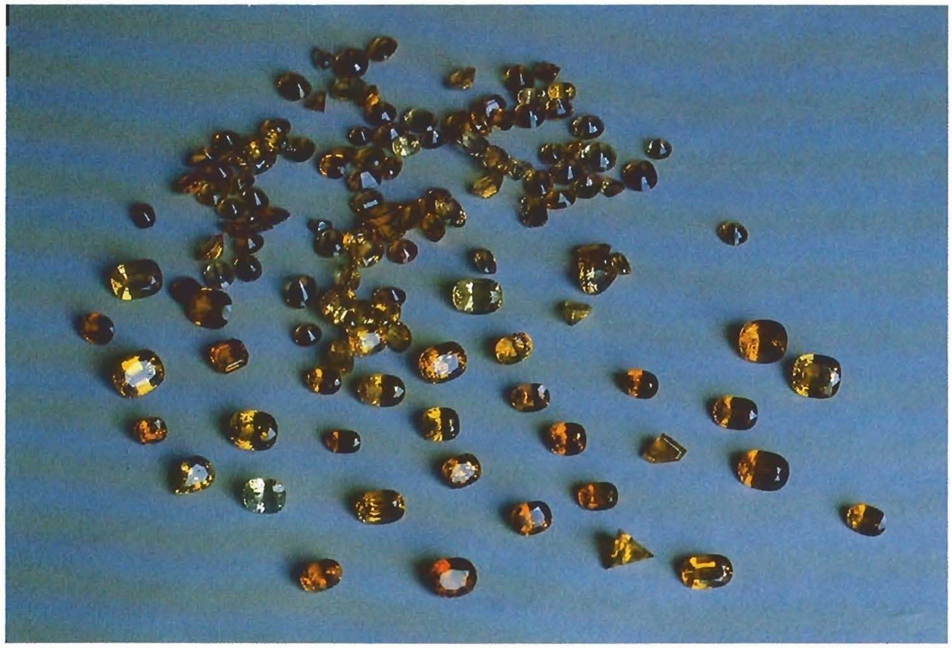


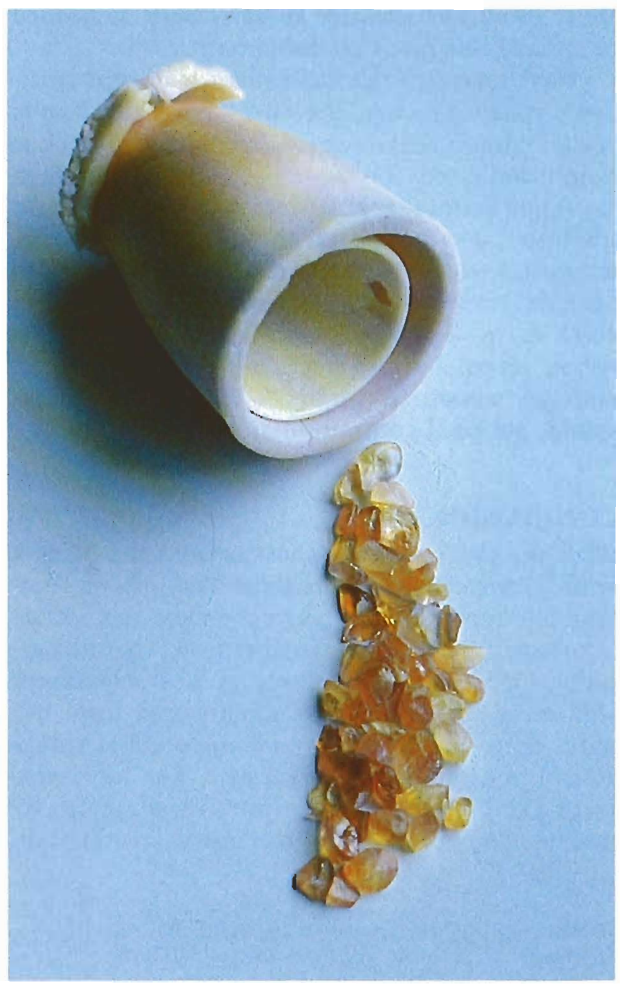
Figure 13. A parcel of faceted golden sapphires after heat treatment. The largest stones are about 10 ct.

titanium which, in conjunction with divalent iron, is responsible for a sapphire's blue color (Nassau, 1981). Any highly included or flawed portions of the rough sapphire are trimmed prior to treatment. The material is heated in an open crucible, that is, in an oxidizing environment, in an oven similar to that described by Abraham (1982) for blue sapphires. The divalent iron is converted to trivalent iron following the simple equation offered by Nassau (1981):

$$4\ FeO + O_2 \rightarrow 2\ Fe_2O_3$$

This conversion results in a yellow sapphire (Lehmann and Harder, 1970). Specifically, to produce this change, the colorless sapphires are heated for about 12 hours at 1000°C to 1700°C in two crucibles, one placed inside the other (figure 14). The corroded surface of the treated rough suggests that the temperatures are at the high end of this estimate. The variation in color is dramatic, some stones remaining colorless while others become a dark, rich golden color. The treaters interviewed were very adamant that no chemicals are used in the crucible with the sapphire. Theoretically, no chemicals are necessary for the conversion of divalent to trivalent iron. The treated rough does show signs of very localized partial melting; this is possibly due to a spattering of the borax in which the corundum-bearing crucible is packed during the heating process. (The borax would be an excellent flux to promote melting in the corundum, as it is in the diffusion treatment of this material.)

Figure 14. Heat-treated golden sapphires with the pair of crucibles used in heating.



The actual mechanism for the appearance of the golden yellow color in the sapphire is open to speculation until the extensive research required to provide a conclusive answer can be completed. According to George Rossman, of the California Institute of Technology (personal communication, 1982), trivalent iron alone will produce a pale yellow color, but cannot be called upon for the rich golden color observed in many of the treated stones seen in Chanthaburi (figure 13). Rossman suggests that perhaps we are seeing incipient exsolution of the trivalent iron as submicroscopic iron oxides in the corundum lattice. This mechanism would be very similar to the exsolution of hematite in plagioclase feldspar giving rise to the golden color of sunstone. In the case of plagioclase, the hematite may become coarse enough to result in aventurescence. This phenomenon has not been observed in sapphire, although the process is not unlike the exsolution of titanium oxides (rutile) in corundum to produce the familiar "silk" inclusions. As noted above, however, detailed research will be needed to answer this question for certain.

With regard to the identification of heat treatment in these stones, the GIA Gem Trade Lab is of the opinion that once irradiation (fade test) has been eliminated, the source of color in brownish to orangy yellow sapphire may be ascribed to heat treatment on the basis of the rare and somewhat unnatural nature of this hue. Additional clues to heat treatment are the absence of an iron line at 4500 Å in the spectroscope, subdued fluorescence, internal stress fractures, pockmarked facets, and abnormal girdles* (Robert Crowningshield, personal communication, 1982).

CONCLUSION

With the decline in production from the Mogok area of Burma, the Chanthaburi-Trat area of Thailand has become of world importance as a source of rubies and sapphires. Furthermore, the increasingly sophisticated methods of heat treatment stemming from the Chanthaburi area have not only increased the supply of fine-colored rubies and blue sapphires substantially, but have also introduced relatively large amounts of previously rare "golden" sapphire of fine color. Greater technological sophistication has also been applied to the actual mining of the corundum to increase the supply of rough to the market. Reduced military activity in the adjacent gem fields in Kampuchea (Cambodia) in recent months suggests a return to importance of this area as well, contributing to the overall gem potential of the region.

**Editor's note: These latter two characteristics are discussed and illustrated (figures 13 and 14) in the Gem Trade Lab Notes section of this issue.*

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