May/Jun 2011
Vol. 86, No. 3

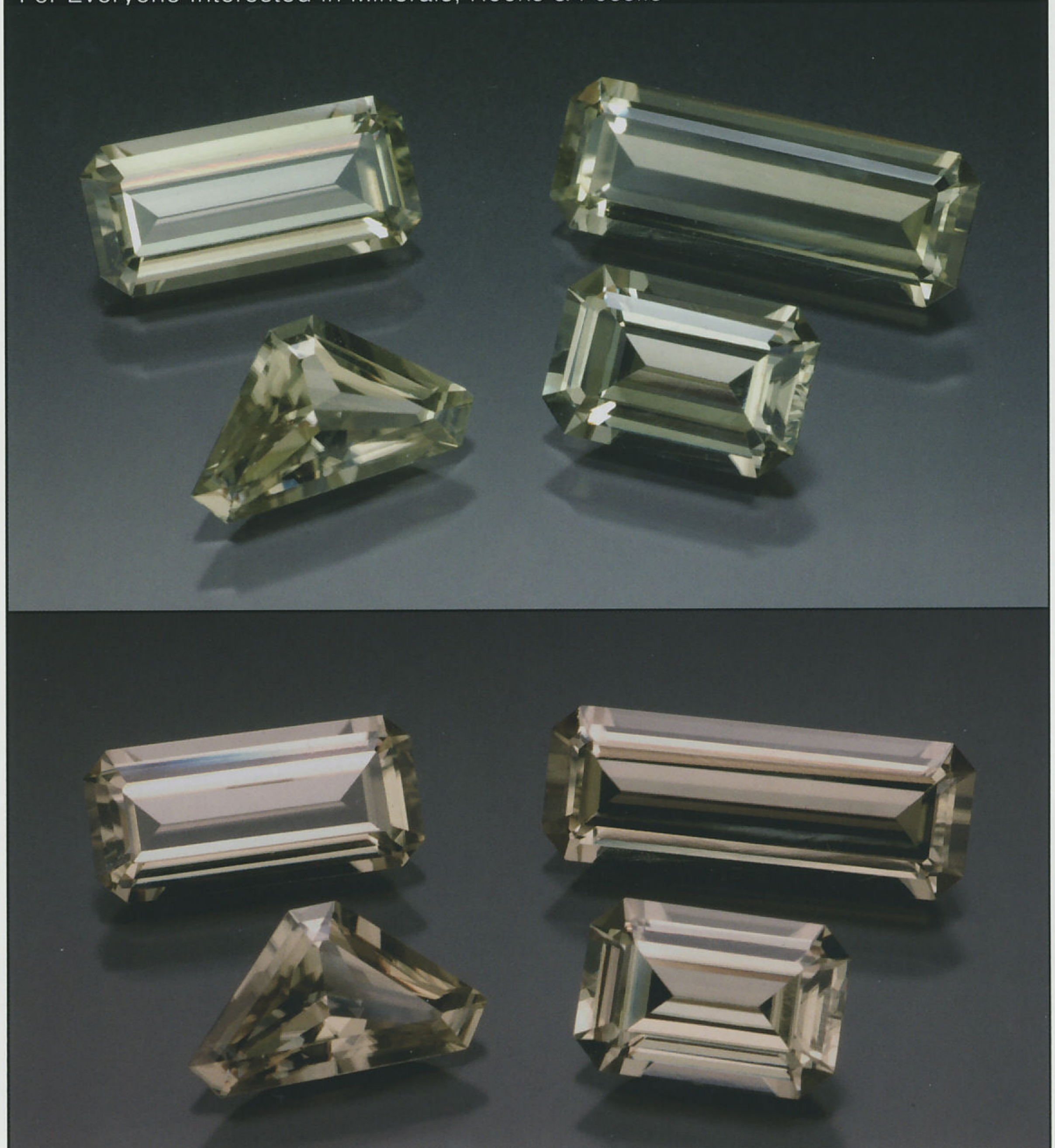
Rocks & Minerals

For Everyone Interested in Minerals, Rocks & Fossils

Upper Michigan Collecting

New York State Fulgurite

Hoedown in New Mexico



$8.95US $8.95CAN

Gem Diaspore from Turkey

www.rocksandminerals.org

MURAT HATIPOGLU
Gemology and Jewelry Program
Izmir Multidisciplinary Vocational School
Dokuz Eylul University
35160 Buca-Izmir, Turkey
murat.hatipoglu@deu.edu.tr

STEVEN C. CHAMBERLAIN
3140 CEC
Center for Mineralogy
New York State Museum
Albany, New York 12230
sccham2@yahoo.com

A Gem Diaspore Occurrence near Pinarcik, Mugla, Turkey

Figure 1 (above). Satellite photograph of the Anatolian Peninsula comprising most of modern Turkey. The red square indicates the location of the gem diaspore occurrence near Pinarcik on the southwest Aegean coast in the Milas-Mugla region. William Besse map.

Figure 2 (left). Satellite photograph of the region of the Menderes Massif where the gem diaspore occurrence is located in southwestern Turkey. Although the village of Danisment is closest as the crow flies, the village of Pinarcik is the closest by road. William Besse map.

Diaspore has generally not been a popular mineral with collectors. Aside from several classic localities such as the nepheline-syenite pegmatites at Ovre Åro, Norway, the emery schists at Mramorskoi in the Russian Urals, and the marbles at Campolongo, Switzerland, displayable diaspore specimens have been few and far between. Collectors of American classics will be familiar with the fawn-colored prismatic crystals from Corundum Hill, Newlin Township, Chester County, Pennsylvania, or the lavender tabular crystals from the emery mines near Chester, Hampden County, Massachusetts. Diaspore is most commonly, with gibbsite and boehmite, a main constituent of metamorphosed bauxite deposits (diasporites) (Gordon, Tracey, and Ellis 1958; Hemingway, Kittrick, and Peryea 1989; Park and MacDiarmid 1975), but in that geological setting it rarely comprises interesting specimens. In addition, diaspore also occurs as hydrothermal mineralization below 960°F in fractures and pegmatites (Hill 1979; Keller 1978; Klug and Farkas 1981; Loffler and Mader 2004; Perrotta 1998; Tsuchida and Kodaira 1990). These deposits sometimes yield larger and more interesting crystals.

Recently, however, hydrothermally mineralized fracture zones cutting a metabauxite deposit in a marble bed of the Menderes Massif in southwestern Turkey have been yielding unprecedented single crystals, V-twins, crystal groups, and gem rough (being marketed under the commercial name "zultanite") (Zultanite Gems LLC 2009). Even though 60 percent of the large diaspore crystals are an opaque pale green, the others are often transparent and darker olive-oil-green in daylight or equivalent light sources. At this locality, unique diaspore crystals occur abundantly in hydrothermal veins with large crystals of calcite, muscovite, and chloritoid, all on a goethite-rich matrix. However, because the deposit is being mined for gem rough, the accessory minerals are rarely preserved. Although two twin laws for diaspore are typically listed in the literature, we believe this locality is the first occurrence of significant large contact twins for the species; neither Goldschmidt's *Atlas der Krystallformen* (1916) nor *Dana's System of Mineralogy* (Palache, Berman, and Frondel 1944) illustrates any twins. Moreover, most of the unique diaspore crystals from this occurrence show a pronounced alexandrite-like color change from daylight to incandescent light. Here we present a detailed description of the locality.

Location

There is a large metamorphic region called the Menderes Massif in western and southwestern Turkey, formed by regional alpine metamorphism during the Precambrian to Paleocene (Candan et al. 2007; Durr 1975). Although the Menderes Massif includes many metabauxite (diasporite and emery) deposits occurring as lens and thin veins (Brinkmann 1968; Smith 1850; Yalçın 1987), the one of particular interest is a metabauxite (diasporite) deposit that is producing outstanding diaspore and associated minerals found in Ilbir Mountain, located between the Aegean Sea and Bafa Lake in the Milas (Mugla) region, as shown in figures 1 and 2. This occurrence is about 120 miles south-southeast of Izmir and 400 miles southwest of Istanbul at coordinates 37°27′5″N, 27°30′16″E in the Milas (Mugla) region. Although the nearest villages as the crow flies are Danisment and Camici (Bafa) (fig. 2), the village of Pinarcik is the nearest village from which the deposit is accessible by road. Pine forests cover the deposit, which has an area of about 3 square miles where diaspore crystals can be obtained. To date, two adjacent openings have been made, one on *Kucuk Camlik Tepe* (Little Pine Grove Hill) (fig. 3) and one nearby on *Buyuk Camlik Tepe* (Big Pine Grove Hill) (fig. 6).

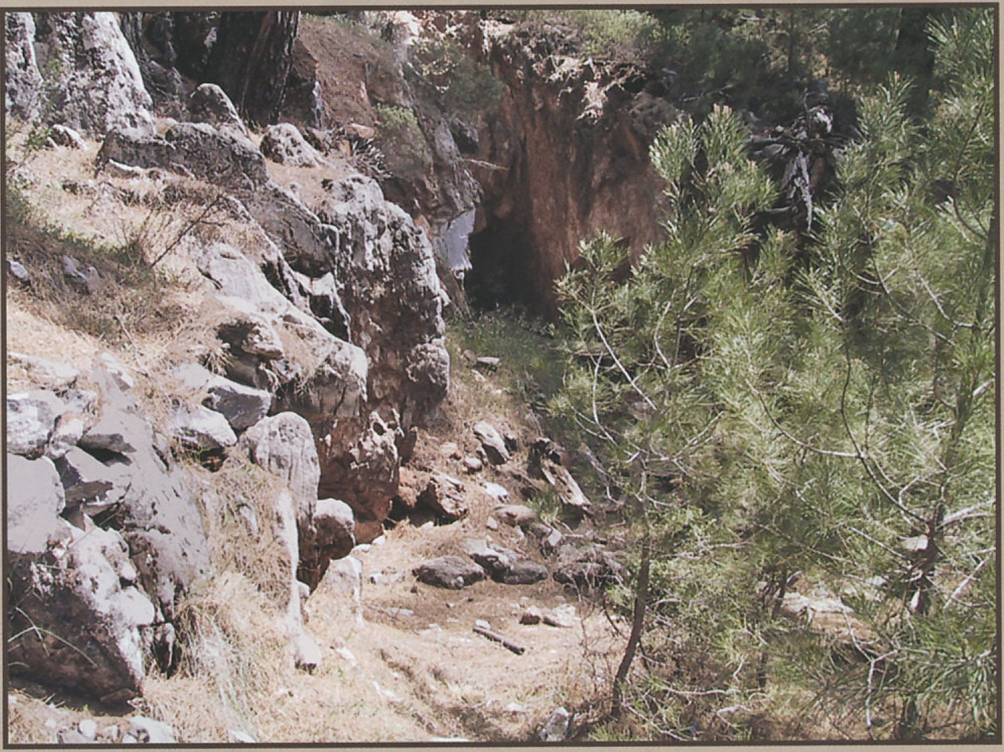


***Figure 3.* The Little Pine Grove Hill pit. This photograph shows the older workings in the Triassic-Cretaceous-aged gray marbles and diasporites of the Menderes Massif before current mining operations began. Murat Hatipoglu photo.**

History

Metabauxite ore in this area was discovered in 1949 (Onay 1949), and the exploration during the decade between 1962 and 1972 established its economic viability (Wippern 1965). From 1972 to 1982, the Etibank Mining Company (a government corporation) mined diasporite as an ore of aluminum. During this time, the value of the diaspore crystals as gem rough was not well understood and no systematic effort was made to recover and preserve them. Indeed, the official production inventory of Etibank does not mention any diaspore crystal production. Unofficially, however, it appears that several tons of V-twins and gem-quality crystals of diaspore were collected and illegally exported, especially between 1978 and 1982. Photographs of cut diaspore gems began appearing in the gemological literature as early as 1980 (Lab notes 1987; Duroc-Danner 1987; Gem news 1985, 1994, 1995; Scarratt 1980) where diaspore was treated as a rare gemstone material. More published information followed. Although diaspore specimens were offered for sale at rather high prices at the Munich Show, the Basel Show, and the Tucson Show during this period, general awareness of their existence among collectors is more recent, and many

Dr. Murat Hatipoglu is an assistant professor at Dokuz Eylul University in Turkey. He is the coordinator of the Gemology and Jewelry Program in the Izmir Multidisciplinary Vocational School and director and senior staff gemologist of the Dokuz Eylul Gemological Testing Laboratory.

Dr. Steven C. Chamberlain, a consulting editor of Rocks & Minerals, *is the coordinator of the Center for Mineralogy at the New York State Museum.*

Figure 6. **The hydrothermal veins containing diaspore crystals mainly formed in fracture zones at the border of the brownish-black diasporitic metabauxite and the gray marble belonging to the Triassic-Cretaceous periods (235–65 Ma) of the Mesozoic Era, as shown here in the old workings on Big Pine Grove Hill. Murat Hatipoglu photo.**

The upper surface of the limestone developed a karstic topography with many lens and pocket-shaped sinkholes. The karstic sinkholes were filled with Al-, Fe-, and Si-rich bauxitic ores derived from the ferruginous clays produced by the breakdown of the feldspar and feldspathoid minerals of the underlying gneisses. Later, dark gray limestone containing significant detrital materials and patches of mudstone accumulated in the basin and covered the filled-in karstic surface. Ultimately, the region was subjected to a second episode of regional alpine metamorphism between the Cretaceous and end of the Paleocene periods. The underlying gneisses were further metamorphosed; the mudstones were metamorphosed to schists, and the carbonate rocks, to marbles. The bauxite ore in the massive limestone was metamorphosed into a metabauxite principally consisting of diaspore (i.e., a diasporite). Finally, starting in the Miocene Period (Ozer et al. 2007), sedimentary rocks partially covered the metamorphic rocks.

The large diaspore crystals and accessory minerals of interest to collectors formed in dissolution cavities and tectonic fractures at the contact of the marble and the diasporite (fig. 6). The mineralized zones form lenses 2–3 yards wide at a constant elevation for a distance of about a mile. Relatively high-temperature hydrothermal solutions at or just below 960°F remobilized constituents of the diasporite and marble and deposited diaspore, muscovite, chloritoid, and calcite in the open spaces. These crystallized minerals are accompanied by specular hematite (specularite) and earthy goethite. Although there is no evidence of postdepositional metamorphism in these vein minerals, some crystals show evidence of deformation by postdepositional tectonic activity. More rarely, diaspore crystals formed in voids in zones of brecciated lenticular metabauxite with emery that lies in alternating layers of gneisses and schists.

Minerals

The hydrothermal mineralization in the fracture-filling veins of this deposit includes several species, only some of which form well-crystallized specimens of interest to collectors. These are discussed individually below. In general, the matrix of the crystallized specimens consists of a mixture of goethite, ferroalluaudite, corundum, diaspore, and quartz. Even the species listed individually are not yet being produced as desirable mineral specimens in any appreciable quantity, because current operations are aimed at producing gem rough (e.g., zultanite).

Calcite, $CaCO_3$, occurs as white to pale yellow, transparent to translucent rhombohedral crystals to 18 cm (fig. 7).

Chloritoid, $(Fe^{2+},Mg,Mn)_2Al_4Si_2O_{10}(OH)_4$, forms dark green to almost black, tabular crystals to 5 cm.

Diaspore, AlO(OH), occurs as single crystals, groups of crystals, contact twins (V-twins), and groups of contact twins. Much of the material recovered consists of prism frag-

Figure 7. **Calcite crystals of pseudocubic rhombohedral habit are a common accessory mineral in the diaspore-rich hydrothermal veins. This specimen is 8.5 cm wide. Murat Hatipoglu photo.**

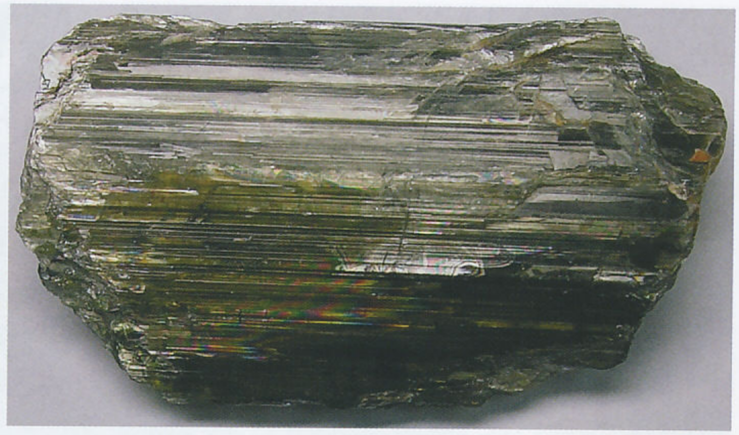


Figure 8 (left). **Hakki Babilik (left) and Dr. Halil Sarp, Natural History Museum, Geneva, Switzerland, inspect diaspore gem rough at the home of a local diaspore miner. Murat Hatipoglu photo.**

Figure 9 (above). **Fragment of a 12-cm diaspore crystal weighing about a pound (0.454 kilograms). Murat Hatipoglu photo.**

ments suitable for faceting (fig. 8). Some individual crystals are rather large, as illustrated by the crystal section in figure 9, which weighs almost 500 grams and is more than 7 cm long. Terminated crystals are relatively rare and may have irregular terminations (fig. 11) or relatively sharp terminations that are usually formed by the prism {061}. Some diaspore crystals are curved or bent, reflecting postdepositional deformation. Single crystals exhibit several distinct habits. Blocky prismatic crystals have a square or rectangular cross section and are dominated by the pinacoids {100} and {010}, which are typically smooth or only lightly striated. Flattened prismatic crystals are dominated by the heavily striated prism {110} and have a diamond-shaped cross section. Either habit can be terminated by the prism {061}, which can be symmetrically developed or distorted to show only one large face on the termination (fig. 10). Some prismatic crystals are tapered toward a point, which typically does not show distinct faces. Contact twins have (061) as a composition plane with

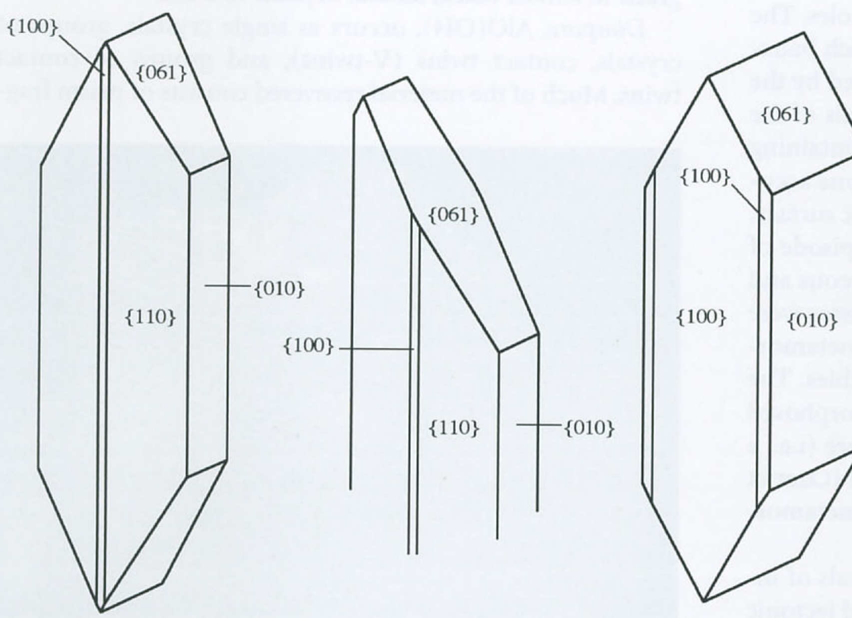


Figure 10 (above). **Three idealized crystal drawings of single diaspore crystals. On the left, a crystal dominated by the prism {110} is terminated by {061}. In the center, the termination is distorted, showing only one face of {061}. On the right is a blockier crystal dominated by pinacoids and terminated by {061}.**

Figure 11 (right). **Most diaspore crystals from the deposit are not sharply terminated but have complex, somewhat melted-looking terminations, as shown on this 3.6-cm crystal. This photograph was taken with incandescent light, hence the champagne color. IRocks.com photo.**

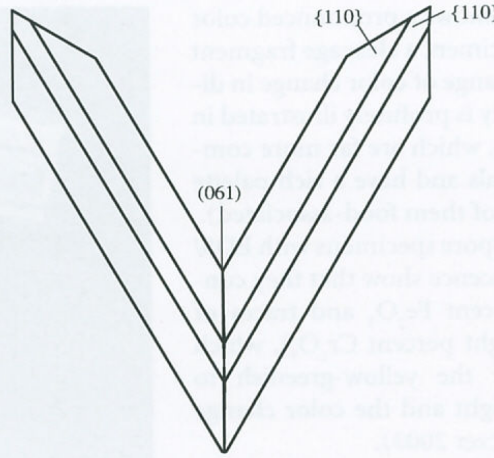


***Figure 12 (far left).* Examples of diaspore V-twins. The twin at the upper left is 8.5 cm; that at the lower right, 7.4 cm across. Murat Hatipoglu photo.**

***Figure 13 (left).* Ideal drawing of a V-twin of diaspore. The contact plane is (061).**

no reentrant angles on the outside of the V-twin. The paired crystals forming the arms of the V can be either columnar or tapered (fig. 12). Figure 13 shows an idealized drawing of a diaspore contact V-twin on (061). Figures 14 and 15 show two views of what must be one of the most aesthetic diaspore specimens in existence.

The matter of the color of the diaspore crystals from this deposit is complicated by the fact that individual specimens show a greater or lesser amount of color change from daylight to low-watt incandescent light (Gem news 1994; Shoval, Gaft, and Panczer 2003). In daylight or equivalent illuminators, crystals range from almost colorless through pale, medium, and dark green, but also yellowish-green shades, pale amber, and brown (due to included goethite). In low-watt incandescent light, the color may range from lavender to amber (champagne-colored) to rose-red to an orange-red. The color in incandescent light depends on the dominant wavelength of the illumination. As the spectrum shifts toward longer wavelengths (lower color temperatures), the color is often richer. Figures 14 and 15 show the color change in this specimen due to a higher color-temperature lighting in figure 14 and a lower color-temperature lighting

***Figure 14 (left).* Multiple interlocking V-twins of diaspore. It was photographed, while the specimen belonged to Leonard Himes, to show the color in daylight. The specimen is 9 × 5.6 × 3 cm. Jeff Scovil photo.**

***Figure 15 (right).* A different orientation of the specimen shown in figure 14. It was photographed to show the color in incandescent light. Jim and Gail Spann specimen. Stuart Wilensky photo.**

in figure 15. Figure 16 shows a pronounced color change in another specimen, a cleavage fragment parallel to {010}. The range of color change in diaspore from this locality is profusely illustrated in faceted stones (fig. 17), which are far more common than uncut crystals and have a rich palette of color names (many of them food-associated).

Our analyses of diaspore specimens with EDS/SEM and X-ray fluorescence show that they contain 1–1.5 weight percent Fe_2O_3 and traces of chromium (0.057 weight percent Cr_2O_3), which probably account for the yellow-greenish to greenish color in daylight and the color change (Shoval, Gaft, and Panczer 2003).

Goethite, FeO(OH), forms earthy masses with the other minerals in the veins.

Hematite, Fe_2O_3, occurs sparingly as masses of specular crystals.

Muscovite, $KAl_2\square AlSi_3O_{10}(OH)_2$, forms pale yellow, tabular crystals to 20 cm.

Thoughts on the Uniqueness of This Occurrence

Why are diaspore occurrences with this quality of specimens not more common? Also, why are these diaspore crystals almost uniquely transparent and flawless? The answer to the first question almost certainly lies in the complex geological history of the region. Partly because Turkey sits at the junction of several continental plates, its geological history is a continuing sequence of metamorphism and tectonic activity. Regional metamorphism of the original sedimentary soft bauxite deposits into hard, brittle diasporite deposits was followed by a period of tectonic activity that caused brittle deformation of the diasporite, leaving it cut by open fractures. Another period of fairly high-temperature metamorphism caused hydrothermal fluids to leach components from the fine-grained walls of the fractures and recrystallize them as larger crystals in the open spaces of the fractures themselves. Our continuing studies suggest that no new compositional components were added during this process, so the key contributing factors lie in the complex sequence of events in the geological history—a sequence that was not repeated in any of the world's many other bauxite deposits.

We are continuing to investigate the nature of the gem diaspore itself. One might expect that these flawless, transparent crystals would be quite pure, except for the trace elements that cause the remarkable color change from daylight to incandescent light. Surprisingly, we have found quite the opposite. Although we are reporting the details elsewhere, analysis by a variety of advanced techniques shows that this diaspore deviates in significant ways from ideal diaspore. The specific gravity and refractive indices are slightly differ-

Figure 17 (above). **Four faceted Turkish diaspores cut by John Bradshaw. The largest stone is 2.87 carats. Note the color change from daylight (top) to incandescent (bottom) illumination. Jeff Scovil photos.**

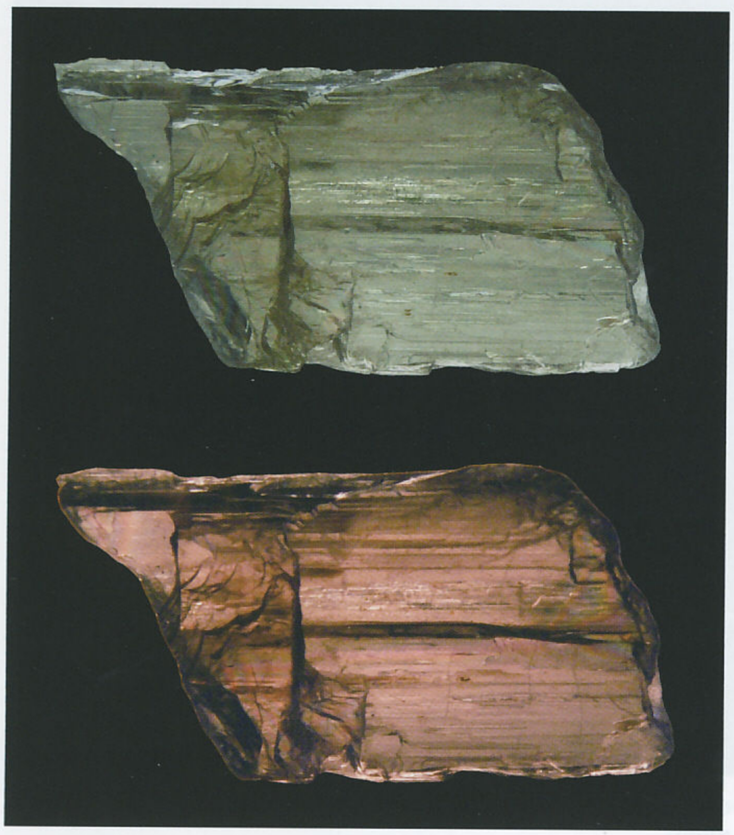


Figure 16. **Color change in a 4.5-cm gem cleavage fragment of diaspore. The top view shows the appearance in daylight; the bottom, in incandescent light. Steven C. Chamberlain specimen and photo.**

ent from expected values. Moreover, the chemical composition has a much higher level of impurities than might be expected. Optical methods show the diaspore to be seamlessly uniform and pure. X-ray analysis and imaging at high magnification with a scanning electron microscope, however, both reveal that this diaspore exhibits numerous submicroscopic, polycrystalline inclusions of other minerals including the chlorite donbassite as well as boehmite, gibbsite, corundum, hematite, ferroalluaudite, ilmenite, goethite, chlorotoid, muscovite, margarite, calcite, and quartz. Obviously, these polycrystalline arrays do not interfere with the optical properties that make the diaspore a striking cut stone, but they also would not seem to explain why these crystals contain so much gem rough. We have tentatively concluded that it must be the conditions of crystallization that account for the uniqueness of these diaspore crystals as gem material.

Discussion

Although all modern mineralogy references list two twin laws for diaspore, virtually all specimen examples of twinning on either {021} or {061} have, until very recently, been microscopic. The V-twins with contact on {061} from Pinarcik, Turkey, are the first important examples to be discovered. Moreover, they are being recovered in sufficient quantity from this large deposit so that in time every collector of twinned crystals ought to be able to have one.

The best single crystals from Pinarcik are among the finest diaspore crystals ever recovered. Only the very recently discovered diaspore crystals in marble from Pan-Lin-Inn-Chauk, Mogok, in the Burmese Stone Tract in the Mandalay Division of Myanmar, Burma, are as fine.

Already much has been made in the marketplace and the gemological literature about the large, flawless diaspore faceted stones cut from gem rough from this locality. Moreover, the wide range of marked color change from daylight to incandescent light is prompting many to compare zultanite (Turkish diaspore) favorably with the alexandrite variety of chrysoberyl.

Fortunately, the best crystals and groups of crystals share all the characteristics that have made the cut stones so interesting. Unfortunately, mining and recovery have emphasized production of gem rough, not mineral specimens. We hope this article will increase collectors' interest in the crystal specimens from Pinarcik, Turkey, and encourage production of mineral specimens from this unusual deposit.

ACKNOWLEDGMENTS

We thank Gail Spann, Leonard Himes, Elise Skalwold, Jeff Scovil, and Dr. David Bailey for their assistance in preparing this article. We thank Drs. John Rakovan, Anthony Kampf, and Peter Modreski for very helpful reviews and William Besse for preparing the maps.

REFERENCES

Brinkmann, R. 1968. Geotektonische Gliederung von West Anatolien. *Bulletin of the MTA–Turkey* 66:61–74.

Candan, O., O. O. Dora, E. Korolay, R. Oberhansli, G. Rimmele, M. Cetinkaplan, F. Chen. 2007. Polymetamorphic evolution of the Pan-African basement and Paleozoic–Early Tertiary cover series. In *Proceedings of Menderes Massif colloquium,* 74–81.

Duroc-Danner, J. M. 1987. Diaspore: A rare faceted gem. *Journal of Gemology* 20:7–9.

Durr, S. 1975. *Uber Alter und geotektonische Stellung des Menderes-Kristallins/SW–Anatolien und seine Aequivalente in der mittleren Aegaeis.* PhD thesis, University Marburg/Lahn, Germany.

Gem news. 1985. World's largest diaspore. *Gems & Gemology* 21 (1): 57–61.

———. 1994. Color-change diaspore from Turkey. *Gems & Gemology* 30 (4): 271–80.

———. 1995. Diaspore from Turkey. *Gems & Gemmology* 31 (1): 59–71.

Goldschmidt, V. 1916. *Atlas der Krystallformen.* Vol. 3. Rochester Mineralogical Symposium 1986 reprint.

Gordon, M., J. I. Tracey, and M. W. Ellis. 1958. *Geology of the Arkansas bauxite region.* U.S. Geological Survey professional paper 268.

Hemingway, B. S., J. A. Kittrick, and F. J. Peryea. 1989. Relative solubilities of corundum, gibbsite, boehmite, and diaspore at standard state conditions: An addendum. *Clays and Clay Minerals* 37:566–67.

Hill, R. J. 1979. Crystal structure refinement and electron density distribution in diaspore. *Physics and Chemistry of Minerals* 5:179–200.

Keller, W. D. 1978. Diaspore recrystallized at low temperature. *American Mineralogist* 63:326–29.

Klug, A., and L. Farkas. 1981. Structural investigation of polycrystalline diaspore samples by X-ray powder diffraction. *Physics and Chemistry of Minerals* 7:138–40.

Lab notes. 1987. Diaspore, a rare gem material. *Gems & Gemology* 23 (1): 43–49.

Loffler, L., and W. Mader. 2004. Anisotropic X-ray diffraction peak broadening and twinning in diaspore-derived corundum. *Journal of European Ceramic Society* 25:639–48.

Onay, T. Y. 1949. Uber die smirgelgesteine sudwestanatoliens. *Schweizerische Mineralogische und Petrographische Mitteilungen* 29: 357–492.

Ozer, S., B. Sarı, I. Ozkar-Ongen, and V. Toker. 2007. Rudist, foraminifera and nanoplankton biostratigraphy of the Upper Cretaceous–Lower Tertiary sequence of the Menderes Massif: An approach to the age of the metamorphism and relation of the rock units. In *Proceedings of Menderes Massif colloquium,* 44–50.

Palache, C., H. Berman, and C. Frondel. 1944. *The system of mineralogy of J. D. and E. S. Dana.* 7th ed. Vol. 1. New York: Wiley & Sons.

Park, C. F., Jr., and R. A. MacDiarmid. 1975. *Ore deposits.* San Francisco, CA: W. H. Freeman and Company.

Perrotta, A. J. 1998. Nanosized corundum synthesis. *Materials Research Innovation* 2:33–38.

Ring, U., C. Johnson, R. Hetzel, and K. Gessner. 2003. Tectonic denudation of a Late Cretaceous–Tertiary collisional belt: Regionally symmetric cooling patterns and their relation to extensional faults in the Anatolide belt of western Turkey. *Geological Magazine* 140:421–41.

Scarrat, T. R. 1980. Faceted diaspore. *Journal of Gemmology* 17: 145–48.

Shoval, S., M. Gaft, and G. Panczer. 2003. Luminescence of Cr^{3+} in natural and calcined diaspore. *Journal of Thermal Analysis and Calorimetry* 71:699–706.

Smith, J. R. 1850. On emery in Asia Minor. *American Journal of Science and Arts,* 2nd series, 10:354.

Tsuchida, T., and K. Kodaira. 1990. Hydrothermal synthesis and characterization of diaspore, α-$Al_2O_3 \cdot H_2O$. *Journal of Material Science* 25:4423–26.

Whitney, D. L., C. Teyssier, S. C. Kruckenberg, V. L. Morgan, and L. J. Iredale. 2008. High-pressure–low-temperature metamorphism of metasedimentary rocks, southern Menderes Massif, western Turkey. *Lithos* 101:218–32.

Wippern, J. 1965. Die Diasporit—und Schmirgellagerstaetten in der Umrahmung des Menderes-Massives. Unpublished M.T.A. Report, Ankara, Turkey.

Yalçın, U. 1987. *Petrologie und geochemie der Metabauxite SW–Anatoliens.* PhD thesis, Bochum Ruhr-University.

Zultanite Gems LLC. 2009. http://www.zultanite.[redacted] ❑