Brookite and Anatase

from near Georgetown El Dorado County California

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Brookite, in fine, pale golden brown, tabular crystals with typical hourglass-shaped inclusions, occurs in association with deep blue, euhedral, bipyramidal anatase crystals and several accessory minerals in soil about 6 km from Georgetown, El Dorado County, California.

INTRODUCTION

A well-known locality northeast of Georgetown, El Dorado County, California, where fine quartz crystals exceeding 40 cm in size were mined from the 1930's to the 1980's, has yielded fine crystals of brookite, anatase, ilmenite and clinochlore. This is the first recorded locality in California where these two TiO_2 polymorphs occur together. In fact, both brookite and anatase have only rarely been identified in the state. Palache *et al.* (1941) mention brookite "with anatase upon quartz, near Placerville, El Dorado County, California." They may be referring to this locality as Placerville is the only town of any size nearby. Pemberton (1983) lists both minerals occurring as tiny vesicle fillings in lava and in pegmatites. Rutile, the third TiO_2 polymorph, is not found at Georgetown, but is known from many other California localities, sometimes in large and spectacular crystals.

The Georgetown locality is on National Forest land; access is open and collecting is allowed, though there are many private homes in the immediate area. Finding the exact locality is difficult even for those familiar with the region.

All of the minerals reported here are found in lateritic soils derived from the weathering of shales with intruded quartz veins within Paleozoic undifferentiated rocks in a broad area approximately 6 km northeast of Georgetown, at an elevation of 900 meters. The general geology of the area is recorded by Oliver *et al.* (1985).

COLLECTING AND CLEANING

Collecting at this locality involves several steps. First, the soil is collected in buckets, after removing the larger rocks. Second, the soil is sieved through a 7-mm wire mesh to remove all of the quartz cobbles and organic material. Third, the soil which passed through the first sieve is passed through a 5-mm sieve. Fourth, the material collected by the second sieve is rinsed and dried and examined carefully for loose crystals. It is important that all of the sieving be done with large amounts of water to reduce the crystal breakage. Also, be forewarned that the soil is so rich in finely divided iron oxides that it will permanently stain all clothing, tools and work areas a dark rust-orange. Finally, all recovered crystals must be cleaned in an ultrasonic cleaner.

MINERALS

Anatase TiO_2

Georgetown anatase commonly forms euhedral, doubly terminated crystals with the forms $p\{011\}$ prominent, $q\{111\}$ very tiny,

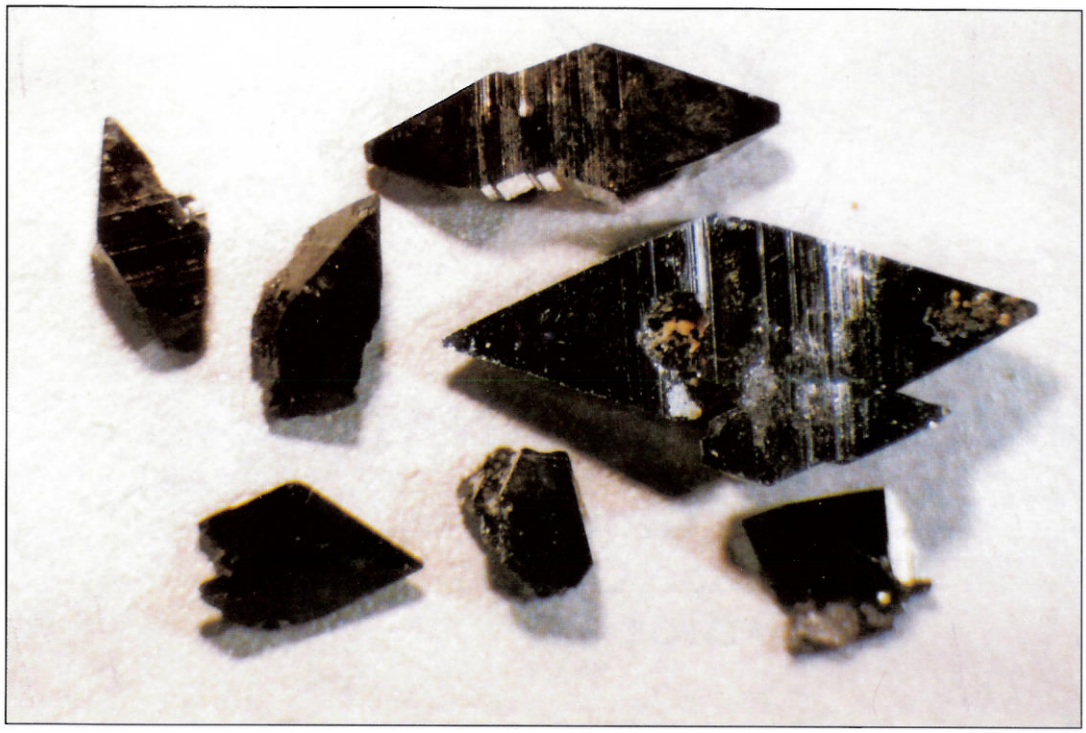

Figure 1. An assortment of loose anatase crystals up to 6.9 mm.

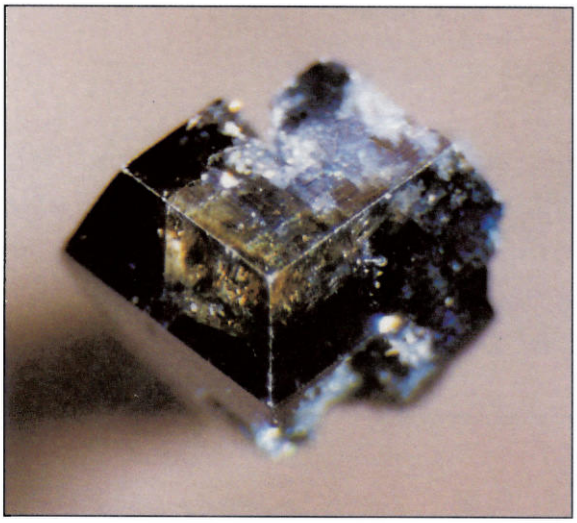

Figure 2. Tabular anatase crystal, 2.3 mm.

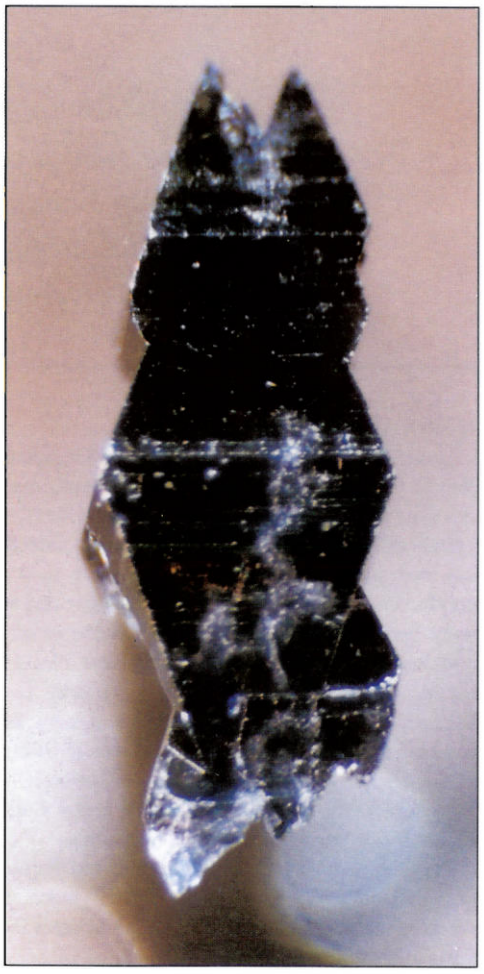

Figure 3. Sceptered anatase crystal, 4.1 mm.

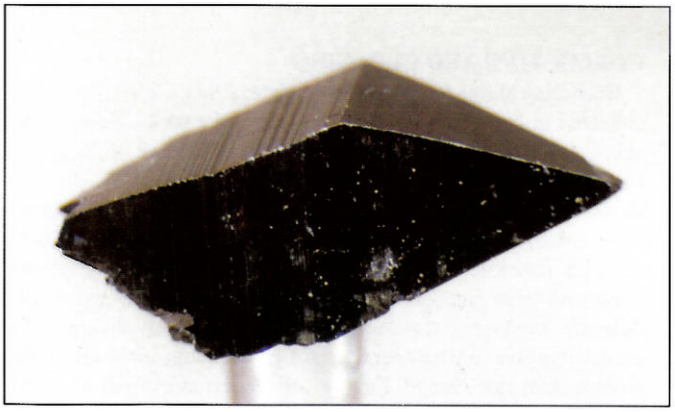

Figure 4. Anatase crystal, 6.4 mm.

$a\{010\}$ as striations, and occasionally form $c\{001\}$. The crystals are a translucent deep blue color, ranging to black in some of the larger specimens. The maximum size is over 1 cm, but the majority of the crystals are only about 3 mm long. Most of the anatase crystals are very smooth and lustrous, but a few once had clinochlore inclusions which have been weathered out of the anatase, leaving a deeply pitted surface with channels throughout individual crystals. Anatase crystals attached to quartz are present, though uncommon, and are quite unattractive.

Figure 5. **Brookite crystal, 4.5 mm.**

Figure 6. **Brookite crystal, 4.7 mm.**

Brookite TiO_2

Georgetown brookite crystals always show a broken point of attachment, presumably from quartz. All of the crystals are tabular on $b\{010\}$ and elongated along $c\{001\}$. Other forms present include $a\{100\}$, $y\{012\}$, $M\{120\}$, $l\{140\}$, $t\{201\}$, $d\{403\}$ and $e\{111\}$. The crystals are a transparent, pale golden brown with an hourglass-shaped deep brown inclusion pattern common to this species. Like the anatase, most crystals are smooth and lustrous, striated on $b\{010\}$ parallel to $a\{100\}$; rare crystals contain weathered clinochlore inclusions. Crystals up to 2 cm are known, but 8–10 mm crystals are the most common.

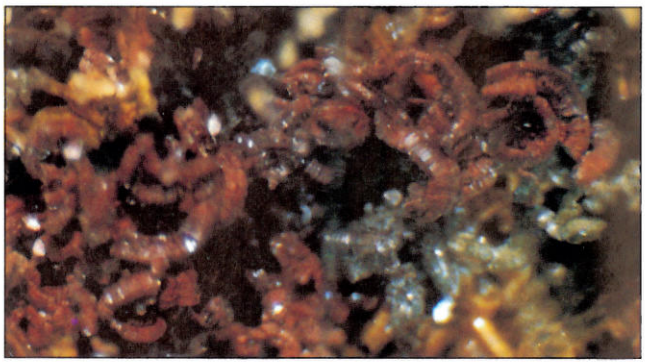

Figure 8. **Weathered clinochlore in quartz; view 6.4 mm. across.**

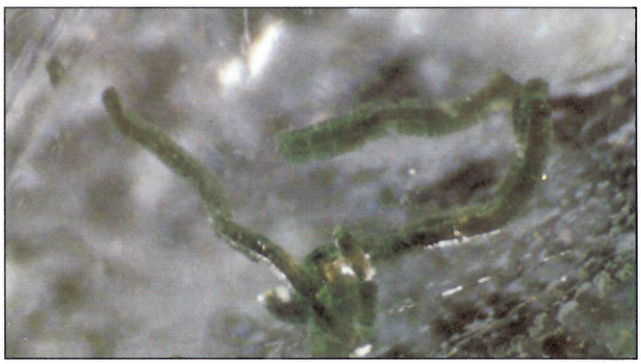

Figure 7. **Unweathered clinochlore in quartz; view 4.3 mm. across.**

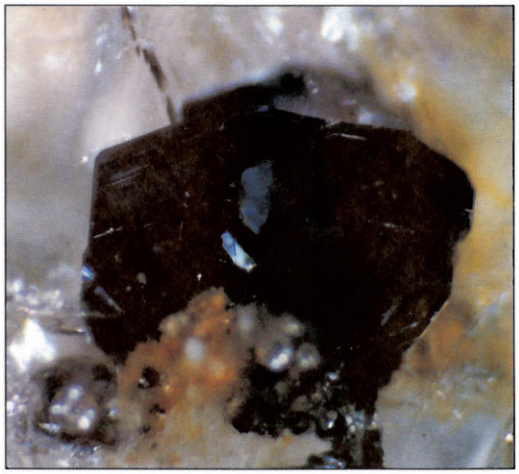

Figure 9. **Ilmenite crystal group, 1.4 mm, in quartz.**

Clinochlore $(Mg,Fe)_5Al(Si_3Al)O_{10}(OH)_8$

Clinochlore at Georgetown occurs as pale green stacked plates of crystals resembling inchworms. All of the material is small, about 0.75 mm in diameter and up to 1 cm long. Only the clinochlore which is completely sealed within quartz crystals is actually intact. Any clinochlore exposed to weathering, e.g., at the surface of a quartz crystal, is completely altered to dark rust-orange, fine-grained, massive iron oxides.

Ilmenite $FeTiO_3$

Ilmenite occurs in two forms: loose broken plates in the soil associated with the anatase and brookite, and as fine, small, totally euhedral inclusions within small transparent quartz crystals. Some specimens of ilmenite are apparently damaged though fully enclosed in quartz, which would seem to indicate a geological fracturing episode sometime late in the formation of the deposit. The identity has been confirmed by EDS analysis.

Quartz SiO_2

Quartz is the mineral which brought the locality to the attention of early mineral collectors. Very large crystals have been mined from the soils in the surrounding areas, and cobbles of milky white quartz up to 10 cm are abundant. Fine transparent crystals are common but are small, usually under 1 cm. Transparent shards of broken crystals are often found which contain attractive ilmenite and clinochlore inclusions. Crystals in excess of 3 cm are rare on the surface, though one example 9 cm long showing 4 levels of phantoms was found in 1991. The phantoms are composed of clinochlore or a similar mineral, based on visual identification. Finally, some small (1–2 cm) quartz crystals show spectacular voids where a previous mineral was coated by the quartz and then leached away, producing a phantom outline. These voids are up to 3 mm across and hexagonal-tabular in aspect. Their form would rule out all minerals known to occur at the locality, with the possible exception of clinochlore.

Table 1. **Paragenetic position of minerals near Georgetown.**

Mineral	*Early*				*Late*
Quartz	———	———	———	———	———
Clinochlore		———	———	———	———
Ilmenite					———
Anatase					———
Brookite					———

PARAGENESIS

The paragenetic relationships of the minerals were deduced from a megascopic examination of the loose samples within the soils. It should be noted that very few of the mineral specimens found have shown any relational associations because nearly all crystals are found loose in the soils. Only a few specimens are known in which an anatase crystal was found perched upon quartz from this locality. From the appearance of the brookite and anatase, one can see that at the time of formation, they were probably attached to quartz crystals, as points of attachment are common. A four-member quartz phantom containing clinochlore is indicative of multiple episodes of quartz and clinochlore deposition. There was an apparent episode of faulting or fracturing late in the last quartz deposition episode which is shown by the fact that occasional ilmenite plates are broken or chipped though completely enclosed by quartz. Also, because both anatase and brookite are largely unassociated with quartz, it would indicate that they formed late in the mineralization sequence and subsequently broke off during the massive weathering or excavation. No anatase or brookite has been observed fully enclosed within any of the quartz crystals at this locality.

ACKNOWLEDGMENTS

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REFERENCES

OLIVER, H. W., ROBBINS, S. L., and ROBERTS, C. W. (1985) *Bouguer gravity map of the Sacramento Quadrangle, California, 1:250,000.* Map No. 1B. California Division of Mines and Geology.

PALACHE, C., BERMAN, H., and FRONDEL, C. (1941) *Dana's System of Mineralogy,* seventh edition, Vol. I. John Wiley and Sons, Inc., New York.

PERBERTON, H. E. (1983) *Minerals of California.* Van Nostrand Reinhold Company, New York, 591 p.