Minerals of the Kaokoveld district Kunene region, Namibia

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Minerals of the

KAOKOVELD DISTRICT

Kunene Region, Namibia

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The Kaokoveld copper district is currently an excellent source of fine minerals, particularly dioptase, wulfenite, malachite, the world's best shattuckite, and other secondary copper and lead species. Ongoing exploration and mining activity in the area will likely continue to provide specimens for some time to come.

INTRODUCTION

Namibia has long been a major source of collector-quality mineral specimens, especially the secondary base metal minerals from famous localities like the Tsumeb, Kombat and Otavi mines, and more recently from the Skorpion mine. Over the last two decades there has been a near continuous production of excellent dioptase and, more recently, cerussite, cuprite, malachite, shattuckite and wulfenite specimens from northwestern Namibia in the Kaokoveld district of the remote Kunene region. Associated minerals include rare secondary bismuth species such as bismuth-rich mottramite, beyerite and bismutite.

Dioptase, particularly well known from Tsumeb and Guchab (Bezing *et al.*, 2007), has also been found in the Kaokoveld region as world-class specimens, but unlike Tsumeb and Guchab these specimens come from relatively shallow workings and have largely been mined by small groups of artisanal miners and/or collectors specifically for specimens, rather than metal content. Consequently the mining by hand has led to greater preservation of material.

In the last five to ten years these workings have also become a source of excellent shattuckite, barite, anglesite and wulfenite. The main sources are the Omaue mine, the Okandawasi, Onderra, Ongankwa and Kandesei pits and the Van der Plas and Otuani mines. These mines have been described previously, primarily in the German literature (Palfi, 2005; Von Bezing *et al.*, 2007; Niedermayr *et al.,* 2008; Schnaitmann and Jahn, 2010; Brandstätter, 2012). The two senior authors have worked on copper exploration programs in the area since 2008; the other authors have been involved in dioptase mining in the area for the last 20 years. This has allowed us the opportunity to visit the workings and study the geology of this fascinating area.

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SITE ACCESS

The Kaokoveld mining district is located in the Kunene region of northwestern Namibia. The main mining areas, located approximately 10 km from the main road between Opuwo and Sesfontein, are connected to the capital city of Windhoek by a paved two-lane

Figure 1. **Location map showing the location of the Kaokoveld mines between Opuwo and Sesfontein in the Kunene Region, northwestern Namibia. The locations of some other well known mining sites are marked as well.**

highway. There are two main turnoffs to the site: approximately 55 km from the town of Sesfontein and 80 km south of Opuwo. The Omaue mine is conveniently situated adjacent to Camp Aussicht. In total, reaching the turnoff road to the mining area at the northern access point takes about an hour, after covering a distance of 40 km. The South turnoff to the mine areas is about 20 km long but the quality of the road is very poor and takes a similar period of time. The road leads to the South part of the mining area via a camping area where a rest camp is located. The developed road network is of quite poor quality within the main mining area going all the way from south to the north of the area. Much of the driving access is along dry river beds that are not passable in the wet season.

Namibia has a temperate and subtropical climate characterized by hot and dry conditions with little rainfall along the coast. Temperatures are moderated by the cold Benguela current while

Figure 2. **Location of the various mines and mineral occurrences in the Kaokoveld area.**

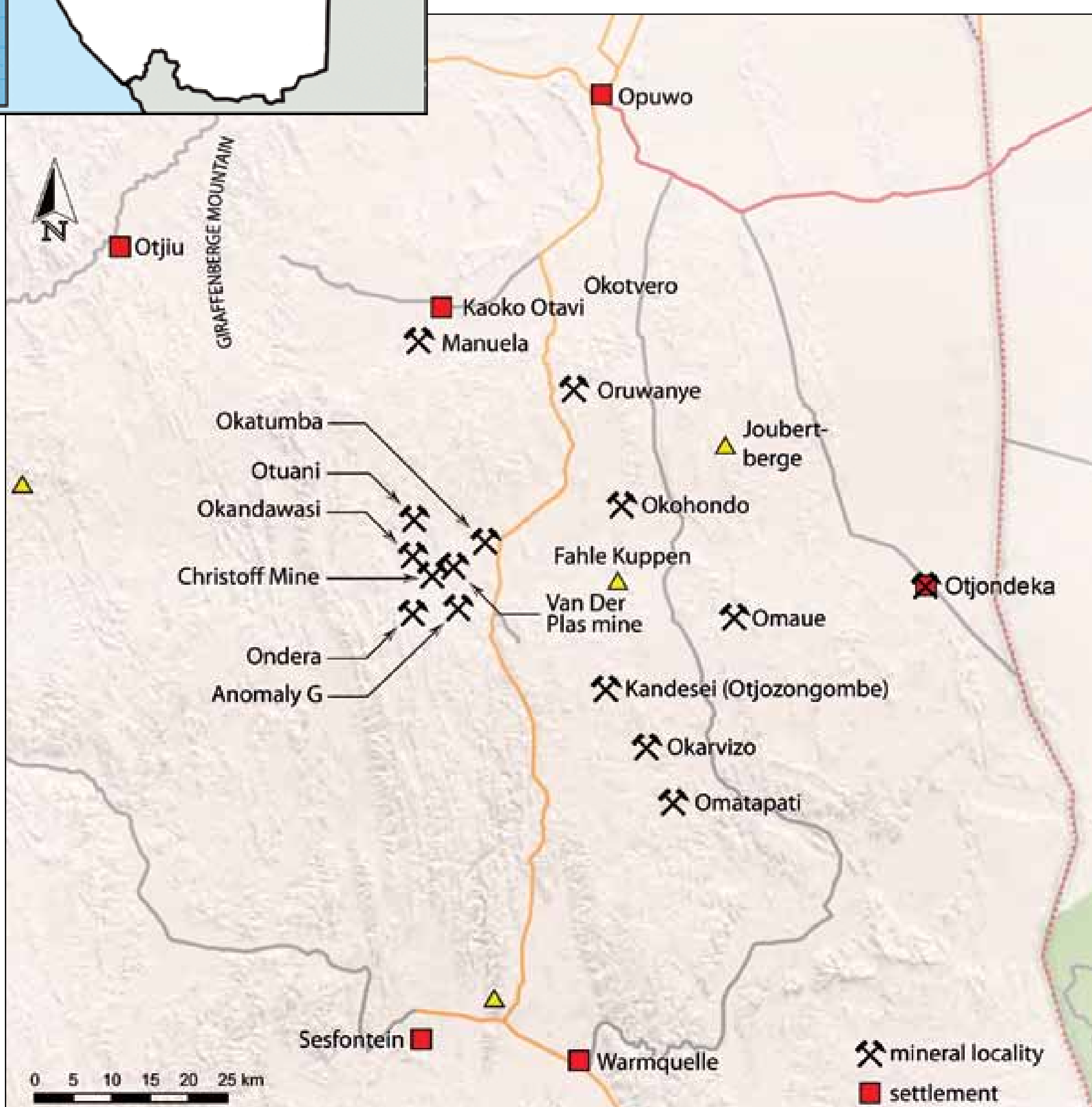

Figure 3. The Otuani open pit and box cut, in operation since 2006. The workings exploit a horizon ofbornite and chalcocite ore. Robert Bowell photo, October 2010.

***Figure 4*. Mineralization exposed in the Okohongo pit, developed at the base of a copper-silicate-rich breccia 2 meters thick. Robert Bowell photo, October 2011.**

periods of winter drought alternate with excessive summer rainfall between November and April, with the interior experiencing slightly higher rainfall. Average annual precipitation in the capital city of Windhoek is 360 mm (14 inches) and the average temperature range from 43° to 68°F in July and 63° to 84°F in January. These average temperatures are typical of the central plateau which has an average elevation of approximately 1,600 meters.

The lower average elevation of the mining area results in somewhat higher average temperatures. The location in the northern part of Namibia means that seasonal rainfall begins slightly earlier but is of roughly the same magnitude as that recorded for Windhoek. Consequently all specimen mining stops by early December and in general is not resumed until mid-April.

GEOLOGICAL SETTING

The Damara Orogen in Namibia consists of a 400-km-wide northeast-trending intracontinental arm and a north-south-trending coastal arm. The mining area is situated in the coastal arm, formed during late Proterozoic to Early Palaeozoic time in a rifting environment (Ajagbe, 1999a,b; Miller, 2008). The north-northwestern rift underwent multiple phases of subsidence, but ophiolites and ultrabasic rocks are not present in the area. The earliest unit in the rift is the Nosib Group which, in the mining area, is dominated by coarse clastic sedimentary rocks. The quartzite found in the northwestern part of the mining area is a part of this formation.

The sedimentary rocks hosting all of the mineral occurrences in the area were deposited in intercontinental rift basins in which

Figure 5**. Massive copper-lead-barite mineralization in the Okandawasi pit (sometimes referred to as Kandesi pit, the Kaokoveld mine, or the Old German mine) is situated at the top of Okomunwe Hill and is the largest excavation for mineral specimens in the area. Robert Bowell photo, July 2011.**

Figure 6**. Folded chalcocite-galena-barite mineralization in the Okandawasi (Kandesi) pit Robert Bowell photo, July 2011.**

carbonate rocks of the Otavi Group dominate and overlie the Nosib terrigenous sediments. The Otavi Group is divided into three Subgroups and one formation: a lower Ombombo Subgroup, the Chuos formation, the middle Abenab Subgroup and an upper Tsumeb Subgroup.

The Obombo Subgroup consists of intercalated limestones, slates, shales and dolomites. These rocks host most of the stratiform deposits of disseminated and partially oxidized pyrite, chalcocite, galena and bornite. Contemporaneous vein and stockwork mineralization (quartz and quartz-chlorite-carbonate veins and stringers with copper and lead sulfides) occurs in both the Obombo and Abenab carbonate rocks. The lower part of the Obombo Subgroup, also known as the Lower Omao sequence, is divided into four main stratigraphic units; the Lower Omao hosts all known copper occurrences in the mining district.

The Chuos Formation, up to 150 meters thick, lies conformably above the Ombombo rocks in the western and eastern parts of the mining area on the limb of the anticline. The unit is composed of poorly sorted conglomerate and iron-bearing quartzite.

Sitting above the Chuos Formation in the mining area are carbonate rocks of the Abenab Subgroup. This unit is composed of massive dolomite and reef stromatolite limestone with minor intercalated argillaceous shales near the top of the sequence. North of the mining some mineralized, copper-rich breccias are hosted within this unit, presumably a reflection of the competency of the unit and the role of the carbonates in buffering mineralizing fluids. Some karst features occur in the mining area within this unit.

Metamorphism in the area equates to the prehnite-pumpellyite facies based on the calcite-dolomite-quartz assemblage, the absence

Figure 7. **The Okandawasi (Kandesi) pit. Robert Bowell photo, October 2010.**

of tremolite and talc and the development of muscovite and chlorite in the more argillaceous units, possibly indicating conditions close to the boundary with lower greenschist facies.

The Weathering profile in the mining area is not particularly well developed due to physical erosion in the steeply undulating terrain of the mining area. Consequently regolith profiles consist of poorly developed shallow calcareous soils extending no more than 50 cm on slopes with a very thin or non-existent organic soil and leaf litter cover. Current drainage flows on shallower slopes and along valley floors have deposited alluvial sediments to 2 meters or more in depth. In places, solution weathering of the carbonate hosts rocks and migration of carbonate in groundwater has partially cemented these clastic alluvials to form calcrete or caliche deposits in which the clastic fragments are cemented by calcite and clay minerals. Smectite-rich clay patches do occur and locally form dambo soil horizons with associated springs and shallow perched aquifers.

The rocks of the region are intensively folded. Within the central part of the anticline the folding shows the disharmonic characteristics with both secondary and tertiary level folding. The dip of the layers varies from 30° or 40° to vertical. The folds are usually inclined with the western dipping of the axis plane at 30° to 40° (Miller, 2008). Tectonic features include (usually overthrust) faults of west-southwest orientation, accompanied by intensive hydrothermal secondary alteration and mineralization. The north-south-orientated faults within the anticline area usually correspond to the zones of argillization, silicification and base metal mineralization. In the transition zones between the central anticline to west of the EPL and the east syncline significant thrusting can be observed that offsets the regional geological fabric. The rocks in the area of the thrust faults are intensively mineralized by hematite.

Three principal mineral assemblages have been mapped and sampled in the mining area: (1) Stratiform disseminated copper sulfide with associated pyrite and galena secondary minerals of copper, lead and iron; (2) Stockwork mineralization containing quartz veins hosting lenticular or pocket-like copper sulfides with associated galena and secondary minerals; and (3) Fault-related quartz veining with lenticular concentrations and stringers of chalcocite, galena and associated secondary minerals.

The primary ore at Okatumba consists mainly of chalcocite with minor bornite, galena and pyrite. Tetrahedrite and sphalerite are present but rare. Silver appears restricted to trace amounts in galena. The main gangue minerals are quartz, chlorite, calcite and barite. All three types or ore assemblages have been heavily oxidized in the mining area, especially in the zones of stockwork and fault-controlled mineralization. The oxidation zone can reach a depth of 50 meters or more (as revealed by core drilling). Numerous copper-bearing secondary minerals occur in the weathered zones.

Oxidation and weathering of the primary ore has led to supergene enrichment of copper at the base of oxidation zone, but not as the typically expected mineral assemblage of cuprite and native copper but rather as copper silicate minerals. Most likely this occurred during the Quaternary period when the area was undergoing tectonic uplift with dry climate with short rainfalls.

DESCRIPTION OF THE PROSPECTS

The copper-rich mineralization in the Kunene Copper Belt has been actively explored for over 50 years. Despite this no large deposits have ever been located. Mineral exploration is still being carried out in the area by Teck Cominco, INV Metals, Kaokoland Mining and Exploration Company and Siberia Metal Traders as well as a number of independent prospectors. The majority of the specimen mining is being undertaken by members of the local Herero tribe. Only one organized mechanical mining operation, by Kaokoland Mining and Exploration, is currently active, at Okomunwe, and this produces on the order of 400 tonnes per month of copper concentrate from a rich chalcocite and malachite ore typically grading 15% to 25% copper. There is also some production from other Kaokoveld Mining Exploration operations such as Okandawasi which is processed at the Otuani site.

One of the biggest challenges facing collectors of Kaokoveld copper minerals is keeping track of the names of the various prospects in the area (Lowmayr *et al*., 2008; Niedermayr *et al*., 2008; Bowell and Cook, 2009; Schnaitmann and Jahn, 2010). The problem was exacerbated by early exploration reports which applied some names to more than one prospect. For example, Onderra, the locality for excellent Wulfenite crystals, is situated approximately 10 km south

***Figure 8*. View looking towards the anomaly G workings, theonly occurrence of conichalcite in the Kaokoveld area. Robert Bowell photo, March 2009.**

of the Otuani mine but is also the name for two exploration licenses (Onderra East and West) located further to the south. In addition some pits have more than one name, bestowed by different operators or obfuscated by the crystal sellers in order to keep a location secret. The Okandawasi pit is variously known as Kandesi (also used for a pit to the south of Omaue mine) or the Old German mine. In addition the site has been known as the Kaokoveld mine after the name of the current operators, Kaokoland Mining and Exploration, and it has been reported that the locality name Otjikotu has been cited by American dealers for minerals coming from both of the Kandesei pits (Niedermayr *et al*., 2008). Our preferred name in this article is the name used by the current mine owners or operators, and it is recommended that this name be adopted. Table 2 provides a summary of these names and the listed mineralogy for each locality. The mineral occurrences in the area are discussed here, from north to south, and are shown in Figure 1.

Mineral excavations vary considerably from large pits at Otuani and Okandawasi to small trenches in the vicinity of Okohongo. Some attempts have been made to provide a more formal, and safer, method of mining for specimens but so far little progress has been made except on the properties of the Kaokoland Mining and Exploration Company and at the Omaue mine. The known mineral localities are as follows.

***Figure 9*. Copper mineralization in the bottom of the Christoff mine pit, situated close to the Okandawasi pit. In 2007 the Christoff mine produced an exceptional haul of dioptase crystals. Robert Bowell photo, May 2010.**

Figure 10. **Entrance to the Omaue mine. Note the chrysocolla-rich vein almost a meter thick to the left of the portal. Robert Bowell photo, September 2009.**

Okohongo

The Okohongo locality consists of a small pit developed at the base of a copper-silicate-rich breccia 2-meters wide. Minor work has taken place there intermittently over two decades, but no exceptional mineral finds have been recorded.

Otuani

The Otuani locality is a large open pit and box cut that has been in operation since 2006. The workings exploit bornite and chalcocite ore with a copper content of up to 25%, exposed over 4-meter area. Above the primary ore is a zone of malachite, dioptase and chrysocolla.

Onderra

The small Onderra pit was initially developed in 2005 on lead-copper mineralization in the limestone country rock. Over time the pit has been extended by local Herero workers. The small subsidiary pits in this area have yielded fine wulfenite specimens.

Okandawasi

The Okandawasi pit (sometimes referred to as Kandesi pit, the Kaokoveld mine, or the Old German mine) is situated at the top of Okomunwe Hill and is the largest excavation for mineral specimens in the area. More than 20 minerals have been reported from this pit. The workings exploit pods rich in chalcocite and copper silicate mineralization exposed in the apex of folds within the Obombo and Abenab units. Okandawasi has been the main source of fine dioptase and shattuckite specimens over the last five to eight years and is currently being expanded along strike and to the east; additional pockets continue to be found.

Christoff mine

Situated close to the Okandawasi pit and also mined by the Kaokoland Mining and Exploration Company, the Christoff mine pit has also (like the Okandawasi pit) been referred to as the Old German mine. In 2007 the locality produced an exceptional haul of dioptase crystals and has also yielded some fine cerussite, cuprite and mottramite specimens as well.

Van Der Plas mine

The Van Der Plas mine, also located close to the Okandawasi pit, began in 2009 to produce excellent cerussite twin crystals up to 4 cm in length as well crystal groups. The mineralization is an extension of the mineralized zones at Okandawasi and shows an almost identical mineral assemblage. Some of the wulfenite crystals from this locality reach up to 6 cm in size, but they are commonly coated by a mixture of clay, manganese oxides and silica that is almost impossible to remove without damaging the wulfenite surface.

Omaue Mine

The Omaue mine at Camp Aussicht has been the premier producer of dioptase from Kaokoveld region for over 20 years and has been operated and developed by Marius Stiener. Although the original locality is now depleted, prospecting on site has identified new areas of mineralization in the same geological host rock and Steiner hopes that these will also yield dioptase crystals. On occasion this site has produced excellent yellow anglesite and barite as well.

Okatumba

The Okatumba mine lies approximately halfway between Opuwo and Sesfontein, about 500 meters from the main road close to the village of Okatumba. The location has been mined by a local prospector, Jaco Smith from Usakos, with the help of local miners, and they have recovered some excellent wulfenite specimens, the best of which are in Jaco's collection.

Otjozongombe (Kandesi)

Further to the south of Omaue is the Otjozongombe prospect, also referred to as the Kandesi prospect by some of the local miners. This locality exploits dioptase-rich mineralization almost identical to that found at Okandawasi.

Okapanda (Otjhowe)

A small excavation called the Okapanda pit is located on the side of Okomunwe Hill to the south of the main mining area there. This may be the same as the Otjhowe prospect described by Schnaitmann and Jahn (2010); Otjhowe is the name of a local farm. Workings in this area have been intermittently active and in the last two or three years have yielded some excellent dioptase.

Okarvizo

The large Okarvizo pit developed to the south-southwest of Okomunwe Hill exploits a chrysocolla-rich breccia containing pockets of small, in some cases doubly terminated dioptase crystals. The

Figure 11. **Cerussite V-twin, X cm, from Kaokoveld. Marshall Sussman specimen; Wendell Wilson photo.**

Figure 12. **Cerussite, 7.1 cm, from Kaokoveld. Jürgen Tron specimen; Jeff Scovil photo.**

dioptase in this breccia is occasionally coated by mottramite and vanadinite.

Omatapati

The small Omatapati open pit is said to have produced lapidary-grade Chrysocolla and good dioptase.

Okakuyu

The Okakuyu workings are the southernmost locality known for secondary copper mineralization. On our last visit we saw chrysocolla, planchéite, malachite and dioptase on the dumps.

MINERALS

Anglesite $PbSO_4$

Anglesite is a common secondary mineral in the Kaokoveld deposits. It has been found as colorless, gray or yellow crystals and is generally associated with calcite, cerussite, chrysocolla, dioptase, hematite, malachite and quartz. The best material was mined between 1998 to 2002 from the Omaue mine, where terminated anglesite crystals to 2 cm were recovered. The only other notable anglesite specimens from the area are colorless, terminated crystals to 2 mm on galena recovered in 2011 from an exploration trench close to Otuani.

Apachite $Cu_9Si_{10}O_{29}\cdot 11H_2O$

Greenish blue botryoidal crusts of fine needles of apachite have been found on chrysocolla from the Okandawasi pit (identified at the University of Miass in material collected in 2008). The individual needles are approximately 0.1 to 0.3 mm in size.

Azurite $Cu_3^{2+}(CO_3)_2(OH)_2$

Azurite is surprisingly rare in the Kaokoveld district and generally only in the form of malachite pseudomorphs after azurite up to 1.5 cm. Azurite has been collected as rough crystal fragments up to 4 cm in size from the Van Der Plas mine and up to 1.5 cm from Okandawasi pit; historically it has also been reported from the Omaue mine.

Barite $BaSO_4$

Barite is a common mineral throughout the Kaokoveld district. As with anglesite it forms crystals that vary from colorless to gray to yellow, in habits that can easily be mistaken for anglesite. Excellent crystals of barite were recovered in 2011 from the Okomunwe area and from Okapanda as well.

Transparent lemon-yellow blades up to 1.5 cm on white calcite have been reported from Onderra (Schnaitmann and Jahn, 2010). Similar material has been collected from the Christoff mine and from the Van Der Plas mine. At the latter occurrence barite is associated with malachite and shattuckite as well. An unusual fibrous form of barite, mostly to white to yellow in color, has been found at Okatumba (Niedermayr *et al.,* 2008).

Beyerite $Ca(BiO_2)(CO_3)_2$

Beyerite was first identified in material from the Kandesi pit (Niedermayr *et al.,* 2008) and has since been found at Okandawasi and

***Figure 13*. Dioptase crystals on matrix, 12.3 cm, from Kaokoveld. Rob Lavinsky (*The Arkenstone*) specimen, now in the Pinnacle collection; Joe Budd photo.**

at the Christoff mine. It occurs as millimeter-size rosettes, spherules and radial-fibers with adamantine luster associated with mottramite (sometimes Bi-rich), shattuckite, malachite, calcite and dolomite.

Bismutite $(BiO)_2CO_3$

Bismutite was reported by Schnaitmann and Jahn (2010) from Okatumba, where it occurs as yellow, platy, botryoidal crusts with adamantine luster associated with malachite and wulfenite. It is almost indistinguishable from beyerite.

Bornite Cu_5FeS_4

Bornite occurs as scattered disseminations in carbonate rocks. It commonly contains thin lamellae of chalcopyrite and forms intergrowths with chalcocite. Microprobe analyses have shown that bornite contains trace amounts of silver. A recent bornite-rich zone uncovered in August 2012 had yielded some of the first crystals of bornite from the Kaokoveld area. The zone contains ore grades typically of 10–15% copper with silver up to 420 mg/kg (or 13.5 ounces per ton).

Calcite $CaCO_3$

Calcite is a common mineral throughout all of the known workings in the Kaokoveld district. Large rhombohedral crystals, many showing an attractive mosaic of hematite and manganese oxide inclusions, are known from the Okomunwe, Okandawasi and Van Der Plas mines. At Onderra, calcite occurs as transparent to milky white crystals associated with dioptase that is very reminiscent of classic Tsumeb calcite-dioptase specimens.

***Figure 14*. Gemmy dioptase crystal, 1.8 cm, from Kaokoveld. Rob Lavinsky (*The Arkenstone*) specimen; Jeff Scovil photo.**

Figure 15. **Dioptase crystal cluster, 4.7 cm, from Kaokoveld. Marshall Sussman specimen; Jeff Scovil photo.**

Figure 16. **Opaque dioptase crystal on matrix, 4.6 cm, from Kaokoveld. Irv Brown specimen; Jeff Scovil photo.**

Cerussite $PbCO_3$

Good cerussite crystals have only been noted relatively recently from the Kaokoveld district. Exceptional V-twin crystals up to 3 cm have been recovered from the Van Der Plas mine. Prismatic crystals up to 1 cm with metallic luster have been recovered from the same locality and from the Christoff mine. At Okatumba similar cerussite crystal combinations have been collected in association with massive shattuckite and malachite (Schnaitmann and Jahn, 2010).

Chalcocite Cu_2S

Chalcocite is the main ore mineral in the district but is rarely found as terminated or well-defined crystals. Massive chalcocite does occur, particularly in the apex of folds and commonly associated with malachite and other secondary copper minerals, although some of what has been called chalcocite may instead be djurleite (see below). At Okandawasi masses of chalcocite up to 30 cm have been found along the axis of tight isoclinal folds on the limb of a large anticline in Abenab limestone.

Chenevixite $Cu^{2+}_2Fe^{3+}_2(AsO_4)_2(OH)_4 \cdot H_2O$

Chenevixite has been reported from the Omaue mine by Palfi (2005). Arsenate minerals in general are scarce in the Kaokoveld mineralized zones, in stark contrast to Tsumeb.

Chlorargyrite AgCl

Pale, waxy, yellowish green masses of chlorargyrite to 1 mm associated with cerussite, namibite and beyerite have been found at the Okandawasi pit. Although chlorargyrite has not been at any

***Figure 17*. Dioptase crystal fan, X cm, from Kaokoveld. Marshall Sussman specimen; Wendell Wilson photo.**

***Figure 18*. Dioptase crystal cluster, X cm, from Kaokoveld. Marshall Sussman specimen; Wendell Wilson photo.**

***Figure 19*. Dioptase crystals on quartz, X cm, from Kaokoveld. Marshall Sussman specimen; Wendell Wilson photo.**

***Figure 20*. Dioptase crystal group with shattuckite, X cm, from Kaokoveld. Marshall Sussman specimen; Wendell Wilson photo.**

other Kaokoveld occurrences, geochemical analysis of oxide ores periodically show silver. The highest silver content, up to 270 mg/kg, is from Otuani, most likely in the form of microscopic chlorargyrite inclusions or in relict argentiferous galena.

Chrysocolla $(Cu,Al)_2H_2Si_2O_5(OH)_4 \cdot nH_2O$

Chrysocolla is common to the entire specimen digging areas in the Kaokoveld district. Lapidary-grade chrysocolla has been mined for two decades in large volume and sold as Lapidary rough. More recently, because of rising copper prices, hand-sorted chrysocolla ore has been shipped to the Tsumeb smelter for commercial processing. In general, chrysocolla occurs as massive, occasionally botryoidal material and generally covers or replaces the other copper silicate minerals except for a second generation of dioptase.

Conichalcite $CaCu^{2+}(AsO_4)(OH)$

The rare arsenate conichalcite has only been observed at one place located in the exploration license 3799 area near the Kandesi pit at what is called "anomaly G." There in shallow workings it occurs with chrysocolla, mimetite, malachite, planchéite and shattuckite. It forms pale green, sub-vitreous, botryoidal to reniform crusts.

Copper Cu

Native copper occurs as rare disseminations in carbonate rocks. The particle sizes range from visible (about 1 mm) to microscopic (0.01 mm). In some areas native copper has been replaced by cuprite which forms fringes and is often itself replaced by malachite (see below).

Cuprite $Cu^{+}_{2}O$

Cuprite is widespread although never abundant in the Keokoveld district, and to date has been found at the Otuani, Okandawasi, Christoff, Van Der Plas and Kandesi mines. It typically occurs as massive material associated with chrysocolla and malachite but cubes and octahedral crystals up to a few millimeters in size have also been collected.

Dioptase $Cu_6Si_6O_{18} \cdot 6H_2O$

Dioptase is the most attractive and desirable of all the minerals found in the Kaokoveld district. It is generally restricted to and is best developed in dolomite host rocks. In comparison to dioptase from Tsumeb and elsewhere it has a slight bluish tint to the typical emerald-green color and forms thinner, more elongated crystals. The most common associations are quartz, malachite, planchéite and shattuckite. At least two generations of dioptase exist in the district. The first is widespread in most of the workings and typically occurs as small crystals no more than 1 cm, with most being less than 5 mm. Where dioptase is preserved it is commonly coated by quartz and, more rarely, by hemimorphite giving a "sugar-coated" appearance; these specimens are particularly common at Okandawasi, Kandesi and Okatumba.

At Onderra small dioptase crystals to 5 mm are associated with wulfenite in white quartz. In some cases first-generation dioptase is associated with a kaolinite-like matrix containing spherical shattuckite aggregates and minor amounts of calcite. Much of the dioptase in this occurrence is unfortunately badly preserved.

At many of the localities a second generation of dioptase on chrysocolla appears to be the last copper silicate to have precipitated. This later generation of dioptase includes some of the finest crystals that have come in recent years from the Christoff, Kandesi, Okandawasi, Okarvizo and Omaue locations, as individual crystals to 9 cm. More typically they range from a few millimeters to 3 cm in size. Doubly terminated crystals of dioptase up to 3 cm in size have been collected from these localities. One of the finest, from Otjihowe, is a 1.5-cm, doubly terminated crystal on calcite (Schnaitmann and Jahn, 2010).

Figure 21. **Malachite (non-pseudomorphous), X cm, from Kaokoveld. Marshall Sussman specimen; Wendell Wilson photo.**

Figure 22. **Malachite pseudomorphs after cuprite, 3.6 cm, from Kaokoveld. Luis Burillo specimen; Jeff Scovil photo.**

At Omaue, second-generation dioptase is typically associated with honey-yellow barite, chrysocolla, malachite, planchéite, shattuckite and more rarely anglesite and wulfenite. At the Christoff and Okandawasi mines second-generation dioptase is often found partially coated by mottramite (some of it bismuth-rich) and beyerite. At the Kandesi mine highly lustrous crystals up to 2.5 cm in size have been found on a matrix of bright yellow, glassy lustered calcite rhombohedrons described by Schnaitmann and Jahn (2010).

Djurleite $Cu_{31}S_{16}$

A thin-section study conducted at the Institute of Mineralogy (Miass) identified much of what has been considered in the field to be massive "chalcocite" is in fact djurleite. This is particularly true of the sulfide-rich veins in the Okandawasi pitSeltene, massive, gelegentlich angelaufene Klumpen bis 3 cm Größe in massivem Shat-tuckit, Malachit und Quarz haben sich als Djurleit erwiesen (Analyse G. Niedermayr). Djurleite is associated with shattuckite, malachite and quartz.

Dolomite $CaMg(CO_3)_2$

Although much of rock of the Ombombo and Tsumeb subgroups is primarily dolomite, relatively little dolomite in collectable crystal form has been found in the workings. Calcite locally can contain a few percent magnesium. However, dolomite is generally restricted to forming small (less than 5 mm), pearly crystals, generally as a late-stage precipitate on the copper silicates.

Galena PbS

Galena is common in many of the deeper workings and even in some veins at some surface. It generally occurs as massive to cubic galena, often partly corroded. It is associated with calcite, cerussite, chalcocite, leadhillite, mimetite, mottramite and quartz.

Goethite $Fe^{3+}O(OH)$

Goethite is widespread in the district, generally as earthy aggregates but also as inclusions of fine black needles to 2 mm in quartz, calcite and barite.

Hematite Fe_2O_3

Hematite-bearing ironstones occur in the Abenab subgroup throughout the field district. Within areas of copper mineralization it has been reported as crystals at Okatumba, where it occurs as single crystals and masses up to 4 cm in size associated with shattuckite, beyerite, bismutite and Bi-rich mottramite (Schnaitmann and Jahn, 2010).

Figure 23. **Malachite pseudomorphs after cuprite, 3.3 cm, from Kaokoveld. Luis Burillo specimen; Jeff Scovil photo.**

Hemimorphite $Zn_4Si_2O_7(OH)_2{\cdot}H_2O$

Hemimorphite has only been found as partial to complete coatings on dioptase, malachite and shattuckite in specimens from Okandawasi, Kandesi and Okatumba.

Iodargyrite AgI

Iodargyrite is listed as coming from the Kandesi mine by Niedermayr *et al*. (2008)

Lanarkite $Pb_2O(SO_4)$

Lanarkite has been reported from the Van der Plas mine by Brandstätter *et al*. (2011). A possible lanarkite specimen has been found by the authors at this site: a greenish-white prismatic crystal spray within a quartz vug associated with anglesite.

Leadhillite $Pb_4(SO_4)(CO_3)_2(OH)_2$

Leadhillite has been reported as gray tabular crystals up to 1 cm associated with anglesite, cerussite and galena at the Van der Plas mine.

Malachite $Cu_2^{2+}(CO_3)(OH)_2$

Malachite is the most common copper mineral in the mining area, occurring at all locations and in a variety of associations and habits. The most common habit is fine, fibrous bundles and sheaf-shaped spherical aggregates. These can reach up 3 cm in diameter, and are found associated with all of the copper silicates, particularly shattuckite. At the Kandesi, Okapanda and Okandawasi workings these malachite spheres can also have a thin coating of transparent crystalline quartz. Malachite is rarely present as primary crystals, though some have been reported from the Kandesi prospect associated with quartz, calcite and dioptase (Schnaitmann and Jahn, 2010). Malachite has been found in radial clusters and groups up to 3.2 cm in diameter, associated with shattuckite, wulfenite and quartz at several localities including the Okatumba and Okarvizo prospects, sometimes associated with small (less than 2 mm), yellowish white, tabular wulfenite crystals.

Good pseudomorphs of malachite after azurite and cuprite have been collected by the authors from the Okandawasi prospect. Malachite pseudomorphs after native copper have been reported from the Otjihowe prospect, as dendrites up to 1.8 cm (Schnaitmann and Jahn, 2010). These pseudomorphs are said to be typically found embedded in chrysocolla and are similar appearance in appearance to specimens from the White Pine mine in the Keweenaw Peninsula (Wilson and Dyll, 1992).

Mimetite $Pb_5(AsO_4)_3Cl$

Mimetite, like other arsenates, is rare in the Kaokoveld district. It occurs as millimeter-sized, yellowish white barrels with conichalcite and galena at "anomaly G" near the Kandesi prospect.

Mottramite $PbCuVO_4(OH)$ *to* $(Pb,Ca,Bi)VO_4(OH,O)$

Mottramite is present throughout the Kaokoveld area as dark green to olive-green crusts, and also as lime-green crusts showing a high bismuth content, particularly at the Christoff and Okandawasi pits where it coats dioptase and is associated with beyerite.

At the Onderra workings, dark green mottramite coats wulfenite and has produced pseudomorphs of wulfenite on calcite. Mottramite also occurs as a coating as thin coating on dioptase and as inclusions in quartz at the Okatumba mine.

Namibite $Cu(BiO)_2VO_4(OH)$

Namibite has been reported by Niedermayr *et al*. (1978) from the Kandesi prospect, where it forms small patches of dark green platy crystals associated with other bismuth minerals and chrysocolla. It has also been identified as bright green, complex crystals associated with beyerite, bismuth-rich mottramite and chrysocolla from the Christoff mine.

Planchéite $Cu_8(Si_4O_{11})_2(OH)_4{\cdot}H_2O$

Planchéite is widespread throughout the mining district, generally as a replacement of first-generation dioptase but is generally coated, at least in part, by shattuckite and chrysocolla. The best specimens have been recovered from the Okandawasi and Kandesi pits.

Platternite PbO_2

Plattnerite is a rare mineral found as brown crusts associated with cerussite at the Van der Plas mine.

Pyromorphite $Pb_5(PO_4)_3Cl$

Although not identified in this study, pyromorphite has been reported as small yellow crystals associated with shattuckite at the Okatumba workings (Schnaitmann and Jahn, 2010).

Quartz SiO_2

Quartz is the main gangue phase in the breccia mineralization throughout the area. It occurs as massive white quartz (as at the Omaue mine) and as smoky and yellow-orange hematite-included terminated crystals. The best crystals have come from the Kandesi and Christoff mines. At least two generations of quartz can be discerned in the mineralization: a massive, milky white quartz that also hosts sulfide mineralization, and a second generation of generally smaller but better developed crystals, some reaching up to 10 cm in length (Schnaitmann and Jahn, 2010). Inclusions of chrysocolla, shattuckite, planchéite and (more rarely) dioptase have been seen in second-generation quartz.

Figure 24. **Shattuckite pseudomorph after a quartz crystal, 9 cm, from Kaokoveld. Marshall Sussman specimen; Jeff Scovil photo.**

Figure 25. **Quartz crystals on shattuckite, 6 cm, from Kaokoveld. Neil and C. Prenn; Jeff Scovil photo.**

Figure 26. **Quartz crystals on shattuckite, 4 cm, from Kaokoveld. Neil and C. Prenn; Jeff Scovil photo.**

Although not as well-developed, these crystals are reminiscent of the Messina mine quartz crystals that contain inclusions of ajoite and planchéite.

Scrutinyite α-PbO_2

Scrutinyite has been reported by Brandstätter *et al*. (2011) from Van der Plas mine; the mineral is indistinguishable physically from plattnerite.

Shattuckite $Cu_5(Si_2O_6)_2(OH)_2$

The Kaokoveld district has without produced doubt the finest shattuckite specimens in the world (Bowell and Cook, 2009). Typically it occurs as concentric radial aggregates growing on planchéite, often with a velvet-like appearance. It is generally the next to last copper silicate mineral to form, succeeded only by second-generation dioptase. Shattuckite can also occur as botryoidal

Figure 27. **Drusy quartz on shattuckite on quartz, 7.5 cm, from Kaokoveld. Martin Zinn collection; Jeff Scovil photo.**

Figure 28. **Malachite (non-pseudomorphous) in a shattuckite-lined pocket, 8.2 cm, from Kaokoveld.** ***Marcus Budil*** **specimen; Jeff Scovil photo.**

aggregates coated by quartz. The most common form however is as massive breccia cement and vein infilling associated with quartz, calcite, malachite and chrysocolla.

The color varies somewhat from one locality to another, from pale turquoise-blue as at the Kandesi and Omaue workings, to a rich dark blue color as at the Okandawasi pit. The color in the spherical aggregates ranges from a darker blue in the center to a pale blue rim or the reverse. As with dioptase, it is often found partially or completely coated by quartz, and excellent examples of this have been recovered from the Christoff mine and the Okandawasi pits. Shattuckite is associated with most of the other minerals but particularly with planchéite, chrysocolla and quartz.

Shattuckite pseudomorphs after quartz and first-generation dioptase have been collected from the Okandawasi pits. Shattuckite pseudomorphs after 3-cm quartz crystals have been reported from the Okatumba workings (Niedermayr *et al.,* 2008). A single specimen of shattuckite after wulfenite has been reported from the Okatumba workings (Schnaitmann and Jahn, 2010).

Silver Ag

One specimen of a silver wire on goethite, chrysocolla and calcite is known from Okandawasi pit. The two wires are approximately 2 to 4 mm in size.

Tenorite $Cu^{2+}O$

Tenorite has been described from the Omaue mine where it occurs as thin, dull black crusts associated with iron oxides. Given its lack of distinguishing features in hand specimen and its simple chemistry, many more unrecognized occurrences are likely to exist.

Vanadinite $Pb_5(VO_4)_3Cl$

Only one occurrence of vanadinite has been previously reported from the Kaokoveld district, from the locality at Otjintheka (Niedermayr *et al.,* 2008). No similar occurrence has been discovered in the lead-rich mineralization near the Otuani workings or at Van der Plas mine, and neither locality contains anomalously high vanadium concentrations (less than 100 mg/kg, similar to mineralization throughout the district).

Wulfenite $PbMoO_4$

Wulfenite, though not abundant except at the Onderra pit, is widespread throughout the district and occurs in a range of colors

Figure 29. **Shattuckite on a quartz crystal, 6 cm, from Kaokoveld. ICS specimen; Jeff Scovil photo.**

Figure 30. **Malachite (non-pseudomorphous) in a shattuckite-lined pocket, 9.2 cm, from Kaokoveld. Martin Zinn collection; Jeff Scovil photo.**

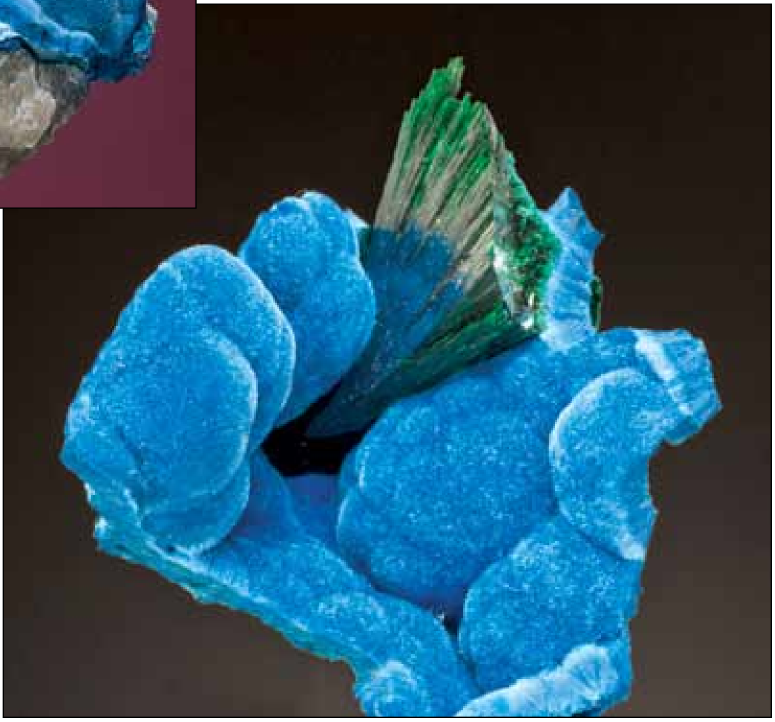

Figure 31. **Malachite (non-pseudomorphous) in a shattuckite-lined pocket, 5.7 cm, from Kaokoveld. Jeff Starr collection; Jeff Scovil photo.**

Figure 32. **Malachite (non-pseudomorphous) on quartz-coated shattuckite-lined pocket, 8.2 cm, from Kaokoveld. Rob Lavinsky (*The Arkenstone*) specimen; Joe Budd photo.**

Figure 33. **Malachite (non-pseudomorphous) on quartz-coated shattuckite-lined pocket, 11.5 cm, from Kaokoveld. Scott Rudolph collection; Joe Budd photo.**

from pale white through lemon-yellow, orange, yellowish brown and dark brown. Crystal size also varies considerably, from millimeter-size up to a reported 15 cm (Schnaitmann and Jahn, 2010).

At the Onderra pit and at the Van der Plas mine, where the largest wulfenite specimens have been reported, they are commonly found coated with kaolinite, goethite, malachite and mottramite. Generally the habit is tabular, although some prismatic crystals have also been collected. A common assemblage is wulfenite with shattuckite and/or dioptase. At the Okandawasi pit small plates of lemon-yellow to orange-yellow wulfenite occur associated with shattuckite in quartz. Typically these form small millimeter-sized crystals. The most visually stunning combinations are the wulfenite-dioptase specimens from the Omaue mine, also reported from the Kandesi pit (Schnaitmann and Jahn, 2010). At the Otjindeka and Okatumba workings wulfenite is commonly hosted by iron-stained and partially corroded quartz; these wulfenite crystals display a darker central core and many have corroded edges. The Okatumba and Onderra

Figure 34. **Wulfenite crystals, X cm and X cm, from Kaokoveld. Marshall Sussman specimens; Wendell Wilson photo.**

pits generally have produced the best quality wulfenite in the area (Niedermayr and Schnaitmann, 2010).

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Figure 35. **Wulfenite crystal, X cm, from Kaokoveld. Marshall Sussman specimen; Wendell Wilson photo.**

Figure 36. **Wulfenite crystal group with drusy quartz coating, X cm, from Kaokoveld. Marshall Sussman specimens Wendell Wilson photo.**

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