



## Alpine Minerals: A review of the Most Famous Localities of the Central Swiss Alps

Stefan Graeser

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*Geology has remunerated people in the Central Alps for the lack of useful ore deposits by a remarkable richness in spectacular and rare minerals.*



# Alpine Minerals

A Review of the Most Famous Localities of the Central Swiss Alps



*Figure 1 (above). Quartz "gwindel" (elongation along  $a$ -axis), Fiescher-gletscher. Size about 14 cm. Specimen: N. Burgener, Fiesch.*

*Figure 2 (left). Rose fluorite and quartz, Göschenalp, Canton Uri. Fluorite octahedron about 8 mm across. Private collection.*

**STEFAN GRAESER**  
Natural History Museum  
CH-4001 Basel, Switzerland  
and  
Mineralogical Institute of the University  
CH-4056 Basel, Switzerland

Unless otherwise noted,  
all photos by Walter Gabriel

A thorough description of Alpine minerals would produce a work of numerous volumes. As a mineralogist who grew up in Binntal—one of the most famous mineral localities of the Alps—and spent most of his spare time in this region and who, moreover, dedicated most of his scientific research to this valley and to the mineral occurrences in the Central Alps, I am focusing this description of Alpine minerals on the minerals and mineral occurrences of the Central (= Swiss) Alps.

#### HISTORICAL DATA

Minerals have been collected in the Alps since prehistoric times, both for aesthetic purposes and as material for the construction of tools for daily use. During excavations in Gallo-Roman sites in southern Switzerland (Canton Valais, Binn) several crystal treasures were discovered that consisted of numerous well-shaped quartz crystals from the adjacent mountains. As early as around A.D. 78 Plinius, in his famous work *Historia Naturalis*, described the professional search for quartz crystals in the Alps, telling of people who tried to extract crystals from cavities in such inaccessible regions of the mountains that the use of ropes was required—a procedure that has not changed much during the past two thousand years. The discovery of a Roman bronze dagger near the Albrunpass, a passage of the Alps between Binntal and Italy that was frequently used by Roman legions in the first century A.D., gave proof that even Roman soldiers tried their hand as mineral collectors: The dagger broke with the attempt to extract quartz crystals from an Alpine fissure. The blade remained in the fissure until it was found accidentally in 1966.

During the Middle Ages quartz was mainly appreciated as raw material for the production of ground vessels such as goblets and bowls; obviously, for this purpose the colorless quartz realized a better price than the dark-colored smoky quartz. Throughout the Middle Ages, up to the late eighteenth century, the accepted theory was that quartz was nothing more than common water changed to a solid crystal by extremely cold temperatures. One of the first to oppose this theory was Hottinger (1698) in his work titled *Krystallogia*.

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*Dr. Stefan Graeser is head of the mineralogy department at the Basel Natural History Museum and is also head of a mineralogical working group in the Mineralogical Institute of the University of Basel.*

Probably the first systematic mineral collecting in the Alps began in the eighteenth century as a result of prospecting in relatively low-grade mineral deposits. However, some kind of search for minerals in the Binntal must have existed much earlier, leading, in 1609, to an announcement forbidding the excavation of crystals in the area of cattle pastures. The first attempt to denote mineral occurrences on a geographic map



**Figure 3. Diopside, Cervandone (Italy). Length of crystals 10 mm. Specimen: P. Imhof, Brig.**

(primarily of economically useful minerals) was undertaken by G. S. Gruner in 1760 and 1775, followed in 1817 by the much better known essay of Placidus a Spescha.

Scientific mineral research was introduced mainly by foreign (English, French, and German) mineralogists in the early eighteenth century. It began with the first descriptions of new minerals, in particular sulfosalt minerals from the Lengenbach quarry in Binntal—which, at least in part, are still valid today. During this period most of the famous collections of Alpine minerals that served as the basis for the mineral collections in several large natural history museums in Switzerland and abroad were assembled (for example, the outstanding collec-

tions by David Friedrich Wiser, Gustav Seligmann, Carl Bosch, Frederick N. Ashcroft, and Heinrich Baumhauer).

In recent times one organization played a very important role in the improved knowledge of a unique mineral locality in the Alps, namely, the Lengenbach quarry in Binntal. In 1958, due to the initiative of Prof. Ernst Niggli and the Bernese Natural History Museum, a syndicate was founded (*Arbeitsgemeinschaft Lengenbach*) with the specific purpose to make the rare and distinctive sulfosalt minerals from Lengenbach quarry accessible to modern research. The syndicate has worked successfully for many years and has initiated numerous scientific publications; however, it presumably will discontinue its activities this year.

### MINERAL-FORMING PROCESSES

Minerals may occur in nature in two different ways: (1) as *rock-forming* minerals that are closely intergrown with other minerals in the surrounding rocks and, therefore, in most cases are xenomorphic (without an individual crystal shape); or (2) as *fissure minerals* that formed in any cavity of the rocks (fissures, druses, vugs, and miaroles) and, therefore, could develop their characteristic shape in a more or less ideal manner.

that served as a means to transport material but hot gases (in miarolitic cavities).

As a matter of fact, fissure minerals are of much greater importance for mineral collecting than are rock-forming minerals; therefore, it is common practice to remove the matrix from idiomorphic rock-forming minerals (garnets, in particular). Such specimens look very similar to real fissure minerals, but actually they are not. Starting from these considerations, it becomes obvious that fissure minerals will be the most important subject in this article.

The development of fissure minerals clearly depends on several factors, among them (1) the formation of cavities in the rocks and (2) the kind and origin of substances required for the growth of crystals in the cavities. The way these factors influenced mineral growth is closely connected with the geologic history of the Alps and their development into a folded mountain chain.

### Influence of Alpine Mountain-Building (Metamorphism)

The formation of the Alps represents, in terms of global tectonics, the product of the collision of two continental plates, the

Eurasian and African plates. This event started about 100 million to 80 million years ago with the closing of the Tethys Sea and led to a crustal shortening and collision mainly during the Tertiary Period. To a certain degree these forces are still active today (earthquakes around the Alps). The extreme shortening of the crust effected a huge overthrust of rock nappes (sediments and volcanic and plutonic rocks, including their crystalline basements) in a thickness of several kilometers. In the realm of the Central Alps we can discern at least four different nappes (mostly clearly separated by sedimentary layers between the gneiss nappes). This accumulation of rock nappes of kilometers of thickness resulted, of course, in a strong transformation and metamorphism of the underlying rocks: Primary granites

changed to gneisses, limestones to marbles, and so on. From thermodynamic calculations based on minerals that formed under these particular conditions, the temperatures and pressures resulting from these processes reached several kilobars in pressure and several hundreds of degrees centigrade in temperature. These conditions of elevated pressures and temperatures had great influence on the formation of Alpine-fissure minerals.

**Pressure:** The upfolding of nappes and their overthrust led to extreme stress and strain conditions in the rocks and hence caused the opening of extensional Alpine fissures at greater depth. Depending on rock properties and the magnitude of the strain components, the rock was fractured or sheared, giving rise to the formation of fissures or fractures. Fissures only formed when the rocks were cool enough to become brittle. The temperature of transition between ductile and brittle

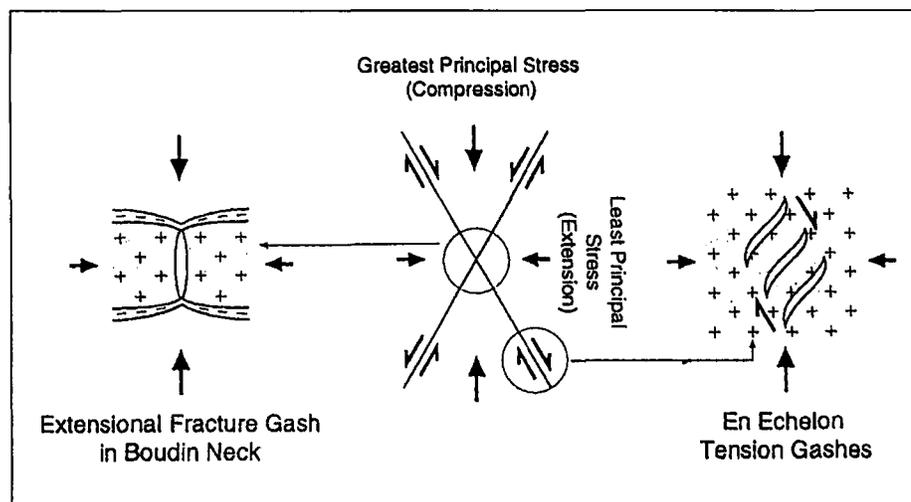


Figure 4. Formation of mineral-bearing fissures in the Central Alps depending on rock properties and strain components (Mullis 1995).

*Rock-forming minerals* are the common type of minerals formed by magmatic processes. They are generally completely xenomorphic, as can easily be seen by looking through a polarizing microscope at a thin section of a granite. They are also produced by metamorphic processes acting on any kind of rocks under elevated temperatures and pressures. In both cases, however, under certain circumstances, minerals may grow into completely euhedral crystals, mostly depending on the respective mineral species: Certain minerals, such as garnets, kyanite, tourmaline, some feldspars, and pyrite, tend to develop as euhedral crystals even as rock-forming minerals.

*Fissure minerals*, which develop in cavities in rocks, are generally products of hydrothermal activity, by which the necessary ingredients for the formation of crystals were transported into the cavity by fluids. In some cases it was not hot water

depends on the physical properties of rocks. In granites, gneisses, or calcareous mica schists this temperature lies around 400° to 500° C (Mullis 1995). In the massifs of the Central Alps the fissures have a horizontal extent (as a consequence of vertical uplift), whereas in the realm of the Penninic nappes the fissures are set in vertical order (generally in systems of parallel fractures and fissures) due to horizontal movement.

**Temperature:** Fissures and fractures that formed during movements within the rocks did not remain as vacua, of course, but were filled with water. This water originated partly from the decomposition of phyllosilicate minerals in the surrounding rocks and partly from underlying calcareous marine sediments in the nappe region. Consequently, the water was greatly enriched in dissolved substances, mainly in CO<sub>2</sub> and chlorine. The original compositions of these hydrothermal solutions may be determined from the study of fluid inclusions in fissure minerals, especially in quartz (e.g., Mullis 1995). Hydrothermal solutions, enriched in CO<sub>2</sub> and chlorine, under pressure/temperature conditions of 4–5 kilobars/400°–500° C, certainly represent a highly corrosive fluid. This means that fluids circulating in fissure systems will have a dissolving influence on the surrounding rocks and, consequently, will be enriched with the elements of the corroded rock-forming minerals. In the course of time, combined with decreasing temperatures and pressures due to the erosion of the mountains, the hydrothermal solutions became oversaturated and began to precipitate the dissolved substances, thus forming euhedral crystals in the cavities.

### Role of Lithology (Composition of Rocks)

It was the German mineralogist Johann Georg Koenigsberger (1874–1946) who, by very detailed studies of fissure minerals in the Central Alps, was the first to discover that the material required for the growth of fissure minerals did not originate from great depths in the earth, as had been the common interpretation, but was leached from the country rock around the fissures by hot aqueous solutions. This leaching process, leading to a strong alteration of the country rock, is most clearly visible by a remarkable decoloration of the rock around the fissures. From observations and statistics on innumerable fissure parageneses, Koenigsberger recognized the close relationship between the minerals present in a fissure and the respective country rock.

The consequence of the relation between country rock and fissure minerals is, of course, that the number of different minerals occurring in cavities of rocks within a restricted area will increase with the number of rock types with different chemical compositions. This might be the reason for the large variety of distinct mineral species appearing in the Penninic realm, in particular, where numerous rocks of completely different genetic and chemical types were juxtaposed by tectonic events (upfolding).

The following are some of the most abundant rock types and their possible hydrothermal fissure products produced by regional metamorphism.

- *Acid magmatic rocks* (granites, rhyolites, and others with

SiO<sub>2</sub> contents up to 70 weight percent and their metamorphic equivalents, the gneisses) occur not only as weakly metamorphosed granites in the central massifs (Aare and Gotthard massifs) but also as gneisses in the crystalline core of Penninic nappes. These are the country rocks of the spectacular quartz fissures discovered during the last centuries. In most cases this quartz appears in its dark-colored variety, smoky quartz. Associated with the quartz are various feldspar minerals, such as orthoclase (adularia) or albite, and some micas and Be minerals (milarite, phenacite, and bavenite) if granitic pegmatites were involved.

Characteristic minerals are (smoky) quartz, feldspars, fluorite, and Be minerals; typically absent is garnet.

- *Ultrabasic rocks* (ophiolites, serpentinites, and peridotitic rocks with very low SiO<sub>2</sub> contents but high percentages of Ti, Mg, Fe, Ca, and so on) have become famous for their distinctive fissure minerals, such as vesuvianite, diopside, titanite, Fe-Ti garnets (including demantoid), and chlorites. One mineral is notably lacking in this association, namely quartz.

- *Mica gneisses and schists* (sedimentary origin) are often very rich in mica minerals, especially the dark mica, biotite. Biotites have high contents of Fe and Ti, elements that became enriched in the hydrothermal solutions by the leaching process and therefore gave rise to the formation of fissure minerals. Quartz, on the other hand, is of minor importance.

Characteristic minerals are TiO<sub>2</sub> minerals (anatase, rutile, and brookite), hematite, magnetite, and ilmenite.

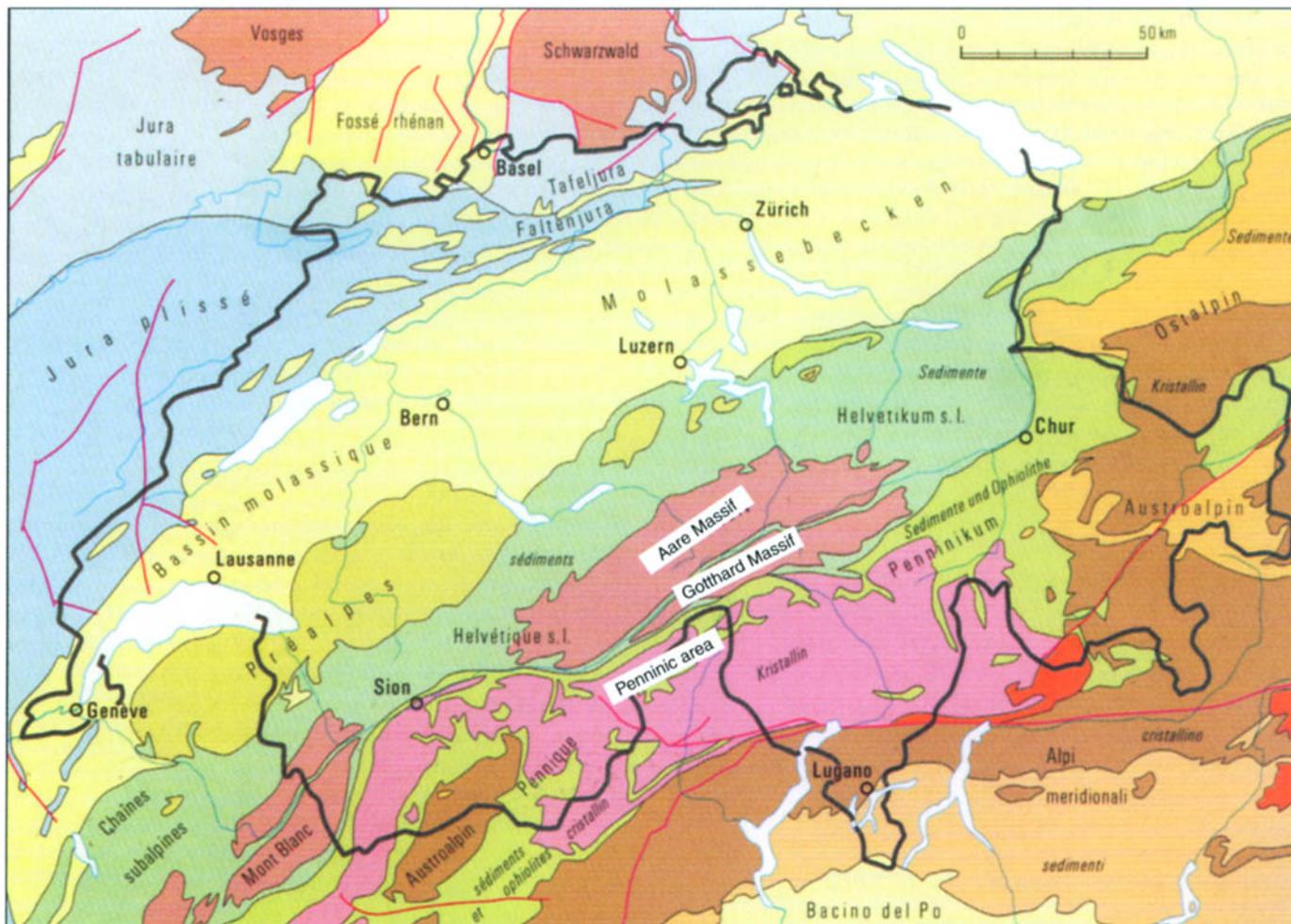
- *Carbonate rocks* (e.g., dolomite). Originally, dolomitic rocks are of remarkable purity, consisting normally of more than 90 volume percent of the mineral dolomite, with only minor quartz and feldspar. Under metamorphic conditions part of the quartz reacted with dolomite, thus forming the Mg mica phlogopite. However, various sulfide ores, which precipitated simultaneously with the carbonates during sedimentation, under special metamorphic conditions may give rise to the formation of very unusual minerals.

Characteristic minerals are dolomite, calcite, and minor quartz.

Although this control by host rock-type may explain the formation of the majority of common fissure minerals, there are numerous minerals in rock cavities whose formation does not fit into this scheme. This brings one more factor into consideration: the role of ore deposits in rocks.

### Special Mineralizations (The Role of Ore Deposits)

The rocks in the Central Alps, like rocks elsewhere in the world, show local enrichments of heavy metal minerals (ores), which have been mined for the extraction of useful elements for thousands of years. This mining activity, at least in Switzerland, came to an almost complete end after World War II due to the unproductive mines in the Alps. One of the reasons for the low productivity might be attributed to the influence of Alpine metamorphism. An event that moved huge rock masses (piled them up and buried others at depth) and that led to fractures and faults obviously has also influenced ore concentrations in these rocks. Metal deposits in the earth's crust are usually accompanied by a number of uncommon elements,



**Figure 5. Geological map of the Central Alps (Switzerland). Courtesy of Landeshydrologie und Geologie, BUWAL (Berne).**

including rare-earth elements (lanthanides). Generally, ore deposits underwent the same leaching process by aqueous solutions as did the rocks, which means that parts of the ores were remobilized, giving rise to the formation of very uncommon fissure minerals with “exotic” elements. Most of the numerous arsenic oxide and arsenic sulfide minerals as well as the spectacular Ba minerals (e.g., armenite) found in the Alps are products of such remobilization processes. The ore deposits, some of which had become enriched to “minable” deposits by certain geological processes, were subjected to contrary processes that destroyed the useful ore concentrations.

A famous Swiss proverb might depict this situation very exactly: “Switzerland is a country that is extraordinarily rich in poor ore deposits.” Yet, perhaps geology has remunerated people in the Central Alps for the lack of useful ore deposits by a remarkable richness in spectacular and rare minerals. And crystals have been successfully sold in the Alps for hundreds of years!

## GEOLOGICAL UNITS

It is not the aim of this article to give a full description of the highly complicated structure of the Central Alps. Yet, as far as the rocks and their metamorphic history are concerned, the dif-

ferent units are of prime importance for the formation and occurrence of fissure minerals. Most of the descriptions that follow are taken from Labhart (1992).

### Central Granite Massifs and Their Basement Gneiss

The northern part of the Central Alps is built up mainly of granitic complexes and their metamorphic cover of older gneisses (*Altkristallin*). Until recent times, the granite massifs

***“Switzerland is a country that is extraordinarily rich in poor ore deposits.”***

were looked upon as autochthonous bodies (beds that have been moved comparatively little from their original foundation); however, today the tendency is to interpret many of them as parautochthonous (Aare massif) or even as a nappe (Gotthard massif) in addition to undoubtedly autochthonous massifs such as the Aiguilles Rouges massif in the southwest. This means that even the massifs are not in their original position but have been moved to a certain degree toward the north by mountain-building forces.

Petrologically, the massifs are composed of magmatic rocks

(generally granites but partly also more basic types such as syenites and granodiorites) of Variscan (late Paleozoic) age. The magmatic complexes are surrounded by older (*Altkristallin*) metamorphic rocks that appear today as a northern and southern zone of various gneisses. These granite complexes were only slightly influenced by Alpine metamorphism.

The granite massifs and their gneiss zones host many of the classic occurrences of Alpine-fissure minerals (mainly quartz crystals of spectacular dimensions), such as the *Grimsel area*, *Göschental*, *Maderanertal*, *Rhonegletscher*, and *Fiescher-gletscher*, within and around the Aare massif.

The area of the massif of St. Gotthard was much more strongly influenced by Alpine mountain-building forces and therefore has been interpreted as a nappe by some authors (Trümpy 1980), who consequently put it into the Penninic realm. This region hosts such classic mineral localities as *Tavetsch*, *Cavradi*, and *Val Cristallina*.

### **Penninic Area**

This zone covers a huge area consisting of the whole of the southern part of Canton Valais (south of the Rhone River), the northern part of Canton Ticino, and the western part of Canton Grisons. The closure of the Tethys Ocean and the collision of the Eurasian and African plates at the end of Early Cretaceous time resulted in an extreme shortening of the crust, producing folds and nappes. This folding process involved marine sediments and their crystalline basement as well. The nappes reached several kilometers in thickness and were moved northward more than 50 kilometers. The consequence of this enormous folding process was that various sedimentary rocks and magmatic rocks of acid and ultrabasic compositions were piled together in nappes. The deepest part of the Penninic nappes is exposed in the Simplon region ("Lepontine nappes"); farther to the east (Canton Grisons) appear the higher units. The metamorphism of the rocks, as a result of the overthrust, reaches higher degrees (greenschist to amphibolite facies) than in the northern part of the Alps.

The Penninic zone hosts such classic regions as *Binntal* (sulfosalt minerals in the dolomites, the famous Ti minerals in the "Lercheltini zone," and the As oxide minerals in the gneisses, discovered in the past twenty to thirty years); the zone of *Zermatt/Saas-Fee* with the spectacular minerals from ophiolitic rocks; and distinctive mineral occurrences in Canton Grisons related to Mn concentrations (*Falotta* and *Val Ferrera*).

### **Helvetic Nappes**

The Helvetic nappes consist exclusively of sedimentary rocks of Jurassic, Cretaceous, and Eocene age, and in eastern Switzerland also of Permian ("Verrucano") and Triassic age. They were sheared off from the crystalline basement in a relatively late phase of Alpine mountain-building and were moved as nappes about 30–50 kilometers to the northwest. Among the sedimentary rocks limestones predominate by far over such other sediments as sandstones, flysch, marls, and shales. Because the Helvetic nappes represent the youngest and uppermost unit in the Alps, they were scarcely influenced by Alpine metamorphism: The metamorphic degree varies from unmeta-

morphosed to beginning lowest metamorphism ("anchizone"). The plastic behavior of the rocks, which was unfavorable for the formation of fissures and, in particular, the chemical monotony of the rocks (mainly limestone), was responsible for the development of a quite simple mineralization in cavities of these rocks, completely different from the rich and diversified mineral occurrences in the crystalline schists. However, this region also shows its peculiarities. In addition to abundant though small quartz crystals and abundant carbonate minerals (calcite, dolomite, aragonite, and strontianite), one mineral in particular, fluorite, is found in spectacular quality.

Some of the best-known occurrences are *Val d'Illicez* (quartz), *Säntis area* (fluorite), *Taminser Calanda* (gold, scheelite, and other minerals), and *Gonzen/Sargans*.

## **FAMOUS MINERAL OCCURRENCES**

### **Central Massifs**

The mineral occurrences in this region lie in a crystalline complex consisting of Variscan granites and steeply dipping gneisses and schists of greater age, which define the northern and southern borders of the granites. The whole zone extends from Lötschental in the southwest to Tödi, a mountain in the northeast, a distance of more than 100 kilometers. A detailed description of the numerous localities is given in Stalder et al. (1973). The rocks of the whole complex were influenced by weak Alpine metamorphism (greenschist facies). With few exceptions, the rocks show relatively high SiO<sub>2</sub> contents; consequently, the most spectacular fissure mineral is quartz (as colorless "Bergkristall" or smoky quartz, rarely amethyst). The most important mineral associations in the fissures may be expressed by the following parageneses (according to Weibel et al. 1990):

1. quartz, fluorite, calcite, adularia, chlorite;
2. quartz, hematite, adularia, albite, chlorite;
3. quartz, adularia, apatite;
4. ankerite, quartz, muscovite, sphalerite; and
5. adularia, quartz, epidote, fibrous amphiboles ("amianth"), titanite.

These associations merely represent a simplified scheme, to which some uncommon species have to be added for certain locations.

### **Grimsel Area**

It was the mineral quartz, in particular, that was responsible for the high reputation of the area among mineral specialists. Even between 1719 and 1740, the remarkable quantity of about 30–50 tons of colorless quartz was extracted from fissures at the *Zinggenstock* locality, with one single crystal supposedly 400 kilograms. Most of the material was sold to Milano (Italy) for polishing purposes(!). Only three pieces were left; they may be viewed at the Natural History Museum in Bern. Another spectacular find was made by the brothers Ruffbach in 1966. Again it was the *Zinggenstock* locality but this time at an altitude of about 2,700 meters above sea level; therefore, the quartz occurred as pale smoky quartz. Excellent

dark smoky quartz again was discovered at the *Gerstenhörner* (2,900 meters above sea level); the find comprised about 770 kilograms in all, with individual crystals up to almost 50 kilograms).

Another highly regarded mineral from the Aare massif is fluorite, especially in its distinctive rose-colored variety. Fluorite has been discovered in this region in octahedral crystals in sizes up to 10 centimeters as colorless, green, or rose-colored varieties, mostly in close association with quartz.

Excellent material could be collected in connection with the construction of the extensive galleries for hydroelectric powerstations in the Grimsel area between 1950 and 1975. By an extraordinary stroke of luck it was possible to preserve one of the large Alpine-mineral fissures in its original state. It was discovered during the construction of a gallery almost 2 kilometers inside the mountain and about 500 meters below the surface. It was secured by screens of armored glass and steel doors and subsequently was placed in custody of the Bernese agency for nature preservation and may be seen by request. Representing one of the most impressive fissures in the Swiss Alps, it is 14 meters long and is full of large colorless quartz crystals in association with calcite, fluorite, chlorite, and rare galena, pyrite, adularia, epidote, titanite, apatite, biotite, and milarite.

Characteristic general mineral associations in granitic-granodioritic rocks are quartz (colorless, smoky quartz, and rarely amethyst), calcite, and chlorite, with minor adularia and albite. Less common are fluorite, apatite, hematite, pyrite, galena, sphalerite, and minor zeolites, epidote, titanite, brookite, and anatase.

### Fieschergletscher

This is a region in the southwestern part of the Aare massif comprising, besides the granitic region, the southern gneiss cover of the massif. This leads to a remarkably increased variety of fissure minerals in comparison with the parageneses in granitic rocks. The rocks were deeply eroded by the activity of the glacier (Fieschergletscher), and regres-

sion of the glacier over almost one century successively brought new cavities to light with fresh and well-preserved minerals. Typical fissure minerals from the Fieschergletscher are given in table 1.

The northernmost part of the region (including the most remarkable locality, *Wasenhorn*) belongs entirely to the Aare massif granitic rocks. This locality gained importance with the 1966 discovery of large amounts of pale-colored amethyst by the mountain guide Hubert Volken.

### St. Gotthard Area

The Gotthard massif, unlike its northern neighbor the Aare massif, was influenced by Alpine metamorphism in a much stronger manner. This fact is manifested by the almost perpendicular contacts to the Helvetic sediments along the massif borders and by a remarkably higher degree of metamorphism (upper greenschist to amphibolite facies) as well. For this reason, the whole massif has even been interpreted as a nappe by several authors who, consequently, put it into the Penninic realm in the Alpine area. As in the case of the Aare massif, we may distinguish between a central zone of orthogneiss and a northern and southern zone of paragneiss (or schist), parallel to the central massif. The central part consists of two granitic complexes of Variscan age (Gamsboden and Fibbia Granites) and the Rotondo Granite; farther eastward follow the Medels Granite and the Cristallina Granodiorite, forming a second center. Farther to the east, between the Aare and Gotthard massifs lies the "*Tavetscher Zwischenmassiv*," forming an intermediate massif between the two large granite complexes. The borderline between the Aare and Gotthard massifs is marked by a zone of Permian metasediments (mostly of conglomeratic nature).

The whole zone is characterized by a remarkable wealth in various fissure minerals, due to the occurrence of numerous different kinds of host rocks. Depending on the various host rocks, at least seven different parageneses of fissure minerals can be distinguished (Weibel et al. 1990):

1. quartz, albite, muscovite, calcite, siderite, hematite, ilmenite, rutile, anatase, apatite, monazite, tourmaline, pyrite;
2. quartz (rarely amethyst), hematite, rutile, adularia, strontianite;
3. quartz, adularia, hematite (roses), stilbite, muscovite;
4. adularia, albite (pericline), apatite, axinite, danburite;
5. quartz, albite, ilmenite, apatite, fluorite, anatase, monazite, xenotime, synchysite, gadolinite;
6. albite (pericline), adularia, titanite, prehnite; and
7. talc, dolomite, magnesite.

Paragenesis one refers mainly to schistose rocks; paragenesis two is restricted to conglomeratic rocks; parageneses three, four, and five are characteristic for granitic to granodioritic rocks; six occurs mainly in basic rocks (amphibolites); and seven is confined exclusively to ultrabasic rocks (serpentinites).

*Gotthardpass*: The region around Gotthardpass, including *Piz Lucendro*, *La Fibbia*, and *Monte Prosa*, is one of the classic mineral regions of the Central Alps in Switzerland. This

**Table 1. Typical fissure minerals from the Fieschergletscher area.**

Nonsilicates	Silicates
apatite	orthoclase (var. adularia)
calcite	fibrous amphiboles ("amianth")
fluorite	bavenite
hematite (roses)	chabazite
ilmenite	epidote
pyrite	heulandite
quartz	laumontite
colorless, smoky, amethyst	milarite
sphalerite	phenakite
synchysite	scolecite
	stilbite
	titanite

**Table 2. Minerals from La Fibbia.**

Nonsilicates	Silicates
quartz	orthoclase (var. adularia)
hematite	albite
rutile	muscovite
xenotime	phenakite
fluorite	titanite
(anhydrite)	bertrandite
apatite	chlorite minerals
	stilbite

Note: The host rocks are metagranites, partly aplitic facies.

**Table 3. Minerals from the railway tunnel from Oberwald-Realp.**

Sulfides	Other nonsilicates	Silicates
arsenopyrite	anatase	orthoclase (var. adularia)
chalcopyrite	ankerite	albite
cobaltite/gersdorffite	brookite	apophyllite
galena	calcite	bazzite
giessenite/izoklakeite	dolomite	clinocllore
pyrite	ilmenite	epidote
pyrrhotite	magnetite	muscovite
sphalerite	mimetite	stilbite
ullmanite	monazite	titanite
	quartz	tourmaline (black)
	rutile	
	siderite	
	synchysite	
	xenotime	

Note: Host rocks are Permian metaconglomerates and gneisses.

**Table 4. Minerals of Cavradi Gorge (Tavetsch).**

Elements, sulfides	Other nonsilicates	Silicates
gold	anatase	orthoclase (var. adularia)
silver	aeschnite	tourmaline (black)
bornite	apatite	
chalcopyrite	azurite	
digenite	barite	
djurleite	bergsлагite	
	brookite	
	fluorite	
	hematite	
	malachite	
	monazite	
	quartz, and	
	var. amethyst	
	rutile	
	strontianite	
	xenotime	

Note: Host rocks are Permian gneisses derived from sandstones to conglomerates.

was found in crystals up to 6 cm across. The luster of the crystals reaches a quality that rarely is equaled by hematites from any other locality. Moreover, the hematite crystals often display a spectacular oriented (epitactic) intergrowth with red prisms of rutile. Typical minerals from Cavradi Gorge are given in table 4.

### Penninic Area

The most striking feature of this region is the close coexistence of rocks with completely different kinds of origin (sedimentary rocks and rocks of primary magmatic origin—from acid to ultrabasic composition) that were piled upon each other by the Alpine folding and were subjected to different degrees of metamorphism—from greenschist facies to amphibolite facies. Consequently, the whole area is characterized by the occurrence of a remarkably large number of minerals. Presumably of decisive influence for the mineralization in fissures is the involvement of huge complexes of marine sediments (Triassic and Jurassic-Cretaceous), which brought along large quantities of water that played an important role in the hydrothermal alteration of the rocks. Additionally, numerous concentrations of ore minerals, mainly in originally magmatic rocks, were also involved in the folding process, leading to very unusual geochemical anomalies that are not completely explainable to date (for example, As minerals in Binntal and the Ba anomaly in the Simplon region).

One of the most striking examples of the occurrence of fissure minerals in the Penninic zone is the Binntal area (*Canton Valais, Switzerland/Alpe Devero, Italy*), which was the subject of various detailed mineralogical studies during the past twenty to thirty years. This, and the fact that the Binntal region has been the main topic of my own mineralogical studies, is the reason for the following quite detailed description of the Binntal mineralogy.



**Figure 6. Phenakite, La Fibbia, St. Gotthard. Length of crystal about 12 mm. Private collection.**

area has become famous, in particular, for spectacular finds of hematite (in the special habit as roses, *Eisenrose*). Additionally, adularia has been collected here in specimens of spectacular size and distinctive habit. Typical minerals from La Fibbia are given in table 2 and from the *Oberwald-Realp* railroad tunnel in table 3.

*Cavradi Gorge (Tavetsch)*: The Cavradi region, too, is among the most famous classic mineral locations of the Swiss Central Alps, known especially for the occurrence of spectacular hematites. Though hematite does not occur here in the highly esteemed *Eisenrose* habit, it

**Figure 7 (right).** Hematite crystal, Lercheltini zone, Binntal. Crystal 34 mm across. Specimen: Basel Natural History Museum.

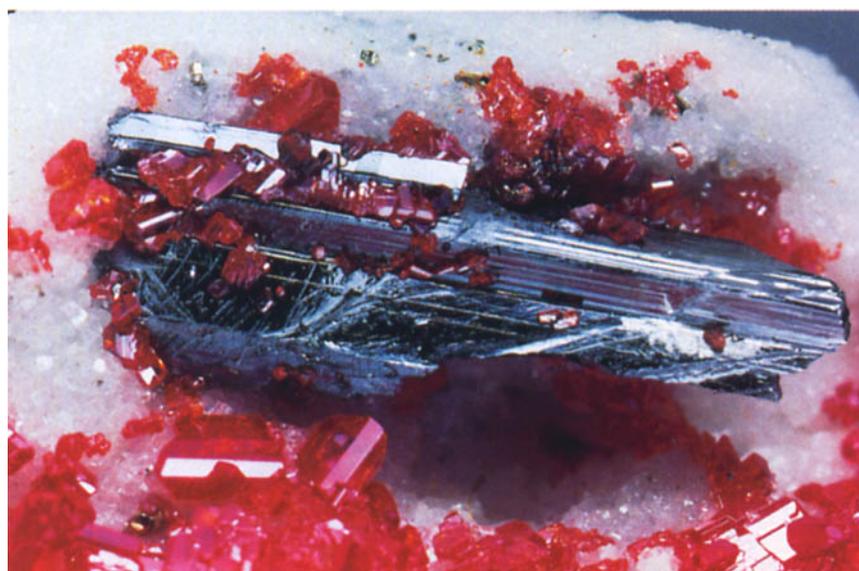
**Figure 8 (far right).** Demantoid crystals embedded in tremolite asbestos, Geisspfad, Binntal. Largest crystal 3–4 mm across. Specimen P. Imhof, Brig.



**Figure 9 (above).** Tilasite, Wannigletscher, Cervandone (Switzerland). Aggregate about 8 mm across. Private collection.

**Figure 10 (above right).** Gasparite-(Ce) (type specimen), pseudomorph after synchysite, Cervandone (Italy). Length of aggregate 5–6 mm. Specimen: Basel Natural History Museum, photo by H. Hänni, Basel.

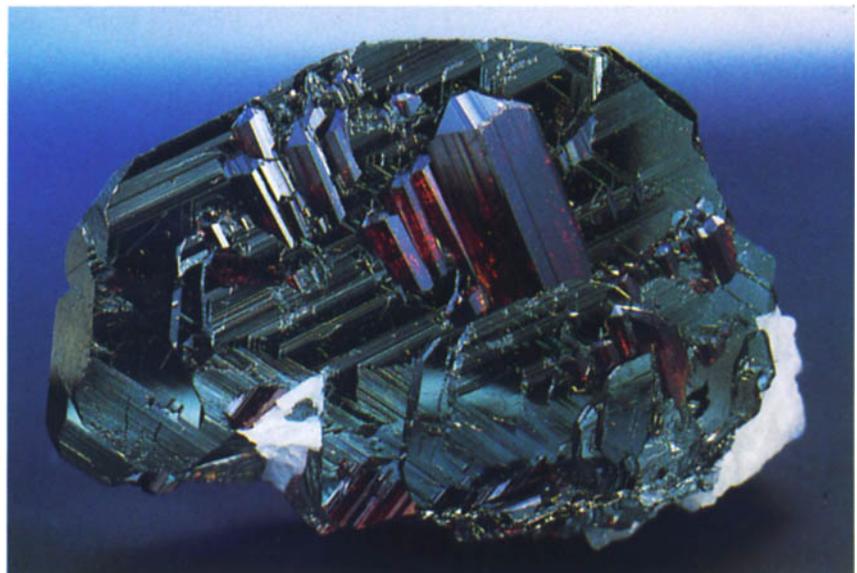
**Figure 11 (right).** Sartorite and realgar, Lenggenbach, Binntal. Sartorite crystal about 12 mm long. Specimen: Basel Natural History Museum.





**Figure 12 (far left).** Hematite (*Eisenrose*) overgrown with epitactic rutile, La Fibbia, St. Gotthard. Hematite about 3 cm across. Specimen: Basel Natural History Museum.

**Figure 13 (left).** Anatase, Lercheltini zone, Binntal. Crystal height about 25 mm. Specimen: Basel Natural History Museum.



**Figure 14 (above left).** Bergslagite, Cavradi Gorge. Largest crystals 2-3 mm long. Specimen: Basel Natural History Museum.

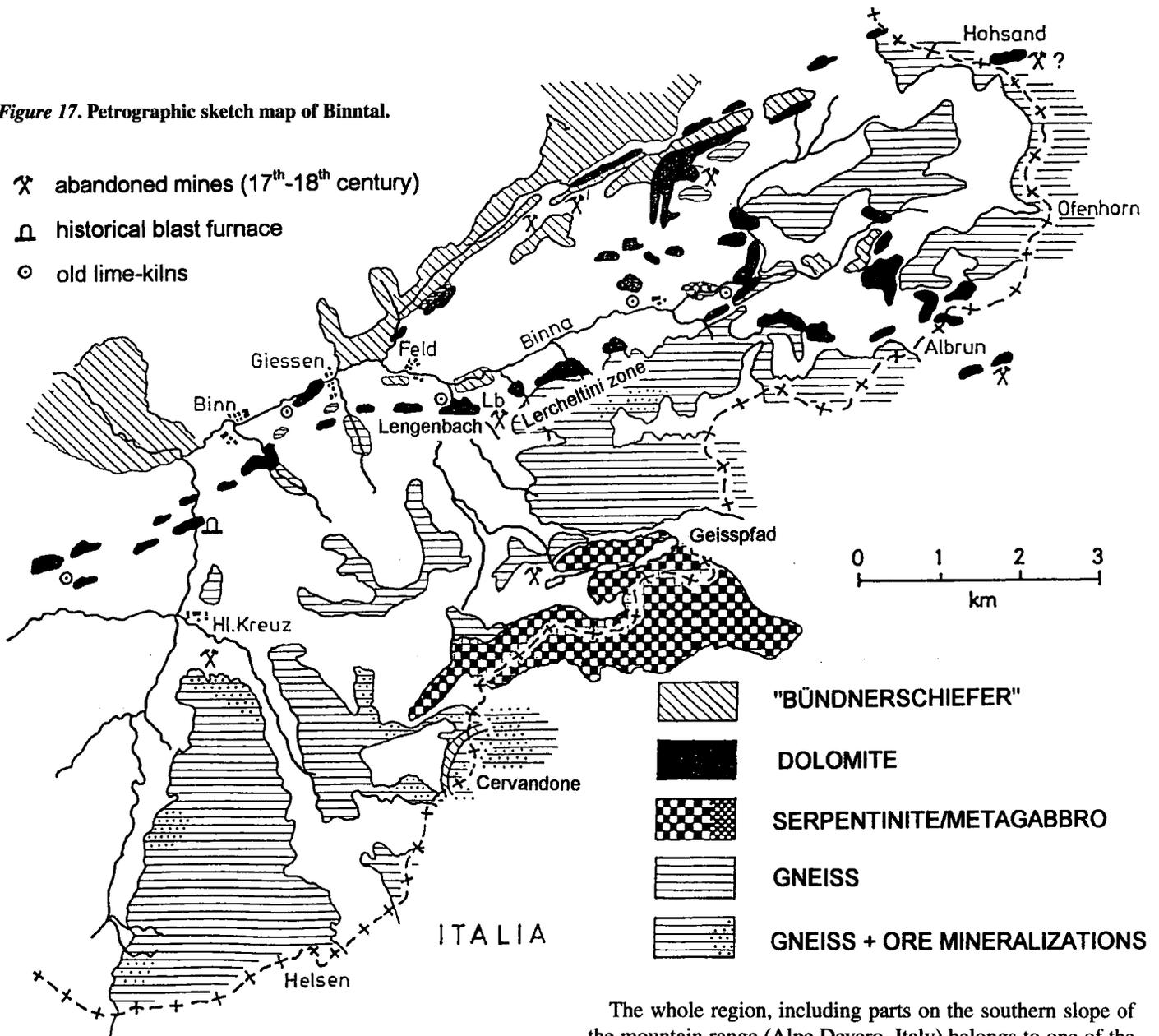
**Figure 15 (above).** Hematite in oriented intergrowth with rutile, Cavradi Gorge. Sample 2 by 3 cm. Specimen: W. Gabriel.



**Figure 16 (left).** Bazzite (=Sc beryl) and stilbite, Furka railway tunnel. Length of longest bazzite crystal about 5 mm. Specimen: Bern Natural History Museum.

Figure 17. Petrographic sketch map of Binntal.

- ✕ abandoned mines (17<sup>th</sup>-18<sup>th</sup> century)
- ▢ historical blast furnace
- old lime-kilns



**Binntal, Canton Valais Region**

The Binntal region undoubtedly comprises the best-known mineral locations in Switzerland and, in particular, those with the longest traditions. For example, the Basel Natural History Museum is in possession of an original label for a Lengenbach sample dated 1797. The famous sulfosalt minerals from the dolomite quarry at Lengenbach have been exploited almost continuously since 1833, and the excellent Ti minerals from Lercheltini were mined more or less commercially throughout the second half of the nineteenth century. Recent mineralogical studies in the region, carried out by the author, led to the discovery of a strong arsenic anomaly in the gneissic rocks that was responsible for the formation of a large number of arsenic oxide minerals in the gneiss fissures, partly arsenites and partly arsenates, some of which turned out to be new mineral species (especially among the arsenite group). The wealth of minerals in the Binntal-Devero region is well documented in two recently published books (Albertini 1991; Schwanz 1994) (see also Graeser 1995b).

The whole region, including parts on the southern slope of the mountain range (Alpe Devero, Italy) belongs to one of the Penninic nappes (Monte Leone nappe). This nappe is composed of numerous rock types that differ in origin, formation, and chemical composition.

The sedimentary rocks include Triassic dolomites (partly as dolomite marble) and rarely *rauhwacke* (dolomitic wacke), while the Jurassic-Cretaceous rocks include *Bündnerschiefer* (metasediments of variable composition between calcareous, quartzitic, and clay-rich varieties).

The crystalline rocks include orthogneiss (mostly occurring as augen gneiss—either metagranite or metarhyolite), paragneiss (several varieties, partly polymetamorphic older sediments), basic rocks (metagabbro and others), and ultrabasic rocks (serpentinites and rodingites).

The Binntal rocks contain several small ore deposits, some of which, as far as is known, were mined between the sixteenth and eighteenth centuries. Pb-Zn mineralization occurs mainly in the dolomitic rocks; one or two of these deposits were mined for lead. A magnetite deposit in dolomitic rocks was mined for a short time in the seventeenth century with considerable suc-

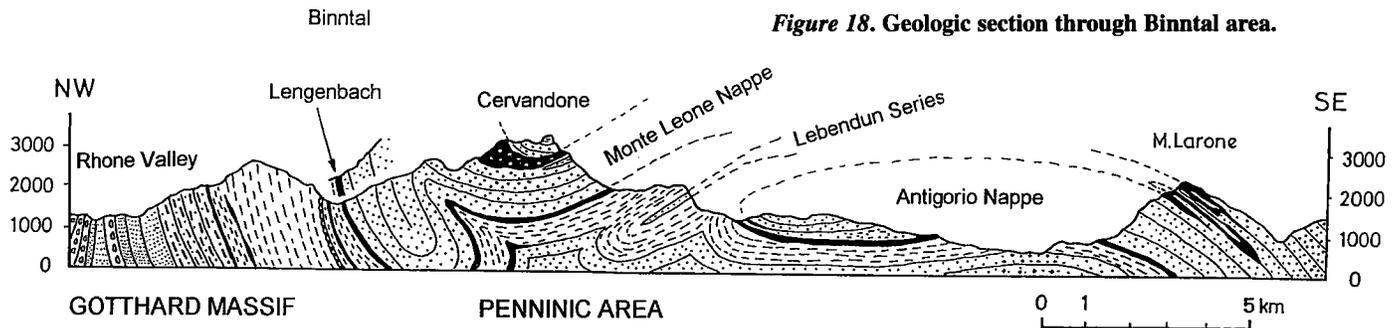


Figure 18. Geologic section through Binntal area.

cess. A hematite-magnetite deposit in the gneisses was also mined during the seventeenth century. In addition, several arsenic anomalies were discovered during the past thirty years; primary ore minerals are tennantite and arsenopyrite. The gneisses throughout the whole area show remarkable enrichment in rare-earth elements (lanthanides), the origin of which is not yet completely understood.

During the Alpine folding process the entire region was subject to metamorphic conditions of upper greenschist to lower amphibolite facies (500°–550° C, 5 kilobars pressure), as proven by the occurrence of kyanite in the Mesozoic rocks.

The combination of all these factors—variety of rock types, distinctive ore deposits, and an appropriate degree of metamorphism—led to the formation of a very uncommon type of

Table 5. Minerals from the Lengenbach quarry.

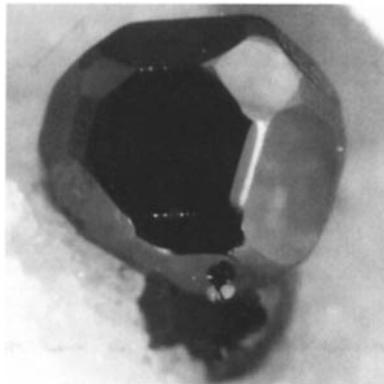
<b>Sulfides, sulfosalts</b>		seligmannite*	$PbCuAsS_3$	<b>Silicates</b>
acanthite	$Ag_2S$	sinnerite*	$Cu_6As_4S_9$	orthoclase (var. adularia)
arsenopyrite	$FeAsS$	smithite*	$AgAsS_2$	albite
baumhauerite*	$Pb_{12}As_{16}S_{36}$	smytheite	$Fe_{13}S_{16}$	biotite
baumhauerite-2a*	$Pb_{11}Ag_7As_{17.2}Sb_4S_{36}$	sphalerite	ZnS	dickite
bernardite	$Tl(As,Sb)_3S_8$	stalderteite*	$TlCu(Zn,Fe,Hg)_2As_2S_6$	hemimorphite
bornite	$Cu_5FeS_4$	stephanite	$Ag_5SbS_4$	hyalophane
chalcopyrite	$CuFeS_2$	tennantite	$(Cu,Ag,Fe,Zn)_{12}As_4S_{13}$	kaolinite
dufrénoysite*	$Pb_2As_2S_5$	tetrahedrite	$(Cu,Ag,Fe,Zn)_{12}(Sb,As)_4S_{13}$	montmorillonite
edenharterite*	$TlPbAs_3S_6$	trechmannite*	$AgAsS_2$	muscovite, and var. fuchsite, and barian var. ("oellacherit")
enargite	$Cu_3AsS_4$	fibrous sulfosalts*	$Pb-As-S$	paragonite
ermigilite*	$Tl,SnAs_2S_6$	wallisite*	$TlPbCuAs_2S_5$	phlogopite
galena	$PbS$	wurtzite-2H, -4H	ZnS	scapolite
greigite	$Fe^{2+}Fe^{3+}_2S_4$	xanthoconite	$Ag_3AsS_3$	thorogummite
hatchite*	$TlPbAgAs_2S_5$			tourmalines
hutchinsonite*	$TlPbAs_3S_9$	<b>Elements</b>	<b>Carbonates</b>	dravite
imhofite*	$(Tl, \square)_3As_8S_{13}$	arsenic	aragonite	uvite
jentschite*	$TlPbAs_3SbS_6$	arsenolam- prite	calcite	
jordanite*	$Pb_{14}As_6S_{23}$	graphite	cerussite	
lengenbachite*	$Pb_8(Ag,Cu)_2As_4S_{13}$	silver	dolomite	
liveingite*	$Pb_9As_{13}S_{28}$		hydrozincite	
lorandite	$TlAsS_2$	<b>Halides</b>	magnesite	
mackinawite (?)	$(Fe,Ni)_9S_8$	fluorite	malachite	
marcasite	$FeS_2$	halite		
marrite*	$PbAgAsS_3$		<b>Sulfates, molybdates</b>	
molybdenite-3R	$MoS_2$	<b>Oxides</b>	anglesite	
nowackiite*	$Cu_6Zn_3As_4S_{12}$	anatase	barite	
orpiment	$As_2S_3$	arsenolite	wulfenite	
pararealgar	$AsS$	brannerite		
proustite	$AgAsS_3$	coulsonite		
pyrargyrite	$AgSbS_3$	goethite		
pyrrhotite	$Fe_{1-x}S$	lepidocrocite	<b>Phosphates, arsenates</b>	
pyrite	$FeS_2$	magnetite	apatite	
quadratite*†	$AgCdAsS_3$	nolanite	gorceixite	
rathite*	$(Pb,Tl)_3As_5S_{10}$	quartz	goyazite	
"rathite-140"*	$Pb_6As_{10}S_{21}$	rutile	mimetite	
realgar	$AsS$	uraninite		
sartorite*	$PbAs_2S_4$			

Notes: Host rock is dolomite (white, mostly "sugary" texture). There are two or three unknown Tl-As sulfosalts under investigation. Additional sulfosalt occurrences in Binntal include Turtshi, Reckibach, and others.

\*type locality Lengenbach

†Graeser and Lustenhouwer 1998

**Figure 19 (right).** Tennantite, in its characteristic pseudoholoedric habit (“binnite”), Lengenbach. Crystal 2 mm. Private collection.



**Figure 20 (below).** Hatchite, Lengenbach, Binntal; crystals clearly display triclinic symmetry. Sample 4 mm. Specimen: W. Gabriel.



mineralization with a remarkable number of altogether different fissure minerals and, moreover, with numerous very uncommon species (the total number of fissure minerals exceeds two hundred species, for at least thirty-five of which Binntal represents the type locality).

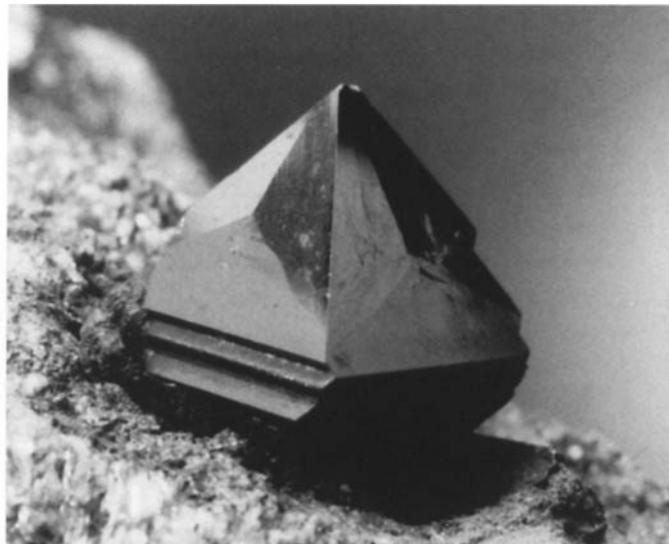
Important mineral occurrences in Binntal include those in the *Lengenbach quarry*, the “*Lercheltini zone*,” the *Cervandone region*, and the *Geisspfad complex*.

*Sulfosalt minerals from the Lengenbach dolomite quarry:* It was mainly the abundance of various uncommon Lengenbach minerals that established the reputation of Binntal as one of the most fascinating mineral regions in the Central Alps. Mineral collecting in Lengenbach started with sporadic activities as early as the eighteenth century and developed to a more or less continuous exploitation from 1833 until now, with a sharp break between 1914 and 1958, in which year the *Arbeitsgemeinschaft Lengenbach* started its activity. The classic old site, which operated until 1986, was closed because of unattractive exploitation and technical problems. In 1987 a new site was opened at a slightly higher level, and it has produced numerous interesting minerals during the past ten years.

Though various silicate and other oxide minerals occur in Lengenbach, the main interest has been focused on sulfide and sulfosalt minerals. It is a strange fact that the mineral parageneses in the two sites are remarkably different from each other though the difference in elevation is not more than 25–30

meters. Whereas in the old quarry Pb-As sulfosalts were dominant, with extremely rare Tl-As-S minerals, Tl minerals became most important at the new site. Within a few years five new Tl sulfosalts were discovered, and at least two unknown phases are still under investigation. Minerals from the Lengenbach quarry are given in table 5.

*Lercheltini zone—commercial mining for anatase:* It is not clear which mineral occurrence was more important for the reputation of Binntal as the “valley of the minerals”—the Lengenbach quarry or the Lercheltini zone. Lengenbach minerals—highly unusual species, most extremely small—have always been the subjects of study by specialists, whereas min-



**Figure 21.** Magnetite, Lercheltini zone, Binntal. Crystal about 13 mm. Specimen: Basel Natural History Museum.

erals of the Lercheltini zone—such as anatase, magnetite, and hematite—became favorite collection specimens because of their spectacular size and, frequently, perfect shape and color. Anatase, particularly, has been collected in wonderful specimens in the Lercheltini zone (from localities including *Gorb*, *Spissen*, *Riggi*, and *Kollergraben*) for almost two hundred years. The crystals sometimes were of such unique quality that even a mineral specialist such as Kennigott (1864) came to the (erroneous) conviction that they represented a species of their own, which he named “wiserine.” It took more than ten years to discover that this was not so. Natural history museums throughout the world preserve excellent anatase crystals from the Lercheltini zone in dimensions up to 50 millimeters in length. For more than a hundred years, this region has been the target of mineralogists and private and professional collectors (*strahlers*). Especially during the second half of the last century, the entire region was mined for minerals in an almost commercial manner.

It is an absolutely incomprehensible fact that, with the exception of the poorly studied and erroneously named arsenic mineral “arsenoferrite,” no arsenic minerals were collected in the whole zone during this period. The first clearly identified arsenic mineral only became known from the Lercheltini zone in 1986 (asbecasite), and subsequently most of the peculiar

**Table 6. Minerals from the Lercheltini zone (As minerals not included).**

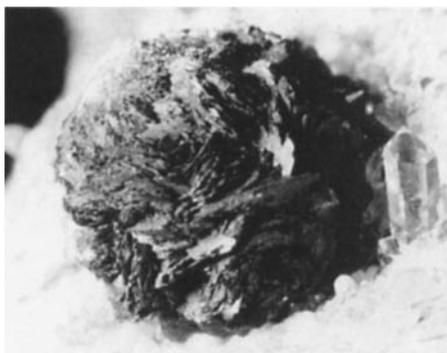
Nonsilicates	Silicates
anatase	orthoclase (var. adularia)
hematite	albite
ilmenite	chlorite minerals
magnetite	muscovite
monazite	titanite
quartz	tourmaline (schorl)
rutile	
xenotime	

Note: Host rock is biotite-rich mica schist to mica gneiss. Individual localities include Gorb, Spissen, Riggi, and Kollergraben.

Binntal arsenic oxide minerals from the Cervandone region were also identified in this zone. Unexpectedly, most of these minerals were discovered in the old exploited anatase fissures; the professional collectors obviously had extracted only the well-known Lercheltini minerals and were not interested in other, unidentifiable material. Minerals from the Lercheltini zone are given in table 6.



**Figure 22. Cafarsite, Wannigletscher, Cervandone (Switzerland). The cubo-octahedral crystal 8 mm across. Specimen: W. Mangold, Naters.**



**Figure 23. Cervandonite-(Ce), Wannigletscher, Cervandone (Switzerland). Aggregate 8 mm across. Specimen: N. Burgener, Fiesch.**

*Arsenic concentrations in the Binntal gneisses:* While working on a thesis on the mineral parageneses in the dolomitic rocks of Binntal (Graeser 1965), I became convinced that, in addition to the arsenic minerals in the dolomites, another arsenic anomaly should exist, presumably in the gneisses, which served as the primary source for all the arsenic in Binntal. After numerous fruitless investigations into the gneisses, these expeditions were finally successful: In 1963 I found traces of a quite extensive ore mineralization in the gneisses around Pizzo Cervandone. The ore, which afterward was determined to be tennantite ( $\text{Cu}_{12}\text{As}_4\text{S}_{13}$ , with minor substitutions by Sb and Bi for As), showed the strong influence of leaching and remobilization processes. This remarkable day also provided me with samples of two unknown minerals that, after detailed studies in the laboratory, turned out to represent new mineral species (asbecasite and cafarsite). Remarkably, both minerals contain up to about 60 weight percent of arsenic oxide, thus giving clear proof of their formation as products of a remobilization and oxidation process (Graeser and Roggiani 1976). In the years following this discovery, the whole region on both sides of the Swiss/Italian border was inundated by

**Table 7. Minerals from the Cervandone region/Gorb (Lercheltini).**

<b>Sulfides</b>		<b>Silicates</b>
arsenopyrite	$\text{FeAsS}$	adularia
bournonite	$\text{CuPb}(\text{Sb}, \text{As})\text{S}_3$	albite
bismuthinite	$\text{Bi}_2\text{S}_3$	bertrandite
chalcopyrite	$\text{CuFeS}_2$	beryl
molybdenite-2H	$\text{MoS}_2$	biotite
tennantite	$(\text{Cu}, \text{Fe})_{12}(\text{As}, \text{Sb}, \text{Bi})_4\text{S}_{13}$	chlorite minerals
		datolite
<b>Arsenates, arsenites</b>		diopside
agardite-(Y)	$\text{Cu}_6(\text{Y}, \text{Ca})(\text{AsO}_4)_3(\text{OH})_6 \cdot 3\text{H}_2\text{O}$	gadolinite
asbecasite*	$\text{Ca}_2(\text{Ti}, \text{Sn})\text{Be}_2\text{Si}_2[\text{O}_2(\text{As}^{3+}\text{O}_3)_6]$	milarite
cafarsite*	$\text{Ca}_8(\text{Ti}, \text{Fe}, \text{Mn})_{6-7}(\text{AsO}_4)_3 \cdot 4\text{H}_2\text{O}$	muscovite
cervandonite-(Ce)*	$(\text{Ce}, \text{Nd}, \text{La})(\text{Fe}, \text{Al})_2\text{Ti}(\text{Si}, \text{As})_3\text{O}_{13}$	titanite
chalcophyllite	$\text{Cu}_{18}\text{Al}_2(\text{AsO}_4)_3(\text{SO}_4)_3(\text{OH})_{27} \cdot 27\text{H}_2\text{O}$	schorl
chernovite-(Y)	$(\text{Y}, \text{La})\text{AsO}_4$	
cornubite	$\text{Cu}_4(\text{AsO}_4)_2(\text{OH})_4$	<b>Other nonsilicates</b>
fetiasite*	$(\text{Fe}^{2+}, \text{Fe}^{3+}, \text{Ti})_3[\text{O}_2\text{As}_2\text{O}_5]$	allanite
gasparite-(Ce)*	$(\text{Ce}, \text{La})\text{AsO}_4$	azurite
graeserite*	$(\text{Fe}, \text{Ti})_4\text{Ti}_3\text{As}^{3+}\text{O}_{13}(\text{OH})$	beaverite
paraniite-(Y)*	$\text{Ca}_2\text{Y}(\text{AsO}_4)(\text{WO}_4)_2$	bismutite
pharmacosiderite	$\text{KFe}_4(\text{AsO}_4)_3(\text{OH})_4 \cdot 6-7\text{H}_2\text{O}$	carbonate-cyanotrichite
strashimirite	$\text{Cu}_8(\text{AsO}_4)_4(\text{OH})_4 \cdot 5\text{H}_2\text{O}$	crichtonite group (senaité, davidite)
tilasite	$\text{CaMg}(\text{AsO}_4)\text{F}$	fluorite
tyrolite	$\text{CaCu}_5(\text{AsO}_4)_2(\text{CO}_3)(\text{OH})_4 \cdot 6\text{H}_2\text{O}$	gypsum
		hematite
<b>Elements</b>		jarosite
gold		magnetite
sulfur		malachite
		rutile
		scheelite
		synchysite
		wulfenite
		xenotime

Notes: Host rocks are pale-colored "two-mica gneisses" (metarhyolites?) in Cervandone region, biotite-mica schists in the Lercheltini zone. Individual localities in the Cervandone region include Wannigletscher, Gis-chigletscher, and Mättital (Switzerland), and Cervandone (Italy). Sulfides are the primary ore minerals in the gneisses (rock-forming minerals).

\*type locality Binntal/Cervandone region

innumerable mineral collectors who brought huge masses of material down to the valleys. From this material, of which large amounts were studied in our laboratory in Basel, numerous different and some new species could be identified. Undoubtedly, the most interesting material represented arsenic minerals, which occur partly as arsenites (with As in As<sup>3+</sup> state) and partly as arsenates (with As<sup>5+</sup>). The much rarer arsenite minerals presumably represent products of an earlier remobilization process; arsenate minerals formed later, perhaps even by oxidation of the older arsenites.

When I was looking for a source of arsenic (Graeser 1965) that might have been responsible for the formation of the As sulfosalt minerals in the dolomites, the southern gneisses in direct contact with the dolomites (Lercheltini zone, particularly Gorb) were naturally of prime interest. Even today, it puzzles me that I could not find one single arsenic mineral in this area, despite very detailed research. It was exactly twenty-five years later that the first As mineral (asbecasite, 1986) was discovered in the Lercheltini zone. However, within the past ten years most of the special Cervandone arsenic minerals have also been found in Gorb, some of even better quality than those from Cervandone (e.g., fetiasite), plus even additional new minerals (graeserite: Krzemnicki 1997). Minerals from the Cervandone region are given in table 7.

*Mineral occurrences in the ultrabasic Geisspfad complex (mainly antigorite serpentinite):* The ultrabasic Geisspfad complex, comprising mainly an antigorite-serpentinite, was derived from an originally lherzolitic rock (Keusen 1972) that was transformed into its present state by various geological processes, mainly as a result of Alpine metamorphism. It forms the border between Italy and Switzerland over a distance of about 5 kilometers, and the whole mass is estimated to be about 5 kilometers<sup>3</sup>. The complex consists mainly of antigorite-tremolite-forsterite, rarely also of chrysotile-forsterite. The ultrabasic complex is surrounded by a basic border facies, which also partly occurs as veins cutting through the central part of the serpentinite. Different from all the other so-called ophiolite complexes in the Alps (Alpine-type ophiolites), which generally are situated entirely within Mesozoic sedimentary rocks (*Bündnerschiefer*), the Geisspfad mass is almost exclusively embedded in gneissic rocks.

The combination of ultrabasic and basic rocks gave rise to a very characteristic type of mineralization. Of particular interest are parageneses that had formed by a Ca metasomatism within the basic rocks (the so-called rodingites). Minerals that were produced by this process (various Ca minerals) mostly display strikingly bright colors, e.g., red (garnet and vesuvianite), green (garnet, epidote, and diopside), yellow (titanite), and white (apatite and zeolites). Rodingites, therefore, mark brightly colored spots in the dark green basic veins. The minerals occur partly as well-developed crystals in cavities of rodingitic rocks and serpentinite, partly also as rock-forming minerals. It is an interesting fact that, under certain metamorphic conditions, the serpentine minerals may recrystallize again to olivine, thus producing in rare cases forsterite crystals of real gem quality.

Even during the last century, and particularly in the first half

**Table 8. Minerals from basic and ultrabasic rocks of the Geisspfad complex.**

<b>Elements, sulfides</b>	<b>Silicates</b>
native copper	antigorite*
chalcocite	chlorite minerals
cubanite	diopside
djurleite	epidote
galena	forsterite
pentlandite	garnets: andradite, and var. demantoid, and grossular, var. hessonite
<b>Other nonsilicates</b>	ilvaite
apatite	prehnite
calcite	preiswerkite*
dolomite	talc
ilmenite	titanite
magnetite	tremolite (partly asbestiform)
magnesite	vesuvianite (partly asbestiform)
	zeolites: natrolite, mesolite, thomsonite

*Notes:* Host rocks are antigorite serpentinite, basic (hornblenditic) veins, partly developed as rodingites. Individual localities include Geisspfad, Schwarzhorn, Fleschhorn (Switzerland), and Cervandone (Italy).

\*type locality Binntal

of this century, the ultrabasic rocks and their basic derivatives have been targeted by Swiss professional collectors. Surprisingly, the strahlers were not so much interested in the Swiss part of the outcrops, but almost exclusively in the locations at the western end of the complex, in Italy. Numerous excellent samples with diopside, epidote, albite, and so on have been collected, especially at one particular location, a small isolated lens of serpentinite in the gneisses, displaying a well-developed basic border facies. Most of these excellent diopside specimens were sold as finds from "Cherbadung, Binntal,"

### ***The ultrabasic rocks and their basic derivatives have been targeted by Swiss professional collectors.***

though, in fact, they originally were collected on Italian territory. The Geisspfad complex even contributed a new mineral species, the mineral preiswerkite, a Na-Mg mica belonging to the brittle mica group. Minerals of the Geisspfad complex are given in table 8.

Presumably, the serpentine polymorph antigorite (described as a new species by Schweizer 1840) originates from the Geisspfad complex: The pebbles found in the Antigorio Valley, which served as type material, undoubtedly were derived from the Geisspfad complex.

### ***Canton Grisons: Oberhalbstein Region***

*Oberhalbstein*, about 100 kilometers northeast of Binntal, still belongs to the Penninic realm. It lies in the Platta nappe, one of the highest parts of the Penninic nappes. The whole region consists mainly of serpentinites and radiolarites. Oberhalbstein is famous for its ore deposits (iron, later manganese),

which have been active for several centuries; the last active mines were manganese deposits, which were worked until after World War II. The primary manganese ore (almost exclusively braunite, a Mn silicate) is included in the radiolarite where it was deposited, presumably as manganese nodules. Both the host rocks and the ore deposits were influenced by Alpine metamorphism of approximately greenschist facies. This process resulted in the formation of numerous fissure minerals, some of which even represented new mineral species. Most of the minerals clearly are remobilization products; therefore, most of them contain manganese and also arsenic, which was enriched in deep-sea sediments by the same processes as the manganese. Most of the arsenic oxide minerals (arsenates) have been identified only within the past twenty years. With respect to the element arsenic, in particular, the similarity to the Binntal arsenic oxide minerals is striking.

Bergslagite from Falotta had been studied before it was described as a new mineral (Hansen et al. 1984), but unfortu-

**Table 9. Minerals from Falotta (abandoned Mn mine).**

Arsenates		Other nonsilicates
arseniosiderite	$\text{Ca}_2\text{Fe}_2(\text{AsO}_4)_2\text{O}_2 \cdot 3\text{H}_2\text{O}$	anatase
bergslagite	$\text{CaBe}(\text{AsO}_4)(\text{OH})$	aragonite
brandtite	$\text{Ca}_2\text{Mn}(\text{AsO}_4)_2 \cdot 2\text{H}_2\text{O}$	calcite, and
conichalcite	$\text{CaCu}(\text{AsO}_4)(\text{OH})$	var. man-
geigerite*	$\text{Mn}_2(\text{AsO}_4)_2(\text{AsO}_3\text{OH})_2 \cdot 10\text{H}_2\text{O}$	ganocalcite
grischunite*	$\text{NaCa}_2\text{Mn}_2\text{Fe}(\text{AsO}_4)_6 \cdot 2\text{H}_2\text{O}$	hematite
kemmlitzite	$\text{SrAl}_2(\text{AsO}_4)(\text{SO}_4)(\text{OH})_6$	kutnohorite
manganberzeliite	$(\text{Ca}, \text{Na})_3(\text{Mn}, \text{Mg})_2(\text{AsO}_4)_3$	malachite
sarkinite	$\text{Mn}(\text{AsO}_4)(\text{OH})$	manganite
tilasite	$\text{CaMg}(\text{AsO}_4)\text{F}$	todorokite
		triphykite
	Silicates	
	albite	piemontite
	ardennite	rhodonite
	braunite	spessartine
	muscovite	sursassite*
	parsettensite*	tinzenite*

Note: Two unknown species are still under investigation. Host rocks are radiolarites. Individual localities include Falotta, Parsettens, and others.

\*type locality

nately the scarcity of material did not allow a wet-chemical analysis of Be (which could not be determined by microprobe; Graeser 1995a). Minerals from Falotta are given in table 9.

### Helvetic Zone

The Helvetic zone ("nördliche Kalkalpen," *Helveticum*) forms a frame around the crystalline center of the Alps toward the north, from France through Switzerland, to Austria. The whole zone consists mainly of limestones, and to a lesser degree of marls, sandstones, and a few dolomitic and rarely volcanogenic rocks. Though the rocks were folded and formed nappes as a result of the Alpine orogeny, the material remained

almost untouched by metamorphism because it represented the highest part of the Alps that never was buried below other complexes and thus never became exposed to higher temperatures and pressures. Consequently, the typical process of fissure opening is lacking, in general, and the more or less monotonous composition of the host rock (mainly limestones) led to

**Table 10. Typical minerals in Helvetic limestone (Unteriberg, Canton Schwyz; Welbel et al. 1990).**

Carbonates	Other nonsilicates	Silicates
ankerite	barite	glauconite
aragonite	celestine	muscovite
calcite	fluorite	
dolomite	pyrite	
	quartz	

mineral parageneses with few variations. The cavities in the (mostly) calcareous rocks, therefore, are not real fissures but have generally formed by the activity of hydrothermal fluids. Due to the limestone character of the host rock, various carbonate minerals represent the most common mineral species. Locally, one mineral in particular—fluorite—occurs in astonishing abundance and occasionally even achieves commercial importance. During the nineteenth century colorless fluorite from one locality (Oltscheren, near Brienz, Canton Bern) was mined for use in the optic industry. Typical minerals in Helvetic limestone are given in table 10.

However, in addition to the poor and quite monotonous mineralization in the Helvetic limestones, there occur also parageneses with surprisingly great varieties. One such locality is the *Taminser Calanda*, a mountain in eastern Switzerland near Chur in Canton Grisons. Gold, as a very uncommon mineral, was collected here in marvelous specimens in small quartz and calcite veinlets in schists of Dogger (Middle Jurassic) age (aggregates up to  $2 \times 8$  cm). The precious metal was so abun-

**Table 11. Minerals of Taminser Calanda (Goldene Sonne) (Welbel et al. 1990).**

arsenopyrite	galena	quartz
azurite	goethite	scheelite
brochantite	gold	siderite
calcite	malachite	synchysite
cerussite	muscovite	tetraedrite
dolomite	pyrite	wulfenite
fluorite		

dant that it was mined commercially throughout the nineteenth century ("*Goldene Sonne*"). Minerals from Taminser Calanda are given in table 11.

A few kilometers farther to the east in the same region (Felsberg), some additional special minerals have been discovered (sphalerite, stibiconite, and zinkenite). Generally, mineraliza-

tion in the eastern part of the Helvetic zone seems to display parageneses of a greater variety than those in the western part.

## SOME UNUSUAL ALPINE MINERALS

**Armenite**,  $\text{BaCa}_2\text{Al}_6(\text{Si}_9\text{O}_{30})\cdot 2\text{H}_2\text{O}$ , orthorhombic/pseudo-hexagonal

The mineral armenite, originally discovered at the Armen mine near Kongsberg, Norway, in 1877, was described as a new species in 1939 (Neumann 1939). Neumann already realized that the mineral showed close relations to the Be mineral milarite,  $\text{KCa}_2\text{AlBe}_2(\text{Si}_{12}\text{O}_{30})\cdot 1/2\text{H}_2\text{O}$ , the Ba-Al equivalent of which it represents (substitution of K by Ba, and of Be by Al). Until around 1980, Kongsberg with its extremely rare and tiny crystals remained the only known armenite occurrence. Subsequently, the mineral was discovered at various locations, such as in 1986 near the Simplon Pass in Switzerland. The material, found by a young strahler, was of really splendid quality with respect to size and shape (Graeser 1993).

*Morphology*: Crystals are of (pseudo) hexagonal habit, colorless, and completely transparent. The largest reach about 50 mm in length. By alteration the crystals change into a milky, nontransparent state.

*Occurrence*: Armenite formed in fissures of pale-colored, fine-grained gneiss. Petrographic study of the rock showed that it contains considerable zoisite, quartz, feldspar, and mica minerals. Because the whole rock contains more than 10 weight percent of BaO, all feldspars and micas occur as the Ba equivalents of the respective minerals.

**Cafarsite**,  $\text{Ca}_8(\text{Ti,Fe,Mn})_{6-7}(\text{AsO}_3)_{12}\cdot 4\text{H}_2\text{O}$ , cubic

The material that led to the description of the new mineral cafarsite was discovered while I was looking for an arsenic deposit in the gneisses that might serve as a source for the various As sulfosalts in the dolomitic rocks (Graeser 1966). The first traces of the unknown material were found near Cervandone Peak, on the border between Switzerland and Italy. When news about cafarsite (and other minerals) became known a few years later, the whole region was inundated by numerous private collectors and strahlers, who occasionally extracted extraordinary material from fissures in the region. Whereas the crystals I had found rarely exceeded about 10 mm, subsequent finds of crystals of several centimeters and several hundreds of grams were reported. Thus the cafarsite presumably represents one of the largest crystallized minerals described as new species within the last thirty years.

*Morphology*: In general, cafarsite crystals always clearly display their cubic symmetry. Dominant forms are either hexahedron or octahedron, mostly accompanied by a pyritohedron {310} and the dodecahedron. In fresh state, cafarsite shows a bright black color with distinct red internal reflections. The mineral alters quite easily, changing to a pale brown material that readily falls to pieces. This altered material could easily be mistaken for a slightly altered pyrite (which crystallizes in the same crystal class), a fact that presumably prevented an earlier detection of the mineral as a new species.

*Occurrence*: Cafarsite, which represents a product of the

remobilization of As ores in the gneisses during Alpine metamorphism, formed in the gneiss fissures. As an arsenite mineral it likely belongs to an early stage of formation in the fissures.

**Jentschite**,  $\text{TlPbAs}_2\text{SbS}_6$ , monoclinic

From the various new minerals, Tl sulfosalts in particular, that have been described from the Lengenbach quarry during the past seven years (stalderite, erniggliite, edenharterite, jentschite, and quadratite), I will pick out just one example that appears as one of the most interesting “young” Lengenbach minerals (Graeser and Edenharter 1997). The first sample of the new mineral was discovered at the new working site in Lengenbach among material collected in 1987 for members of the *Arbeitsgemeinschaft Lengenbach*. Though the study clearly indicated an unknown mineral species, the minute amount of extremely small and polysynthetically twinned crystals did not allow an unequivocal final determination at that time. Five years later, in 1992, some excellent additional samples were collected that permitted completion of the study. Jentschite is very similar in appearance to other Lengenbach Tl sulfosalts such as edenharterite, hutchinsonite, or even hatchite and wallisite. In comparing the formulae of edenharterite and jentschite, it becomes obvious that the two minerals must be closely related:

edenharterite	$\text{TlPbAs}_3\text{S}_6$	orthorhombic
jentschite	$\text{TlPbAs}_2\text{SbS}_6$	monoclinic

By substitution of one of the 3 As atoms by 1 Sb atom in the edenharterite formula, the symmetry is lowered to the monoclinic system. This change in symmetry is caused by the fact that all Sb atoms sit on one special position in the structure, as the subsequent structure determination proves (Berlepsch 1996).

*Morphology*: Jentschite is among the “larger” examples of the new Tl minerals in Lengenbach: It may even reach approximately 2 mm in length! Crystals are elongated along the *c*-axis and have a lathlike habit; the monoclinic symmetry is usually recognizable. Most jentschite is twinned (polysynthetically), and occasionally nice gypsumlike twins may be observed. Like most of the other Tl sulfosalts, jentschite is opaque black with high submetallic luster; thin fragments, however, are translucent red.

*Occurrence*: Together with numerous other sulfosalts, jentschite occurs in small cavities in the Triassic dolomite at the new working site in Lengenbach. As in the case of most of the other Tl sulfosalts, the occurrence of jentschite is mainly restricted to the new site; it seems to have been lacking in the classic old quarry.

**Milarite**,  $\text{KCa}_2\text{AlBe}_2(\text{Si}_{12}\text{O}_{30})\cdot 1/2\text{H}_2\text{O}$ , hexagonal

The Be mineral milarite was described as a new species by Kenngott in 1870. The name was intended to symbolize its first occurrence in Val Milà (Canton Graubünden). Yet, at least at that time, no milarite was known from this location; the first milarite samples undoubtedly were discovered in the neighboring Val Giuv. Presumably, strahlers tried to conceal the true

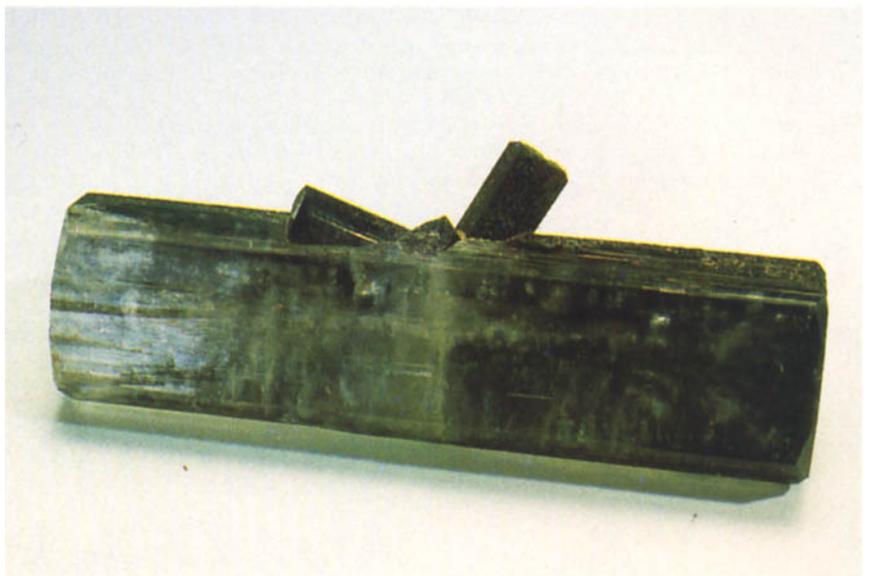


**Figure 24 (above).** Jentschite, Lengenbach, Binnental; one crystal shows twinning according to the gypsum law. Largest crystal 2 mm long. Type specimen: Basel Natural History Museum.

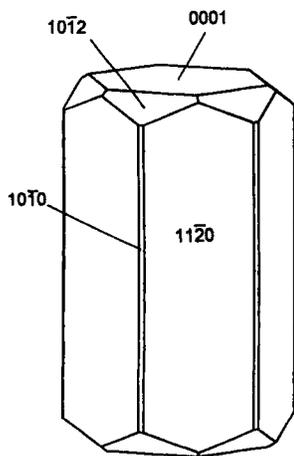


**Figure 25 (above right).** Armenite, Wasenhorn, Simplon area. Length of crystal about 30 mm. Specimen: M. Andres, Brig.

**Figure 26 (right).** Milarite, Fieschergletscher. Length of crystal 44 mm. Specimen: H. Volken, Fiesch.



**Figure 27 (below).** SHAPE drawing of a milarite from Fieschergletscher.



occurrence by giving a false locality. In contrast to the closely related mineral armenite, milarite has so far kept its hexagonal symmetry, though optical phenomena could also point toward an orthorhombic structure. While preparing a *SHAPE* crystal drawing, I realized that if I used the modern crystallographic axial ratio  $a : c = 1 : 1.328$ , the only hexagonal dipyrmaid form present yielded the indices  $\{10\bar{1}2\}$ ; the unit dipyrmaid  $\{10\bar{1}1\}$  does not exist. This is the reason why Kennigott reported a different axial ratio of  $1 : 0.662$ .

In 1995, the local strahler Hubert Volken discovered milarites of extraordinary quality and size in the Fieschergletscher region (Canton Valais). The find comprised single crystals up

to 5 cm in length, some of absolutely transparent, colorless quality, some also with chloritic inclusions.

**Morphology:** Milarite displays only a very restricted variety of crystal forms. Normally the number of different forms does not exceed four—two prisms,  $\{10\bar{1}0\}$  and  $\{11\bar{2}0\}$ ; one dipyrmaid,  $\{10\bar{1}2\}$ ; plus the hexagonal pinacoid  $\{0001\}$ , which is absent in many cases.

**Occurrence:** The fissure containing the spectacular milarite crystals lies in the southern part of the Aare Granite (probably in its acid border facies). Near the fissure the granite appears very strongly leached. In addition to milarite, another Be mineral, bavenite,  $\text{Ca}_4\text{Be}_2\text{Al}_2\text{Si}_9\text{O}_{26}(\text{OH})_2$ , has been identified; it occurs as hairlike fibers, mostly grown on milarite.

#### ACKNOWLEDGMENTS

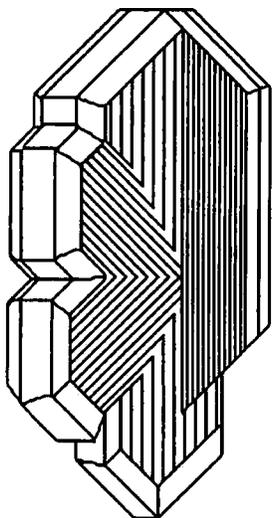
With few exceptions, all the mineral photographs were taken by Walter Gabriel. I am very grateful to him for always readily carrying out my photographic wishes (most material is extremely small). I am also greatly obliged to Peter Modreski and George Robinson who kindly corrected the English version of the text.

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