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Introduction to the Geology of the Bergell Alps with Guide for Excursions

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Zusammenfassung

Dieser Führer zur Geologie der südlichen Bergeller Alpen beschreibt Gesteine und deren m
neralogische Zusammensetzung, geologische Strukturen und die mutmassliche Entst
hungsgeschichte. Insbesondere enthält er Vorschläge für interessante Exkursionen, die sc
wohl Geologen als auch wissenschaftlich interessierten Laien einen Einblick in die ausseroı
dentlich vielfältigen Gesteine verschaffen. Ein ausführliches Verzeichnis der Originallitera
tur ist vor allem für Spezialisten wertvoll. Als geologische Unterlage wird Atlasblatt 7(
Sciora, der Geologischen Karte der Schweiz 1:25 000, Blatt 8, Engadin, der Geologische
Karte der Schweiz 1:200 000 und Foglio 7–18, Pizzo Bernina-Sondrio der Carta Geologic
d'Italia empfohlen. Der mit der italienischen Sprache vertraute Leser wird auf die Erläut
rungen zum Atlasblatt Sciora verwiesen.
Der Tertiäre Bergeller Granit ist mit ca. 30 Millionen Jahren einer der jüngsten Granite i
Europa und nicht nur wegen seines Alters ungewöhnlich. Die Verbreitung ist gering, im Ve
gleich zu den Graniten der Amerikanischen Kordillera oder des Himalajas als auch zu de
Herzynischen Granitmassiven der Zentralalpen (z. B. Aaregranit), Schwarzwald und Vog
sen. Während die Rahmengesteine auf der Ostseite (Forno) einer recht normalen Kontak
metamorphose unterlegen sind (Andalusit und Fe-reicher Cordierit), liegt der westliche Te
des Granits wie eine Decke auf Migmatiten und hochmetamorphen Gesteinen, deren Min
ralparagenesen (z. B. Mg-Cordierit, Sapphirin) auf hohen Druck hinweisen. In diesem B
reich ist es oft schwierig zu entscheiden, ob die Metamorphose ein Effekt der Granitplatz
nahme ist oder ob Granitisation ein Ergebnis der Metamorphose ist, die sich im Westen übe
weite Bereiche bis ins Tessin erstreckt (Lepontin). Die variablen Metamorphosenbedingun
gen sind durch typische Mineralparagenesen belegt, deren Verbreitung gut dokumentie
ist. Von besonderem Interesse sind ultrabasische Gesteine (je nachdem mit Enstatit, Anthc
phyllit, Tremolit oder Antigorit, Fig. 12), Karbonatgesteine (mit Wollastonit, Diopsid, Tr
molit und Plagioklas von Anorthit bis Albit) und tonige Schiefer (mit Sillimanit, Disthe
Andalusit, Cordierit, Staurolith, Sapphirin, Enstatit, Fig. 13–14). Bergeller Granit und Be
geller Tonit sind von einheitlicher chemischer Zusammensetzung und zeigen nicht Übe
gänge, wie sie für magmatische Differentiation typisch sind (Fig. 5). Aber wegen der weitg
henden Rekristallisation und durchgreifenden Deformation ist es schwierig, die ursprüngli
chen Gesteine zu erkennen, die während der Alpinen Metamorphose mobilisiert wurde
Gruf Migmatite, wie sie unter dem Granit auftreten (im Westen), haben eine ähnliche grano
dioritische Zusammensetzung und kommen als Ausgangsgestein für den Bergeller Granit i
Frage. Bergeller Tonalit enhält viele Relikte von Kalksilikaten, Ultrabasiten und Amphiboli
ten mit schönen Übergängen im oberen Val Sissone, und es wird vermutet, dass sie Aus
gangsgesteine andesitisch-basaltische Vulkanite des Kontinentalrandes und der Ozeani
schen Kruste darstellen. Es ist unwahrscheinlich, dass Bergeller Granit und Tonalit einma
ein homogenes Magma waren, was sich schon aus der Struktur ergibt. Tonalit und Amphi
bolit umhüllen den Granit mehr oder weniger mächtig auf allen Seiten (Fig. 6).
Wie erwähnt, hat der Granit Deckencharakter, wie die flachen Strukturen im Val Code
(Ligoncio) und Val Trubinasca und die Fenster von Bagni Masino, Valle del Ferro und Albi
gna bezeugen (Fig. 7). Die Wurzel des Granits ist am besten im Val di Mello erhalten, abe
geophysikalische Daten weisen auch hier darauf hin, dass sich der Granit nicht in grosse Tie
fen erstreckt.
Typisch für den Bergeller Granit, ausser in einem zentralen Kern, sind Alkalifeldspat-Gross
kristalle (Fig. 3). Es ist oft schwer zu entscheiden, ob sie Phaenokristalle oder Porphyrobla
sten darstellen. Jedenfalls wäre Kalifeldspat eine der letzten Phasen, die in einem granochio
ritischen Magma kristallisieren würde (CONDLIFFE und MOTTANA, 1975, 1976). Die Orien

tierung der Grosskristalle, oft in einer Matrix von mylonitischem Quarz und Glimmer, wird auf postintrusive Deformation zurückgeführt und nur in Ausnahmefällen auf magmatischen Fluss.
Wir stellen uns vor, dass während der Kreidezeit die N-europäische Platte und die Italienische Platte, die ursprünglich durch ozeanische Kruste voneinander getrennt waren, sich näherten (Fig. 15a). Bei dieser Kollision kam es zu intensiver Gebirgsbildung, während der der nördliche Kontinent (Pennin), ozeanische Kruste und eingeschuppte Mantelteile von südlichen Kontinenten (Austroalpin) überfahren wurde (Fig. 15b). Die versenkten Gesteine erwärmten sich und erreichten Metamorphosebedingungen nahe der Anatexis. In den Bergeller Alpen wurden in tiefen Bereichen (20–25 km) ursprüngliche Krustengesteine aufgeschmolzen und intrudierten nach oben in übergelagerte Krustengesteine amphibolitischer, granitischer, pelitischer und kalkiger Zusammensetzung. Die Mobilisierung umfasste vor allem granitische Gesteine (Bergeller Granit), aber auch tiefliegende Amphibolite (Tonalit). Im weiter südlich liegenden Adamello erreichten die Intrasionen ein höheres Niveau, nahe der Erdoberfläche und erzeugten eine enge Kontaktaureole in sedimentären und kristallinen Gesteinen der Südalpen.
Im Bergell war die Intrusion von andauernder Deformation begleitet, die dieselben Paralleltexturen erzeugte im Granit und Rahmengesteinen. Kristallisation des Magmas erfolgte zwischen 10 und 15 km, und in diesem Bereich ist es oft schwierig, Effekte der lokalen Kontaktmetamorphose von denen der anhaltenden Regionalmetamorphose zu unterscheiden. Gegenwärtig liegen Granit und Tonalit als relativ kleine Körper konkordant im Stapel der penninischen Decken, und es ist fraglich, ob die Wurzel des Granits noch existiert (Fig. 15c).

Da sich dieser Führer an ein internationales Publikum richtet, erscheint er in englischer Sprache. Neben einer deutschen Zusammenfassung enthält er ausführliche deutsche Abbildungslegenden und Exkursionsbeschreibungen.

Acknowledgments

With great pleasure I acknowledge the help and support of friends and colleagues during all the stages of preparation of this report. I am most indebted to the people of Val Bregaglia, to whom I dedicate this guide. They offered splendid hospitality during the time in the field, particularly my good friends Remo and Dina Maurizio with whom I spent many rewarding hours. Mr. Arpagaus from the EWZ generously let me use guardian houses and funiculars which greatly facilitated the fieldwork. Joan Bossart did a wonderful job in editing and typing versions of this manuscript, and credit for the excellent reproduction goes to Dr. J. P. Müller and U. Frey of the Natur-Museum in Chur.

1. Introduction

Easily accessible in the heart of Central Europe, the Val Bregaglia or Bergell Valley has long fascinated visitors with its history, rich wildlife and unique vegetation which contains elements of arcto-alpine and mediterranean affinity. But most are drawn by the beauty of its mountains, whether as climbers of the classic routes in Val Bondasca, Val Albigna and Val Forno, as hikers on the more gentle slopes of the north side of the valley, or simply as visitors to Soglio. This guide attempts to give an introduction to the formation of these mountains, their composition, and their possible geological history – both to the geologist and to the tourist with a background in the natural sciences. Whereas, for the sake of accuracy, some of the descriptions are fairly technical, I have tried to keep conclusions and the guide to excursions at a level sufficiently general so that they can be followed by the interested layman. I emphasize the area covered by the Sciora quadrangle, 1296 of the Geological Atlas of Switzerland. For those who prefer to read the native tongue spoken in the valley, a description of geologic features in Italian accompanies that map, which is available in bookstores through the Geological Commission. This area contains what are today known as the Bergell Alps and specifically the central portion of the Bergell granite. This conspicuous rock was already mentioned by STUDER (1851) and first recognized as a Tertiary igneous rock by STEINMANN (1913) and CORNELIUS (1913) on the basis of crosscutting relationships with the higher Peninne nappes. STAUB (1918) introduced the names «Bergell granite» and «Bergell massif» and portrayed it as a classical case of a postkinematic magmatic intrusion. This proposition was countered by DRESCHER-KADEN and STORZ (1926) who suggested on the basis of structural observations concordant recrystallization as an origin. The two opposite views became entrenched over the following 15 years (e.g., STAUB, 1924, 1958 versus DRESCHER-KADEN, 1929, 1940, 1948, 1969). In the late sixties CRESPI and SCHIAVINATO (1966), GYR (1967), MOTICSKA (1970), and H.-R. WENK (1970), initiated new detailed field investigations of the area. They were later joined by others in an attempt to provide quantitative data (e.g., TROMMSDORFF and EVANS, 1972; BUCHER, 1977; GAUTSCHI and MONTRASIO, 1978). In this new debate the Bergell granite, with its many facets, attracted world-wide attention.

The consensus among many of the present investigators of the area is that the Bergell granite and associated granitic rocks have not formed by fractionization of a parental basaltic liquid at great depth nor are they the result of purely metasomatic recrystallization without participation of granite melts. Remelting of preexisting rocks and anatexis with moderate chemical exchange, homogenization and only subordinate differentiation have likely been the principal mechanisms. A picture emerges of enormous complexities which are due to the interaction of processes such as granitization and igneous activity, highgrade regional metamorphism and deformation, related or unrelated to the contact metamorphism near the granite. All this takes place in a narrow space of less than 30 km and, depending on which observations from which locality are emphasized, conclusions can be reached which are diametrically opposite. Because individual observations are of such crucial importance, and because they vary to such a great extent, it is difficult to summarize this formation. In this guide I try not to sacrifice details for the sake of a uniform general model. Some researchers have suggested that knowing the detailed structure and the rocks of the area too well may be unproductive for genuine interpretation. I disagree, and maintain that every new observation adds to our understanding. My purpose here is to stimulate the reader to go into the field, look at the geology and collect specimens for later analysis. Thus, I suggest some field trips to familiarize the reader with crucial localities and geological settings. This is by far the most important goal of this publication. But first, it seems appropriate to give a brief description of the rocks, structural units and geologic processes which summarize results of recent research. Those who wish more detailed accounts are referred to the original literature.

2. Lithology

The following section describes the main rock types encountered in the southern Bergell Alps. The classification is based on petrography rather than tectonic units, since tectonic identification of these highly metamorphosed rocks is often ambiguous. In this zone with mobilized migmatites and igneous contacts, boundaries are often transitional and should be considered with this limitation in mind. A similar classification is used in the Sciora quadrangle of the Geological Atlas.

2.1. Pennine Nappes

As will become clear during the discussion of structure, Bergell granite is emplaced in Pennine nappes, concordantly to the south and west and discordantly to the northeast. These surrounding nappes consist of metamorphic rocks of various metamorphic grades ranging from greenschist to granulite facies and different compositions, including granitic, calcic, pelitic, carbonate, and ultramafic. This section deals with a brief petrographic description. For a more comprehensive (and perhaps more subjective) discussion of relationships the reader is referred to subsequent sections on structure and metamorphism.

2.1.1. Carbonate rocks and quartzites

Carbonate rocks are rare and, apart from the Cima di Vazzeda-Sissone area, are confined to narrow bands in other units. In the central Alps metamorphic carbonates have been traditionally attributed to the Mesozoic. While there are no fossils in the Bergell Alps to support this view it seems reasonable, particularly for carbonates at Cima di Vazzeda and Passo Scermendone (S. Corni Bruciati) which are associated with quartzites. This is typical of Pennine stratigraphy. About half of the carbonate rocks at Vazzeda-Sissone are dolomitic, the other half calcitic marbles which are transformed by the tonalite. Excellent contact metamorphic assemblages occur in the upper Val Sissone (coord. 776.5/129.5). An important assemblage in Val Sissone dolomite is brucite (probably pseudomorphs after periclase)-dolomite-calcite. In impure dolomites calcite-dolomite-spinel and calcite-diopside-forsterite are characteristic of high temperatures ($\approx 675°$ C) and tremolite-dolomite-forsterite-calcite of lower temperature ($<570°$C). Minerals of the humite group are commonly associated with forsterite (DEVERIN, 1937, E. WENK, 1963). In calcite rocks wollastonite, anorthite, grossular, diopside, vesuvianite are frequently found. A blue variety of diopside has been described by H.-R. WENK and MAURIZIO (1970). Phase relations and metasomatic transformations with emphasis on composition of fluid phases have been studied by BUCHER (1977). Marbles of the Bergell contact region contain some of the purest anorthite (An > 98) observed in nature (E. WENK et al., 1967). Rhodonite occurs with wollastonite in calcsilicate inclusions in tonalite at Casera Sceroia (coord. 765.85/124.4).

2.1.2. Leucocratic granitic gneisses

In the northwestern corner of the quadrangle large homogeneous units of Tambo gneiss are exposed. They constitute the easternmost extension of this nappe which contains predominantly granitic rocks and extends as far west as Val Mesolcina (25 km). The outcropping rocks in Val Bondasca are platy muscovite-biotite-alkalifeldspar plagioclase gneisses in the upper art. They are quarried at Promontogno and Soglio, providing excellent plates with almost perfect flat surfaces (Fig. 1). They are used in construction, masonry, and sculpture. Most of the roofs in the Bergell Valley are covered with plates of Tambo gneiss. The metamorphic age has been determined radiometrically by Rb/Sr methods on mica giving 25 m.y. (JÄGER and HUNZIKER, 1969). Originally they were Hercynic granites as established by U/Pb dates of zircons (GULSON, 1973). From Chiavenna to Promontogno all plagioclase is albite. But proceeding southwards through Val Bondasca biotite prevails over muscovite, and plagioclase increases in An content to 25 percent. The texture changes to augengneiss with alkalifeldspar porphyroblasts. Particularly near the contact with the underlying Gruf migmatites Tambo gneisses show a coarse porphyritic texture resembling megacrystic Bergell granite. The composition of Tambo gneisses is very uniform, corresponding to a true granite, whereas that of Bergell granite is rather granodioritic.

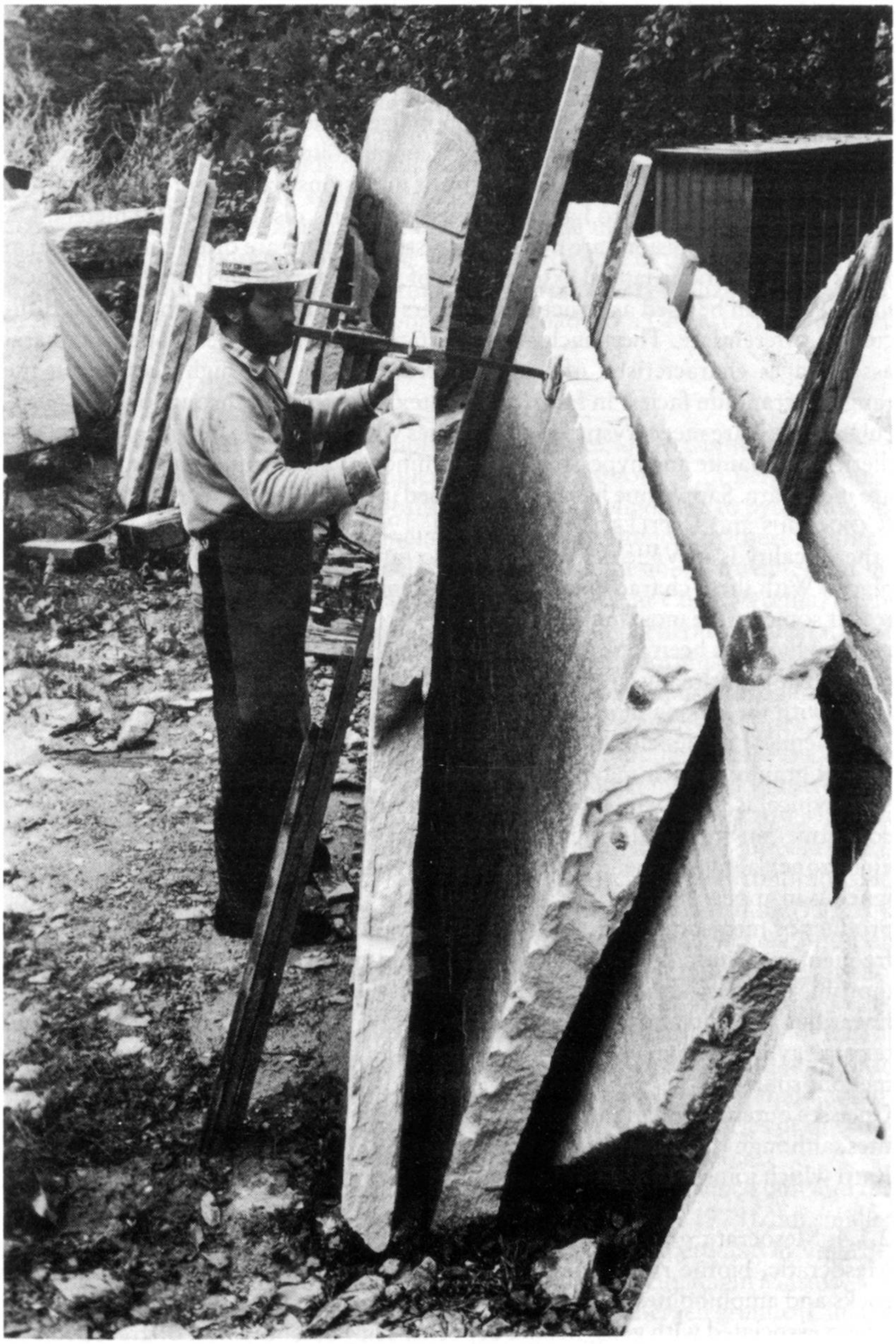


Figure 1. Large slab of Tambogneiss with perfectly planar surface. Schuhmacher quarry, Soglio. – *Grosse Platte von Tambogneis mit perfekter Spaltbarkeit und Oberfläche. Steinbruch Schuhmacher unterhalb Soglio.*

2.1.3. Migmatites of the Gruf complex

Tectonically the deepest units exposed in the Bergell Alps are isoclinally folded biotite-oligoclase (An 20–30)-alkalifeldspar (Or 90–95)-gneisses. Rocks are heterogeneous with leucocratic, partially mobilized phases, dispersed in mesocratic material which consists of biotite schists, amphibolites, more rarely ultramafics and calcsilicates in inclusions or swarms of inclusions sized from a few centimeters to a meter. It is rare to have no inclusions over a distance of 100 meters. On the other hand, inclusions are not evenly distributed but are often concentrated in zones of considerable lateral extent, some of which are outlined on the geological map. They can be used as structural markers in this unit which otherwise is difficult to differentiate. These inclusions, particularly pelitic types, contain mineral assemblages characteristic of high temperature and very high pressure in the range of granulite facies. In fact, local anatexis is common throughout. Of particular interest are megacrystic granitic phases which resemble Bergell granite. Cordierite, sillimanite and hypersthene are common, while corundum and sapphirine are more rare. Sapphirine has been described in detail from Coeder (760.7/125.2) (CORNELIUS and DITTLER, 1929; BARKER, 1964; H.-R. WENK et al. 1974) (Another locality is in Valle del Conco, but so far sapphirine has not been found in place.) With these characteristic mineral assemblages, the Gruf unit seems to represent some of the most highly metamorphic rocks in the Alps, presumably basement, which has been juxtaposed with higher Pennine nappes during a late stage of rapid uplift. Already REPOSSI (1916) pointed out the resemblance of parts of the series with the «Zona diorito-kinzigitica» = Zone of Ivrea of the southern Alps. The chemical composition of Gruf migmatites is remarkably similar to that of Bergell granite, which may indicate a genetic relationship (WENK et al., 1977). Very typical is the isoclinal folding which occurs on all scales. The Gruf complex constitutes an anticlinal structure as is documented by such marker beds as the Sivigia-zone, a hypersthene and hornblende bearing biotite-labradorite gneiss, igneous in appearance but, as can be seen in the riverbed south of Alpe Sivigia, the product of metasomatic alteration of an ultramafic breccia. Gruf gneisses show frequent mylonitic deformation which should be distinguished from postmetamorphic cataclastic shear zones. Lineations in the mylonites conform strictly with lineations and fold axes in the nappes. These mylonites show microstructures and textures typical of dynamic recrystallization and must be considered as high grade metamorphic rocks.

Gneisses outcropping in the window of Bagni Masino are related to Gruf migmatites, although it would be more precise to classify them with the zone of Valle dei Ratti which joins the Gruf complex to the south (MOTICSKA, 1970).

2.1.4. Mesocratic gneisses and pelitic schists

Mesocratic, biotite rich gneisses are not of large extent. Rather, like carbonate rocks and amphibolites, they form thin beds, many probably of metasedimentary origin associated with geosynclinal deposits. They are, however, of great petrologic interest because they contain index minerals which help define the metamorphic history (see section 5). Most of these plagioclase gneisses contain muscovite, sillimanite or fibrolite and garnet, more rarely perthitic alkalifeldspar. Large, well crystallized sillimanite is common throughout Val Codera, at the base of Val d'Albigna, in Val Sissone (with mullite, H.-R. WENK, 1983a) and Val Preda Rossa-Cataeggio. Along the eastern contact, enveloping the Bergell igneous rocks which contain sillimanite in pelitic inclusion zones, there is a zone of andalusite-bearing schists extending to Ciresc-Vöga in the north and Cataeggio in the south. There the border between the fields of andalusite and sillimanite intersects the field of kyanite which commonly contains staurolite. Near these two localities pelitic schists contain all three aluminosilicates in the same thin section (Fig. 2a), and it is likely that metamorphic conditions were close to those of the «triple point» defining temperature and pressure during metamorphic recrystallization. Excellent and easily accesible outcrops are along the new road from Ciresc to Vöga (coord: 762.3/132.75).

2.1.5 Mafic and Ultramafic rocks

Amphibolites occasionally carry biotite and chlorite, quartz is subordinate or missing, and some high grade samples in the contact zone with Bergell granite contain diopside. Plagioclase composition varies from oligoclase to bytownite depending on rock composition and metamorphic grade. Frequently there are intergrowths of calcic and sodic plagioclase (oligoclase-andesine-bytownite). Of interest is an oligoclase-labradorite-anorthite intergrowth at Corte Vecchia, Bagni Masino. Poikiloblastic and porphyroblastic textures are generally typical for the border zones, while in the central part of high-grade metamorphism, lepidoblastic fabrics dominate. There is considerable variation in the composition of amphibolites, particularly with respect to their Mg-content (H.-R. WENK et al., 1977), but the general elemental distribution is similar to that of amphibolites in the Ticino area farther west (E. WENK et al., 1974). Effects of contact metamorphism in amphibolites have been studied by H.-R. WENK (1979) and GAUTSCHI (1980) at Cavloccio-Maloja and in Val Ventina. They observed in the outer aureole coexisting pargasite and actinolite, indicating almost greenschist facies conditions. In these rocks H.-R. WENK (1979) found coexisting albite and anorthite (Fig. 2b). Some of the amphibolites show pillow structures (e.g., coord. 776.6/134.0), an extension of the zone discovered by Montrasio (1973). These pillow zones are accompanied by manganese (Mn) mineralization (Ferrario and Montrasio, 1976) indicative of their origin as oceanic basalts. Amphibolites in the vicinity of the tonalite contact both north and southwest of Rifugio del Grande show signs of in situ mobilization, sometimes with extreme crystal growth lending them a gabbroic character (coord. 777.3/130.3) and resembling a tonalite facies of the southern Adamello contact zone at Alpe Bazena (SCHIAVINATO, 1946).

Ultramafic rocks occur as two major masses, the Disgrazia-Malenco unit and the Chiavenna zone which extends into Val Bondasca (SCHMUTZ, 1978), but smaller lenses are common in Gruf migmatites (e.g., at Rifugio Vaninetti and in Valle del Conco and associated with amphibolites (e.g., near Cavloccio, Bagni Masino, Val Bondasca) and tonalites (Passo di Mello) and even within Bergell granite (Cima di Murtaira, Val Trubinasca). Most of them are predominantly composed of olivine (Fo 10–20) which often shows secondary hydrothermal alteration to talc, chlorite, brucite and serpentine. Enstatite is a common accessory mineral. TROMMS-

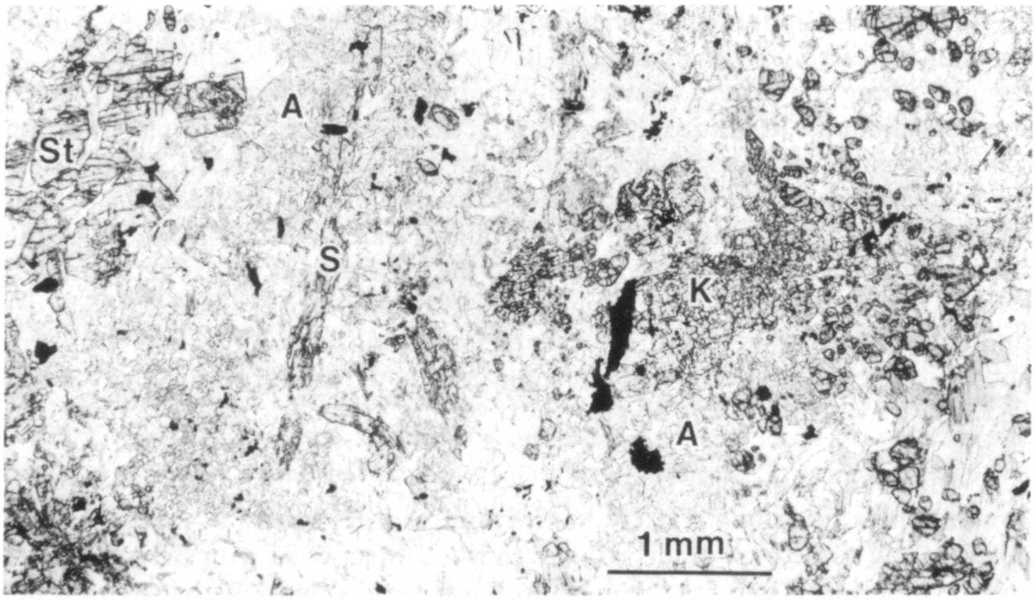


Figure 2a. Thin section of pelitic schists with three aluminosilicates from Cataeggio. K kyanite, A andalusite, S sillimanite, St. staurolite. Plane polars. – *Petrographischer Dünnschliff eines pelitischen Schiefers mit drei Aluminosilikaten von Cataeggio. Die ausserordentliche Assoziation entspricht dem Tripelpunkt, der Kristallisationstemperatur und Druck definiert (ca. 650 °C, 5.5 kbar). C Disthen, A Andalusit, S Sillimanit, parallel polarisiertes Licht.*

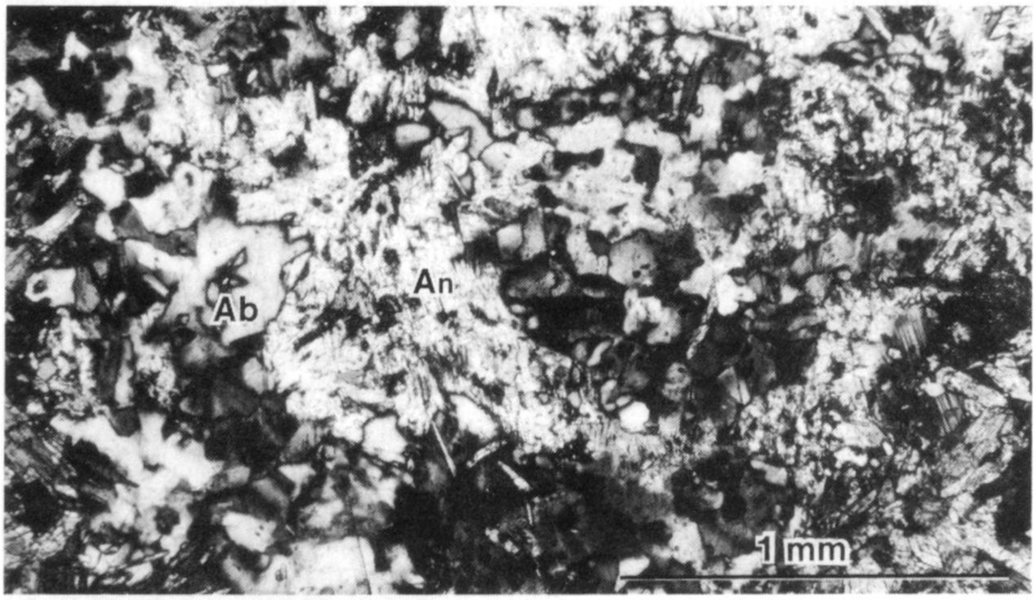


Figure 2b. Thin section of porphyroblastic albite-anorthite amphibolite from Alpe Cavloccio. Ab albite, An anorthite. – *Petrographischer Dünnschliff von Porphyroblastenamphibolit von Alp Cavloccio. Das Gestein zeigt Verwachsungen von Albit und Anorthit und dokumentiert, dass die beiden Endglieder der Plagioklasreihe bei Metamorphosegrad an der Grenze der Grünschiefer und Amphibolitfazies im Gleichgewicht sind. Ab Albit, An Anorthit. Gekreuzte Polarisatoren.*

DORFF and EVANS (1972) have studied effects of contact metamorphism of tonalite on the Disgrazia ultramafics and were able to map transformation of originally antigorite schists to olivine, talc-tremolite-olivine and anthophyllite-olivine schists approaching the contact. Good anthophyllite schists are exposed at coord. 776.4/123.8 and as an inclusion in tonalite at 776.3/127.75. Antigorite in the olivine fels at the southern contact of the Disgrazia massif is interpreted as secondary, replacing olivine. It is particularly well developed along shear zones. It is probably a fair assessment of today's view that at least the larger ultramafic bodies represent mantle fragments which were juxtaposed with ocean floor basalts and sedimentary rocks during the main phase of deformation in the Alps.

2.2. Bergell Complex

This unit includes a variety of igneous rocks of early Tertiary age (30 –35 m. y.). As will be discussed in the structure section (4), most of these rocks are deformed. Contacts are often gradational, and there is some ambiguity in defining units.

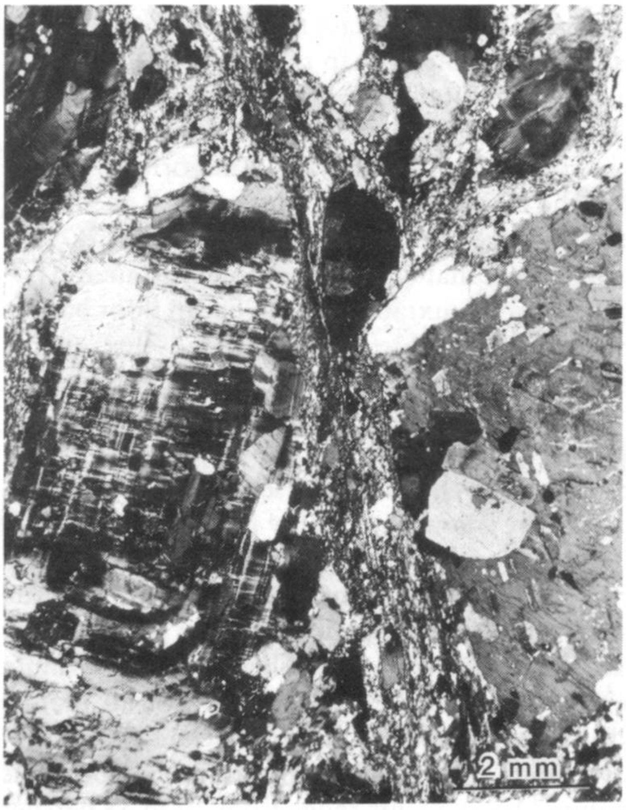
Bergell granite *(Bergeller Granit, Ghiandone)*, is either megacrystic or, in the central portion, equigranular. Its composition ranges from granite to granodiorite (see section 3). Large alkalifeldspars with an albite (Ab) content of 7–12 percent are perthitic and appear microscopically as orthoclase. They generally contain more or less euhedral and oriented plagioclase inclusions. Almost all granite samples show frequent myrmekitic texture. Alkalifeldspar associated with myrmekite and large megacrysts have similar chemical composition. Plagioclase is generally homogenous, and anorthite (An) contents range from 20 to 38 percent and average to 25, orthoclase (Or) content is about 1.5 percent and constant throughout the massif. Plagioclase occurs as rather large euhedral crystals and as small inclusions in alkalifeldspar, both having the same composition. Rarely (particularly in the northeast corner of the granite body) does plagioclase show either normal or oscillatory zoning.

The main femic mineral is a greenish-brown biotite partially altered to chlorite. Subordinate phases are hornblende and muscovite. Magnetite, apatite and allanite are common accessories.

Microscopic textures are typical of intense deformation (Fig. 3a). Many large feldspar crystals are broken and bent. Quartz is either strongly undulatory or flattened, with signs of dynamic recrystallization. In the northeast corner where deformation is least distinct, quartz shows undulatory extinction, but more commonly polygonization is more advanced, and we observe a fine recrystallized aggregate.

Feldspars are generally resistant to deformation, although some are bent and rounded. The euhedral contours of feldspars even in strongly strained granites explain why deformation in granite is easily overlooked in hand specimens. The alignment of megacrysts may be largely due to deformation, even though plastic deformation at high metamorphic grade and magmatic flow is sometimes difficult to separate (Fig. 3b). Deformation is most pronounced in the vicinity of the northern contact.

Figure 3. Megacrystic Bergell granite. – *Bergeller Granit mit Alkalifeldspat-Grosskristallen.*



a. Thin section illustrating deformation of fine-grained quartz and mica around the stronger alkalifeldspar megacrystals, crossed polars (Cant la Foja, N. Pizzo Cengalo). – *Petrographischer Dünnschliff, der die Verformung von Quarz und Glimmer um die mechanisch stärkeren Alkalifeldspäte illustriert. (Cant la Foja, N Pizzo Cengalo.)*

b. Aligned alkali feldspar megacrysts near the contact (Alpe Trubinasca). – *Orientierte Feldspat Grosskristalle im Granit nahe am Kontakt. Auch dies ist Augenschein für Deformation im festen Zustand. (Alpe Trubinasca.)*

Bergell granite frequently contains inclusions of mafic material, either biotite gneiss or hornblende-biotite gneiss (Fig. 4a). These are sometimes concentrated in swarms and represent probably mainly undigested relics, particularly where old gneissic textures are preserved. Zones of amphibolites included in granite at Gemelli, Sciora Dadent, Passo Zocca and along the northeastern contact are interpreted as roof pendants.
Dikes and pockets of mobilized megacrystic granite and augengneisses are found throughout the Gruf complex. A large dike extends from Btta. della Tegiola to Cima di Codera, but similar rocks occur as far west as Val Trebecca. They are indistinguishable in composition and texture from megacrystic Bergell granite and suggest that Gruf migmatites may be the source of this Tertiary igneous rock.
Whereas most Bergell granite contains conspicuous alkalifeldspar megacrysts, a central portion (Sciora-Cacciabella-summit of Cengalo, Cantone-Casnile) is equigranular but of similar composition. The transition between megacrystic and equigranular granite is gradational, extending over 100–500 m. The structure of the equigranular facies can be described as a flattened cylinder with a horizontal east-west trending axis. A similar smaller body exists southeast of Cima del Barbacan in Val Masino.
Very rarely does Bergell granite display a **spherical texture** such as at M. Rosso and at Cima di Murtaira. This texture is clearly different from classical spherical granites, e.g., in Scandinavia, and we attribute it to resorption effects of melanocratic material in leucocratic granite.
Cameraccio granite is a homogeneous granitic rock from the border between megacrystic Bergell granite and tonalite and is similar to the equigranular variety of Bergell granite. These two rocks may actually represent the same unit although the contact between Bergell granite and Cameraccio granite is usually sharp with occasional cross cutting relations, whereas the contact between megacrystic and equigranular Bergell granite is gradual.
Microgranites are associated with the central granite body and occur as large dikes or lenses both in granite and country rocks. In contrast to Bergell granite, microcline (Ab 5–10) is the dominant alkalifeldspar; plagioclase (An 15–30) is zoned and usually hydrothermally altered with large muscovite flakes in the core region and myrmekite is common. Quartz is deformed and undulatory; in some samples we observe recrystallization. Brownish-green biotite frequently shows halos around tiny inclusions. Muscovite is the dominant mica. Epidote minerals are present in most thin sections but there is generally no allanite. Microgranites associated with Bergell granite resemble in the field **Novate-granite** (PICCOLI, 1961).
Aplites differ from microgranites particularly by finer grain size and a clear excess of light mica. Plagioclase is less altered but more intensely deformed, with quartz extremely fine grained and strung out into highly flattened grains.
Pegmatites with graphic texture of alkalifeldspar and coarse perthite exsolution contain garnet, tourmaline, beryl (STAUB, 1924b), columbite and sporadically dumortierite (HUGI and HIRSCHI, 1925), cosalite, jamesonite, bismutinite, scheelite, apatite, niobite, molybdenite, ferrimolybdite, monazite, xenotime, triplite and uranophane. Rare minerals occuring in the Bergell Alps are mainly of scientific in-

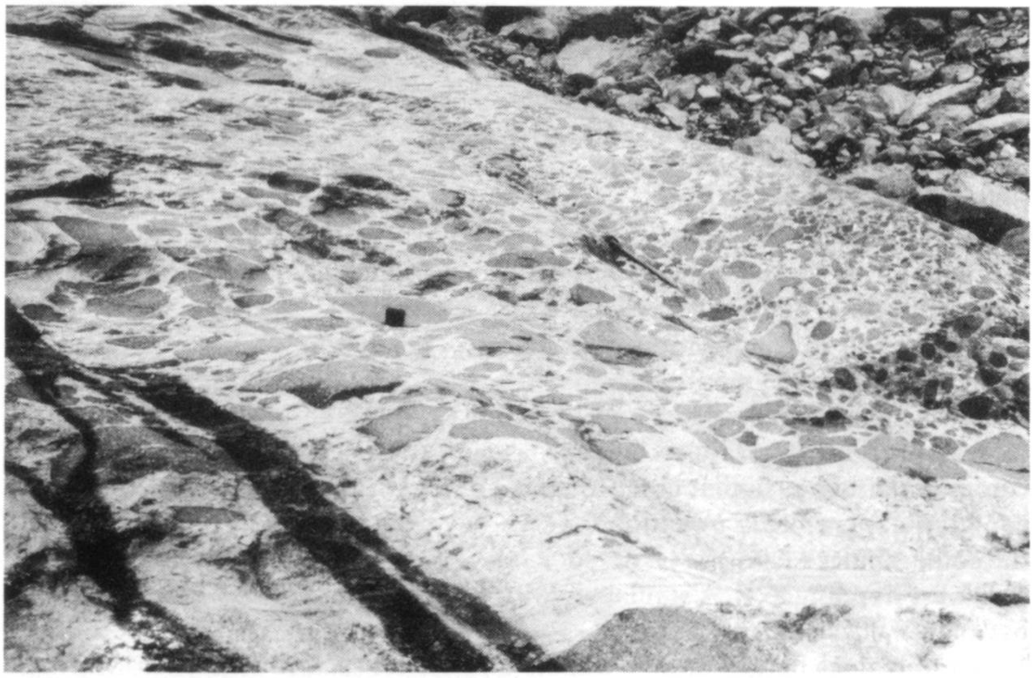


Figure 4a. Swarm of mafic inclusions at the base of Bergell granite (Alpe Cengalo). – *Schwarm von basischen Einschlüssen in Bergeller Granit. Es wird vermutet, dass diese nur teilweise verdautes Ausgangsmaterial amphibolitischer Zusammensetzung darstellen. (Alpe Cengalo.)*

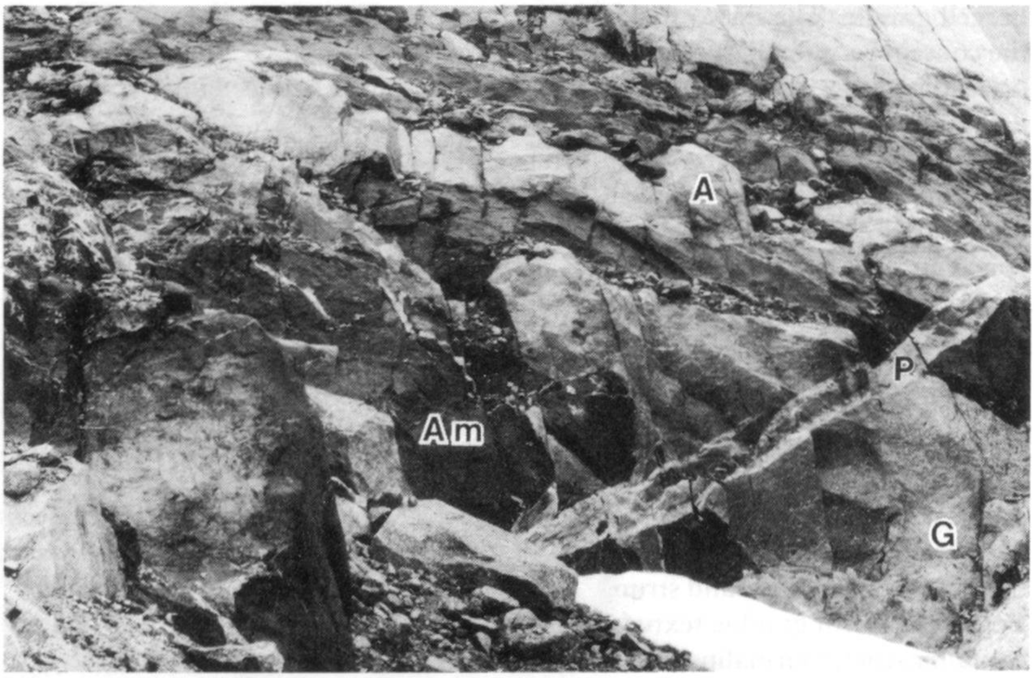


Figure 4b. Pegmatite (P) and aplite (A) dike crosscutting megacrystic Bergell granite and amphibolites (Am) near the roof of the granite (Val Porcellizzo, S.W. Passo di Bondo). – *Pegmatit und Aplitgänge durchschlagen Bergeller Granit. (S. W. Passo di Bondo.)*

terest. The most popular mineral, beryl, is not of gem quality, and other minerals occur in minute quantities. The museums at Stampa, Morbegno and Chiesa provide good collections. For more information the reader is referred to PARKER (1954, 1973), DEVERIN (1937), HIRSCHI (1924,1925), HUGI (1931), MAURIZIO and SCHATZ (1973), MAURIZIO (1973), MAURIZIO and LAREIDA (1975), MAURIZIO and WEIBEL (1982), and PEREGO (1979).
Pegmatites are often zoned with micaceous and quartzofeldspathic layers. An of plagioclase is 10–15 percent. They crosscut Bergell granite, Gruf migmatites and metamorphic rocks at the northern contact (Fig. 4b).
Bergell tonalites are strongly lineated hornblende-biotite gneisses, epidote, chlorite, sphene and often alkali-feldspar bearing. In composition most are tonalites as defined by STRECKEISEN (1976), a few, mainly in the western part, are quartzdiorites. Plagioclase ranges in composition from An 28 to An 85, but most compositions center around An 45–50. Apart from some unusual samples, normal and more rarely oscillatory zoning is not very pronounced. It extends from An 35 to An 55 with both calcic core and sodic rim being quite homogeneous. Alkalifeldspar is very pure, more so than in Bergell granite, and is generally recognized by myrmekitic texture. Quartz is present in most tonalite, often undulatory or recrystallized. There is a striking abundance of epidote, often with orthitic cores.
Tonalitic rocks envelope the granite on the whole northern, western and southern side, but their largest extent is in the south. They are separated from granite by a heterogeneous **transition zone** about 200 m wide where hornblende-rich and granitic material alternate as well as megacrystic and non-megacrystic rocks. The outer limit of megacrysts does not quite coincide with the first appearance of amphiboles. A good region to study the transition zone is Val Porcellizzo. Tonalite shows frequent inclusions of biotite gneiss, amphibolite, ultramafic rocks and marble, proposing oceanic-volcanic rocks as potential source materials. Of particular interest is an inclusion in tonalite of anthophyllite-cordierite-spinel schist west of Passo di Mello (coord. 776.30/127.75).
Hornblendite and **Hornblendegabbro dikes** have been described by NIEVERGELT and DIETRICH (1977) in greenschists of the Suretta nappe at Piz Lizun (corresponding to those units mapped by STAUB, 1921a, as «gabbro»), GAUTSCHI and MONTRASIO (1978) in Malenco ultramafics and associated gabbros belonging to the Margna nappe, and H.-R.WENK (1981a) in muscovite schists of the Margna nappe near Maloja pass. An occurrence in marbles at Cima di Vazzeda close to the granite contact may be related. In all these dikes large hornblende and, more rarely, plagioclase phenocrysts occur in a groundmass with poikilitic texture of amphibole and plagioclase. There is significant hydrothermal alteration, with secondary quartz and calcite probably replacing volcanic glass. These dikes show little deformation, and GAUTSCHI and MONTRASIO (1978) have documented imprints of contact metamorphism in dikes in the vicinity of the Bergell tonalite, suggesting that they are older. They may be related to the widespread, early Oligocene andesitic-basaltic magmatism in the western (DAL PIAZ et al., 1979) and eastern Alps (BECCALUVA et al, 1979), which has been compared with volcanism along continental margins, but at this point a relationship to Bergell igneous processes cannot be ruled out. Occasional gabbroic dikes crosscut Bergell granite in Upper Valle dei

Ratti, Pizzo Badile (south of summit), Val Forno east of Cima dal Largh, Sella del Forno and Torrone. It is uncertain whether they are related to the porphyritic dikes described above.

2.3 Geomorphology

The southern Bergell Alps are covered by 20 percent Quaternary, 10 percent ice and permanent snow and 70 percent of outcrops of crystalline rocks.

Alluvium is confined to relatively steep river fans and a few flat alluvial beds in the large river valleys in Val Bregaglia, Val di Mello and Val Codera. Terraces are only observed near Castasegna and Bondo, the latter probably representing an old lakebed which is partially eroded by the present river. Alluvium contains excellent selections of major rock types which is particularly important because igneous rocks are not easily accessible. A visit to streambeds before entering the backcountry is recommended. The Maira (e.g., near Pranzaira) and the river from Val Codera (near Novate) contain a splendid collection of polished boulders of Bergell contact rocks, Bergell igneous rocks, and Gruf migmatites.

Colluvium is common in higher regions with steep talus slopes, for example north of Cima di Codera, and covers alluvial beds in Val Codera and Val di Mello. Landslides have occurred in prehistoric times (e.g., one from Cima del Marc dammed the Maira below Bondo, creating a temporary lake), in historic times (the 1618 slide of Piuro-Plurs destroyed an important city), and recently (e.g, in Val Bondasca in spring, 1971). The entire hillside southwest of Bondo-Castasegna, which is a dip slope, is unstable, as indicated by slumping beds and sliding of quaternary units. Buckling of gneisses and sagging hillslopes resulting in flat areas and even subsidiary valleys parallel to the slope are well exposed along the road from Bondo to Ciresc. The whole rock complex has remained more or less coherent. Movements were possibly initiated by lubrication on ultramafic layers (Ganda Rossa).

In the Pleistocene all of the Bergell Alps were covered by glaciers. **Moraines** are prominent features, not only in the still glaciated valleys of Forno, Albigna, Bondasca and Preda Rossa but also as terraces along Val Bregaglia, which have been used since medieval times as cattle pastures. Boulders of Bergell granite reached various places on the north slope of the Bergell valley, but they are only locally concentrated, such as at Durbegia, Creista (large blocks), San Pietro and Soglio. In these moraines Julier granite is generally much more common, indicating that the total extent of Bergell granite was rather limited.

Terminal moraine walls depict a pattern of stepwise regression. Some are marked on the map with dates which have been assigned on the basis of old topographic maps and photographs. During the last years the Forno glacier has been receding more than 30 meters each year, at a time when most other Swiss glaciers have been advancing (KASSER and AELLEN, 1979; MAURIZIO, 1981). The recession is partially due to surface contamination with dark, heat absorbing soot particles from nearby industrial centers in Italy. The central and lateral moraines of the Forno and Albigna glaciers show very little mixing of components during transport, with dominantly carbonate components from Cima di Vazzeda and hornblende diorite in Albigna dominating for many kilometers. Older moraines are covered by vegetation. The Pleistocene Bergell glacier originated in the Upper Engadine, as is documented by boulders of Bernina and Julier granite and unmetamorphic limestones. The steep gradient southwest of Maloja must have given rise to impressive ice cascades, accompanied by high energy glacial streams which produced large glacier mills, some still preserved near the castle ruins at Maloja. Limestones in the moraines from the Upper Engadine were used for lime production and ruins of furnaces can still be found in many places (MAURIZIO, 1972). While the topography on the Sciora quadrangle has been greatly influenced by glaciers, it is quite different from the morphology of Adamello where large, U-shaped valleys such as Val di Genova and Valle di Nambrone, carved into solid granite, are reminiscent of the morphology of extensive granite massifs. In contrast, the Bergell morphology is structurally controlled. Valle del Forno, Val Preda Rossa and Val Sissone are parallel to the contact, while Val di Mello is parallel to the strike in the foliated rootzone of the granite.

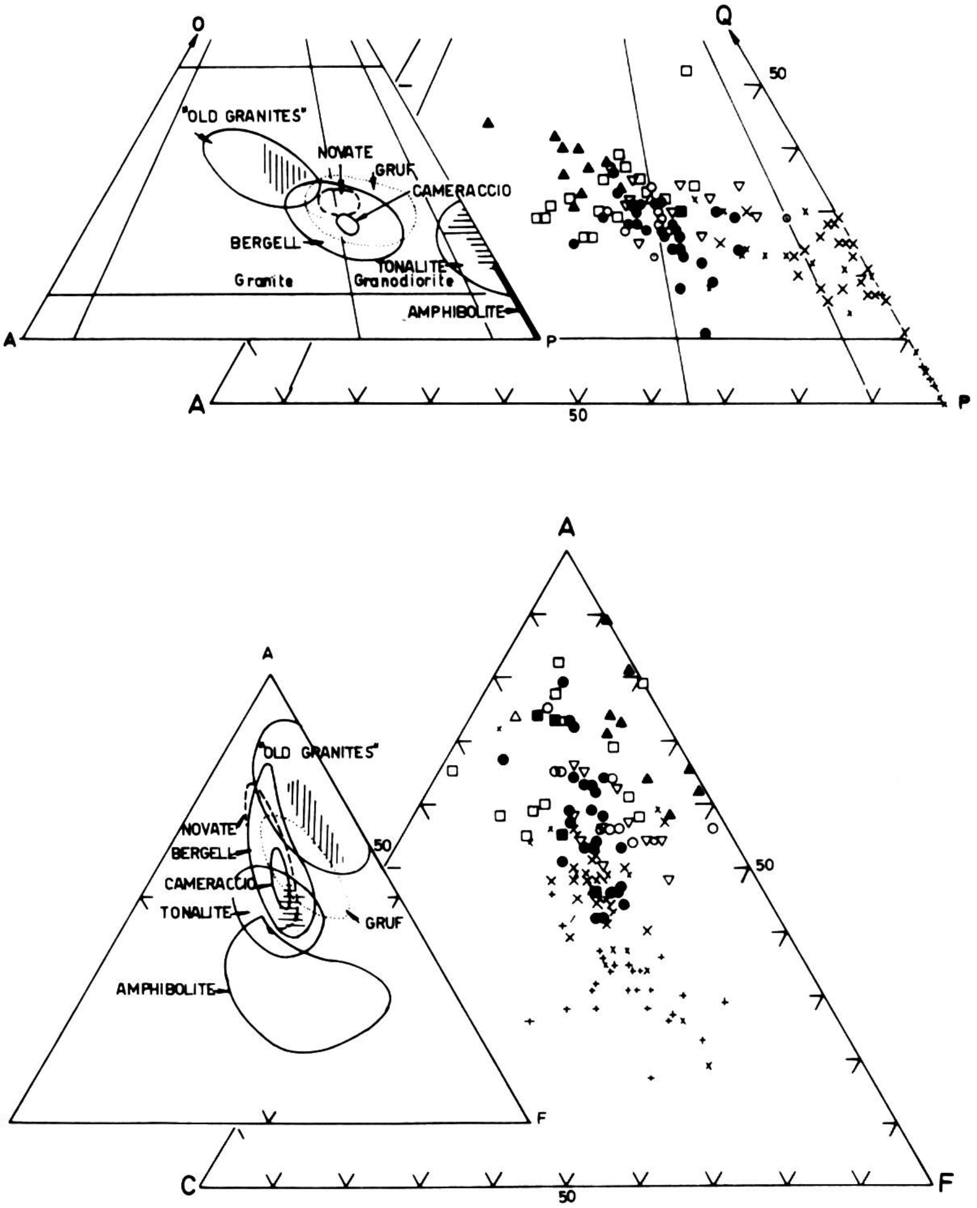
The morphological evolution of the Bergell area in Tertiary is a fascinating topic which so far has received little attention. It lies outside my expertise but a few comments seem appropriate, if only to entice a geologist to undertake a comprehensive study, which is of great significance for modeling of structural movements in this sector of the Alps. STAUB'S (1952) imaginative study can serve as a basis for new quantitative investigations which ought to be based on clast distributions in alluvial terrace deposits, moraines and molasses north and south of the Alps. The Bergell Alps are situated at the intersection of watersheds of the Po, Inn, and Rhine, and the location of this point changed considerably during Tertiary times. Clasts from Bernina granites are found in Oligocene beds of the northern Alpine molasse. In the Pliocene the Maloja pass region became a classic example of two competing river systems, the Inn and the Maira (HEIM, 1878). The Inn system, with a gradient of only 0.8 percent between Maloja and Finstermünz (900 m over 100 km), extended at least into Val Maroz and Val del Cam before it was eroded by the Maira system, with a high gradient of 6 percent between Maloja and Chiavenna (1700 m over 20 km). In earlier Tertiary times there was competition between longitudinal rivers extending parallel to the Alpine chain *(Längstäler)* and those perpendicular to it, but considering the tremendous erosion, identification of ancient river systems based on recent topography is extremely tenuous, and STAUB'S (1952) reconstruction must be taken with caution. In the Bergell Alps the north-south and east-west patterns are both very pronounced. The Oligocene clasts of Bergell granite in conglomerates near Como (PFISTER, 1921; CITA, 1957, GUNZENHAUSER, 1985) will be commented on later.

3. Chemical composition of granitic rocks

The chemical composition of granitic rocks, those young Tertiary ones discussed above and older granitic rocks in the nappes, have been studied by MOTICSKA (1970), RICHARDSON, et al. (1976), and WENK, et al. (1977).
Prealpine granites in the upper Pennine nappes are generally rich in K, poor in Ca, Mg, Fe. SiO_2 ranges from 68 to 77 percent and averages 72. All these rocks plot in the field of normal granites in the normative Q-P-A (quartz, plagioclase, alkali-feldspar) diagram in Figure 5a.
As pointed out first by WEIBEL (1960), megacrystic «Bergell granite» is not a true granite but occupies a broader field ranging from granite to granodiorite, which is distinctly different from old granites (Fig 5a). There is minor variation in composition and no regional pattern can be deciphered, neither for major elements (H.-R. WENK et al., 1977) nor for rare earths (MOTTANA et al., 1978). Local heterogeneity may have been caused by partial differentiation from a homogeneous magma, as indicated by good correlations of SiO_2 and CaO. But chemical heterogeneities of the original material contributed to the geographically irregular scatter of compositions. No intrusive relations are observed in the field between megacrystic types of different compositions. Also there is no chemical difference between the equigranular variety which composes the central part of the body and the megacrystic type. Cameraccio granodiorite is a chemically very homogeneous, equigranular variety and plots in the center of the field for Bergell granite. Dikes and small masses of megacrystic granite within Gruf migmatites are similar and represent either extensions of Bergell granite itself or evidence for in situ formation of granite from migmatites. There is a striking similarity between Gruf migmatites and Bergell granite (e.g., CHRISTIE, 1979).
Novate granite resembles Bergell granite in composition, but the few analyzed samples show a considerable spread with a rather good linear correlation in the A-C-F (aluminium, calcium, ferromagnesium) diagram which is different from other granitic rocks (Fig. 5b). We regard it as evidence for contamination of this granite with country rocks, which agrees with field relations showing numerous inclusions (PICCOLI, 1961) and discordant U-Pb ages of zircons (GULSON and KROUGH, 1973).
The average composition of tonalite» is intermediate between that of Bergell granite and amphibolite and statistical analysis demonstrates that it is more closely related to the latter. There is no clear regional zonation but a tendency for a melanocratic type rich in CaO near contacts with amphibolite and in the southwestern extension. Tonalites from the central portion of the massif are similar in composition, suggesting that this rock suite has been thoroughly homogenized before its emplacement. Inclusions of tonalite in Bergell granite are exceptionally rich in K_2O and MgO. It is noteworthy that about half the analyzed Bergell tonalites have less than 20 percent quartz in a Q-P-A diagram (with Q+P+A = 100 percent), particularly those in the western part, and ought to be classified as quartz diorites. For historic reasons, and without reference to actual composition, we use the terms Bergell tonalite as well as Bergell granite to describe genetically related groups of rocks. The Italian terms serizzo and ghiandone may be more ap-

a

b



■ Novate Granite
▽ Gruf Migmatite
▲ «Old Granites»
X Tonalites
● Bergell Granite
⊙ Inclusion and Contact
○ Microgranite
□ Aplite and Pegmatite Dikes
x Inclusion and Contact
+ Amphibolites

Figure 5. Q-P-A (a) and A-C-F (b) diagrams illustrating the chemical composition of granitic rocks in the Bergell Alps (WENK et al., 1977). – *Die chemisch-mineralogische Zusammensetzung der granitischen Gesteine in den Bergeller Alpen dargestellt in ternären normativen Diagrammen (WENK et al. 1977).*
(a) Quarz-Plagioklas-Alkalifeldspat (Q-P-A). (b) Alkalien-Erdalkalien-Eisen/Magnesium (A-C-F).

propriate but are not well established. Notice the difference in composition between Tertiary igneous rocks of the Bergell and those of the Adamello which are in general depleted in alkalies (BIANCHI et al., 1970).
Various processes contributed to the formation of Bergell tonalite. Mobilization by partial melting of amphibolites is obvious in Val Sissone along the northeastern contact. Mixing of amphibolite material with aplite and pegmatite dikes such as at Monte del Forno and especially with pelitic and leucocratic gneisses changed the chemical composition. Diffusional processes reduced the compositional gradient between tonalite and Bergell granite. Addition of volatile elements such as K and Si to tonalite has resulted in crystallization of quartz, alkalifeldspar and biotite. Metamorphic recrystallization of these rocks may have altered original igneous fabrics considerably. There has been some chemical interaction between granite and tonalite, but it is likely secondary, and these two rocks never formed a homogeneous magma. This follows from field evidence with the lack of large-scale intrusive relationships between the magma types, the clear compositional separation emerging in ternary diagrams and particularly in a statistical analysis. It is further corroborated by the large content of Al_2O_3 and the common presence of epidote in tonalite which is unusual for igneous rocks.
From melting experiments of CONDLIFFE and MOTTANA (1975, 1976) with Bergell granite and tonalite extrapolated to higher pressure a solidus temperature of 670^0 C for Bergell granite and $700–730^0$ C for Bergell tonalite can be estimated for pressures between 3 and 7 kbars. At lower pressures it becomes increasingly difficult to mobilize a tonalitic magma which may explain why tonalite is common at the base and root of the granite body, whereas amphibolites persist at the roof in the Forno-Murtaira area.

4. Structure

In this section an attempt is made to put the various rock units described above into a tectonic framework. There is no question about the identity of some of these structural units, but others are more difficult to classify, since they do not bear a tectonic label in the field. This is particularly true for the high grade metamorphic units on the northeastern side of the granite belonging to the higher Pennine nappes Tambo, Suretta and Margna, and the tectonic map (Fig. 6) ought to be viewed with this in mind.
The Bergell granite has long been presented as a textbook example of a young, post-tectonic intrusion that penetrates the nappe structures like a cancerous tumor. This view was challenged by DRESCHER-KADEN and STORZ (1926), who published a structural map of the northern part of the granite which indicates that foliations and lineations in country rocks and granite are parallel. But only recently has detailed structural work been carried out which confirmed Drescher's observations and led to a new tectonic concept (MOTICSKA, 1970; H.-R. WENK, 1970, 1973).
The general structure can best be explained with maps of planar and linear directions. The overall structural trend in the Bergell Alps is outlined by the contact

Legend for tectonic map

Tertiary igneous rocks

Novate granite and granitic dike swarms

Bergell granodiorite:

– megacrystic

– foliated

– fine grained

Bergell tonalite

Sondrio intrusives

Rocks associated with contact

Amphibolites

Metasedimentary rocks (mainly pelitic)

South alpine

Crystalline basement

Austroalpine

Tonale series

Err-Bernina nappe

Pennine

Margna nappe

Suretta nappe

Tambo nappe (orthogneisses and sedimentary cover)

Intermediate zone Tambo-Gruf

Malenco and Chiavenna ultramafics

Gruf migmatites

Mylonitic facies

Adula units

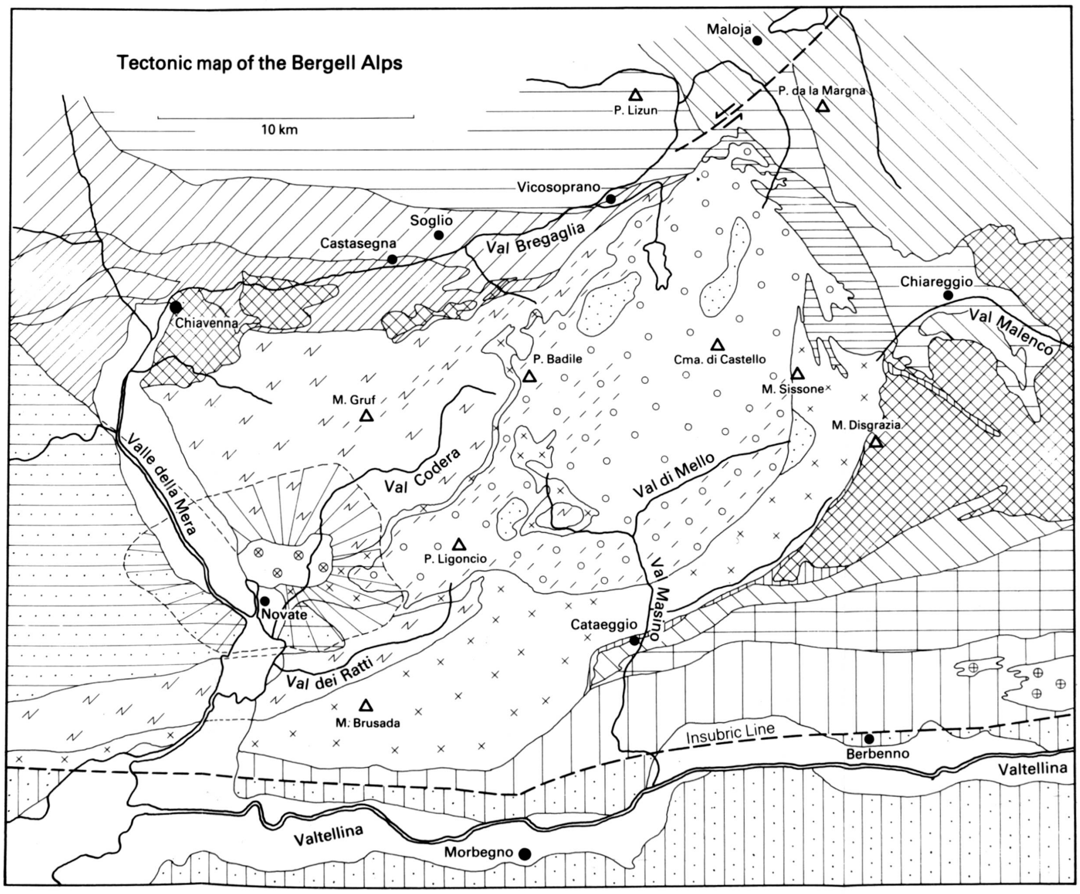


Figure 6. Tectonic map of the Bergell Alps. – *Tektonische Karte der Bergeller Alpen mit Angabe der wichtigsten strukturellen Einheiten.*

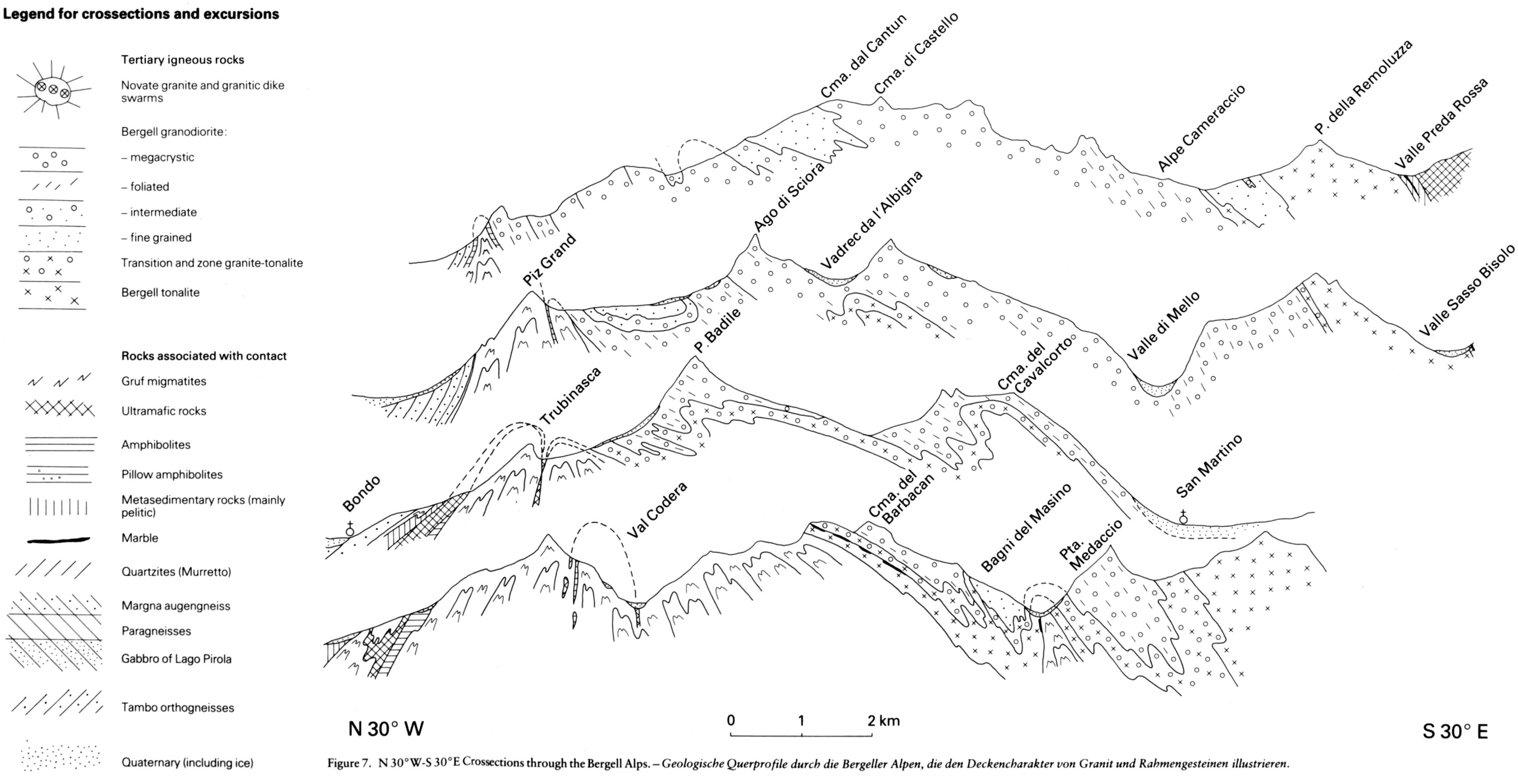


Figure 7. N 30°W-S 30°E Crossections through the Bergell Alps. – *Geologische Querprofile durch die Bergeller Alpen, die den Deckencharakter von Granit und Rahmengesteinen illustrieren.*

between the Bergell granite composing the central part and the metamorphic rocks surrounding it. The west-southwest-east-northeast strike in the west turns southeast-northwest in the east and bends southwest-northeast in the southeast, with steeply dipping fold axes in the Preda Rossa area.

4.1. Frame of the granite

The following discussion of tectonic units begins at the top and proceeds towards the bottom. The tectonic map (Fig. 6) and the cross sections (Fig. 7) should be consulted for reference.

The **higher Pennine nappes** (Sella, Margna and Suretta) are characterized by rocks of medium to low metamorphic grade even in the vicinity of the Bergell granite. The Margna nappe rests above the Bergell granite, and it is not clear if it is in direct contact with it anywhere, although it shows some effects of contact metamorphism.

The **Suretta nappe** is composed primarily of muscovite gneisses, some of granitic origin, in its lower portion, and of metasedimentary rocks in the higher portion. The lowest, clearly identifiable sedimentary rocks are bands of limestone (probably Triassic) and quartzite; the higher units are Jurassic shales, sandstone, and chert, interspersed with ultramafics, all of them metamorphic (Piz Duan). The Suretta nappe is extensively deformed in the vicinity of the granite and may surround the granite as a strongly sheared anticlinal structure to the north and east, but several thrust faults obliterate any direct evidence that these petrographically similar structural units belong together. The Suretta, as well as the Margna nappe, appear to have been emplaced as rather rigid blocks, and the heterogeneity in structure and metamorphic grade – apart from structures close to the Bergell granite – reflects imprints from older geological events. Fault offsets at Maloja and Muretto mark the rather brittle character of the material (WENK, 1983b).

The **Tambo nappe** extends from Piz Tambo in the north almost to the Bergell granite. It is composed of rocks of predominantly granitic composition with muscovite-biotite granites and augengneisses of Hercynic age (GULSON, 1973). The granite layer is about 2 km thick in the Chiavenna area but thins rapidly eastward and disappears, strongly sheared, east of Vicosoprano. Foliations in the gneisses dip uniformly, about 45^0 to the north. Only in the vicinity of the granite does the inclination become steeper, and beds are overturned north of Stampa and Vicosoprano (compare crossections in Fig. 7). The thrust contact with the underlying Gruf migmatites is marked by fine-grained mylonites. A metasedimentary layer, with strongly deformed, probably Triassic marbles, quartzites and rauhwackes and aluminous schists (well exposed south of Passo della Prasignola) constitutes the upper portion of the Tambo nappe.

An entirely different style of deformation begins underneath the Tambo nappe. The **Gruf complex,** composed mainly of magmatitic gneisses, is characterized by isoclinal folding (Fig. 8). The orientation of lineations and foldaxes is well-defined. On the average they dip 15^0 to the northeast. Poles to the foliation lie on a great circle around the lineations (Fig. 9a). To the west, the isoclinal belt forms a broad anticlinorium that narrows into an antiform bordering the Bergell granite to the north. Many of the isoclinally folded Gruf migmatites contain inclusions and some larger bodies of micaschists, labradorite-amphibolites, ultramafics and rarely calcsilicate rocks with mineral assemblages indicating metamorphic conditions close to granulite facies.

To the south the granitic rocks are bordered by the rootzone composed of sericitic gneisses and granites, the latter resembling Bernina granites. They are all sheared and show signs of retrograde transformations. The tectonic identity of those units is uncertain but most likely they represent upper Pennine and Austroalpine units.

Figure 8. Isoclinally folded Gruf migmatites (southwest of Piz Grand, Val Bondasca). – *Isoklinal verfaltete Gruf Migmatite mit mobilisierten Phasen, die den Grossteil des nördlich-westlichen Granitkontaktes darstellen. (SW Piz Grand, Val Bondasca.)*

4.2. Tertiary granitic rocks

The young alpine granitic rocks, lie conformably in most places in this stack of Pennine nappes. At the tectonic level, the Bergell granite, which overlies the Gruf complex to the south of the large anticlinal structure, corresponds to the Tambo nappe which overlies it to the north. In fact, the granite is geometrically best described as a nappe, as is seen in the windows (Val Masino, Valle del Ferro and Albigna) which expose lower tectonic units. Pervasive mylonitic microstructures, particularly of quartz, indicate that emplacement of the granite nappe took place in a solid or semisolid state. A petrographic study of thin sections suggests that the alignment of K-feldspar megacrysts which is a pronounced feature in many places (Figure 3a) is mostly the result of plastic deformation rather than magmatic flow (H.-R. WENK, 1973). The material was more ductile and at higher temperature in the southwestern part than in the northeastern region where deformation was brittle and parts of the original igneous contact are well preserved. A quantitative comparison of measurements of foliations and lineations in granite (Fig. 9b) with an equal number of measurements in migmatites and gneisses shows a striking similarity (Fig. 9a). The anisotropy is also expressed in the magnetic properties (HELLER, 1972). There is no doubt that the migmatites and the granite were deformed in the same strain field and that isoclinal folding may also be the dominant style of deformation in the granite despite its plate-like shape. Thus lineations, fold axes and foliations in the granitic rocks are generally parallel to those of the country rocks; but particularly in tonalite, there are exceptions to the general gentle east dip of fold axes. Lineations in the tonalite bend around the Bergell grannite in the northeast and plunge steeply northwards with typical whirlpool structures in Val Preda Rossa and east as well as west of Cevo. In the southern massive tonalite complex fold axes plunge westward. The linear texture of tonalite given by the orientation of hornblende prisms (MOTICSKA, 1970), displays great complexity and is probably related to mobilization processes and the original emplacement of the tonalite body. However, a detailed structural analysis is lacking.

Contact relations around the Bergell granite are rather complicated and variable. The direct contact rocks are on the whole mesocratic or mafic, either tonalite (hornblende-quartz diorite) or amphibolite, often accompanied by lenses or bands of ultramafic and calcsilicate rocks, and biotite schists. Only rarely and locally is there a direct contact of granite with Gruf migmatites (Val Bondasca-Cengalo) or gneisses and diopside bearing quartzites of probably Suretta affinity (Murtaira-Forno).

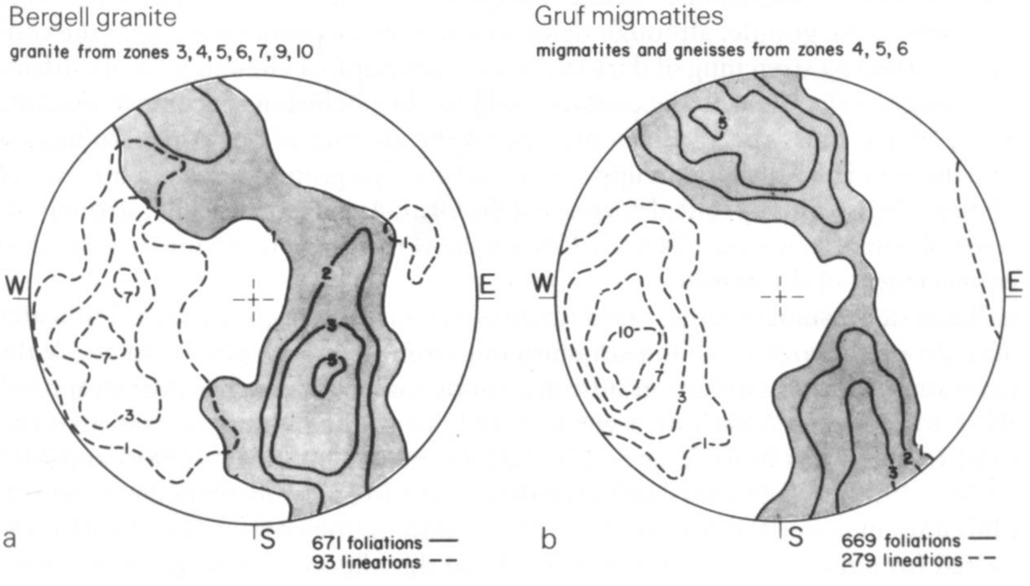


Figure 9. Structural elements in Gruf migmatites (a) and Bergell granite (b) plotted in equal area projection on upper hemisphere. Note the similarity of the two diagrams (WENK, 1973). – *Strukturlemente in Gruf Migmatiten (a) und Bergeller Granit (b), dargestellt in flächentreuer Projektion, obere Halbkugel. Die Verteilung von Lineationsrichtungen und Schieferungsflächen in den beiden Gesteinen ist fast identisch, was nur damit erklärt werden kann, dass beide im gleichen Deformationsfeld verformt wurden. (*WENK*, 1973).*

The eastern contact is well exposed and easily accessible at Sella del Forno-Monte Rosso (from Capanna Forno) and Vedrec Piatte di Vazzeda and upper Val Sissone (from Chiareggio-Capanna del Grande). The country rocks immediately adjacent to the granite show features typical of igneous activity, with crosscutting dikes, angular inclusions, roof pendants and contact minerals such as andalusite and mullite in pelitic schists, and diopside, wollastonite and anorthite in calcsilicate rocks (see e.g., WEIBEL and LOCHER, 1964). Granite and contact rocks have been thrust northeast, producing subvertical and west dipping shear zones in the granite and an anticline in the adjacent nappes well visible in the lower Forno valley and northwest of Muretto Pass. This anticline is quite conspicuous in the field and may represent squeezed relics of the Suretta nappe.
In the area Cima di Murtaira-Lavinair Crusc a large mass of country rock has been affected by the granite intrusion. Pelitic schists contain prismatic andalusite porphyroblasts which are younger than the mica fabric. Pegmatite, aplite and granite veins and dikes extend as far as Piz Salacina to the northeast. These contact metamorphic rocks are offset by a fault from the low grade metamorphic rocks of the Margna nappe. In fact, faulting along the line Isola-L'Ala-Salacina with extensive folding of marbles on the southern side is viewed as due to strain adjustments during emplacement of the granite. It is unlikely that faulting is an extension of the post-Alpine Engadine line (H.-R. WENK, 1983b, Fig. 10).
Progressing west (south slope of Val Bregaglia), the sequence of metamorphic rocks becomes increasingly strained and diminishes into a thin band of cordierite-sillimanite-andalusite-micaschists and amphibolites with occasional calcsilicate and ultramafic inclusions. Strong effects of plastic deformation are visible throughout the granite, although deformation is more pronounced near the contact, marked by stretching of dark inclusions and parallel alignment of alkalifeldspar megacrysts. Close to the contact hornblendite inclusions become abundant. Some of the most spectacular outcrops of the contact are at Alpe Trubinasca (northwest Piz Badile) and in upper Val Codera. The granite rests as a horizontal plate on the isoclinally folded gneisses of the Gruf. A metasomatically, strongly altered ultramafic breccia (ARTUS 1959) on the thrustplane is obviously related to emplacement of the granite.
In Bagni di Masino, tonalites, amphibolites, migmatites, mica schists, calcsilicates and ultramafic rocks – all indistinguishable from rocks in Val Codera and Valle dei Ratti – appear **below** the granite in an anticlinal structure. The petrography of these rocks which constitute a window and not roof pendants, as was assumed until recently, has been described by CRESPI and SCHIAVINATO (1966) and MOTICSKA (1970). A subsidiary small window, exposing only hornblendites and amphibolites in upper Val di Ferro, is a direct continuation of the Masino rocks, expected from the regional 20^{0} northeast dip of the fold axes. Thus the plate structure extends towards the central part of the granite, possibly as far as Albigna. Two large moraines which reach the glacier surface at the junction of the Castello and Ferro glaciers contain abundant amounts of hornblendites and hornblende gabbros, and therefore a window, presently covered by the glacier, may exist in the back part of Val Albigna.

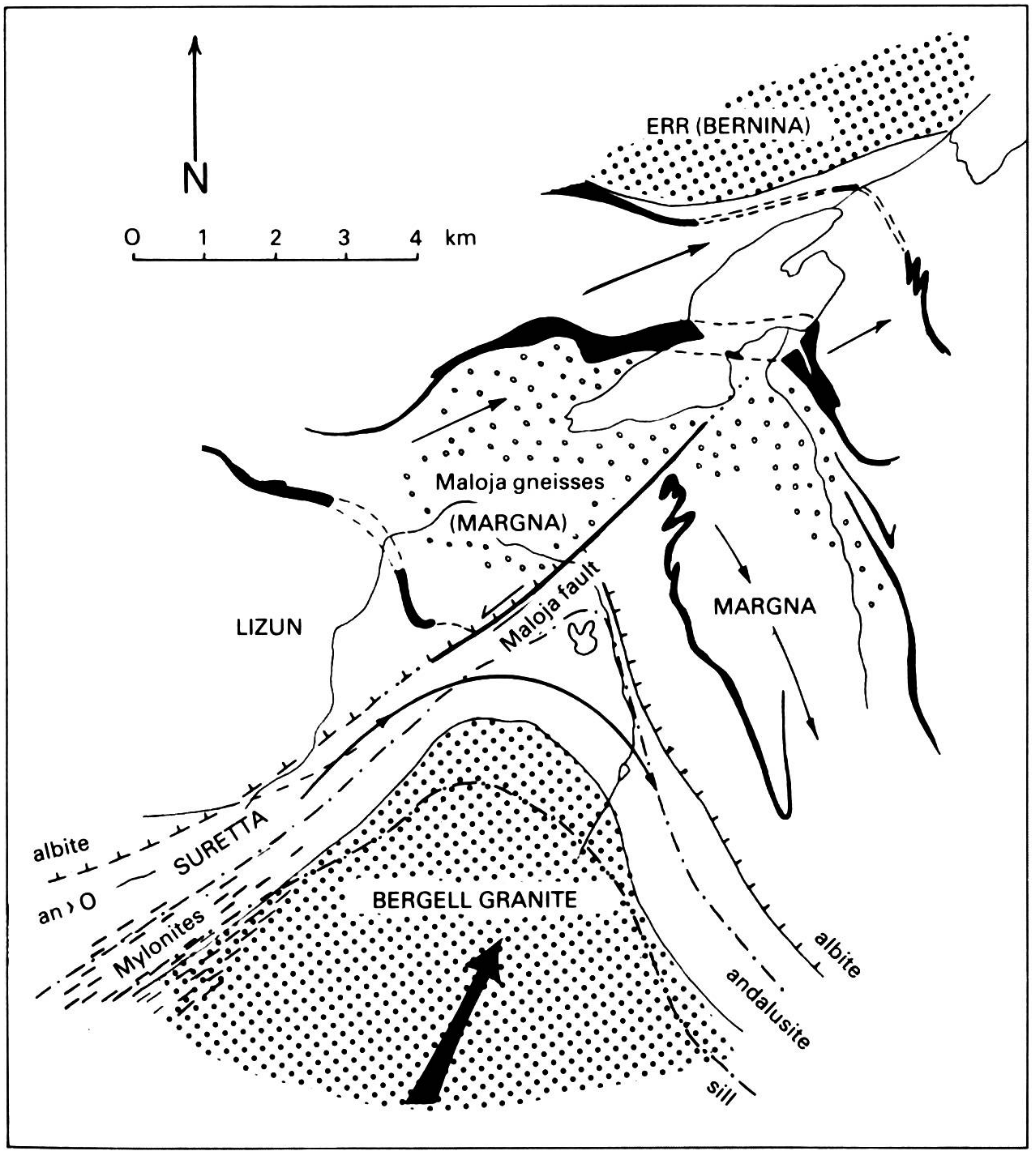


Figure 10. Structural map of the northeast corner of the Bergell complex (modified from WENK, 1984). – *Strukturkarte der Nordostecke des Bergeller Komplexes. Angegeben sind die wichtigsten Gesteinseinheiten (granitische Gesteine punktiert, Karbonatgesteine schwarz), Faltenachsen (kleine Pfeile) und einige metamorphe Isograde. Der grosse Pfeil deutet die mutmassliche Richtung der Platznahme des Bergeller Granits an. Die Malojastörung und die intensive Verfaltung im Margnagebiet wird auf Verformung des Rahmens während der Platznahme zurückgeführt (WENK, 1984).*

The southern border of the Bergell granite consists of a synclinorium in the fairly inaccessible mountains south of Valle di Mello. A narrow syncline of megacrystic granite in upper Valle della Spluga-Alpe Merdarola progresses eastwards into a broad isoclinally folded structure . Isoclinal folding of these rocks is documented by the gradational contact of Bergell granite with tonalite.

These macroscopic structures, ascertained from field evidence, are summarized in the cross-sections (Fig. 7). Excellent three-dimensional outcrops leave little freedom for the interpretation of the geological map. Profiles and structural data indicate strongly that the **Bergell granite is not a postkinematic intrusion.** Throughout, the granite has been deformed – less in the center than near the contact – in a similar strain field as the country rocks. Therefore, formation of the granite had to precede or accompany these tectonic events which are most likely connected with a major phase of the Alpine orogenesis in the area.

Although part of the Bergell igneous rocks are granitic, there is a large portion of hornblende-quartz-diorite and tonalite, most extensive in but not confined to the southern part. At Alpe Sissone, fine-grained amphibolites change into coarse hornblende gneiss of gabbroic character over a distance of a few hundred meters. Some spectacular outcrops near Capanna del Grande and above Alpe Sissone display hornblende crystals up to 5 cm in size. Veins of mobilized calcic material become frequent farther southwest, and this rock of igneous character composes in a massive sequence the whole southern part of the contact with Bergell granite. In most of this «tonalite», many inclusions of dark, hornblende-rich material are observed which – in the field – are most easily interpreted as restites, i.e. undigested relics. Other restites occur in the tonalite far from any contact and include olivine-enstatite ultramafic rocks (Passo di Mello, and at Bagni Masino), cordierite and andalusite-bearing pelitic schists (at Passo di Mello, Valle Preda Rossa) and biotite-alkalifeldspar gneisses (Alpe Cameraccio, Valle dei Ratti). They give us some idea about the original composition of tonalite before the igneous homogenization. In the mountains between Valle dei Ratti and Valtellina, tonalite shows the greatest thickness and is homogeneous. It extends as a narrow tail as far west as Bellinzona (WEBER, 1957).

Tectonically at a much lower level than the Bergell granitic rocks is the nonmegacrystic, Novate granite («granito di San Fedelino», PICCOLI, 1961) which is emplaced in the apex of the Adula antiform and the surrounding units such as the Gruf complex and zone of Bellinzona at least 1,500 m below the lowest outcrops of Bergell granite. It has no, or only irregular, foliation and often appears as a migmatite, replacing country rocks. The center of this granite which penetrates the surrounding rocks as a radiating dike system, is on the eastern prolongation of the Adula antiform. The age is definitely Alpine and E. WENK (1956) and BLATTNER (1972) have related the granitic activity – more anatexis than magmatic intrusion – to the Lepontine regional metamorphism. There is no direct genetic relationship between the Novate granite and the megacrystic Bergell granodiorite.

Microgranitic, aplitic, and pegmatitic dikes which penetrate Bergell granite in large swarms, however, may be related to the Novate granite. These dikes are generally less deformed and more altered than Bergell granite, and crystallized at a later stage. Relative age relations indicate that Novate and microgranitic dikes are usually the oldest, followed by aplites and then pegmatites. But occasionally this age relation is reversed, indicating a rather similar age for all these leucocratic phases. Dikes show a pronounced orientation, striking east-west and dipping gently north (Fig. 11a). The dike pattern is surprisingly independent of all other structures and is also unrelated to the present joint system in the Bergell Alps (Fig.

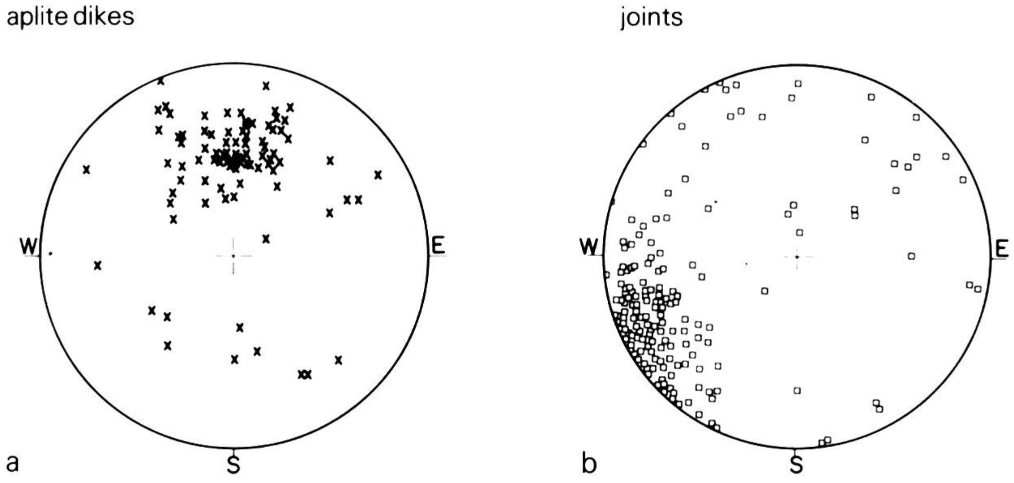


Figure 11. Orientation of leucocratic dikes (a) and joints (b) in the Central Bergell Alps. Equal area projection on upper hemisphere. – *Orientierung von leukokraten Gängen (a) und Klüften (b) im zentralen Bergeller Granit. Es ist beachtenswert, dass zwischen den beiden Verteilungen kein Zusammenhang besteht. Flächentreue Projektion von Polen auf die obere Halbkugel.*

11b). The poles of joint planes coincide mostly with the lineation (ac-joints) and fit well into the regional joint-pattern (H.-R. WENK, 1966). Pegmatite dikes, although particularly common in the Bergell Alps, occur in the whole southern zone of the Lepontine as far west as Domodossola (E. WENK, 1970).

Shear zones are common and find their expression in the morphology with canyons and cliffs outlining them. A north-south trending system dominates. There is usually no displacement along shear planes, and offsets are always small, in the range of cm and dm. Where slick and slides are observed (e.g., at Punta Sertori-Pizzo Cengalo) they are irregular. Occasionally, there is extensive low temperature hydrothermal alteration of granite to sericite-chlorite (at Punta Sertori) and zeolite and clay (Viale). Nowhere west of Silvaplana in the Upper Engadine could we find evidence for an extension of the Engadine line, a fault with supposedly 20 km left lateral offsets in the Lower Engadine, which was active in late Tertiary (TRÜMPY, 1977). In fact, stratigraphy and rock types on both sides of Lej da Segl, from Plaun da Lej to Maloja and Val Fex to Plan Chuncheta are identical. In particular, the limestone marker bed, Muotta Badonda-Blanca-Sasc da Corn-Alp da Pelpreir (Fedoz) shows no offset (Fig. 10). Fault offsets in the Maloja-Casaccia sector are thought to be directly related to the emplacement of the Bergell granite and its contact frame.

5. Metamorphism

The Tertiary granitic rocks of the Bergell rest in a frame of predominantly high-grade metamorphic rocks. Those in the western part are clearly related to the young regional metamorphism of the Lepontine (E. WENK, 1956), while those along the eastern border have more the appearance of contact metamorphic assemblages superposed on an earlier, regional, medium-to-low-grade metamorphic setting. There is still no agreement whether these two events are related, what the times sequence is (e.g., FREY et al., 1974 versus H.-R. WENK et al., 1974), or which is a cause and which is an effect. This complexity distinguishes the Bergell from the Adamello granite, where metamorphism – thermal and hydrothermal – can be directly attributed to the emplacement of the pluton.

The following are metamorphic episodes which predate the formation of Bergell granite in Oligocene: Staurolite and kyanite, partially or completely replaced by chloritoid in mica schists of the Suretta (or upper Tambo?) nappe are attributed to a Hercynian orogeny (H.-R. WENK, 1974), with widespread granitic plutonism in the whole realm of Central Europe.

East of the Bergell granite between the Orlegna river and Val Fedoz the Margna nappe contains dolomitic marbles which bear tremolite and amphibolites with calcic plagioclase. These medium-grade minerals are observed far to the east of the granite contact and are therefore not thought to be a result of contact metamorphism. Carbonate rocks, because of their association with quartzites and gypsum beds are assumed to represent Triassic sediments and therefore neither tremolite nor calcic plagioclase are due to some old, pre-Alpine metamorphism. A post Jurassic regional amphibolite-facies event in the Fedoz-Bernina region has been documented with isotopic ages of phengite and muscovite in Margna gneisses which give ages between 60 and 75 m.y. (JÄGER, 1973). These older regional metamorphic mineral assemblages are overprinted by younger thermal recrystallizations, to the east by the contact metamorphism of the Bergell granite and to the west by the Lepontine regional metamorphism.

Contact metamorphic mineral assemblages have been studied in ultramafics of the Disgrazia and isograds antigorite-talc-anthophyllite-enstatite could be delineated with increasing proximity to the tonalite (TROMMSDORFF and EVANS, 1972, BUCHER, 1977, Fig. 12). Temperature estimates for enstatiteanthophyllite are in excess of 700^0 C at the tonalite contact. GAUTSCHI (1980) and H.-R. WENK (1979) investigated amphibolites in the contact zone between Bergell granite and the Margna nappe and attributed pargasite-actinolite and anorthite-albite to contact metamorphism between Valle Preda Rossa and Maloja.

But while enstatite, wollastonite, anorthite, forsterite and andalusite may be considered contact minerals in the Forno-Sissone region, their distribution extends continuously westwards into the Lepontine thermal aureole. In fact maps of isograds, based on mineral assemblages (e.g., carbonate rocks: TROMMSDORFF, 1966; An-content of plagioclase: E. WENK, 1962; E. WENK and KELLER, 1969; E. WENK and H.-R. WENK, 1984; pelitic schists: NIGGLI and NIGGLI, 1965, H.-R. WENK et al., 1974; ultramafic rocks: TROMMSDORFF and EVANS, 1972) all show highgrade contours enveloping the eastern Lepontine Alps as well as the

Bergell granite and its associated country rocks. This zone of highgrade Alpine metamorphism coincides with the region of late-to-post-tectonic partial anatexis in the southern part of the Lepontine gneiss complex.

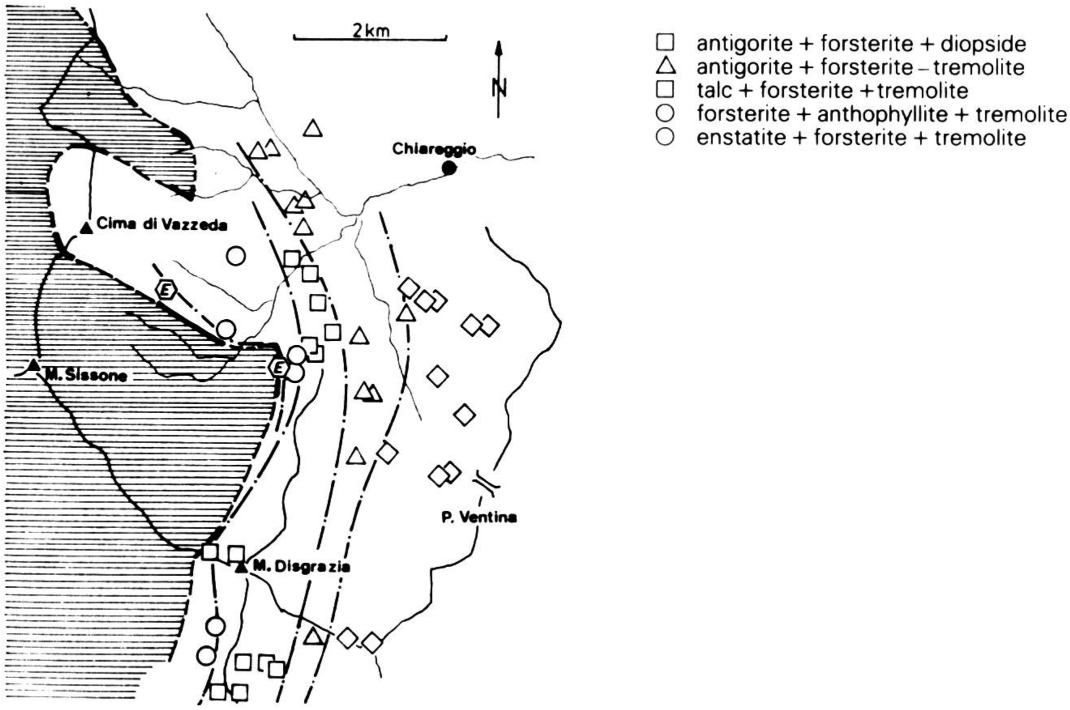


Figure 12. Distribution of index minerals in ultramafic rocks of the Disgrazia area. Bergell tonalite is shaded. (BUCHER, 1977). – *Verteilung von metamorphen Indexmineralien in ultrabasischen Gesteinen der Disgraziagegend. Die progressive Metamorphose wird der Intrusion des Bergeller Tonalites (dunkel schraffiert) zugeschrieben (BUCHER, 1977).*

No geological or textural evidence has been brought forward so far which would indicate that highgrade minerals such as sillimanite (e.g., Val Sissone-Forno-Vöga-Gruf zone of Bellinzona), cordierite (e.g., Murtaira-Preda Rossa-Mera-Verzasca), and wollastonite (e.g., Val Sissone-Albigna-Val Codera-Claro) are not, in their whole field of distribution, the result of the same, general phase of recrystallization – although they did not, of course, form exactly at the same time. The pattern of metamorphic minerals in the Bergell area is particularly fascinating due to the large differences in temperature and pressure over small distances. For example, exposures sampled in the Badile-Forno-Disgrazia group lie 2000 to 3000 m higher above sea-level than those of Valle della Mera, and there is considerable structural ascent from Valle della Mera in the west to Monte del Forno in the northeast due to the easterly axial plunge which in fact surpasses the altimetric rise (in total over 6 km corresponding to more than 2 kb). The rocks exposed in the west, in Valle della Mera, Val Codera, Val dei Ratti and Bagni Masino, record the metamorphic grade at the **base** of the Bergell granite, whereas those of the Murtaira-Cavloccio-Monte del Forno to the northeast reflect conditions in the

roof of the granite. Mineral assemblages in pelitic schists are well suited to illustrate this. Aluminous schists are more common than calcsilicate-rocks, amphibolites and ultramafics, which tend to form narrow zones and lenses, usually parallel to tectonic boundaries. Furthermore, they contain a large number of sensitive index minerals which are independent of the partial pressure of CO_2 and, in the case of aluminosilicates, also of H_2O. In what follows, we discuss their occurrence more fully (Fig. 13).

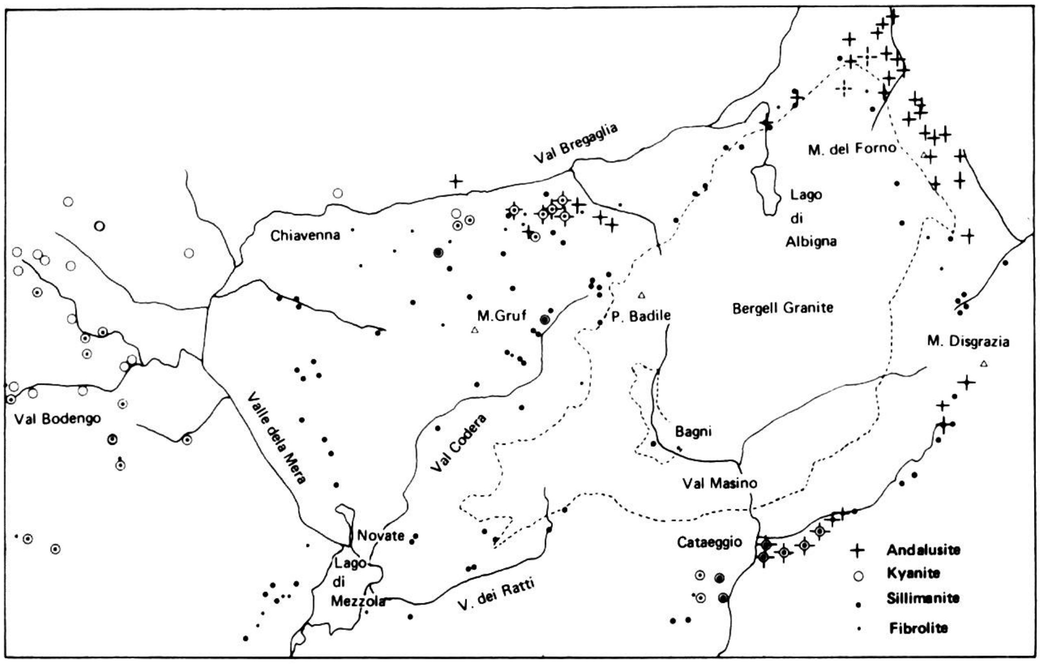


Figure 13. Distribution of aluminosilicates in pelitic schists (modified from WENK, et. al., 1973). – *Verteilung von Aluminosilikaten in pelitischen Schiefern. Die regelmässige Verteilung von Disthen, Andalusit und Sillimanit wird den regional verschiedenen Temperatur-Druckbedingungen zugeschrieben (Abbildung 14) (Ergänzt nach* WENK *et al. 1973).*

The central part of the Bergell Alps from Novate to M. del Forno is characterized by an extensive **sillimanite** zone which comprises the whole Gruf complex, most of the Bergell granite, and adjacent units. The sillimanite zone which covers the zone of Bellinzona in the Lepontine Alps has the most important distribution between Valle della Mera and Monte Forno. **Fibrolite** is common throughout and has a larger distribution which is more difficult to define than that of well-crystallized sillimanite. Textural evidence indicates that fibrolite is often a late alteration product. Sillimanite forms usually from a breakdown reaction of biotite and, more rarely, of muscovite. **Kyanite,** the typomorphic mineral of the Lepontine Alps, extends east to Valle della Mera and enters part of Val Bregaglia and Val Masino, where it borders the sillimanite zone to the north and to the south. **Andalusite** occurs to the east of the sillimanite zone in the contact area of the Bergell granite from Albigna-Val Forno-Preda Rossa. While it is the only aluminosilicate polymorph in the Murtaira-Forno region, it occurs as porphyroblasts in sillimanite and kyanite schists as far west as Cataeggio (to the south) and Vöga-Ciresc (to the north). At both of these localities all three aluminosilicates occur in the same rocks and pressure-temperature conditions must have been close to those of the triple point. It ought to be mentioned that the andalusite described so far is rock-forming and pervasive. Prisms are aligned in the schistosity plane and are more or less parallel to the lineation. There is another type of andalusite in the Central Alps occurring in younger quartz lenses. It is particularly common in the kyanite zone of the Ticino region (KELLER, 1968; KLEIN, 1976) and must be considered a younger generation. There are also occasional finds of such andalusite in the Bergell. A rare and so far unique occurrence for the Alps of submicroscopic **mullite** has recently been described by WENK (1983a) in the Sissone contact zone. **Cordierite** of highest metamorphic grade is common in the high grade zone and is found associated mostly with sillimanite, more rarely with andalusite and kyanite. Hypersthene occurs as a main constituent in a quarter of all cordierite-sillimanite rocks and is here often accompanied by members of the spinel group (hercynite, gahnite), sapphirine and corundum. An aluminous inclusion in tonalite at Passo di Mello contains cordierite in association with hercynite, anthophyllite and biotite. From Valle della Mera eastwards cordierites become increasingly Fe-rich relative to coexisting garnets. **Staurolite** is found within and beyond the kyanite-zone in the northern and southern belt but barely enters the sillimanite field and is always associated with garnet. **Chloritoid** is the young index Fe-aluminosilicate in the Suretta-nappe, either replacing old staurolite or occurring as large bladed crystals in garnet-phyllites and chlorite-gneisses (H.-R. WENK, 1974).

The regional distribution of aluminosilicate minerals in the Bergell Alps is regular and consistent. Also the regular distribution of Fe and Mg on coexisting cordierite, biotite and garnet indicates that equilibrium conditions were closely approached. There are rarely any replacement textures of the aluminosilicates, as they are common in the Ticino. H.-R. WENK et al. (1974) have used thermodynamic reasoning and experimental data for univariant reactions in the system Fe-Mg-Al-Si-O-H to estimate pressure and temperature conditions. The scaling of pressure and temperature relies mainly on experimental data of RICHARDSON (1968), RICHARDSON et al. (1969) and GANGULY (1972). Of course there are uncertainties in these estimates, probably in the order of + 50°C and ± 0.5 kb. Some important curves are illustrated in Fig. 14 which also gives the regional distribution of corresponding assemblages. Comparing the two diagrams – one based on experimental studies, the other on distribution of minerals in the field – we can evaluate their compatibility.

- Only a small part of the sillimanite zone is without anatectic phenomena. A belt about 100m–500m wide exists on the north side of the Bergell Alps that contains well-crystallized sillimanite but lacks anatexis. The Al_2SiO_5 triple point of RICHARDSON et al. (1969) is close to the minimum melting curve of granite but on the low-temperature and low-pressure side, thus leaving a narrow sector for the sillimanite field outside the area of melting (LUTH et al., 1964).
- «Triple-point» rocks usually contain staurolite. But staurolite is rare in the zone of anatexis and has a narrower field than kyanite. At low metamorphic grades it occurs beyond kyanite as is seen in V. Bregaglia.

- Staurolite never occurs together with sillimanite except for rocks near the «triple-point» which contain, in addition, kyanite and andalusite. This is quite different from metamorphic suites in New England and has been discussed by CARMICHAEL (1978), although his interpretation for the Bergell region is unacceptable (H.-R. WENK and E. WENK, 1981).
- In the Bergell region cordierite commonly occurs in the sillimanite and the andalusite-zone, in contrast to the Lepontine Alps where the mineral is restricted to kyanite-bearing rocks (E. WENK, 1968; IROUSCHEK, 1980). It is usually associated with partial anatexis. The Fe/Mg-ratio in cordierite-garnet assemblages is lowest in sillimanite-rocks of the Gruf complex corresponding to high pressure, and highest in andalusite-schists of the eastern contact in the roof of the Bergell granite.
- Chloritoid never coexists with any of the Alpine aluminosilicates and certainly not with sillimanite, which suggests that HOLDAWAY'S (1971) «triple-point» may be at too low a temperature and pressure.

The **depth of burial** of individual tectonic units as implied from field observations has to be in some agreement with pressure determinations. A reasonable estimate can be made for the sillimanite-andalusite transition zone exposed in the Forno area (northeast corner of Fig. 14). The isograd is situated at the roof of the Bergell granite approximately 1 km away from the Margna nappe. CORNELIUS (1935, p. 315–316) calculated a load of 5–6 km for the base of the Margna nappe in the uppermost Bergell valley (1 km Margna nappe, 4–5 km lower and upper Austroalpine elements) and regarded this figure as a reasonable, but possibly low estimate. A maximum burial of 11 km can be read from the profiles of other authors. It appears that a span of 7–10 km (2–3 kb) is correct for this boundary between the fields of sillimanite and andalusite, and for the cover of the Bergell granite. Less reliable are estimates for the «triple-point» near Vöga. Judging from the northern, unthinned parts of the nappes, we have to add 8 to 11 km for the Tambo and Suretta nappes, thus accumulating an overload of 15–20 km in the area of Vöga-Ciresc. This depth of burial of three-aluminosilicate assemblages agrees reasonably with the experimentally determined triple point of 5.5 kb (RICHARDSON et al., 1969).

Among the metamorphic mineral assemblages in the Bergell Alps there are some fairly unique examples which warrant a visit for petrologists. Among them are the sapphirine-cordierite-corundum schists in Val Codera (CORNELIUS, 1916), pelitic rocks with all three aluminosilicates at Cataeggio and at Vöga-Ciresc (H.-R. WENK et al., 1974 mullite-sillimanite schists in Val Sissone (H.-R. WENK, 1983a), and the occurrence of coexisting pure albite and pure anorthite in amphibolites of the Cavloccio zone near Maloja Pass (H.-R. WENK, 1979). Apart from these rare oddities, the Bergell Alps offer a whole spectrum of metamorphic settings in many different rock types, ranging in grade from greenschist to granulite both for contact and regional metamorphism. There is no sharp boundary between these two regimes, the possibility of which DAUBRÉ (1859), who coined the term «regional metamorphism», was well aware. A study of metamorphic minerals demonstrates that a large part of the Bergell Alps reached temperatures at which widespread anatexis and granitization are to be expected.

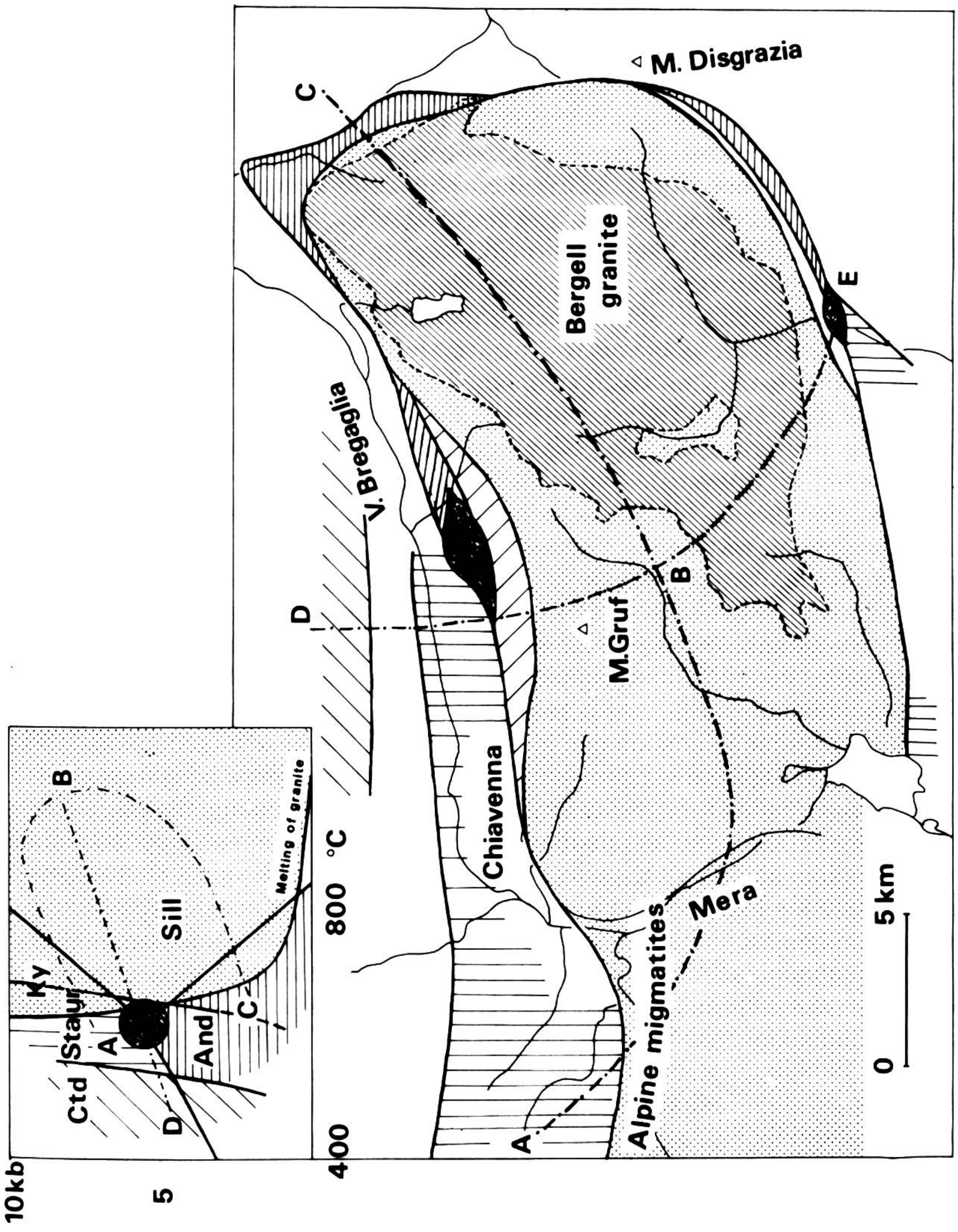


Figure 14. Temperature-pressure phase diagram for important mineral assemblages in pelitic schists and corresponding PT fields in the Bergell Alps. Some PT trajectories in both diagrams are indicated (WENK et al., 1974). – *Ein Temperatur-Druck Phasendiagramm für wichtige Mineralparagenesen in pelitischen Schiefern. Die Temperatur-Druckbereiche sind auch auf der Karte der Bergeller Alpen angegeben. Sie belegen eine Hochtemperaturzone im zentralen Teil, hohen Druck im Norden und Süden und tiefen Druck im Osten, wo das Dach des Granitmassivs aufgeschlossen ist (nach* WENK *et al. 1974).*

6. Age of the Bergell granite

The original argument for a post-tectonic age of the Bergell granite was based on crosscutting igneous contacts (CORNELIUS, 1913; STAUB, 1924a). Although the validity of a postkinematic intrusion concept has been brought into question by recent structural work (WENK, 1973), there is no doubt that the Bergell granite is of Tertiary age. Numerous isotopic age determinations, starting with those of GRÜNENFELDER and STERN (1960) confirmed an age of 30 ± 5 m.y. for the climax of granitic activity. U/Pb ages of zircons in granite and tonalite (GULSON and KROUGH, 1973; GULSON, 1973) are almost concordant, but there is an indication of the presence of some old components which have been assimilated. Most significant are U/Pb ages on monazites which are interpreted as crystallization rather than cooling ages (KÖPPEL and GRÜNENFELDER, 1975). U/Pb ages on zircons of 31.9 m.y. for triple point rocks at Vöga, 30.6 m.y. for metamorphic rocks of the granitic contact in Val Albigna, 26.0 m.y. for Novate granite and for Lepontine gneisses suggests that the peak of thermal metamorphism shifted from east to west.
A minimum age for the Bergell granite is established by granite and tonalite pebbles in the middle Oligocene Molasse between Como and Varese (PFISTER, 1921; CITA, 1957; GUNZENHAUSER, 1985) which gave a radiometric K-Ar age of 28 m.y. for biotite (JÄGER, 1973). If granite in the Molasse comes from presently exposed outcrops this means extremely rapid erosion to remove 6–10 km of overlying nappes above the roof of the granite in order to expose it. Allowing 2 m.y. this would amount to an erosion rate of 5 mm per year (see also WAGNER et al. 1979). Such rapid erosion could have lasted only a short period since Bergell granite still exists in great thickness, indicating only modest erosion during the past 30 m.y. Estimates of present uplift rates based on leveling of 1 mm/year in the central Ticino (GUBLER, 1976) and erosion in the northern Grisons of 0.1–0.4 mm/year (JÄCKLI, 1958) does not seem to apply to the Bergell region, where exposed petroglyphs and glacial polish indicate that erosion was minimal for hundreds of years. Some of these conflicts could be resolved if boulders in the Molasse were presumed to derive from a now eroded western part of the granite nappe above Valle della Mera which may have extended over part of the Ticino culmination (H.-R. WENK, 1973, p. 285). Such a western source, much closer to the place of deposition, would also account for the high frequency of granite boulders in the conglomerate. Bergell granite comprises less than one percent of all presently exposed rocks in the drainage basin of Lake Como and is a minor component in Pleistocene moraine deposits around Como and Lecco. Only in a few locations (such as above Civate towards Monte Moregallo) are there large boulders of Bergell granite. Tonalite exceeds granite in pebbles, but the reverse is true for present day exposures.
A comprehensive and systematic geochronologic study is still lacking and would add information to resolve such crucial questions as to which is older, Bergell granite or Lepontine gneisses. It should be kept in mind, however, that **relative** ages such as contact relations, petrographic textures, stratigraphic evidence and general structural data often provide more **absolute** constraints on the geological history than absolute ages, and the latter have to conform with them.

7. Conclusions

The Tertiary Bergell granite emerges as a rather atypical rock. Its extent is small, not only in comparison to granites in the American cordillera or the Himalayas, but also to the Hercynic Central Alpine granites and to those of the Vosges and the Black Forest. Whereas the eastern border displays a fairly normal contact aureole overprinted on country rocks, the western part rests on migmatites of high metamorphic grade, partially anatectic. Here it is often difficult to decide if metamorphism was the response to granite emplacement or if granitization was a result of metamorphism. Bergell granite is quite uniform in composition and lacks typical patterns observed during magmatic differentiation. Yet it is very difficult to pinpoint its primary source largely due to its penetrative deformation and extensive recrystallization. Gruf migmatites, which underlie it presently and which are of similar composition, are a likely origin. Bergell tonalite contains more relics – calcsilicates, ultramafics and amphibolites – which are evidence for transformation mainly from amphibolites representing volcanic rocks of continental margins and oceanic crust. While there is a transition zone between tonalite and granite indicating a rather low viscosity and some mixing of the two rocks, they both have such distinct composition patterns that it is clear they hardly originated from a uniform magma. The root of the granite body is best preserved in Val di Mello in present day exposures; it has disappeared farther west. But even in the central portion there is no geophysical evidence that Bergell granite extends to great depth.
The megacrystic growth of alkalifeldspar, common to all Bergell granite except for the central portion, has been often commented upon but never analyzed in detail. In most cases the distinction between porphyroblast or phenocryst is ambiguous on petrographic grounds. The alignment of crystals can generally be attributed to deformation and is evidence for neither magmatic flow nor transformation of gneisses. Occasionally megacrysts occur in country rocks and xenoliths, and in this case they are definitely porphyroblasts. Even if Bergell granite was at one time a homogeneous magma, alkalifeldspar would in any case be one of the last phases to crystallize during cooling (CONDLIFFE and MOTTANA, 1975, 1976).

We propose that the collision of the north European and the Italian plates, which gave rise to the main phases of mountain building in the Alps, was accompanied by subduction processes, not only burying the northern Pennine (European) plate but also the intercalated oceanic crust underneath the northwards moving Austroalpine (Italian) plate (Fig. 15a). Fragments of the mantle became incorporated and are today represented by the ultramafic rocks of Disgrazia and Chiavenna. As a result of subduction of northern units, regional metamorphic conditions were reached which were near anatexis, and local melting occurred. At rather deep levels of 20–25 km, preexisting crustal rocks were transformed by in situ partial or complete melting into a young granite which intruded in early Tertiary upwards into overlying accumulates of amphibolites, limestones, and pelites. Some of the deeper seated amphibolites and pelites of the oceanic unit also became mobile and intruded as tonalites. In the case of Adamello (farther south) intrusions reached a

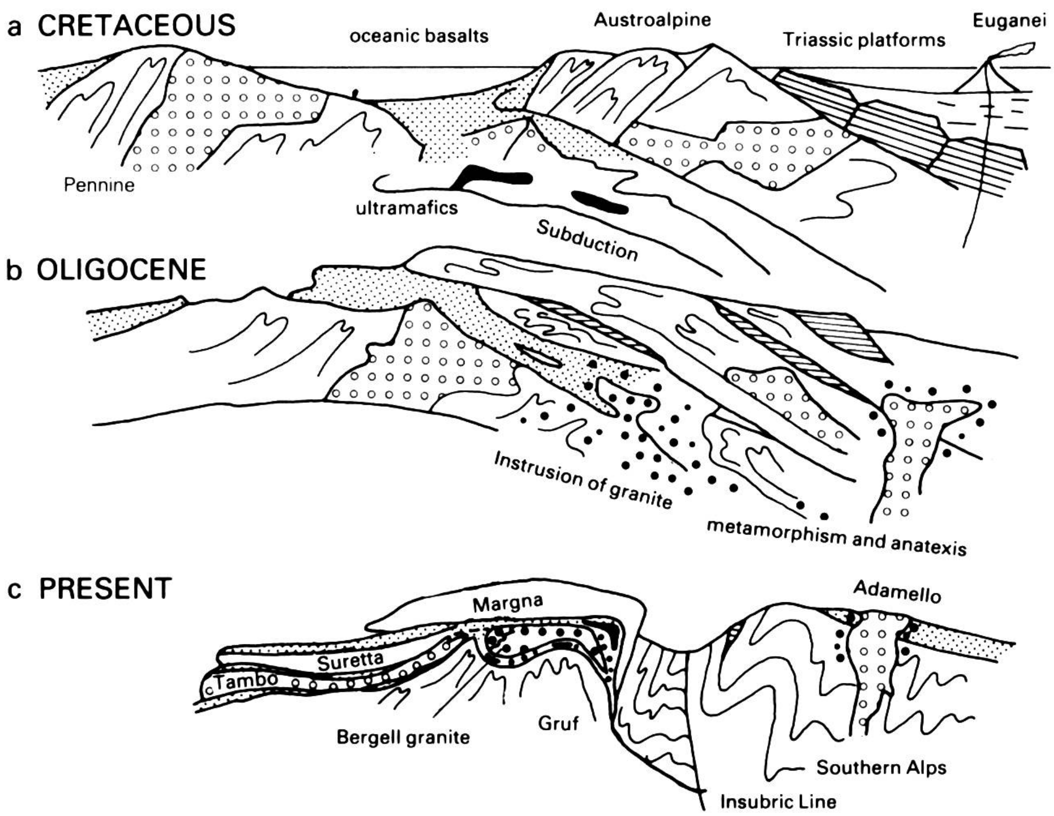


Figure 15. Imaginative model for the geological evolution of the Bergell Alps. – *Hypothetische Zeichnungen zur Entstehung des Bergeller Granits während der alpinen Orogenese. Die Skizzen zeigen die kontinentalen und ozeanischen Krusten während der Kreide (a), die Deformation während der Plattenkollision, die Platznahme des Bergeller Granits und die damit verbundene Kontakt- und Regionalmetamorphose (b) und die gegenwärtige Geometrie (c).*

high level close to the surface and formed a narrow contact aureole in sedimentary and old crystalline rocks of the southern Alps (Fig. 15b).

In the Bergell region there was never a large magma chamber which could separate by differentiation, or even effective homogenization of mobilisates of different composition. The intrusions became part of dynamic events: they crystallized in the surrounding oceanic units which separated overriding Austroalpine from subducted Pennine units, producing in these rocks – which were at the time in a progressive but low grade metamorphic regime – superposed contact effects. In order to be consistent with melting experiments, crystallization of igneous rocks must have taken place above 15 km. In such an environment there is a continuous transition between regional and contact metamorphism, and it is easy to visualize that age relations were reversed locally. The Forno region corresponds to a higher part, where higher grade contact metamorphism left imprints in lower grade regional metamorphic rocks. In Val Codera, on the other hand, temperature conditions of mobilized granite and country rocks were similar. Regional metamorphism outlasted the temporary intrusive event.

Under the influence of the continuing north-south compression, Bergell igneous rocks were juxtaposed in solid state into higher tectonic levels. Where rock rheology permitted, they became extensively deformed. They were emplaced as a nappe concordantly in the stack of higher Pennine nappes (Fig. 15c). The root connecting granite and tonalite with their original source – whatever that means in an anatectic regime – may not exist anymore, or only locally. Among the latest events was the uplift of the Gruf complex, bringing granulite facies rocks in contact with others of much lower metamorphic grade. Part of the tonalite-granite complex reached the surface as early as late Oligocene and was eroded, as documented by Molasse pebbles.

In very general terms the evolution described in the previous paragraphs is not so different from the model originally proposed by Staub (1924a). However his concept of a large cancer – like intrusion of which only the surface is exposed – analogous to the Adamello – is not tenable and shows no understanding of either the internal structure of the granite or its relationship to the frame. Based on our present knowledge the Bergell granite does not seem to be a large pluton but rather a minor magmatic episode. In a regional metamorphic regime, local temperatures became sufficiently high to produce melting. Bergell granite is no longer a classical example of a postkinematic intrusion but rather displays all the multifaceted, complex, and fascinating geological history with aspects relating to almost every field of earth science.

8. Recommended field trips

In this chapter we give a few suggestions for geological excursions. They are not inclusive, but should provide those who are able to undertake all of them, within one week, a general idea of the complex geology of the region. One of the most important goals of this guide and of the geological map is to make this area more accessible to geological investigations. The geological history is by no means resolved, and new evidence from the field can only lead to better understanding. Make your excursions with a critical mind and take these notes as mere suggestions. Sketches outline the geology and the route. The most interesting outcrops cannot be reached by car, and often strenuous climbing – though technically not difficult – is necessary. For mountaineering, available guide books should be consulted, among them:

A. BONACOSSA, G. ROSSI (1975), Guida dei Monti d'Italia, Regione Masino-Bregaglia-Disgrazia, vol. II, Club Alpino Italiano, Milano.

A. BONACOSSA, G. ROSSI (1977), Guida dei Monti d'Italia, Regione Masino-Bregaglia-Disgrazia, vol. I, Club Alpino Italiano, Milano.

H. RÜTTER (1966), Bündner Alpen IV Band, Südliche Bergeller Berge und Monte Disgrazia, Schweiz. Alpen Club, Zollikon-Zürich.

P. NIGG (1968), Führer durch das Bergell, Bergverlag, Rudolf Rother, München.

Some useful general information is provided by the guide:

SCHWEIZ. POST TELEGRAPH TELEPHON, GENERALDIREKTION, Malojastrasse, Oberengadin-Bergell (1950, 1960), 72p.

For topographic maps use Nationalkarte der Schweiz:

1:50,000 268 Julierpass, 277 Roveredo, 278 Monte Disgrazia.

1:25,000 1276 Val Bregaglia, 1296 Sciora.

Important geological maps are:

1:200,000 Geologische Generalkarte der Schweiz, Blatt 8, Engadin, 1964 (ed. A. SPICHER).

1:100,000 Carta geologica d'Italia, Foglio 7–17, Chiavenna (1941), foglio 7–18, Pizzo Bernina-Sondrio, 1970 (ed. G. SCHIAVINATO).

1:50,000 Geologische Spezialkarten der Schweiz, Blatt 90, Geologische Karte des Val Bregaglia (Bergell) (1921, R. STAUB).

1:50,000 Blatt 97 Geologische Karte des Avers (Piz Platta-Duan) (1926, R. STAUB).

1:50,000 Blatt 118 Geologische Karte der Bernina-Gruppe (1946, R. STAUB).

1:25,000 Geologischer Atlas der Schweiz, No. 70, Blatt 1296, Sciora (1977, H.-R. WENK and S. C. CORNELIUS)

For local maps see also the papers of CRESPI and SCHIAVINATO (1966), GYR (1976), MOTICSKA (1970), SCHMUTZ (1978).

Excursion 1: Albigna-Central Bergell granite (1 day) (Figure 16)
Take the cable car from Pranzaira (Vicosoprano) to the dam of the hydroelectric power plant. It brings you to an altitude of 2000 m and right into the Bergell granite. Follow the old road (instead of the faster trail) **(1).** Along it are some excellent outcrops with various granitic phases: Megacrystic Bergell granite, mostly with aligned potassium-feldspar megacrysts, aplite and pegmatite dikes, and occasionally melanocratic inclusions. From the custodian's house at the west side of the dam, cross the dam and take the trail to Capanna da l'Albigna (1 hour) where refreshments are served.
From here I recommend taking a small side trip **(2).** Descend south to the old waterpipe (2300 m) and continue along it eastwards; look at the splendid outcrops with glacial polish and a whole spectrum of igneous structures. But while you are enjoying crosscutting contacts, xenoliths and xenocrysts, keep in mind that the granite has been deformed (to verify this you have to rely on thin sections), and that hydrothermal recrystallization accompanied and outlasted igneous activity.
Retrace your steps to the trail which descends to the lake and follow it southwards along the lake. At times this can be a nuisance due to landslides, and rock and snowfalls. Join the moraine at Pt. 2305 and continue on the glacier southwards. On the cliffs facing you on the eastside there are beautiful swarms of xenoliths in megacrystic granite **(3).**
It is worth your while to spend about an hour looking through the large eastern moraine. In pegmatites it is easy to find crystals of beryl and occasionally cosalite, uranophane and rare phosphates. You may notice that the moraine consists chiefly of hornblende gneiss rather than Bergell granite, particularly near its origin at Pt. 2496. There are no such rocks exposed on the surface (hornblendefelses near Pt. 3012, supposedly roof pendants, are considerably different). The rocks in the moraine resemble the tonalite exposed in Valle del Ferro and Val Porcellizzo underneath the granite and probably originate from a window of tonalite in Val Albigna, presently covered by the glacier. It indicates that the central portion of the granite may also have nappe character and may not extend to great depth. This is a good place for a lunch stop.
Return along the western side. This is best done by climbing from Pt. 131.8/769.7 up to about 2550 and then crossing the Kar of Cacciabella northwards. Here we enter the central, nonmegacrystic part of the granite which extends as a large flattened pipe through the whole massif, from Bondasca to Forno **(4).** Return along the trail to the dam.
Even though it may take an extra hour, you should not use the cable car on your way back. Instead, continue along the trail which leads through the granite contact first along an old road used during the construction of the dam and later on a steep but well-maintained path. Megacrystic granite becomes more and more foliated. The alignment of potassium feldspar megacrysts is (at least in these places) definitely the product of deformation and not of magmatic flow, as evidenced by the mylonitic fabric in the quartzo-micaceous groundmass (e.g., Sasc Primaveira) **(5).** Around 1600 m we enter a zone of tonalite, later of amphibolite, which constitute the contact. At 1580, in the vicinity but not along the trail, there are thin bands of calcsilicates associated with sillimanite-cordierite bearing pelitic schists.

(If you have time, take the level path south from Motta Ciürela. Good outcrops of aluminosilicates are at 770.1/135.6) **(6).** Further down we enter leucocratic augengeneisses which resemble those of the Tambo nappe. Either return to Pranzaira, using the bridge at Pt. 1304, or go directly in to Vicosoprano.
The museum at Stampa offers not only a wide review of Bergell history, craftsmanship and fauna, but also has an excellent display of minerals and rocks. A stop there is a must; use a rainy day for it.

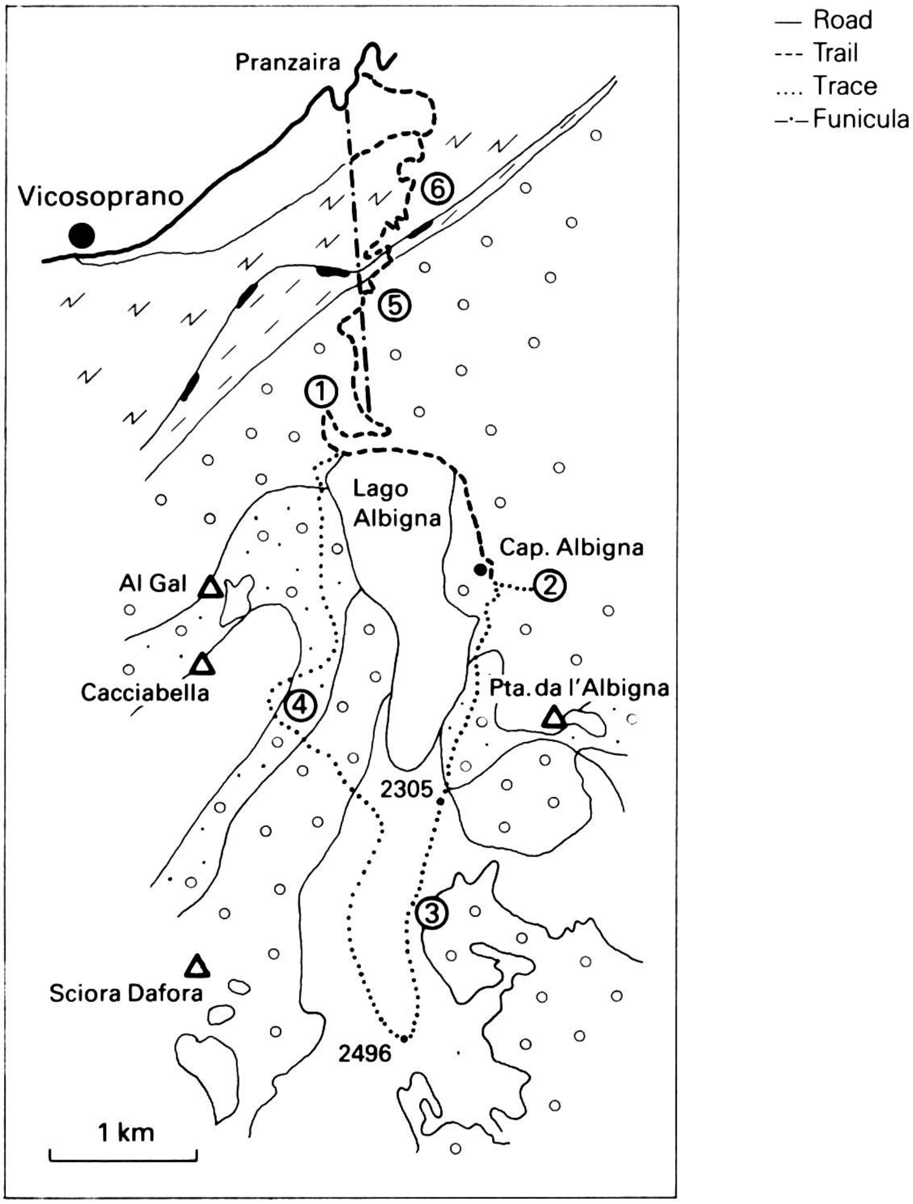


Figure 16. Itinerary for field trip into the Albigna area. (Legend see cross sections.) – *Kartenskizze für eine geologische Exkursion ins Albigna-Gebiet. Zentraler Granit, magmatische Strukturen und Deformation entlang des nördlichen Kontaktes. (Legende siehe Geol. Querprofile.)*

Excursion 2: Val Bondasca-Contact of the Bergell granite (1 day) (Figure 17). The day before the trip you should visit the quarries of Promontogno or Soglio. The latter provides a splendid view of the Bergell Alps, with jagged peaks and steep faces in the granite. The quarries are in platy gneiss, tectonically belonging to the Tambo nappe. This muscovite-biotite-alkalifeldspar gneiss, dated by Rb/Sr at 31 m.y. shows excellent cleavage, so that it can be worked into perfect slabs for roofs, floors, and tables (Fig. 1). It is a metamorphosed Hercynian granite. Still standing in the town of Promontogno is the old Hotel Bregaglia where Röntgen spent many of his summer vacations fascinated by the wilderness of Val Bondasca. The last Bergell bear was killed there in 1867 – it is now in the museum in Stampa.

Park the car in Bondo and proceed along the road towards Val Bondasca. (For a fee you can also drive up to Lera, 1250 m.) At 1000m there is a tunnel that crosscuts Tambogneisses; in contrast to the platy variety of the quarries, these are megacrystic in their lower parts, and conspicuously resemble Bergell granite **(1).** At Prä there is a small dam. Rocks along the river are migmatites, penetratively folded. They belong to the Gruf complex which appears in Val Bondasca as a tight, anticlinal structure (see cross section in Fig. 7). Near Gerp, across the river, is an old mine (1777) of talc-olivine schist (Laveggio) which was used to make cooking pots **(2).** The road ends at Pt. 1247. Follow the trail marked Sasc Fura which crosses the river at Lumbardui. Immediately after the bridge, cross the meadows to Jerta, where a new landslide has exposed Gruf migmatites at their best **(3).** Notice isoclinal folding and extensive dikes of aplite and pegmatite, the latter bearing beryl and tourmaline. Along the cliff is an ultramafic breccia. Outcropping on the southern limb of the anticline, this is the same general bed as that at Gerp on the northern limb.

Return to the trail where there is now a steep ascent of 500 m (1 hour +) to Capanna C.A.I. Sasc Fura. It provides lodging if necessary. Here do not proceed south on the ridge – which would take you to the famous north ridge of Piz Badile – unless you are an experienced climber and wish to have a truly exposed cross section through Bergell granite. Instead, descend slightly along a water pipe towards Saca in Val Trubinasca. Already at Sasc Fura you have noticed tonalites resting above Gruf migmatites and below Bergell granite. They constitute the ridge of La Plota; the lower part of the valley is migmatite. Traverse at 2200 m the lower part of Trubinasca glacier, right in the contact zone of migmatites, tonalite and granite. Tremendous outcrops of swarms of xenoliths, particularly west of Pt. 2218 in the moraine **(4).** Unfortunately high in the cliffs, splendid outcrops consist of ultramafic breccia, peridotite and carbonate rocks. They have been metasomatically altered, resulting in spheroidal textures with olivine in the center and zones of talc-chlorite-actionolite-hornblende-biotite (Artus, 1959). This zone is at the base of the Bergell granite which is exposed at the mountain tops of Piz Badile and Pizzo Trubinasca, clearly forming a sheet which overlies the isoclinally folded Gruf migmatites. The ultramafic zone again corresponds to that observed at Gerp and at Jerta. Notice that all structures (lineations, fold axes, alignment and stretching of xenoliths, alignment of potassium feldspar megacrysts) are parallel in migmatites, contact rocks and granite, indicating that they are caused by

penetrative deformation. In addition to the ultramafic breccia the moraine contains pelitic rocks from the contact zone, with 1-2 cm large, blue-purple cordierites.
It is not advisable to descend into the valley directly or transverse towards Luvartigh on old hunting trails. Rather, return the same way as you came over Capanna Sasc Fura.

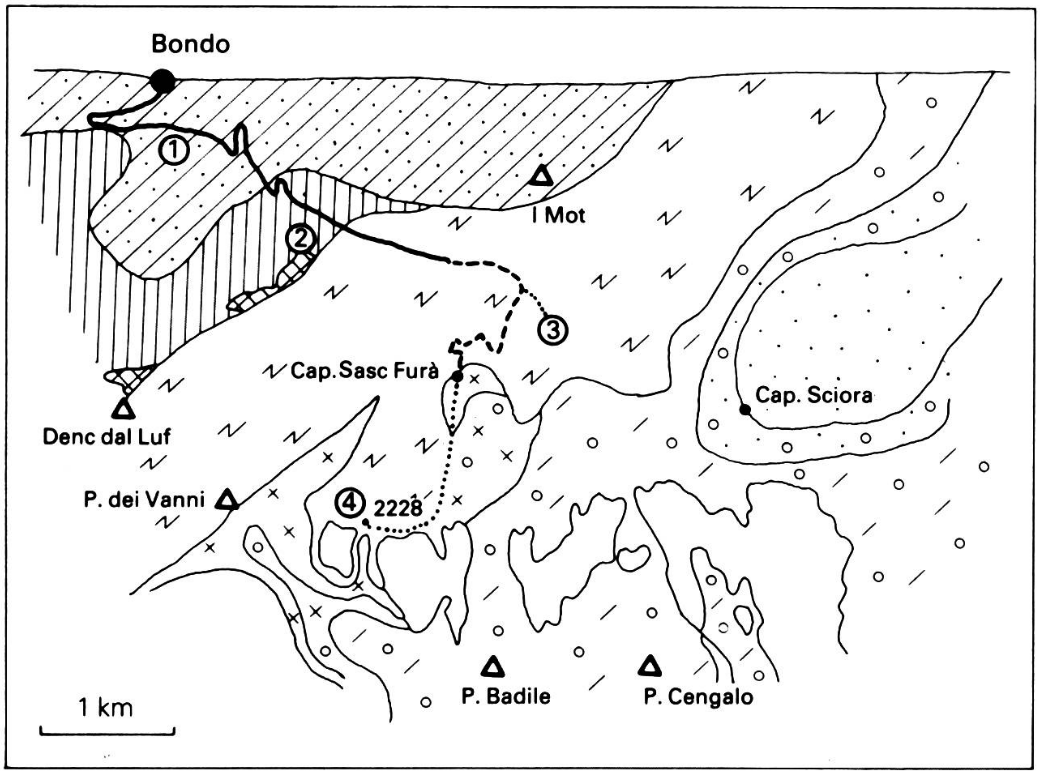


Figure 17. Itinerary for field trip into Val Bondasca. – *Kartenskizze für eine geologische Exkursion ins Val Bondasca. Gneise der Tambodecke, Gruf Migmatite und Granitkontakt im Val Trubinasca, der den Deckencharakter illustriert.*

Excursion 3: Val Codera – Granulite grade rocks of the Gruf complex (2 or 3 days) (Figure 18)
This is a rather strenuous two or three day backpacking trip with more than a 2000 m change in elevation, but it offers an introduction to some of the most unusual rocks in the Alps. Start out again from Bondo, but this time at the intersection at 1010m follow the forest road towards Ciresc (a car can be used up to there, again for a fee). It takes you through pelitic rocks – well exposed at 1070 m – which are staurolite-, kyanite- and sillimanite-bearing. Notice the sag morphology of this dip slope, with buckling of beds and frequent small slides. After about

1½hours you arrive at the meadow of Ciresc. Leave your pack there and follow the road towards Vöga. From about coord. 762.00/132.6 to 762.4/132.75 there are good outcrops of pelitic schists **(1)**. They contain kyanite, sillimanite and particularly in the farther part, porphyroblasts of andalusite. This is the place where the fields of distribution of the aluminosilicate minerals meet, and all three can be found in the same thin section. WENK et al. (1974) contend that conditions were close to equilibrium in the vicinity of the «triple point» during Alpine metamorphism.
Return to Ciresc and follow the trail to Cänt, Vec, Alpe Tegiola. At 1580 m you pass a wonderful spring and observe many boulders of ultramafics. They are part of the Chiavenna ultramafics (SCHMUTZ, 1976) and form large outcorps west of Foppate and at Sot al Cantac. They correspond to those described on Excursion 2 in Val Bondasca and are mostly chlorite and talc-bearing orthopyroxene-olivine felses.
From Alpe Tegiola onwards we are in the Gruf migmatites. Isoclinal folding is the most prominent feature. Particularly in the higher elevation towards Bochetta della Tegiola (steep ascent through a canyon following the Swiss-Italian border) mylonites are very common. Deformation is concentrated in thin bands, with ribbon quartzites and black, flinty looking micaceous layers **(2)**.
Near the pass, a large dike of megacrystic granite crosscuts migmatites, extending as far west as Cima di Codera. It resembles in texture and composition Bergell granite and may be an expression of in situ formation from equicompositional Gruf migmatites. If you can spare an extra hour you should traverse to the West before the final ascent to the Bochetta. The scree displays excellent examples of deformed megacrystic granite and ultramylonites displaying the Gruf complex as a classical ductile mylonite zone (easily accessible outcrops are at 761.7/129.7). Weather permitting, there is a splendid view into Val Codera. Direct your view towards Cima di Gaiazzo, Pizzo Ligoncio. The skyline and most of the cliffs are Bergell granite which rests as a sheet on a thin layer of tonalite, amphibolite and wollastonite-bearing marble. The latter are conspicuous as white bands at Pizzo Porcellizzo. To the right are steep and inaccessible canyons cutting through the core of the Gruf complex. Val Codera is one of the most remote areas in the Alps where you rarely encounter tourists. It was one of the strongholds of the «partigiani» during the second war, and most of the old huts were burnt down during fascist raids. Descend from the pass to 2200 m, then climb again over meadows and at the very end over some cliffs to Bivacco Vaninetti C.A.I. It provides shelter for 8. Blankets are available but sleeping bags are advised.
Look around the bivac. There are again ultramafic rocks **(3)**. If you proceed towards Pizzo Trubinasca you cross through a zone of cordierite-bearing pelitic schists, tonalite into granite on the top. All structures are strikingly parallel. If there is time, an ascent of Pizzo Trubinasca is easy, and the view into Val Bondasca, particularly on the north crest of Badile, is most impressive. Notice that planar structures observed in the granite are almost horizontal. You may wish to visit some of the pegmatite localities (coord. 763.7/129.2) which contain good beryl.

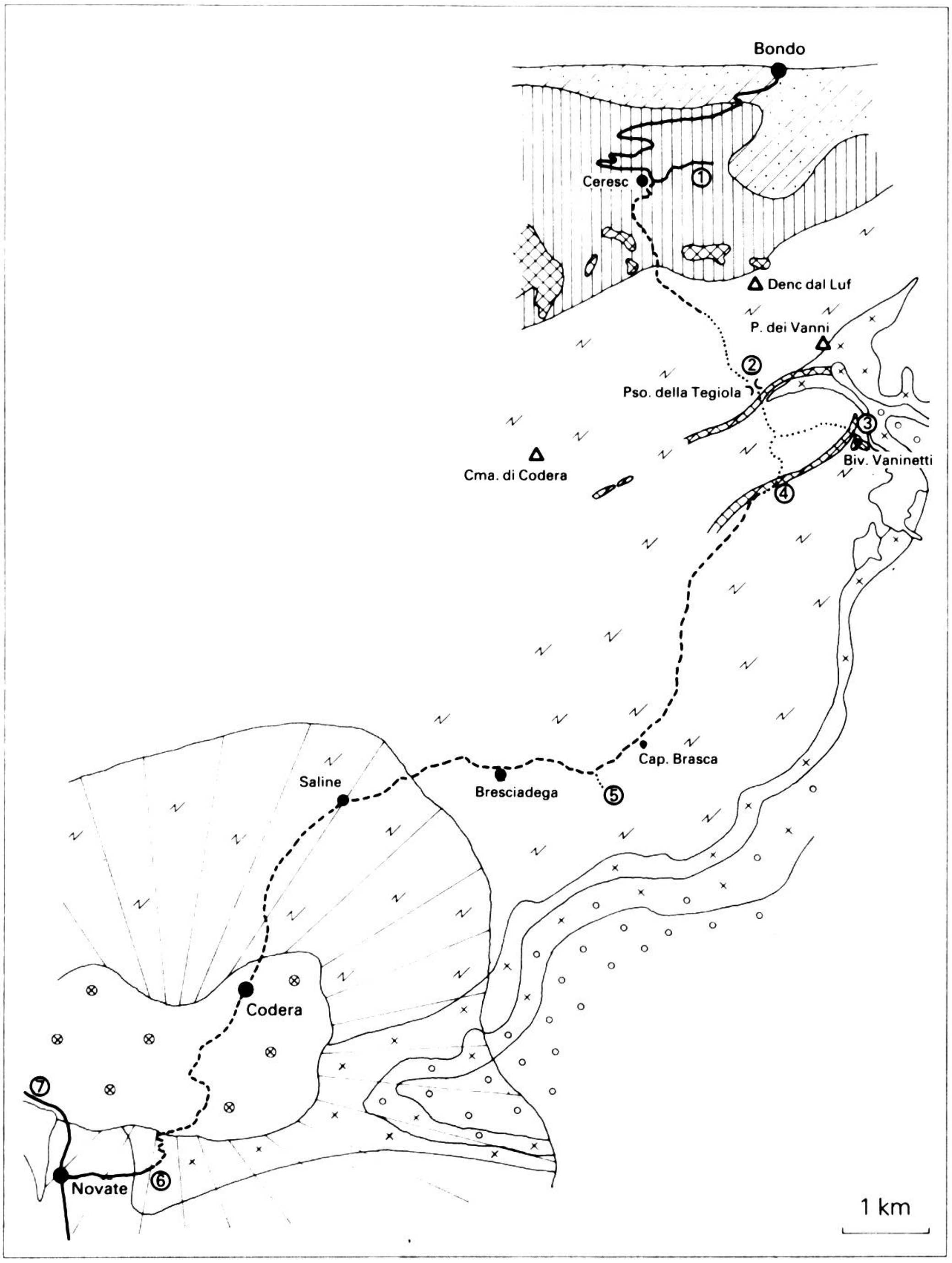


Figure 18. Itinerary for field trip Bondo – Bochetta della Tegiola – Val Codera. – *Kartenskizze für eine geologische Exkursion Bondo–Bochetta della Tegiola–Val Codera. Metamorphose in Peliten (Tripelpunkt Vöga-Ciresc), Gruf Migmatite mit Anatexis und Novate Granit.*

Descend to Alpe Sivigia. It is worthwhile to climp up the river (from 763.7/128.95) for a hundred meters **(4).** It takes you to outcrops of an ultramafic breccia, similar to that at Alpe Trubinasca with metasomatic spheroidal structures. But transformation has been more advanced with partial conversion to a megacrystic diorite-like hypersthene labradorite rock which serves as an excellent structural marker in the otherwise monotonous Gruf rocks.
A good trail takes you down to Codera and the alluvial plane of Coeder. It is recommended to make short side trips to the exits of Valle del Coco and Val Piana. Boulders display the whole variety of granulite facies, metamorphic rocks containing sillimanite, rarely kyanite, hypersthene, garnet, hercynite, magnesium-cordierite, corundum and occasionally sapphirine in aluminous assemblages, indicative of high temperatures and pressures. The best locality of sapphirine bearing schists is that first described by CORNELIUS (1916) at coord. 761.1/125.3 in talus debris **(5).** The actual outcrops must be in the steep inaccessible cliffs immediately above it.
Capanna Luigi Brasca C.A.I. is open for lodging and meals during the summer season. From here there is a well-maintained trail used by farmers. We are quickly descending from an alpine environment to one of almost Mediterranean ambiance. As you move further down, you find an increasing number of crosscutting, microgranitic dikes. They differ in composition, texture, and age from the Bergell granite and are part of the Novate granite which is best exposed in the last steep descent from Codera to Novate. But usually by this stage you have not much spirit or time for geology. Just remember that not many years ago smugglers made this very trip which you have just completed with 50 kg of cigarettes on their backs – in one day.
Novate offers excellent opportunities for a day of rest. Go to the river at coord. 756.0/120.8 for a swim and review the geology which you have just seen in the splendidly polished, huge boulders **(6).** Also take a trip to the quarries of San Fedelino-Riva (coord. 754.5/121.7) to see the young, deep-seated Novate granite and its contact environment **(7).** A detailed description is given by PICCOLI (1957). It outcrops in the anticlinal structure of Monte Berlinghera and is thought to be part of the Lepontine culmination.

Exursion 4: Val Masino – Tonalite, window of Bagni, contact with Ultramafics
(2 days, mainly by car) (Figure 19)
Enter Val Masino from Valtellina. Shortly after the village of Masino the Insubric Line is passed on the narrow winding road. It is difficult to stop there, and one would have to cross the river to see pseudotachylites and limestone mylonites at the immediate contact (coord. 769.3/114.9). (The same rocks are more accessible close to the church of Berbenno 8 km farther east.) Continue to Cataeggio and take the road at Filorera to Sasso Bisolo. Park the car in a hairpin turn at 1000 m and follow an old service road northwards. There are slopes with debris from the construction of a hydroelectric power tunnel extending from San Martino to Biolo **(1).** The cliffs which outcrop are already tonalite, but the contact is immediately southwards (about 100 m above and SE of Cataeggio in the brushy slope

at 770.0/129.9) and marked by calcsilicate rocks with wollastonite-vesuvianite-diopside amphibolites and pelitic schists. The latter are particularly interesting because they contain, in addition to staurolite, the three aluminosilicates. Similar to Ciresc-Vöga, Cataeggio is a point where the distribution fields of kyanite (west), andalusite (east), and sillimanite (north) meet, and there is good evidence for equilibrium. These unique rocks do not exist only in pieces of float but can be found in place if you take the time to follow the trail on the south side of the river. The general distribution of the aluminosilicates is illustrated in Figure 13.

Now return to the main road. You may wish to look at the blocks quarried at Filorera. Certainly stop at Sasso Remenno **(2)**. To the east you see the steeply south dipping sheets of tonalite. At this point we are in the transition zone, with the first megacrysts appearing. Alternating banding of tonalitic and granitic material with strictly parallel textures may be interpreted as due to isoclinal folding, similar in style to the Gruf complex. Progressing further north to San Martino we enter the core of the granite, and if the Bergell granite has any root, it is there. The Val di Mello opens to the east as a deeply carved, U-shaped glacial valley, with little more than megacrystic granite exposed on either side. But we proceed westwards toward Bagni del Masino.

The winding road passes some outcrops of tonalite north of the river. Granite flanks the valley to the south. At Bagni del Masino we are back in metamorphic rocks, mostly isoclinally folded migmatites resembling those of the Gruf **(3)**. These rocks, outcropping in the bottom of the valley and surrounded on all sides by Bergell granite, were previously interpreted as roof pendants. In 1970, Moticska and Wenk discovered, independently, that they constitute a window exposed underneath the granite nappe. This was one of the prime pieces of evidence which led to a reevaluation of the structural geology of the area (WENK, 1973). There is a hot spring with a water temperature of 38 °C. Whether this is related to the deep tectonic level of those rocks, or is an expression of relatively young thermal activity is unknown.

Ponte Baffo south of Cataeggio has an excellent restaurant and hotel where you can spend the night (if there is space – sometimes it helps to tell them that you are a geologist) or at least eat a supper of fresh river trout.

The next day drive up Val di Sasso Bisolo on the road turning off at Filorera. Generally one can ignore the no-driving signs. The road has been damaged in 1978 by an impressive rockfall which covered part of Valpiore. Above Sasso Bisolo you pass through good outcrops of tonalite which occur here in great abundance. Notice the strong and regular lineation with steeply dipping axes. Also take a view to the west where you can see the regional south dip of tonalite plates. While lineations change considerably from steep whirlpool structures to almost horizontal, foliations are constant over a wide area.

The road ends at Preda Rossa. Looking up the valley you see to the left tonalites, to the right reddish-brown ultramafics. You are right in the contact zone, here rather heterogeneous but consisting, as in most other places, of amphibolites, pelites and calcsilicates. Good wollastonite-bearing rocks are found on the trail to Scermendone (coord. 774.4/121.8).

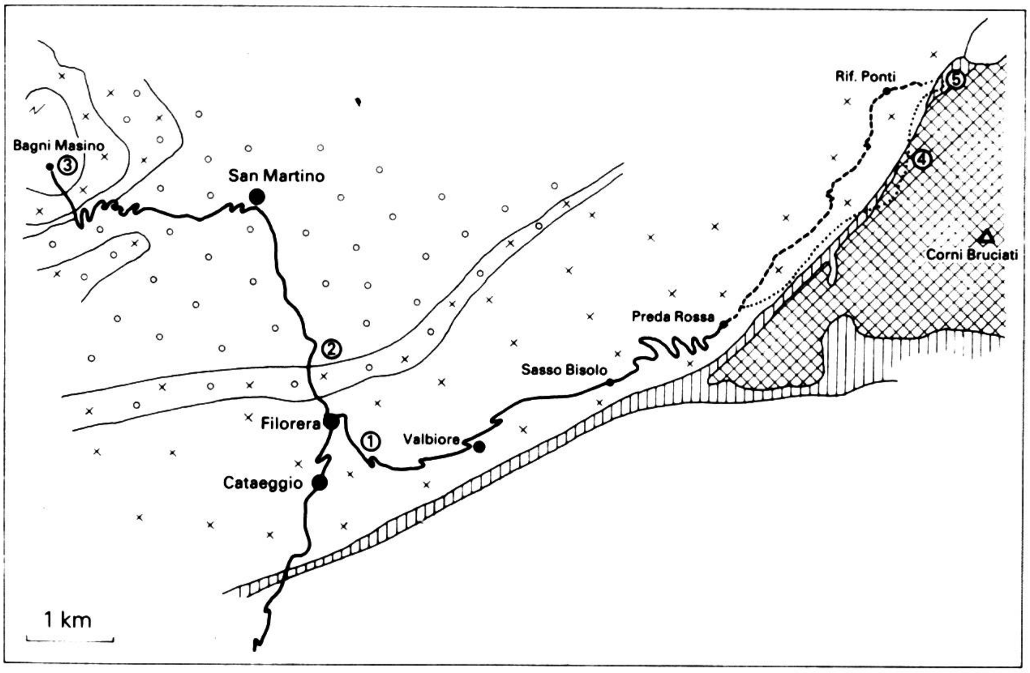


Figure 19. Itinerary for field trip into Val Masino. – *Kartenskizze für eine geologische Exkursion ins Val Masino. Insubrische Linie, Tripelpunkt Cataeggio, Tonalit und Übergang zu Granit, Fenster mit metamorphen Gesteinen in Bagni Masino, Ultramafite und deren Kontakt mit Tonalit im Val Preda Rossa.*

From Preda Rossa do not follow the trail marked Rifugio Ponti C.A.I. but instead use the road which crosses the river and advances on the south side of the alluvial plane.
The ultramafic rocks of Monte Disgrazia-Val Malenco represent a piece of upper mantle probably injected into oceanic crust. It belongs to the zone of calcic-mafic-ultramafic rocks which surround the Bergell granite on all sides. Originally peridotite, it was later serpentinized (cf. Val Malenco-Lanzada-Val Poschiavo). During emplacement of the granitic rocks in the early Tertiary, a prograde thermal metamorphism was over-printed on the serpentinites with a sequence of assemblages antigorite –› olivine –› tremolite –› anthophyllite –› enstatite (TROMMSDORFF AND EVANS, 1972). At the cliffs (coord. 776.25/113.65) there are exposures of excellent anthophyllite rosettes **(4).** Climbing over boulders northeast, you pass through the tremolite into the forsterite zone. At about 2600 m, at the level of the glacier, turn northwest to outcrops at coord. 777.2/152.3 **(5).** This is again the immediate contact zone, with calcsilicates and pelitic rocks. The latter show assemblages of hypersthene-andalusite-cordierite and margarite-corundum. Descending towards Rifugio Ponti we pass into tonalite which, however, contains many inclusions, particularly andalusite schists. The frequent association of tonalite with calcsilicates, amphibolites, ultramafics and pelites suggests that it did not form by differentiation of a homogeneous magma but is a product of remelting of old crustal material.

At this point you could follow the Sentiero Roma into Val di Mello and descend over the polished glacial slabs of Alpe Cameraccio. These illustrate, in a distance of 1 km, the regular transition of tonalite into megacrystic granite. This contact zone is not a typical igneous feature but rather is reminiscent of deformation in a predominantly solid state.
The fastest way to return to Preda Rossa is on the Rifugio Ponti trail.

Excursion 5: Val Sissone – Contact metamorphism (1 day) (Figure 20)
Val Malenco offers a bonanza of rock types and tectonic units. Numerous field trips are possible, but we are concentrating only on outcrops on the Sciora quadrangle. The upper part of Val Sissone contain some of the best exposures of igneous contact and contact metamorphism in Central Europe, and it is not surprising that early investigators were fascinated. Read STAUB'S (1921) enthusiastic account of Monte Disgrazia.

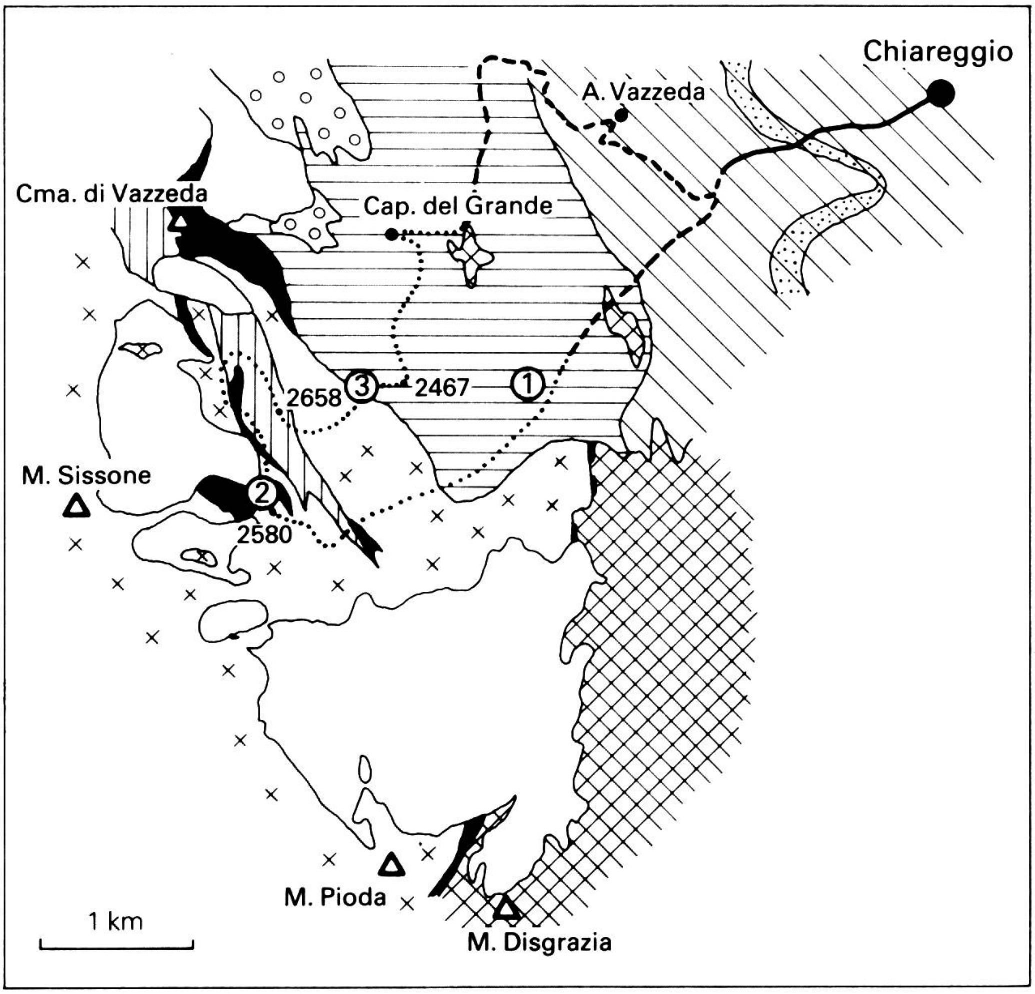


Figure 20. Itinerary for field trip into Val Sissone (Val Malenco). – *Kartenskizze für eine geologische Exkursion nach Val Sissone (Val Malenco). Kontakt des Tonalites, besonders schön mit Marmor (Tremolit) und Übergang von Amphibolit in mobilisierten Tonalit (Cap. del Grande).*

Take the Val Malenco road to Chiareggio and park one kilometer west of Chiareggio at Pian del Lupo. From there take the trail over Forbesina into Val Sissone. Cliffs of amphibolite along the path are penetrated with leucocratic dikes **(1).** Blocks in the stream and the moraine announce beautiful contact structures. Do not get carried away because you will see all of these much better in place. Good outcrops begin at Pt. 2308 (coord. 777.2/129.3). Go up to Pt. 2580 (at the base of the east crest of Monte Sissone) **(2).** From there just wander northwest at the lower end of the Sissone glacier. There is a whole range of contact features, perhaps most striking in carbonate rocks, with interesting minerals (WENK and MAURZIO, 1970), assimilation, and metasomatism. BUCHNER (1977) estimated temperatures during the peak of metamorphism at 800°C. Mullite has been found in large crystals of sillimanite (WENK, 1983).
Descending from Pt. 2658 to Pt. 2438 we cross the contact between tonalite and amphibolites which is gradual, with less and less leucocratic material penetrating amphibolites **(3).** WENK et al. (1977) suggested that the two rocks probably have the same source and represent originally andesitic oceanic crust. Return to Chiareggio unless you want to spend the night at Rifugio del Grande and have another day to study the contact northwest of there and at Passo Vazzeda or to cross over into Valle del Forno.

Excursion 6: Maloja – Cavloccio – Valle del Forno – Contact metamorphism and Bergell granite (Figure 21)
On the trail from Pso. di Maloja (Pt. 1790) towards Orden, you pass through typical Maloja albite-mucovite gneisses with large megacrysts of alkalifeldspar. They were probably originally Hercynian granites but have undergone thorough Alpine recrystallization. All plagioclase is albite. There is some excellent glacial polish with striations indicating that erosion during the past 10 000 years was minimal **(1).**
At Orden, northeast of the old bridge and exposed along the Orlegna river, the Maloja fault extends southwest-northeast and separates the low-grade Maloja zone from the Bergell granite and its metamorphic envelope **(2).** TRÜMPY (1977) views the fault as a large left lateral fault extending from Austria to Chiavenna («Engadine line»), whereas WENK (1984) attributes it to local tectonic adjustments in connection with the emplacement of Bergell granite. Along the road to Lägh da Cavloc one passes through amphibolites and micaschists. At the lake (the best exposures are at coord. 774.3/139.25 and 775.9/138.4) andalusite-garnet schists are common and occur from there to the contact with the Bergell granite **(3).** Andalusite is the prevalent aluminosilicate from Piz Salacina through Cima di Vazzeda. East of Lägh da Cavloc is a porphyroblastic amphibolite outcrop. This is unique, because plagioclase is an intergrowth of pure albite and pure anorthite, which is significant for plagioclase relations (WENK, 1979) **(4).** If you go off the trail, beware of snakes. The Cavloccio region is a favorite place for Vipera berus.
Proceed over Plan Canin into Val Forno. In the background you see the glacier which is receding at a rapid pace. Soon after the dam you pass the granite contact

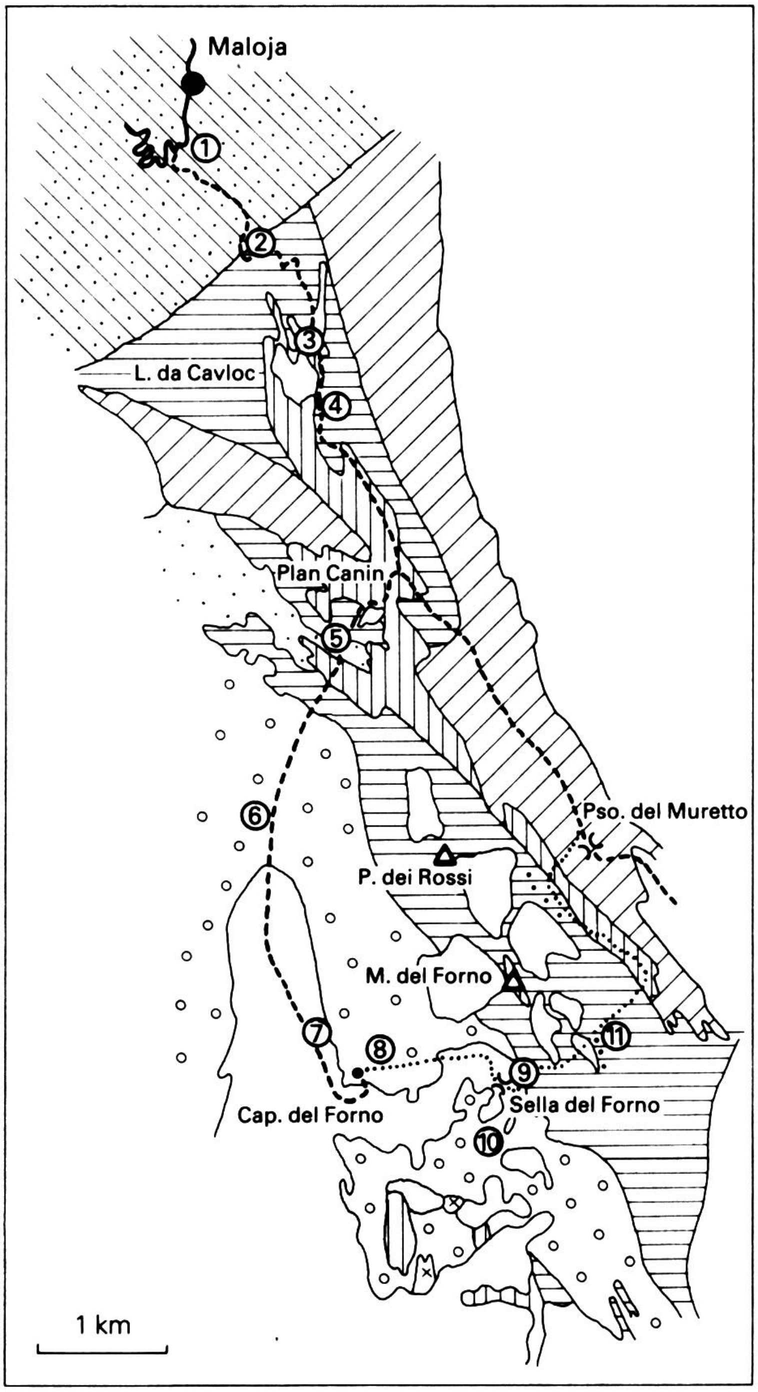


Figure 21. Itinerary for field trip into Lagh da Cavloc-Val Forno-Passo del Muretto. – *Kartenskizze für eine geologische Exkursion vom Malojapass über Cavloccio zum Fornogletscher. Maloja Gneise der Margna Decke, Engadiner Linie, Kontaktgesteine um Alpe Cavloccio mit Andalusitschiefern und Albit-Anorthit-Porphyroblastenamphiboliten, Bergeller Granit und östlicher Kontakt gegen Sella del Forno. Die Murettovariante führt an Pillowbasalten vorbei und Manganmineralien, die auf den ozeanischen Ursprung der amphibolitischen Gesteinsserie hinweisen.*

(5). Its border facies is equigranular, but soon the typical megacrystic granite begins, forming large cliffs on both sides of the valley. Take a few minutes to look at the granite (coord. 773.9/135.4) with crosscutting pegmatite, aplite and lamprophyric dikes and relatively good alignment of megacrysts **(6).** At about 2300 m the path passes onto the glacier. Further up it crosses eastwards two moraines, one consisting predominantly of granite, the other of marble originating from Cma. di Vazzeda. There are excellent specimens of tremolite, diopside and clinohumite **(7).** Behind Cap. del Forno SAC (east-northeast) there are beautiful exposures of granite, with inclusions of marble (anorthite and wollastonite-bearing) and gneisses crosscut by aplite and pegmatite dikes **(8).**
You may return the same way. Alternately (perhaps on a second day, after spending the night at the hut) climb to Sella del Forno, view the splendid dike system which penetrates the contact series composed mainly of amphibolites **(9).** A short side trip south to coord. 775.9/133.3 takes you to outcrops of orbicular granite which is quite rare in the Bergell region **(10).** Climb to Pt. 2944 (northeast of Sella del Forno), then descend towards the northeast, passing through contact metamorphic sequences and amphibolites with pillow structures (e.g., coord. 776.5/133.8, MONTRASIO, 1973), and in those intercalated rhodonite-bearing schists. An old Mn prospect is at 776.7/133.7 **(11).** At 2600 m cross evenly over to Passo del Muretto (Muretto quartzites) and descend to Plan Canin.
This field trip – in a splendid arctic environment – leaves you with an impression of igneous contacts, magmatic intrusions and flow quite different from the field trips to the southwestern part of the granite where effects of deformation and regional metamorphism are emphasized.

Exkursionen

Auf den folgenden Seiten geben wir Vorschläge für ein paar geologische Exkursionen, die uns in einer Woche einen Überblick über die vielseitigen Aspekte des Bergeller Massivs vermitteln. Skizzen geben die Routen an, topografische und geologische Spezialkarten sind unerlässlich. Die meisten interessanten Aufschlüsse sind mit dem Auto nicht zugänglich und erfordern mühsame, wenn auch nicht schwierige Touren durch eine herrliche Gebirgslandschaft. Beachten Sie, dass die deutsche Übersetzung dieser Exkursionsbeschreibungen gekürzt ist. Für Einzelheiten wird auf die englische Fassung verwiesen.

Exkursion 1: Albigna – Zentraler Bergeller Granit (1 Tag), (Figur 16)
Mit der Seilbahn der EWZ kommt man einfach von Pranzaira (Vicosoprano) zum Staudamm der Bergeller Kraftwerke. Am besten folgt man von der Bergstation der alten Strasse mit ausgezeichneten Aufschlüssen von verschiedenen granitischen Gesteinen: megakrystalliner Bergeller Granit mit meist parallel orientierten grossen Alkalifeldspaten, Aplit- und Pegmatitgängen und vereinzelten dunkeln Einschlüssen **(1)**. Man überquert den Damm und steigt zur Albignahütte (SAC) auf, die im Sommer bewirtschaftet ist. Von dort empfiehlt sich ein Abstecher nach Osten – entlang der alten Wasserleitung (2300 m) mit herrlichen Gletscherschliffen und magmatischen Strukturen **(2)**. Nun zurück zum Weg, der zum See absteigt, und dann etwas mühsam durch Felsen und Moränen nach Süden! Bei Pt. 2305 erreicht man den Gletscher.
Es ist empfehlenswert, eine Stunde die verschiedenen Blöcke in der Hauptmoräne zu studieren **(3)**. Wenn man Glück hat, findet man in Pegmatitgängen blaue Berylle. Die Moräne besteht vorwiegend aus Hornblendegneis, nicht aus Granit, der das ganze Tal füllt. Dieser Hornblendegneis gleicht dem Tonalit, der in Bagni Masino unterhalb dem Bergeller Granit vorkommt. Wir vermuten, dass im tiefsten Teil des Val Albigna ein Fenster existiert, gegenwärtig vom Gletscher bedeckt, in dem Tonalit aufgeschlossen ist, und der Granit deshalb auch im zentralen Teil die Struktur einer flachliegenden Decke hat.
Wir überqueren den Gletscher und steigen von Pt. 131.8/769.7 ins Cacciabellakar hinauf. Hier ist ein feinkörniger Granit aufgeschlossen, der sich in einer zylinderförmigen Struktur durch das ganze Massiv von Bondasca bis Forno erstreckt **(4)**. Auf einem guten Weg erreichen wir das Wärterhaus am Damm.
Wer noch eine Stunde Zeit hat, sollte unbedingt zu Fuss nach Vicosoprano absteigen. Wie wir uns dem Kontakt nähern, wird der Granit mehr und mehr verschiefert. Die Orientierung der Alkalifeldspate ist hier offensichtlich ein Ergebnis intensiver Deformation und nicht eine magmatische Fliessstruktur **(5)**. Auf 1600 m durchqueren wir eine Tonalitzone und darauf metamorphe Gesteine mit Kalksilikaten (Wollastonit), Sillimanit und Cordierit **(6)**. Die leukokraten Augengneise am Fuss gleichen denjenigen der Tambodecke.

Exkursion 2: Val Bondasca – Kontakt des Bergeller Granits (1 Tag) (Figur 17)
Am Tag vor dieser Tour sollte man die Steinbrüche in Promontogno oder Soglio besuchen, in denen die Muskowit-Biotit-Alkalifeldspat-Albit-Plattengneise der Tambo-Decke aufgeschlossen sind, die sich durch die ausgezeichnete Spaltbarkeit auszeichnen (Fig. 1). Das metamorphe Rb/Sr-Alter der ursprünglich herzynischen Granite beträgt 31 Mio. Jahre.
Von Bondo geht man zu Fuss (oder gegen Gebühr mit dem Wagen) ins Val Bondasca. Bei 1000 m Höhe durchquert man einen Tunnel. Die hier aufgeschlossenen Tambogneisse sind nicht plattig wie im Steinbruch, sondern enthalten Augen und erinnern an den Bergeller Granit **(1)**. Bei der Staumauer Prä sieht man verfaltete Migmatite, die zum Gruf-Komplex gehören, der im Val Bondasca eine enge Antiklinalstruktur bildet (Fig. 8). Bei Gerp ist auf der Südseite eine alte Lavezmine (1777), die Material zur Herstellung von Töpfen lieferte

(siehe Ausstellung im Talmuseum in Stampa) **(2)**. Die Strasse endet bei Punkt 1247, und wir folgen nun dem Weg nach Sasc Fura. Gleich nach der Brücke gehen wir über Wiesen nach Jerta, wo ein Bergsturz ausgezeichnete frische Proben von Migmatit präsentiert, durchkreuzt von Aplit und Pegmatitgängen **(3)**.
Wir kehren zum Weg zurück und steigen nun steil zur Sasc Fura-Hütte hinauf (1 Stunde). Bei der Hütte erkennen wir Tonalit, der über den Grufmigmatiten liegt. Würden wir weiter gegen die Badilekante emporsteigen (eine auch geologisch lohnende Klettertour), so würden wir weiter oben Bergeller Granit auf Tonalit finden. Aber es ist interessanter, der Wasserleitung nach gegen Westen ins Val Trubinasca einzusteigen. Auf 2200 m, am Fuss des Trubinasca Gletschers sind wir am Kontakt von Migmatit, Tonalit und Granit. Westlich von Punkt 2218 finden wir in der Moräne herrliche Blöcke mit Xenolithschwärmen **(4)**. Eine ultramafitische Breccie ist metasomatisch verändert mit regelmässiger Zonierung Olivin/Dolomit –› Talk –› Chlorit –› Aktinolith –› Hornblende –› Biotit (ARTUS 1959). Die Zone liegt über den Grufmigmatiten, darüber befinden sich Felswände mit Tonalit. Den Gipfelgrat bildet eine dünne Decke von Bergeller Granit. Wir erkennen hier die horizontale Struktur des Granits. Die Deformation ist intensiver als in Albigna. Alkalifeldspäte sind ausgezeichnet geregelt (Fig. 3 b). Es wird empfohlen, wieder über die Hütte abzusteigen.

Exkursion 3: Val Codera – Granulitartige Gesteine des Gruf-Komplexes (2 oder 3 Tage) (Figur 18)
Diese mühsame 2–3-Tagetour mit mehr als 2000 m Höhenunterschied bietet Einblick in einige der ausserordentlichsten Gesteine der Alpen und gleichzeitig in eine wilde Gebirgslandschaft, die schon STUDER (1851) faszinierte.
Wir beginnen wieder in Bondo, aber folgen der Strasse nach Ciresc. Dort lassen wir das Gepäck und folgen dem Strässchen nach Vöga. Von Koord. 762.00/132.6 bis 762.4/132.75 sind gute Aufschlüsse von pelitischen Schiefern zu sehen. Sie sind deshalb ausserordentlich, weil sie alle drei Aluminosilikate Disthen, Sillimanit und Andalusit enthalten. Wir nehmen an, dass die Metamorphosebedingungen denen des Tripelpunktes (650° C, 5.5k6) entsprechen (Fig. 13,14) **(1)**.
Zurück nach Ciresc und auf dem Weg über Cänt, Vec nach Alpe Tegiola. Auf 1580 m, bei einer idyllischen Quelle, durchquert man einen Ultramafitzug. Es ist ein Ausläufer der Chiavenna Ultramafite, die bis ins Val Bondasca reichen.
Von Alpe Tegiola an sind wir in Grufmigmatiten. Isoklinale Faltung und mehr oder weniger häufige Mobilisate sind typisch. Gegen Bochetta della Tegiola zu wird die Deformation intensiver mit zahlreichen Mylonit- und Ultramylonitlagen **(2)**. Letztere sind flintartig feinkörnig und am klassischsten etwas weiter westlich (761.7/130. bis 761.,8/129.75). Ein Abstecher lohnt sich für alle, die an Deformation interessiert sind. Wir finden dort auch Gänge von megakristallinem Granit, der der Zusammensetzung nach dem Bergeller Granit entspricht und andeutet, dass Bergeller Granit durch Aufschmelzung von Grufmigmatiten entstanden sein könnte.
Vom Pass hat man einen herrlichen Blick ins Val Codera und erkennt wieder (wie im Trubinascakessel) die Deckenstruktur des Granits.
Er bildet die Gipfelpartie (Gaiazzo, Ligoncio) und liegt auf Tonalit, Marmor und Migmatit. Wir steigen nun ab bis 2200 m und dann wieder hinauf über Wiesen zum Bivacco Vaninetti CAI (8 Schlafplätze mit einigen Wolldecken). **(3)**
Rund ums Biwak sind Ultramafite (der gleiche Zug wie die metasomatischen Breccien im Trubinasca). Wir steigen zum Pizzo Trubinasca durch Olivinit, Tonalit und schliesslich Bergeller Granit. Vom Gipfel hat man einen eindrücklichen Blick ins Bondasca, besonders auf die Badilekante!
Nun der Abstieg ins Val Codera: Zuerst zur Alpe Sivigia mit kurzem Aufenthalt am Bach,

wo eine ultramafitische Breccie in ein dioritartiges Hypersthen-Labradorit-Gestein übergeht, das sich als guter tektonischer Marker eignet. **(4)**
Aus den Seitentälern Valle del Conco und Val Piana kommen Gerölle von aluminiumreichen Schiefern mit Sillimanit, Hypersthen, Granat, Herzynit, Cordierit, Korund und selten Sapphirin. Am leichtesten zugänglich sind diese Gesteine der Granulitfazies am klassischen CORNELIUS (1916) Fundpunkt (761.1/125.3), im Schutt unter einer leider unzugänglichen Felswand. **(5)**
Cap. Luigi Brasca CAI ist im Sommer bewirtschaftet und ein gutes Nachtquartier vor dem langen Abstieg nach Novate, bei dem wir mehr und mehr mikrogranitische Gänge erkennen, die zum Novate-Granit gehören, der jünger ist, als der Bergeller Granit. Man sieht ihn am besten in den Steinbrüchen von San Fedelino (754.5/121.7). **(7)**
Novate Granit ist intrudiert in die Antiklinalstruktur des Monte Berlinghera, einem westlichen Ausläufer der Lepontinischen Kulmination.
Einen erholsamen Ruhetag verbringt man am besten im Bachbett bei Novate (756.0/120.8), wo man in einem geologischen Garten inmitten polierter Blöcke schwimmen kann, die eine Zusammenfassung der Geologie des Val Codera bieten. **(6)**

Exkursion 4: Val Masino – Tonalit, Fenster von Bagni, Kontakt mit Disgrazia Ultramafiten (2 Tage, hauptsächlich mit Auto) (Figur 19)
Von Masino im Veltlin fährt man auf einer engen Strasse nach Norden und überquert die Insubrische Linie in der Nähe des alten Kraftwerkes am Fuss des Tales. Es ist schwierig anzuhalten, und die besten Aufschlüsse mit Pseudotachyliten und Marmormyloniten sind auf der anderen Seite des Baches im Gestrüpp (769.7/114.9). (Die gleichen Gesteine sind besser zugänglich in der Nähe der Kirche von Berbenno.) In Filorera (nach Cataeggio) nehmen wir die Strasse nach Sasso Bisolo, parkieren in der ersten N-Haarnadelkurve (1000 m) und folgen einer alten Werkstrasse nach Norden. Das Material in den Schutthalden kommt vom Wassertunnel San Martino-Biolo und besteht aus Tonalit (bis etwas südlich des Sasso Bisolo Baches) und Metamorfiten (weiter südlich). Die Kalksilikatfelsen enthalten Wollastonit und Diopsid. Pelitische Schiefer sind besonders interessant, weil sie – wie in Ciresc-Vöga – alle drei Aluminosilikate enthalten (Fig. 2a) und den pT Bedingungen des Tripelpunktes entsprechen (sieh Fig. 13 zur allgemeinen Verbreitung von Sillimanit, Disthen und Andalusit) **(1)**.
Nun kehren Sie auf die Talstrasse zurück. Halten Sie in Sasso Remenno **(2)**. Östlich sehen wir die regelmässig gegen Süden einfallenden Schichten des Tonalits. In Blöcken an der Strasse sehen wir den Übergang zwischen Tonalit und Bergeller Granit mit abwechselnden Bändern von Hornblendegneiss (Tonalit) und megakristallinem Bergeller Granit. In San Martino sind wir im Kern des Granites, und wenn der Granitkörper eine Wurzel hat, ist sie hier und im östlich anschliessenden Val di Mello.
Wir folgen der kurvenreichen Strasse nach Bagni. Am Fusse vom Felsen (767.2/123.5) sind wir wieder in Tonalit und in Bagni in verfalteten Migmatiten vom gleichen Typ wie Gruf. Wir haben hier ein Fenster vor uns, in dem metamorphe Gesteine unterhalb von Tonalit und Granit aufgeschlossen sind **(3)**.
Wir übernachten in San Martino, Cataeggio oder am besten, wenn Platz vorhanden ist, in Ponte Baffo. Am nächsten Tag fahren wir wieder ins Val di Sasso Bisolo. Nördlich befinden sich eindrückliche Tonalitfelswände mit grossen Schutthalden. Ein Bergsturz hat 1978 den Weiler Valbiore zerstört und die Strasse ist immer noch in schlechtem Zustand. Wir fahren bis ans Ende der Strasse in Preda Rossa. Talaufwärts erkennen wir links graue monotone Tonalite und rechts rotbraune Ultramafite. Der Tonalit ist nirgends direkt mit dem Olivinfels in Kontakt, sondern durch eine schmale Zone von Gneiss, Marmor und Amphibolit getrennt (z.B. 775.3/122.7). Der Ultramafitkörper Malenco-Disgrazia repräsentiert wahr-

scheinlich einen Teil des oberen Erdmantels, der in Gesteine der Kruste eingeschoben wurde. Während der Platznahme des Bergeller Granits im Tertiär wurden die ursprünglichen Serpentingesteine progressiv umgewandelt: Antigorit –› Olivin –› Tremolit –› Anthophyllit (TROMMSDORF und EVANS, 1972, Fig. 12). Wenn wir dem Strässchen auf der E-Seite des Tales (nicht dem Weg nach Rifugio Ponti!) folgen, sehen wir Proben der verschiedenen thermischen Beanspruchung im Schutt. Felsen (776.25/113.65) zeigen herrliche Anthophyllitrosetten **(4)**. Wenn wir auf diesem Rücken gegen Nordosten aufsteigen, kommen wir in die Tremolit- und noch höher in die Olivinzone. Auf etwa 2600 m traversieren wir NW zuerst Moränen, dann Gletscher zu einem Aufschluss (777.2/125.3) in der unmittelbaren Nähe des Kontaktes mit Hypersthen, Andalusit, Cordierit, Margarit und Korund **(5)**. Beim Abstieg nach Rifugio Ponti kommen wir bald in den Tonalit, jedoch mit häufigen Einschlüssen von Andalusitschiefern durchsetzt. Die Assoziation von Tonalit mit Kalksilikaten, Ultramafiten, Amphiboliten und Peliten ist nicht nur hier ein Indiz dafür, dass dieses Gestein nicht durch magmatische Differentiation eines homogenen Magmas entstand, sondern durch Aufschmelzung von Krustenmaterial.
Wir kehren auf dem Hüttenweg nach Preda Rossa zurück.

Exkursion 5: Val Sissone – Kontaktmetamorphose (1 Tag) (Figur 20)
Das Val Malenco bietet eine Mannigfaltigkeit von geologisch interessanten Exkursionen. Wir beschränken uns auf eine Exkursion, die direkt mit den Bergeller Intrusiva in Zusammenhang steht und auf herrlichen, vom Gletscher polierten Aufschlüssen Einblick in Kontaktverhältnisse von Granit, Tonalit und Rahmengesteinen verschafft.
Wir parkieren 1 km westlich von Chiareggio in Pian del Lupo und nehmen von hier den Fussweg über Forbesina ins Val Sissone. Die Blöcke im Fluss und in der Moräne geben uns einen Vorgeschmack, aber man sollte im Talboden nicht zuviel Zeit verschwenden. Gute Aufschlüsse beginnen bei Pt. 2308 (Koord. 777.2/129.3) **(1)**. Wir steigen bis Pt. 2580 und wandern von hier nordwestlich am Fuss des Sissone-Gletschers, wo sich ein Spektrum von Kontakterscheinungen, Assimilation und Metasomatose darbietet, am schönsten in Karbonatgesteinen. BUCHER (1977) schätzt die Temperatur am Kontakt auf 800° C. **(2)**
Von Pt. 2658 steigen wir ab zu Pt. 2438 und kreuzen dabei den graduellen Kontakt zwischen Tonalit und Amphibolit mit weniger und weniger leukokratem Material in den Amphiboliten. **(3)** Es scheint, dass Tonalit durch Aufschmelzung von Amphiboliten, mit Zufuhr leukokrater Phasen entstanden ist. Es besteht die Möglichkeit, im Rifugio del Grande zu übernachten mit herrlichem Blick auf den Monte Disgrazia.

Exkursion 6: Maloja – Cavloccio – V. del Forno – Kontaktmetamorphose und Bergeller Granit (1-2 Tage) (Figur 21)
Nachdem wir auf den bisher beschriebenen Exkursionen mit verschiedenen Aspekten des Bergeller Granits vertraut geworden sind – Struktur, Deformation, Regional- und Kontaktmetamorphose – gibt diese Tour einen ausgezeichneten zusammenfassenden Überblick.
Auf dem Weg vom Malojapass (Pt. 1790) nach Orden kreuzen wir durch die Maloja Albit-Mikroklin-Muskowit Gneisse der Margnadecke **(1)**.
Diese ursprünglich herzynischen Granite sind völlig rekristallisiert. Nordöstlich der alten brücke von Orden – und an der Orlegna schön aufgeschlossen – ist die Maloja-Verschiebung, die die niedrig metamorphe Malojazone vom Bergeller Granit und seiner metamorphen Hülle trennt. **(2)** Südlich dieser Linie sind wir in den Amphibolitfazies. Ausgezeichnete Aufschlüsse von Andalusitschiefer findet man in der Nähe des Cavlocciosees (774.3/139.25 und 775.9/138.4). **(3)** Der Andalusit-Granat-Schiefer ist weit verbreitet, von hier bis zum Granitkontakt. Andalusit mit seinem niedrigen Druckbereich deutet an, dass wir uns in der Nähe des Daches des Bergeller Massivs befinden. Östlich des Cavlocciosees sind die einma-

ligen Albit-Anorthit Porphyroblasten Amphibolite aufgeschlossen, ein für Feldspat-Phasenbeziehungen wichtiges Gestein (Wenk, 1979, Fig. 2b) **(4)**
Wir wandern von Plan Canin ins Val Forno. Bald nach dem Stausee beginnt der Granit, zuerst in einer feinkörnigen Randfazies **(5)**, aber bald megakristallin **(6)**. Auf dem Gletscher traversieren wir zwei Moränen. Die erste besteht aus Granit, die zweite, östliche vorwiegend aus Marmor von der Cima di Vazzeda **(7)**. Hier finden wir ausgezeichnete Proben von Tremolit, Diopsid und Klinohumit. Hinter der Fornohütte SAC befinden sich schöne Aufschlüsse von Granit mit Einschlüssen von Marmor und durchkreuzt von Pegmatit- und Aplitgängen. **(8)**
Entweder kehren wir zurück ins Tal oder übenachten in der Hütte. Dann können wir am zweiten Tag zur Sella del Forno aufsteigen, mit herrlichem Blick auf ein Gangsystem, das in die Amphibolitserie der Kontaktzone dringt **(9)**. Ein kurzer Abstecher nach Süden (775.9/133.3) führt uns zu einem im Bergell seltenen Vorkommen von Kugelgranit (ein weiteres befindet sich an der Cima da Murtaira) am Fusse des Monte Rosso. **(10)**
Wir steigen vom Pass aus dem Grat nach bis zu Pt. 2944 und dann hinunter durch Kontaktmetamorphe Pelitserien und Amphibolite. Amphibolite weisen oft Pillowstrukturen auf, die uns daran erinnern, dass die Gesteine ozeanische Basalte und Andesite darstellen (eg 776.1/135.2, Montrasio 1973) **(11)**. Assoziiert mit den Pillowbasalten sind die Vorkommen von Rhodonit-Schiefern. Wir traversieren eben (2600 m) zum Murettopass durch Diopsidquarzite und erreichen den Weg wieder in Plan Canin.

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