Contributions to the geology of the Monte Rosa nappe

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by *Martin Engi*[1]

Preface

Monte Rosa has lost none of its fascination since early pioneers of Alpine geology, over 200 years ago, had started to explore this majestic mountain range. Current research involves several groups in Italy, Switzerland, Germany, France, and the United States, working on topics that range from the mineralogy and petrology of high-pressure rocks to their geochronology and geochemistry, the structural characterization of the tectonic units that form the Monte Rosa nappe, and the geodynamic implications for the Western and Central Alps.

To promote interdisciplinary contacts and help to bridge existing gaps among specialists, the Swiss Society of Mineralogy and Petrology and the Swiss Geological Society decided in 1999 to co-sponsor two events: An international symposium on Monte Rosa geology and a field excursion into the Monte Rosa nappe. Both of these events were planned in memory of Peter Bearth, one of the pioneers of Monte Rosa geology whose centenary was to be honored, and both events were organized by Martin Frey to take place in the autumn of 2000. Martin's tragic and untimely death (September 10, 2000) forced a change of plans. While it was decided still to hold the symposium at the annual meeting of the Swiss Academy of Science (October 12, 2000 in Winterthur), the field trip had to be postponed by one year. Both events ended up commemorating Martin Frey (1940–2000) as well as Peter Bearth (1902–1989).

The present special issue of the Swiss Bulletin of Mineralogy and Petrology assembles contributions made in large part by participants of the symposium and the field trip. While this collection of papers cannot claim to cover comprehensively all of the topics of current interest, and far less yet to present any kind of a conclusive record, this Special Issue nevertheless reflects the state of current understanding and the presently hot topics. They also may help identify and formulate more precisely the problems future research will be facing.

Field Trip Report and Introduction to this Special Issue

MONTE ROSA EXCURSION, SEPTEMBER 3–8, 2001

By way of introduction to this Special Issue on the geology of the Monte Rosa nappe, a brief account of the four-day field trip is presented, emphasizing the main topics discussed and the occasionally hot debates held. With many of the current protagonists of ideas and interpretations on the geology of Monte Rosa assembled in select areas, to examine primary evidence at outcrops, to relate these to other pertinent field locations, and to recall relevant results from many laboratory studies, lively and engaged discussions were ensured. Not surprisingly, these rarely lead to an immediate synthesis of previously conflicting views. However, the open debates certainly have allowed the participants to gain a more complete and balanced appreciation of local situations, to assess their relevance to problems of a larger scale, and to become aware of complexities and remaining uncertainties.

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The 28 participants comprised three research generations, from young Ph.D. students to seasoned researchers, and including specialists from various fields, representing a total of 11 institutions:

Mark van Baalen, Harvard
Lukas Baumgartner, Mainz
Andrea Bistacchi**, Padova
Christian Chopin, Paris
Giorgio V. Dal Piaz, Padova
Christian de Capitani, Basel
Larryn Diamond, Leoben
Martin Engi, Bern
Nikolaus Froitzheim, Bonn
Paolo Garofalo, Leoben
Antonio Guermani**, Padova
Clark Johnson, Wisconsin
Julia Kramer, Basel
Tom Lapen, Wisconsin
Ronan LeBayon, Basel
Catherine Leyx, Paris
Nancy Mahlen, Wisconsin
Neil Mancktelow, Zürich
Matteo Massironi, Padova
Henri Masson, Lausanne
Thorsten Nagel*, Bonn
Peter Nievergelt, Zürich
Volker Osterholt, Bonn
Sabine Pawlig, Mainz
Jan Pleuger, Bonn
Martin Robyr, Lausanne
Albrecht Steck, Lausanne

* first two days only
** last two days only

The following brief itinerary of the field trip recalls and highlights the days in the field. Hardly any references to the extensive literature and classic geological maps are given here; the reader is referred to the authoritative review provided by G.V. Dal Piaz in this Special Issue. However, the field trip report does include pointers, where appropriate, to the other papers contained in this issue. Names of topographic locations used refer to the Swiss topographic maps 1:50'000, sheet 284: Mischabel, and sheet 294: Gressoney.

Monday, September 3, 2001

Arrival: Zermatt–Riffelberg
Participants meet at Täsch, travel by train and rack railway to Riffelberg above Zermatt. For many of us, facing the majestic Alpine scenery on this splendidly clear fall evening brings up old memories of previous encounters in this area. Niko Froitzheim gives a brief introduction to the regional geology visible and outlines the route planned for this field trip: two days shall be spent in the northern parts (Zermatt and Mattmark areas), followed by two days in the southern parts of the Monte Rosa nappe (Val d'Ayas). Giorgio Dal Piaz recalls a memorable field trip with Peter Bearth, which lead them to the exact same spot at Riffelberg on September 1, 1963, almost to the day 28 years ago.

Tuesday, September 4, 2001

Gornergrat–Stockchnubel–Drive to Saas-Grund
Starting into a grey morning, with a few snow flurries greeting us at Gornergrat, Niko Froitzheim outlines the regional context and program of the day: To examine a section along the northern margin of the Monte Rosa nappe, from Gornergrat (3095 m) steeply down to Gornergletscher (2650 m), along the glacier to Stockchnubel (3047 m), and back to Riffelberg (2582 m). Units crossed in the course of the day include the Zermatt-Saas ophiolite unit, overlying the dominantly sedimentary Gornergrat units and the Stockhorn unit, through which we continue down into the Furgg zone that forms the contact with the Monte Rosa metagranites. Focal points of the day include first the detailed contents of several units of detached cover sediments, their internal polyphase deformation and mutual position. From mid-day on, discussions move on to the relation of the (in)famous Furgg zone to these sedimentary subunits and to the main mass of the Monte Rosa nappe.

– The sedimentary series in the Gornergrat area, formerly regarded as an integral part of the Monte Rosa nappe, have recently been recognized as an independent tectonic segment in front of the Stockhorn unit. Detailed stratigraphic and stuctural studies have recently lead the Lausanne group (lead by Albrecht Steck and Henri Masson) to identify several subunits, including the Mesozoic packages of the Cimes Blanches (Triassic? carbonate), the Gornergrat unit *sensu stricto* (Permotriassic, clastic), and the Tuftgrat unit (low to middle Jurassic, variable facies). Collectively, these subunits form a complexly folded wedge between the tectonically higher Zermatt-Saas unit and the Monte Rosa nappe. A detailed account of this new interpretation, based on several thesis projects, remains to be published.

– Descending to the Gornergletscher, the field trip crosses along the base of the Stockhorn paragneisses and then into the Furgg zone. In the area south of Tufthorn, this extensive but fairly narrow unit separates the Stockhorn unit from the main body of Monte Rosa metagranites. Traversing towards the east along the glacier towards Stockchnubel, good exposures of this classic portion of the Furgg zone reveal fragmented mafic dikes in felsic bands and trails, as well as metasedimentary

lenses. In suitable mafic and pelitic rocks, there is clear evidence of eclogite facies conditions and subsequent retrogression. The significance of the Furgg zone remains highly controversial, as is evident in three papers in this Special Issue (DAL PIAZ, 2001; KELLER and SCHMID, 2001; LIATI et al., 2001). At the outcrop, a lively discussion ensues among proponents of different views: Based largely on structural work, Niko Froitzheim views the Furgg zone as an extended shear zone including ophiolitic components; Albrecht Steck instead recognizes in the Furgg zone an originally coherent, though partially dismembered, stratigraphic section ranging from (upper?) Paleozoic to middle Jurassic in age. This latter view, based largely on evidence near Monte della Preja (north of Antronapiana, not visited by field trip), interprets serpentinite bodies – such as those at Stockchnubel – not as original elements of the Furgg zone. Whether juxtaposed by folding or accreted to the Furgg zone by thrusting, these would be derived from either the overlying Zermatt-Saas unit or the underlying Antrona unit.

– Another point of contention discussed at the outcrop concerns the relation of the latter two units to each other: Do they represent one and the same paleogeographic domain, or were they derived from two different oceans? This question is closely linked to the original position and tectonic evolution of the Monte Rosa nappe as a whole. An elegant and simple model recently advocated by FROITZHEIM (2001), who derives this nappe from the southern European margin, gives rise to incisive questions and a general warning by Albrecht Steck: "In the Alps, the simplest models that explain a number of observations at some point in time have not always proven the most correct in the long run!" The debate also surfaces in two papers of this Special Issue, by KELLER and SCHMID (2001) and LIATI et al. (2001).

The field trip participants have ample time to discuss and ponder these questions further, on the hike back via Rotboden to Riffelberg. Following the descent by rack railway to Zermatt, and on to Täsch, a short drive leads a fairly tired bunch of geologists to Saas-Grund, the starting point of the next day's excursion.

Wednesday, September 5, 2001

Mattmark dam site–Drive to Val d'Aosta and Val d'Ayas–Champoluc

A sunny but crisply cold morning sees the participants early in the upper Saas valley, near the Mattmark dam. A regional introduction by Niko Froitzheim and Julia Kramer emphasizes the polyphase deformation in and relative positions of tectonic units in the footwall of the Zermatt-Saas unit, i.e. of the Portjengrat unit, the Furgg zone, and the Monte Rosa nappe. The tempting plan to examine these in detail in the glacially polished exposures below the Allalin glacier, the threat of an ice fall from that glacier forces another change in the programme, for safety's sake. Instead of visiting another part of the Furgg zone (note the paper by LIATI et al., 2001), we decide to study first a section in the pre-granitic basement of the Monte Rosa nappe, then the polyphase deformation within the metagranite itself, and finally the evolution of a high-pressure shear zone containing whiteschists.

Starting at the western end of the Mattmark dam, evidence of the polymetamorphic evolution is examined in metapelites. Coarse garnet porphyroblasts, overgrowing a pre-Alpine schistosity, may represent pre-Alpine relics; fist-sized microlithons containing garnet and cordierite a short distance further south are further indications of pre-Alpine metamorphism. These local relics contrast with the dominant assemblages made up of paler garnet, phengitic white mica, chlorite, and local kyanite; these are interpreted as the Alpine high-pressure assemblage, as they appear to dominate where the Alpine schistosity is stringent, indicating more pervasive deformation. Here, as elsewhere in the Monte Rosa nappe, relics of Permian metamorphism (see ENGI et al., 2001) are not uncommon in pelitic and mafic rocks, despite the strong Alpine overprint.

Excellent exposures of the deformation features in Monte Rosa metagranite along the road west of the Mattmark lake are examined next. This absorbs the tectonically inclined participants of the field trip in debates over the relation of the visible mesoscopic features to recent regional tectonic reconstructions involving the Monte Rosa nappe. Meanwhile, petrologists fancy the phantastic blocks of the Allalin metagabbro along the road, with their complex textural evidence, such as coronitic domains, resulting from the eclogite facies metamorphism of the Zermatt-Saas unit.

At the end of the morning, all participants reunite in bright sunshine at the northeastern corner of the lake, where whiteschists are studied in metasomatically altered shear zone in Monte Rosa metagranite at a roadcut some 300 meters south of the dam. With Mg-chloritoid and phengite included in assemblages with talc and kyanite, pressure conditions in excess of 20 kbar have recently been estimated by Ronan LeBayon and co-workers. A debate ensues over the reliability of the mineral equilibria used, notably in view of their sensitivity to assumptions about the activity

of H_2O. This leaves some participants unconvinced whether reported pressure conditions should be viewed as a reliable measure of the (minimum) depth of burial of the Monte Rosa nappe.

Following a picknick lunch below the Mattmark dam, the excursion sets out for the drive down the Valais via Visp to Martigny, and across the Grand Saint Bernard pass to Italy. The first stop in the Aosta valley introduces another set of topics altogether to the field trip. High above the town of Fenis, Matteo Massironi gives an overview of the brittle deformation features that have regionally affected the Austroalpine-Pennine nappe stack since the Oligocene. Fault-bound blocks characterize the regional architecture, and recent detailed mapping by the Padova group has clarified the style and effect of several interacting fault systems, including those responsible for bringing up the Monte Rosa unit in the lower Val d'Ayas. One of the major faults, the Aosta-Ranzola fault, can be studied along the road south of Fenis. At an altitude of 860 m this normal fault, dipping ~60°N, is seen to cut through serpentinites in which listvenites occur, a peculiar hydrothermal fault breccia.

The field trip then continues the drive down from the middle of Val d'Aosta to Verrès, where we turn up into Val d'Ayas, traversing the tectonic window of Monte Rosa basement rocks. Finally reaching Champoluc, the group is greeted with classic Italian hospitality at Hotel Favre.

Thursday, September 6, 2001

Gold district near Brusson–Walk to Rifugio Mezzalama

Participants awaken to another splendidly clear fall morning. Before returning to the lower Val d'Ayas, to study the window of the Monte Rosa nappe, a short drive takes us up to the Colle de Joux, situated right on the Aosta-Ranzola fault. This stop provides an exceptional panoramic view, and Giorgio Dal Piaz seizes the opportunity to introduce to the Italian side of the Monte Rosa nappe and its geological context: To the South of the Aosta valley, the peaks at the horizon encompass several eclogitic lower Austroalpine elements (M. Glacier, M. Rafray, M. Emilius). These overly the ophiolitic Piedmont zone, with eclogitic Zermatt-Saas unit at the base, topped by the lower pressure Combin unit. To the West, the external (Helvetic) domain is towered by Mont Blanc, whereas to the North of Val d'Aosta, Upper Austroalpine elements (in blueschist facies in the Pillonet klippe) form both the top of the nappe pile and some of the dominant peaks (M. Mary, Dent Blanche).

The filed trip then returns to Brusson in Val d'Ayas and, guided by Larryn Diamond, the focus returns to the effects of post-nappe brittle faulting and associated fluid flow. In the serpentinite/listvenite quarry at Sizan hydrothermal fluid-rock interaction evidently is synchronous with brittle deformation, and the kinematics along the Ospizio-Sottile fault changed from normal to sinistral movement. A short drive north leads us from the Piedmont ophiolite nappe into the Monte Rosa basement. We examine augengneiss along the small road north of Arcesa, before making our way up to the gold mines to the east above Brusson. Here, the participants get a chance to study the arguably most rewarding effects of fluid activity in the region, responsible for the deposition of hydrothermal gold-quartz veins known since Roman times in the Brusson area. Just south of that town, the Monte Rosa window is truncated by the (Aosta-)Ranzola fault, dipping 70°N, with a throw of >500 m. The effects of steep normal faults within the Monte Rosa granite were crucial also to the formation of the gold deposits, such as Ciamusera Mine, where epigenetic sulfide veins hosting the gold are clearly associated with these faults and with abundant sets of dilational joints. As in the case of listvenite formation, all evidence again indicates fracture control of the fluid flow and of the associated wallrock interaction.

After this visit in the "Monte Rosa Gold District" and a picknick lunch, the field trip returns to Champoluc and transfers to four wheel drive vehicles that take us up from Saint Jacques (San Giàcomo, 1689 m) to Pian di Verra (Veraz) superiore (2382 m). From there, we hike in groups up to the Rifugio Mezzalama (3036 m), situated between the two tongues of the Ghiacciaio di Verra. Along the trail we encounter the entire spectrum of high-grade metamorphic rocks, and Giorgio Dal Piaz, the Doyen of the southern Monte Rosa, greets each of them as an old friend ... As we gain altitude, the late afternoon sun once again offers splendid views of a truly impressive panorama, ranging from Castor (4228 m) and Piramide Vincent (4215 m) towering above us, to the Ligurian and Cottian Alps, far below in the southwest. Although the ice-packed peaks of the "Queen of the Alps" above us are indeed turning rose-colored, we learn that Monte Rosa actually derives its name from "Ruas", meaning glacier in the local patois.

Upon arrival at Rifugio Mezzalama, delightful smells from the kitchen are welcoming us. In the course of the evening, the icy northerly winds pick up, and a few snow flurries make us wonder how

the last day to be spent in the field on this trip may turn out. But, with the cabin as densely packed as it is with climbers and geologists, sufficient heat is generated quickly, and a cozy atmosphere builds up in no time, leaving little space for worries.

Friday, September 7, 2001

Geology near Rifugio Mezzalama–Return to Champoluc

The morning starts cold and with a few flurries still, but the sky is blue again. To everyone's relief, very little fresh snow has fallen during the night, yet this vernier made the rocks rather slippery to hike on. Hence, the plan to traverse steeply to the base of Punta Perazzi is abandoned in favour of a safer tour, first above and then to the west of the cabin. Giorgio Dal Piaz outlines the geology of the southern Monte Rosa nappe: From Castor (4228 m) to the Perazzi ridge, the roof of the Monte Rosa granite is exposed, with numerous granitic veins cutting through and into the roof of mica-schists. The intrusive contact is transposed, with strain gradients increasing upward towards the tectonic contact with the Zermatt-Saas unit.

– The view to the west exposes basal parts of that ophiolite unit in the ridge below Punta di Rollin (3296 m), where a flat lying swarm of yellowish rodingitic gabbro dikes cuts dark serpentinites. The mantle series is topped by 400–500 m of pillowbasalt metamorphosed to glaucophane-phengite eclogites, in the Vallone delle Cime Bianche, only slightly further to the west. (In this section, the extrusive sequence is thus in direct contact with the mantle series, but massive Fe–Ti-metagabbro bodies do occur in Valtournanche and Valle di Gressoney).

– The view to the south, down into the upper end of Val d'Ayas, exposes the southwestern margin of the Monte Rosa unit, the metagranites of which first vanish beneath the pre-intrusive roof, which in turn disappear below the Zermatt-Saas unit further south. Near that tectonic contact, but typically within the Monte Rosa nappe, a narrow belt of highly fragmented character occurs. It contains mafic and subordinate marble boudins, commonly within a matrix of felsic gneiss and garnet schist. This laterally extensive unit is repeated at least at one deeper level, within the Monte Rosa metagranites, where a similar high-strain belt is found, for example below the eastern horizon formed by the ridge from Piramide Vincent (4215 m). Following DAL PIAZ (1964) these complex, heterogeneous belts have been regarded as southern equivalents of the Furgg zone, although mafic fragments in the south are more commonly albite-amphibolites rather than eclogites, and the spectrum of lithologies in boudins is different here than in the Stockchnubel or Monte della Preja areas.

Hiking up towards the northeast of Rifugio Mezzalama for a few hundred meters, the field trip first encounters variably polydeformed Monte Rosa granite, ranging from porphyric granitoid to mylonitic schist, associated with a progressive transposition of felsic dikes to parallel the Alpine schistosity. Antonio Guermani presents recent results on the internal deformation of the Monte Rosa intrusives, emphasizing the evolution of shear zones. It is clear that a comprehensive interpretation of the tectonic implications for the Monte Rosa nappe as a whole will require a regional investigation of these structures in the intrusives and their present frame.

A portion of this frame is well exposed in the glacially polished slabs of rusty gneiss of the roof series encountered as we leave the intrusives. These polymetamorphic paragneiss units include meter-size calcsilicate and marble bodies, as well as granitoid orthogneiss layers and various dikes. Predictably, a discussion breaks out over the age of this lithologically heterogeneous, highly deformed package, and a correlation with the Furgg zone is debated. Dal Piaz has separated that zone from highly strained parts of the Monte Rosa roof units based on their different metamorphism. Pre-Alpine granulite facies assemblages (with cordierite and sillimanite) remain as relics in the latter (despite Alpine high-pressure overgrowths by fine grained kyanite), whereas fragments in the Furgg zone typically have eclogitic relics. In several areas, Dal Piaz has recognized a transition from the deformed intrusive roof into a narrow trail of Furgg zone located at or near the contact to the Zermatt-Saas unit. One such transition is visited next, at the edge of the glacier (Grande Ghiacciaio di Verra, at 2980 m). Here, mafic boudins folded within a felsic matrix are in contact with siderite-rich chlorite-albite amphibolites of the Zermatt-Saas unit; on the western end of the glacial tongue serpentinite and gabbro-derived rodingite mark a continuation of the same unit. A short distance further east, on the way back to the Rifugio Mezzalama, thin trails of carbonate are interleafed with orthogneiss and (sub)pelitic schists containing meter-size calcsilicate boudins. Are all of these fragments derived from Paleozoic or older protoliths? Or may they represent Mesozoic remnants? How can the Furgg zone be delimited reliably in the field? These questions are debated as the field trip returns to our cabin, to enjoy a last sandwich lunch at 3000 m, in pleasant sunshine, before descending into the Vallone di Verra.

Problems associated with the definition and possible interpretation of the Furgg zone are evident in three papers of the present Special Issue: KELLER and SCHMID (2001) delineate the location of the Furgg zone at the northern margin of the Monte Rosa nappe (upper Val Loranco) and propose that it was derived from the continental Portjengrat unit. LIATI et al. (2001) dated zircon cores from a retrograded (but originally eclogitic) metagabbro lens that they attribute to the Furgg zone on the basis of the regional map by STECK et al. (2001). However, the detailed geological map by KELLER (2000) delimits the Furgg zone differently in that area, hence it is not entirely clear whether the ages obtained by LIATI et al. for this sample pertain to the Furgg zone. Finally, in reviewing facts and ideas about this enigmatic unit, DAL PIAZ (2001) emphasizes differences in its petrography and tectonic position, at the scale of the Monte Rosa nappe, notably between the occurrences at its northern margin and in the southwestern and southern part of the nappe.

Two more outcrops are visited on the hike down. First, we examine a steep shear zone cutting the metagranites in NW–SE direction, above a small glacial lake (625.1/84.0/2730 m). Metasomatic effects that lead to the formation of spectacular kyanite–talc–chloritoid schists are discussed by Sabine Pawlig. She has obtained a number of puzzling geochemical results, a first set of which are presented in the paper by PAWLIG and BAUMGARTNER (2001). As in the whiteschists visited at Mattmark dam, the discussion returns to the conditions and timing of the high pressure metamorphism. The regional study included in this Special Issue (ENGI et al., 2001) found no evidence of the previously proposed Cretaceous high pressure overprint; yet from these southern whiteschists Pawlig reports a broad range of Ar–Ar dates (170–240 Ma) obtained on high pressure phengite. The interpretation is not clear.

Ductile deformation in the metagranite is the topic at the final stop (at 2670 m) on the way down to Pian di Verra. In a fold hinge of the Monte Rosa gneiss, a weak crenulation cleavage appears to develop, again testifying to possibly important internal deformation in the intrusive series, a topic in dire need of further study.

Following a pretty hike out the valley, groups of tired field trip participants reunite down at St. Jacques, where they reward and refresh themselves with blueberry gelato. To finish, an excellent dinner at Hotel Favre in Champoluc ends this memorable field trip in style. Most participants travel back home the next morning, but among the few staying on to do field work are Giorgio Dal Piaz and some of the youngest students of Monte Rosa geology. The next chapters are thus under way!

Acknowledgments

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