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METAMORPHISM AND MAGMATISM IN THE WESTERN ITALIAN TYROL **

Many of the ideas stated in the following were published several years ago (see references). This work is a summary of them with some slight additions and further comments.

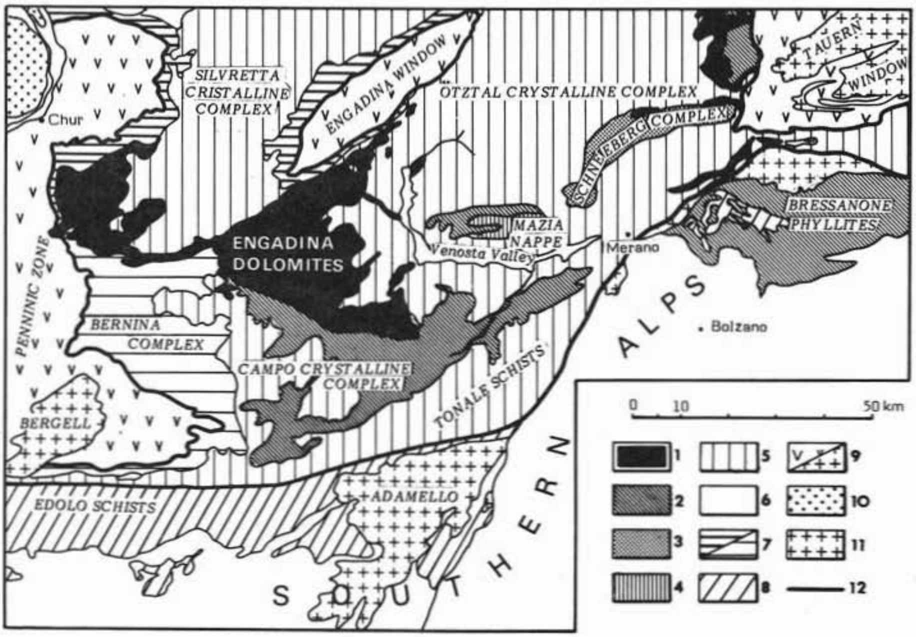

Fig. 1. — Area discussed in this paper. - 1) Sedimentary Austroalpine cover; 2) pre-Permian phyllites; 3) *Schneeberg crystallin*; 4) Mazia Nappe crystallin; 5) Oetztal, Silvretta, Campo, Tonale, etc. crystallin; 6) sedimentary and volcanic Sudalpine cover; 7) sedimentary and crystalline rocks of Lower Austroalpine; 8) Sudalpine crystallin; 9) Pennidic flysch and calcschists, granitoid intrusions; 10) Helvetides; 11) periadriatic intrusions; 12) tectonic and overthrust lines (after TOLLMANN, 1963, mod.).

Lithostratigraphy

In the western Austroalpine area between the Giudicarie Line and the northern and western territorial frontiers of Venosta (fig. 1), the pre-Permian metamorphic

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formations of sedimentary origin are divided into two main complexes, the lower being substantially gneissic with the so-called « *banded paragneisses* » and the upper substantially phyllitic or micaschistous with the so-called « *phyllites l.s.* ». The boundary between these complexes is transitional and marked by the appearance towards the top of the paragneisses (i.e. towards the phyllites) of marbles, often typically associated with amphibolites and quartzites, the two latter lithotypes also occurring in the paragneisses and phyllites.

On the contrary the marbles, absent in the paragneissic formation, characterize most of the phyllitic complex, although their distribution is seemingly irregular. The so-called « *silver micaschist* » formation or « Lasa micaschists » of the literature associated with the marbles of Passiria and partly with those of the Venosta and Sole Valleys, represent zones of greater metamorfism in the lower levels of the « phyllitic » complex ([1]).

The transition from « phyllites » to paragneisses may be seen as following two types (fig. 2). The first (Ultimo Valley, Sluderno, Gavia) is characterized by the appearance of scarce thin layers of marbles and by progressive increase upwards of the pelitic component, with gradual transition from paragneisses to phyllites sometimes several hundred of meters thick.

Instead, the second type (Passiria Valley) is characterized by plentiful amphibolic, micaschistous or phyllitic, and sometimes quartzitic intercalations, alternating with paragneissic levels. The marbles of this transition are generally found in thick layers and sometimes show shallow platform features. All these rocks, also called « alternance series », seem to feed most of the typical stratoid metalliferous deposits of the basement.

The lithotypes mentioned up till now are everywhere associated with old acidic orthoderivatives (« orthogneisses » and porphyroids) together with dykes and small eruptive masses of Alpine age with orogenic character, among which are typical garnet andesites. Porphyroids are particularly frequent at the base of the « phyllite l.s. » complex.

Lherzolitic bodies, although interesting from the petrologic and geological viewpoints, are infrequent. They are mostly included in the paragneissic rocks, and only occasionally in the phyllites.

Angular unconformities and conglomeratic layers have never been noted in the transition zone between these two complexes. In the quartzites of the « phyllitic » complex, the age of the zircons is archeozoic as in the paragneisses, while there are no traces of zircons of age corresponding to that of the granitoid gneisses.

([1]) *Paragneisses*: quartz, oligoclase-albite, common micas, garnet, ilmenite; often chlorite, staurolite, kyanite, sillimanite, somewhere andalusite, cordierite and paragonite. *Phyllites*: common white micas, chlorite, quartz, albite, garnet, ilmenite; often biotite; sometimes staurolite and paragonite; rarely andalusite, kyanite and chloritoid. *Silver micaschists*: micas (including paragonite), quartz, oligoclase-albite, garnet, ilmenite, staurolite, chlorite; somewhere kyanite and sillimanite; rarely chloritoit.

Owing to the above-mentioned features, therefore, the two complexes are regarded as closely associated stratigraphically.

The Austridic Complexes of « paragneisses » and « phyllites l.s. », are compo-

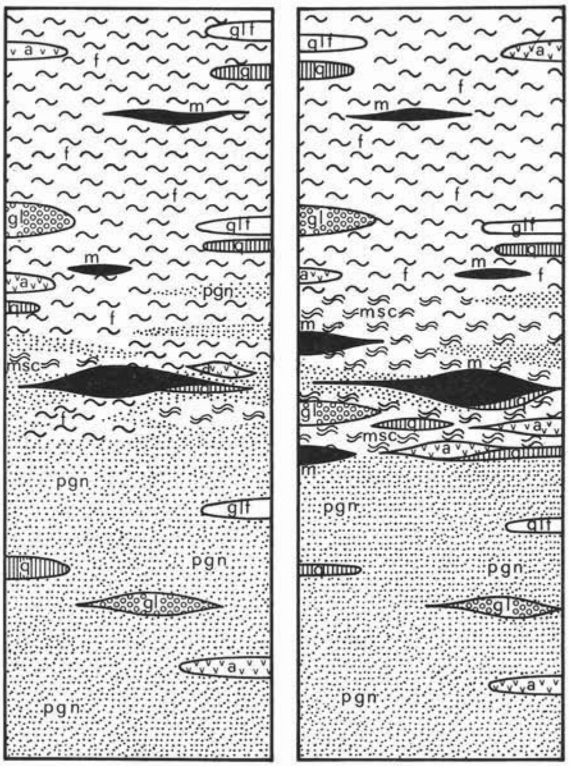

Fig. 2. — The two principal types of lithostratigraphic sequences of the Austridic basement. - *pgn*: banded paragneisses l.s.; *msc*: silver micaschists; *f*: phyllites; *a*: amphibolites and prasinites; *m*: marbles and other carbonatic rocks; *gl*: coarse-grained K-feldspar leucogneisses (« metagranitoids » or « orthogneisses » p.p. Auct.); *glf*: fine-grained K-feldspar leucogneisses (« porphyroids », feldspathized gneisses Auct.); *q*: quartzites; *lh*: lherzolites and serpentines.

sitionally, stratigraphically, mineralogically and structurally very similar to the paragneissic and phyllitic complexes of the Southern Alps, at least from the Brenner Valley to Lake Como.

Metamorphic history

The original materials composing the two formations of « paragneisses » and « phyllites l.s. », as well as the respective intercalations, show that they were involved substantially in a single large-scale tectonic-metamorphic cycle, divided into several syn-kinematic and post-kinematic « high- and low-pressure » crystallization phases, which deformed and metamorphosed them.

During its early kinematic phases (fig. 3), this cycle or orogenesis was characterized by low to medium temperatures (the appearance of syn-kinematic staurolite is rare). *The present schistosity formed everywhere during this stage in the two complexes, in the form of S_1 and a more evolved S_2.* Small temperature differences, crystallization length, or other factors, produced grain-size differences.

Lithostatic pressure during these initial phases must have been at least medium, in order to allow stability of almandinic garnet, a mineral which may be found almost everywhere in the phyllites and paragneisses. In any case, the pressure was at least higher than that of the typical static andalusite phase, during which garnet often becomes instable (see later).

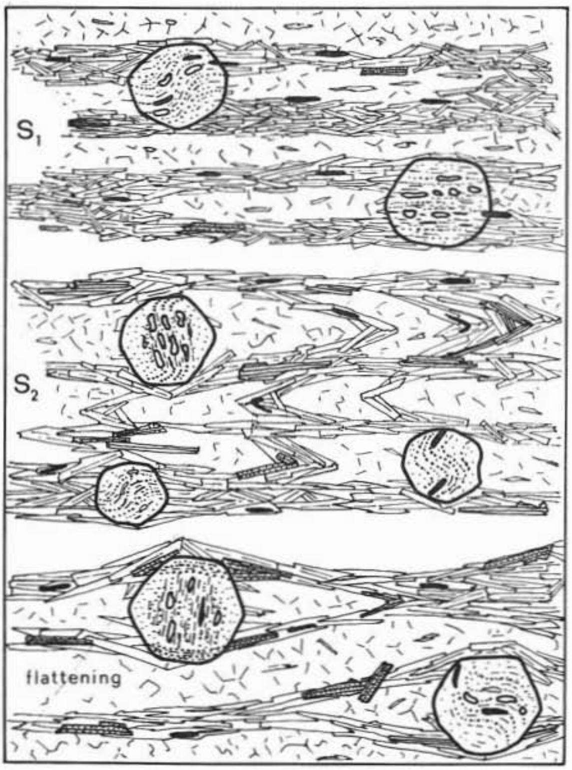

Fig. 3. — Main deformational phase of the metamorphism. Typology of the formation of the main schistosity and history of the coeval porphyroblasts (generally garnet, rarely staurolite and albite-oligoclase). Fold and transpositions are formed meso- and macroscopically (« Schlingen tektonik »). Variations in grain size are connected to variations in temperature and length of heating.

The characteristic minerals, staurolite, kyanite, andalusite, cordierite and sillimanite, grew in successive static phases together with oligoclase or albite porphyroblasts and more garnet. Their occurrence took place according to a typical sequence (Fig. 4) composed initially of garnet in minute crystals or rims, followed by staurolite, kyanite, poikiloblastic plagioclase, andalusite, cordierite, sillimanite, and a younger plagioclase which sometimes rims the previously-formed porphyroblasts.

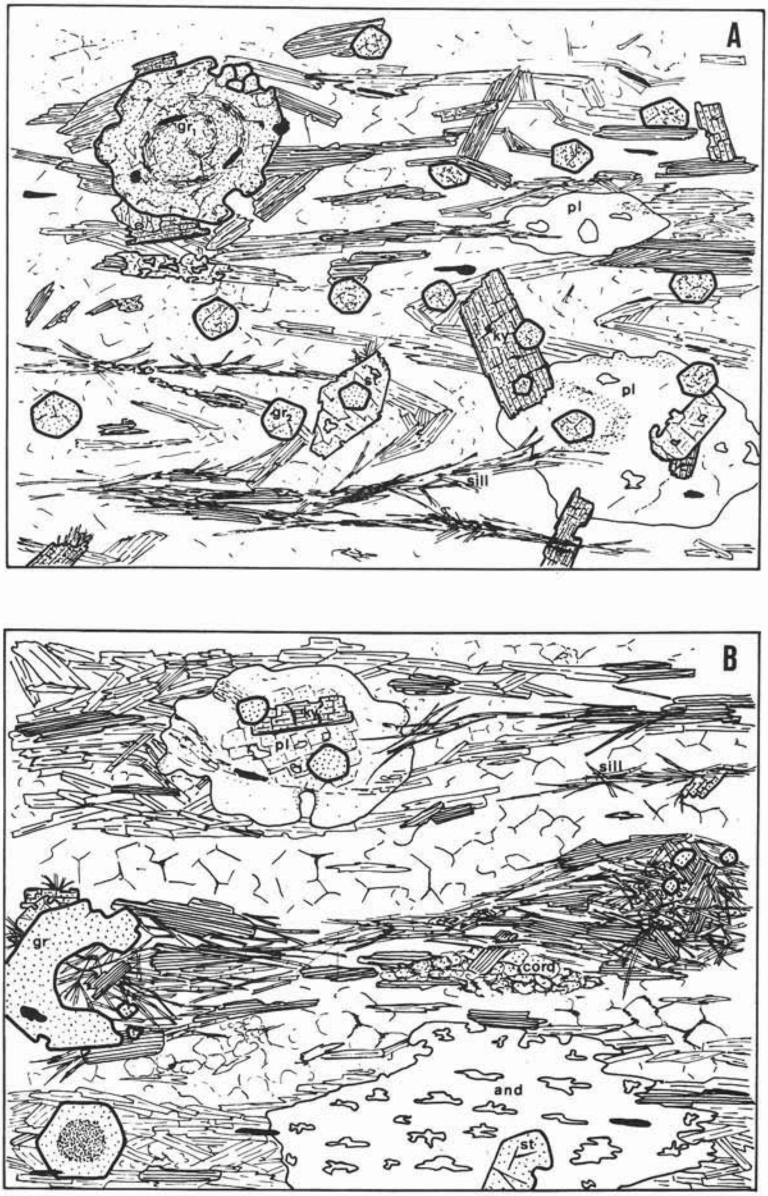

Fig. 4. — Typology of the sequence of the main post-kinematic minerals. Only porphyroblasts of albitic plagioclase appear in the less metamorphic rocks; at slightly higher temperatures another generation of garnet appears (gr_2), sometimes staurolite (and andalusite) together with late albitic or oligoclasic poikiloblasts; at high temperatures, after gr_2 first staurolite and then kyanite may appear (a quite frequent case) and/or andalusite (scarce), cordierite (rare), sillimaniite (very frequent); plagioclasic poikiloblasts almost always close these crystallizations. Concomitant increases in grain size linked to the variations of chemico-physical conditions also appear. Recrystallization and porphyroblastesis of the micas. - A) Areas with kyanite only; B) areas with andalusite: characteristic microstructures which sometimes appear overlying the previous ones; the instability of garnet is to be particularly noted.

The appearance of andalusite, cordierite and often of sillimanite, is typically coupled with instability of garnet.

A general increase of temperature in the post-kinematic phases is widespread, although very variable. The isograds often cut the paragneiss-phyllite boundary with the appearance of characteristic minerals in the phyllitic complex too. However in general the phyllitic complex appears much less lipped by these thermic culminations and, mainly for this reason, turns out overall to be less metamorphic than the paragneissic one. This arrangement shows clearly the polarity of the stratigraphic sequence.

These post-kinematic minerals, normally cut the microfolds as well as more or less transposed micro-mesostructures which conform in the two complexes, and whose genesis is therefore to be linked with the formation of the main schistosity. These micro- and meso-structures show geometric features that also conform to the megastructures (« Schlingen tektonik ») which typically characterize the Austridic basement.

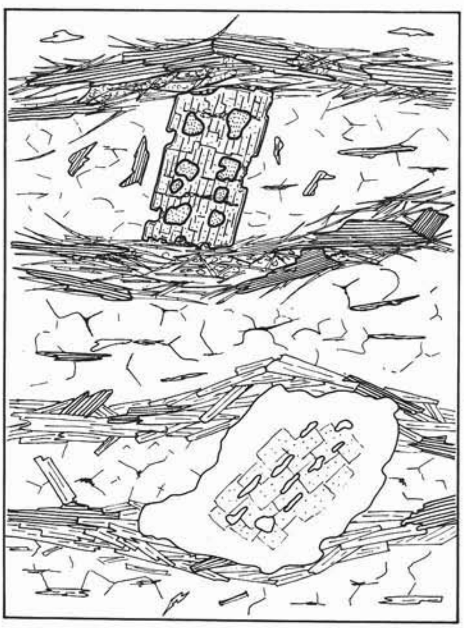

Fig. 5. — Rare or only scarcely found microstructures. In one case only, kyanite with an *Si* of small garnets was observed, discordant with a garnet-free sillimanitic *Se*. Less rare are plagioclasic porphyroblasts with a discordant *Si* in fractured or pecilitic cores, with clear, post-kinematic outer rims.

The post-kinematic mineral isograds cut the above-mentioned megastructures and these phenomena testify in the crystalline basement the prealpine age of most of the folds.

A deformation parallel to S_2 between the kyanitic and sillimanitic blastesis has been occasionally noted (fig. 5), and is shown by the rotation of kyanite porphyroblasts with internal planar foliation. The occurrence af this deformation in some other cases is also documented by slightly rotated plagioclasic poikiloblasts with static rims.

That this deformation caused the schistosity of the granitoid gneisses is not supported by the field and laboratory data, which indicate how these (with only very rare exceptions) always show very marked schistosity even where kyanite, staurolite and porphyroblastic plagioclase show no traces whatever of postcrystalline rotations. This seems to be very significant in greatly folded outcrops in which these minerals, as we have already said, undisturbedly cut the axial-plane schistosity and the transposed folds. Later deformations were followed by crystallizations which are too insignificant to justify the schistosity of such gneisses. There is therefore no doubt that the schistosity of the granitoid gneisses must be attributed to the same main dynamic event previously mentioned.

Similarly, the metamorphism responsible of the main schistosity of the « phyllitic » complex cannot be correlated with a schistose event distinct and later than the one which affected the « underlying » paragneissic complex, owing to their similar tectonic-metamorphic history, close stratigraphic relationships and crosswise attitude of typical post-kinematic isograds with respect to the phyllite-paragneiss boundary and to large-scale tectonics. The lack within the paragneissic complex of micro-structural evidence correlable with a differents schistose event of the phyllites, or with our comments on the granitoid gneisses, give weight to this conclusions. The retrocession of the characteristic minerals into sericite (paragonite + muscovite) and chloritoid (rarely granoblastic kyanite) is generally an unimportant static phenomenon, sometimes promoted by clastic deformation, and occurs not only in the paragneisses but also in some « phyllites ». Its age is probably « alpine ».

The pressure of the post-kinematic kyanite phase has been estimated at 5-8 kb. This pressure regime probably also characterized the main deformational phase of the two complexes. This would justify the presence of eclogites in the Oetztal, unless these lithotypes were slabs of rocks older than the embedding sediments, as is the case of the lherzolites and serpentinites of the Ultimo Valley, those within the phyllites of the Martello Valley, or in the amphybolites of the high Venosta Valley. The genesis of acidic magmas corresponding to the present orthogneisses may be neither directly linked to the schistose phase of the paragneisses (since it is characterized by inadequate temperatures) nor to the post-kinematic kyanite phase, which is later than their foliation and never associated with the formation of potassic feldspar. As regards the static phase following the kyanite phase, it was probably characterized by pressures around 4 kb in the typical areas of andalusite or instable garnet, while it was probably slightly higher in the zones where the garnet shows a lesser degree of instability, chemism being equal. The definition for this phase of « low-pressure event », must therefore be used with caution at the present time. Temperatures probably reached maxima around 650° C with the formation of most of the sillimanite occurring in the Austridic sector. In this phase too, the crystallization of aluminium silicate without the formation of K-feldspar is relevant.

These thermal effects, characterized by pressure lower than that of the synkinematic phase, might have affected composition of the white micas, particularly in low-grade metamorphic rocks.

Relics of the phases preceding the main phase described above are exceptional. The Parcines orthogneisses were perhaps injected into already schistose rocks, but these must have been of very low grade, considering the low crystallinity of the relics and their mineralogical association (quartz, feldspar, micas, chlorite). These rocks may possibly represent the prodrome of the main metamorphic event.

As regards the Ultimo Valley, some of its paragneissic rocks (« Tonale Schists » p.p.) include most of the lherzolite slabs and show an association which is unique over the whole of the Austric domain: K-feldspar + kyanite. The latter is present in two generation, one pre- and the other post-kinematic. The association K-feldspar + kyanite$_1$ has been provisionally referred to a pre-Schlingen event of undefined age which took place at 10 kb and 750° C. Slabs of deep crust may have been enveloped in the original Austridic products together with other lherzolitic ones, and thus involved in the « Schlingen tektonik ». The Oetztal eclogites and lherzolitic intercalations may therefore be of similar origin.

In conclusion, it is highly probable that the para- and ortho-rocks of the western Austridic sector were substantially involved only in a single important schistose event, followed by two main phases of post-kinematic crystallization.

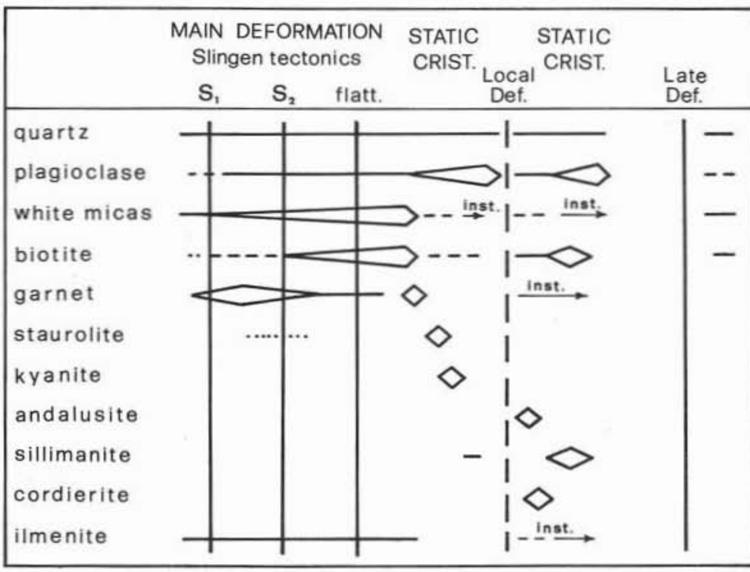

Fig. 6. — Summary diagram of the sequence of main deformations and crystallizations in the Austridic basement.

At the moment it is difficult to estimate if the andalusitic (and sillimanitic) static phase was the « tail » of the previous kyanite phase or, on the contrary, if it was an independent event. The andalusite outcrops are too scanty to allow a fair evaluation.

The Permo-Mesozoic covers and « andesitic » dykes of the Ortler and Venosta, were not significantly involved in Alpine metamorphisms.

Typical metamorphic reactions

Some metamorphic reactions are characteristic of the Austridic domain, and were recognized even before recent experimental results.

The most widespread is certainly represented by a mainly static plagioclasic poikiloblastesis (oligoclase and albite), which often transforms metapelitic lithotypes into gneissic ones. This reaction was mostly caused by the instability of paragonite and by a process of muscovite purification, both often pseudomorphically substituted by feldspar. It is also triggered at low temperatures, generally in static environments, after garnet crystallization. According to the results of unpublished researches (A. GREGNANIN & E. M. PICCIRILLO), this is a fundamentally isochemical phenomenon. The aluminium brought into play does not form aluminium silicates, but takes part in a complex mineralogical rearrangement of the rock.

Another very widespread reaction, causes the appearance of sillimanite by means of a process involving muscovite and some iron minerals, in the presence of graphite. This reaction produces biotite but not K-feldspar at the expence of muscovite. Garnet transformation, as an effect of the low-pressure static phase, is particularly evident in the andalusite and/or cordierite areas. This garnet transformation proceeds from the core towards the rims, through clouding in the low temperature phases. prevalent biotitization at an intermediate grade, and typical substitution by biotite + sillimanite at a high grade, coupled with the disappearance of almost all the muscovite and opaques into the surrounding groundmass.

From the above, it is clear that all the metamorphic rocks of sedimentary origin of the western Austridic sectors, of high and low grade, turn out to be significantly lacking in K-feldspar with the exception of the granulites of the Ultimo Valley and adjacent areas.

Magmatism

With the exception of the Younger Hercynian Massifs, in the Austridic sector considered, the prevailing magmatism took place in two distinct phases, one Upper Ordovician-Devonian, the other « Alpine ». Regarding the first, existing chemical analyses deal with three particular types of K-feldspar leucogneisses (fig. 7).

The first group represents rocks of the Parcines « orthogneiss », a mass typical for its migmatites, aged 440 m.y. Many of the « orthogneissic » augen intercalations of the Western Tyrol are composed of similar litotypes, i.e. somewhat biotitic, and are of the same age. Others are very scarce in biotite, although they are augen-gneisses, and show mesoscopic features which place them near the second group of analyzed leucogneisses.

The second group includes some stratoid intercalations of Passiria with large, medium or fine grain size (Tumulo gneisses).

It should be pointed out that all these augen-gneisses are found both in the complex of paragneisses, and in that of the « phyllites ». Owing to the abundance of very large sub-euhedral K-feldspar crystals, it is highly improbable that many of these lithotypes can be considered as metavolcanics.

Lastly, the third group of analyses deals with other stratoid intercalations found in the paragneissic complex, characterized by groundmasses somewhat similar to those of the paragneisses themselves, but on which however « flaser » or K-feldspar and/or chess-board albite show up clearly. Similar intercalations have also been observed in the phyllites, besides more typically porphyroidic facies.

Fig. 7 clearly shows that although they are in any case subalkaline, the three rock groups are of slightly different chemism.

The typical augen-« ortogneisses » of the first group are tendentially of granitic-granodioritic composition and may be placed within melts which originated by upper crust anatexis. Melts of this type are generally related to tectonic phenomena associated with high-grade metamorphism (« pleni »-orogenic phase). But it is equally well known, through the numerous examples of the Younger Hercynian Massifs, Permian Volcanic Platform, and Triassic Magmatism (if « orogenic ») found in the Alps, that similar melts also occur long after the conclusion of an orogenesis. In the zones here described, it is certain that the melts were intruded before or

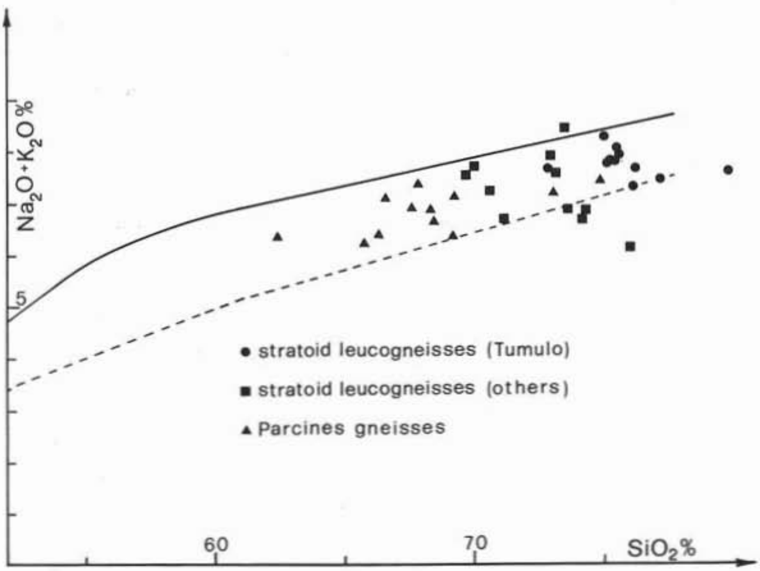

Fig. 7. — SiO_2/alk diagram of the K-feldspar leucogneisses.

during the main schistogeneous metamorphism and that, moreover, they were not generally produced *in situ*, in that the country rocks were of low metamorphic grade at that time.

The third group shows chemical features belonging to some ignimbritic platforms (see above). In the past, some considerations have suggested that these gneisses were generated through the feldspathization of paragneisses. However, in the light of new knowledge, a preferable hypothesis is that these are partly meta-ignimbrites or meta-tuffites. If this is true, at least what we have already said about the chemism of the « orthogneisses » is valid for these rocks too, and it is also possible that they are anorogenic materials.

The second group contains lithotypes which sometimes approach chemically and texturally the « orthogneisses », and sometimes the probable « metavolcanites » (« porphyroids »), so that the previous discussion may be extended to them.

Lastly, among the « magmatic » lithotypes, the « pegmatites » should be mentioned. They are often discordant with respect to the major structures, and appear to be only slightly oriented. Occasionally they show large crystals of postkinematic undeformed kyanite (S. Chiesa, A. Gregnanin, E. M. Piccirillo, unpublished data). Their age has been evaluated at about 350 m.y. in the nearby region of Silvretta.

The « Alpine » magmatism is typically and exclusively represented by dykes and small masses. A few of these are slightly metamorphic. They all cut the macroscopic folds, in the sedimentary covers too, and some of them intersect the overthrust planes of the large structures. Their geological age is thus mostly post-« Lepontine ». Their radiometric age is given by only three data (89, 49, 32 m.y.). Chemism is typically calc-alkaline, with potassium enrichment in some cases. Some dykes also include « magmatic » garnets. Chemical features indicate that these rocks are to be referred to an orogenic magmatism of active continent margin type, although with slightly diversified characteristics of « Alpine type ». Now, the only probable subduction in the Alps is of Cretaceous age. Suppositions have been made about a second paleogenic collision, contemporary with the overthrusting, or regarding it as an extension of the first collision into the Oligocene. But these hypotheses raise several doubts from the geological viewpoint. The presence of a mainly late andesitic magmatism thus presents serious problems of interpretation on the relationship between magmatic evolution and subductive processes, and in general on the philosophy of the genesis of the andesitic magmas.

Age of metamorphism and conclusions

Age determinations on the pre-Permian cycle which was responsible for the main metamorphism on the Austroalpine rocks, are based on structural analyses in connection with radiometric data on the acidic magmatites and with paleontological evidences found in other Austridic sectors.

As regards radiometric ages, we are dealing with magmatic events dating between 440 and 420 m.y. (rarely 350 m.y., which is the age of certain pegmatitic gneisses from Silvretta). In the Western Austrides, pegmatites are generally only slightly schistous and often discordant with respect to the mesoscopic structures. The « augen-gneisses » dated in the literature are embedded in the « paragneissic » formation. Similar rocks also occur in the « phyllitic » formation, which might therefore have a sedimentation age « pro parte » of more than about 420 m.y.. Its quartzites show archeozoic zircons as in the paragneisses, with no traces of younger ones. Nothing is known here of the ages of the porphyroidic intercalations. It is known that at least part of a similar acidic volcanism developed during the Upper Ordovician-Silurian in pre-Permian Austroalpine Basement. On the other hand, the paleontological age determinations carried out on some lithotypes of austroalpine «phyllitic» complexes have given Upper Ordovician-Devonian ages.

Considering the petrographic and structural premises presented above, indicating *the common metamorphic history of « paragneissic » and « phyllitic l.s. » formations, and the involvement of the above-mentioned magmatites in the main schistose metamorphism of the embedding rocks, it must be concluded that the age of the orogenic cycle responsible for the present schistosity and generally for all the pre-Permian metamorphic associations observable in the Western Austridic Basement, cannot be greater than 440 m.y., and it is probable that it is at least partly less than about 370 m.y.*

The occurrence of two metamorphic events (« Caledonian » Auct. and « Hercynian » Auct.) is difficult to justify in the sector in question. In it the presence of two distinct basements, an older « paragneissic » of higher grade and high pressure, the other « phyllitic » of lower grade and low pressure, as postulated by some Authors, is not evident. Instead, what has been observed shows *the unicity of the Austridic basement and the complexity of the « Hercynian » metamorphic cycle.* There are no significant traces of overprints of schistose metamorphisms on the principal one, or relics of possible large-scale schistose events older than the common one.

The formation of eclogitic rocks may be inserted within the picture proposed, but it is more probable that those outcropping in the Austroalpine schists are old metamorphic slabs which were enveloped into the « paragneissic » and « phyllitic » complexes before the main metamorphism, as in the case of the lherzolites.

The presence of acid magmatism with an « orogenic » chemical character does not necessarily imply a coeval orogenic event.

As regards the relics in the granitoid gneisses, they now turn out to be only slightly metamorphic and perhaps exceptionally folded. These features are very different from those hypothetized for the « Caledonian » metamorphites and do not justify the fact that at least part of the outcropping crystalline basement underwent an older orogenic cycle.

Owing to the variable use of the terms « Caledonian » and « Hercynian », sometimes employed to distinguish phases of the same orogenesis of different age, and sometimes in order to distinguish two paleozoic orogeneses, not necessarily coeval with the true « Caledonian » and « Hercynian » ones, it would be desirable to discard them for the metamorphic events of the Alps.

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