Geology of the Zentralgneiss around the Kleiner Mühldorfersee in the Reisseck area of the Eastern Tauern

By R. J. Norris and E. R. Oxburgh *)

With 5 figures

Geologie des Zentralgneises in der Umgebung des Kleinen Mühldorfersees im Reißeckgebiet der östlichen Tauern

Von R. J. Norris and E. R. Oxburgh

Mit 5 Abbildungen

Zusammenfassung

Im untersuchten Gebiet können sechs lithologische Hauptgruppen unterschieden werden: (1) Biotit-Augengneise, (2) leukokrate Augengneise, (3) feinkörnige Gneise mit verstreuten kleinen Feldspat-Augen, (4) gebänderte Gneise, (5) Amphibolite, (6) Leukogranite. Obertags- und Untertags-(Tunnel-)Aufschlüsse zeigen, daß der Biotit-Augengneis alle anderen Gesteinsgruppen unterlagert und daß im Kontaktbereich gewöhnlich der offenbar intrusive Leukogranit auftritt. Die meist horizontale bis schwach geneigte Schieferung wird im mesoscopischen Bereich von drei Gefügegenerationen überprägt: (1) frühe Isoklinalfalten, meist nur als schenkellose Faltenscharniere in der Hauptschieferungsebene erhalten und mit unterschiedlicher Achsenrichtung, (2) offene bis subisoklinale Biegefalten mit ungefähr horizontalen NW-SE-Achsen und SW-fallenden Achsenflächen. Diese Falten überprägen die älteren Isoklinalfalten und bewirken stellenweise die Entwicklung einer neuen Schieferung. (3) Flexuren und „Großknickungen" mit E-W-Achsen überprägen die Biegefalten. Die vorherrschende Faltenachsenrichtung sowohl im regionalen als auch im mesoskopischen Bereich liegt NW-SE und nahezu horizontal.

Abstract

Six main lithological groups are recognized in the area studied: (1) Biotite Augen Gneiss Group, (2) Leucocratic Augen Gneiss Group, (3) Dispersed Augen Gneiss Group, (4) Banded Gneiss Group, (5) Amphibolite Group, (6) Leucogranite Group. Surface and sub-surface (tunnel) exposures indicate that the biotite augen gneiss underlies all other lithologies and that apparently intrusive leucogranite is commonly present at the contact. The foliation which is generally horizontal or gently dipping is folded by three generations of mesoscopic scale structures: (1) early isoclinal folds, commonly preserved only as limbless hinges within the plane of the main foliation and with variable axial directions, (2) open to sub-isoclinal buckle folds with NW-SE near horizontal axes and SW dipping axial surfaces. These folds fold the early isoclines and are locally associated with the development of a new foliation, (3) flexures and "mega-kinks" with E-W axes which deform the buckles. On both regional and mesoscopic scales the controlling fold axis direction is NW-SE and close to horizontal.

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*) Address: Department of Geology and Mineralogy, University of Oxford, Parks Road, Oxford, England.

Introduction

This article is concerned with the field relations and structure of a group of orthogneisses, paragneisses and amphibolites within an area of Zentralgneiss near the south-east corner of the Tauern Window. The structural studies have been carried out as an essential preliminary to detailed geochemical work in the area. The area described lies about 2 km south of the Reisseck and is shown in Fig. 1. Not only does the high relief in the area afford excellent opportunities for establishing the three-dimensional distribution of rock-types but additional information is available from a series of hydroelectric tunnels: one of us (E. R. O.) carried out the mapping of the tunnels in 1963 thanks to the kind cooperation of the Österreichische Draukraftwerke A. G. A brief report was published at the time (Oxburgh, 1964), but the main discussion was postponed until the surface observations, largely made by R. J. N., were complete. No detailed geological map of the area described is available although it is partly covered by the 1 : 50,000 map published by Exner (1954) in his discussion of the geology of the south-east corner of the Tauern Window.

The age of the rocks in the area mapped is not known. Orthogneisses from the Badgastein area, however, similar in lithology and situation to those described below have been analyzed in radiometric age studies by Lambert (1964). The Rb/Sr whole rock isochron method indicates a late Palaeozoic time of intrusion of the original magma. Although the orthogneiss of the present area may, in part, be of similar age, it is not clear whether the metasedimentary and amphibolitic units represent part of the country rock into which the orthogneiss was intruded as a granitic magma, or whether they belong to a later group of rocks deposited unconformably upon an eroded orthogneissic basement, or whether indeed there was any original direct relationship between the two groups, i. e., their present juxtaposition could have been brought about by tectonic movement.

Lithologies

General: The areal distribution of the major lithological groups is shown in Fig. 2. It is not possible to show the distribution of individual lithologies in an area as complex as this, and the map shows only groups of lithologies. These lithological groups, whilst inhomogeneous within themselves, tend to show consistent relationships to each other. The descriptions which follow are based upon those characteristics of the rocks which are recognizable in the field; detailed thin-section petrography will not be discussed here.

The lithological groups recognized are:

1. Biotite Augen Gneis Group: The principal and characteristic lithology of this group is a mesocratic gneiss, having a biotite-rich ground-mass, and con-

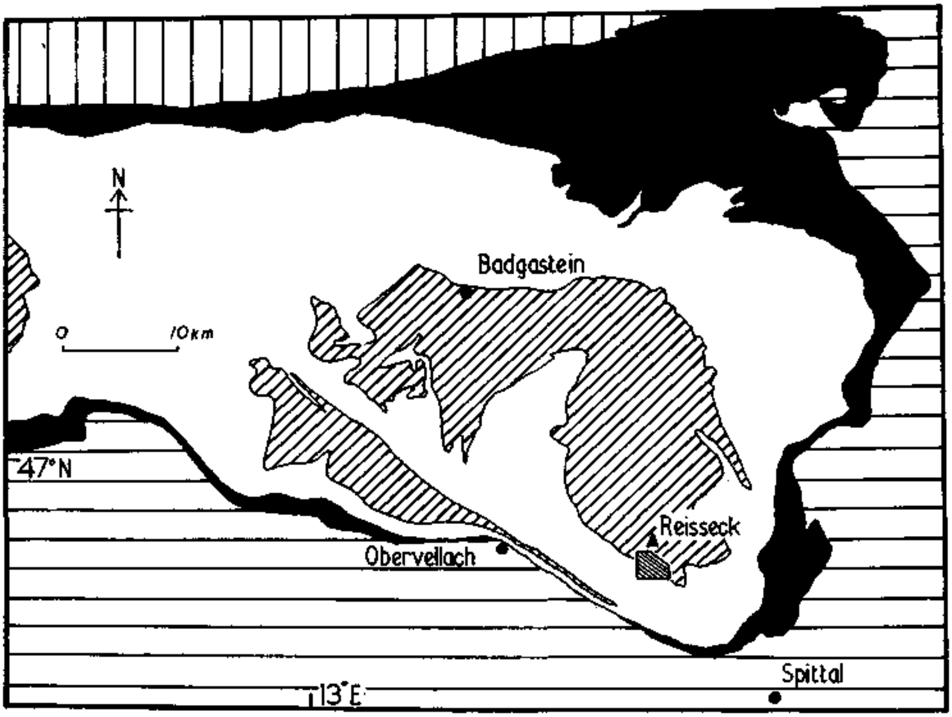

Fig. 1. Location map showing the eastern end of the Tauern Window; vertical ruling, Grauwackenzone; black, Unterostalpin rocks; white, Schieferhülle and Randgneis; wide oblique ruling, Centralgneiss; horizontal ruling, Oberostalpin rocks; close oblique ruling, the area described.

taining megacrysts ("augen") of K-feldspar up to 4 cm. in length, which are usually either flattened within the mica foliation, or elongated parallel to a mica lineation. Within some augen, especially, the larger ones, biotite inclusions are commonly concentrated in concentric zones. Toward its outcrop margins, the rock becomes more leucocratic, and often strongly deformed, with quartz forming thin streaks up to 10 cm. long. Shear zones occur within the body of the gneiss, along which the rock develops an unusually strong foliation at a slight angle to the main foliation; the augen are drawn out into feldspathic streaks and the grain size is considerably reduced. Frequently white mica is developed, especially around the deformed augen. The rock is invaded by both concordant and discordant quartzofeldspathic veins.

2. Leucocratic Augen Gneiss Group: The typical lithology is a leucocratic, muscovite-rich rock with 1—2 cm. augen (occasionally 4 cm.) which are commonly strongly deformed parallel to the foliation or lineation. This rock type, however, grades into a number of other lithologies which are included in this group. In places the rock is so rich in muscovite that it resembles a muscovite schist with knots of feldspar. Elsewhere the rock has a fine-grained, muscovite-poor ground-mass, containing K-feldspar megacrysts, up to 2 cm. in length. This facies, however, appears to grade into the former, although a transition has not

been observed; both types are shown together on the map (Fig. 2). At a few localities the rock is biotite-rich, and begins to resemble the biotite augen gneiss described in the previous section. These occurrences are, however, of local extent, and show gradations into the more typical lithology.

3. Dispersed Augen Gneiss Group: This lithology has a fine-grained biotite-rich, quartzofeldspathic groundmass containing dispersed, small (1 cm.) augen. These tend to be streaked out parallel to the foliation, and nowhere exhibit an angular

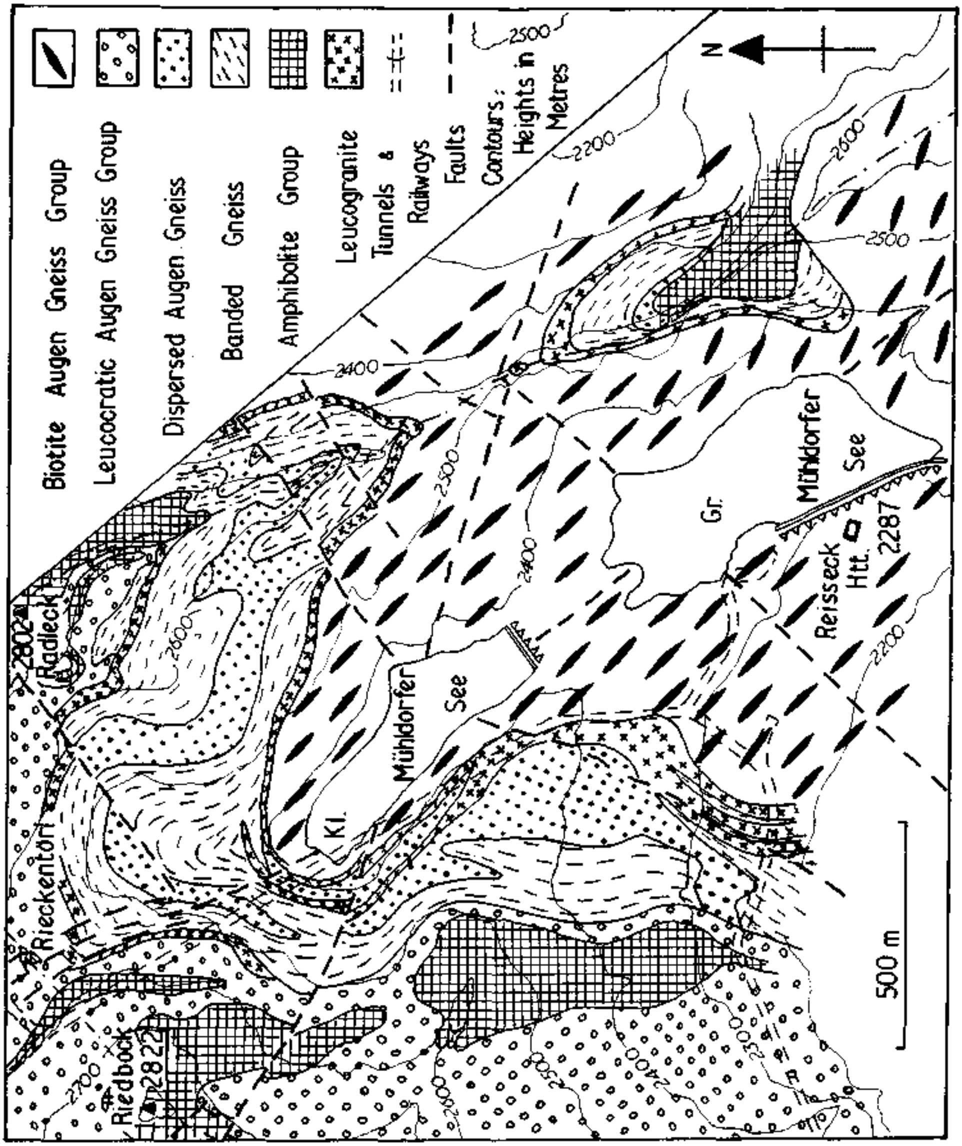

Fig. 2. Geological map of the area.

shape. The rock is often banded in meso- and melano-cratic bands on the scale of a few centimeters. Locally lens-shaped masses of amphibolite, 5—6 m. long, lie parallel to the foliation.

4. Banded Gneiss Group: The principal lithologies are schistose, biotite gneiss and feldspar-quartz-biotite leucogneiss, they are both fine-grained and are interbanded on a scale of 4—5 cm. Occasional bands are aplitic, however, and may represent strongly deformed intrusive veins. The compositional banding is usually the principal planar feature in these rocks.

5. Amphibolite Group: This group is a rather heterogeneous group of metamorphic lithologies, consisting of several types of amphibolite associated with other lithologies. The principal type is finely banded amphibolite, consisting of feldspar-amphibole rocks, small amounts of biotite schist, and occasional coarse-grained, massive amphibolites. The amphibolites are associated and interlayered with banded gneisses similar to those described under 4, and with a mesocratic rock, which has a biotite-rich ground-mass and rodded feldspar (B-tectonite), giving a rather streaky appearance. As all these lithologies are closely associated in the field, they are mapped together as the Amphibolite Group.

6. Leucogranite Group: The leucogranites of the area are highly leucocratic, fine-grained rocks, consisting principally of feldspar and quartz, with small amounts of biotite defining a foliation. This foliation is rather weak by comparison with that of the other more micaceous groups, and hence the rocks have a blocky appearance in outcrop. They tend to occur in thin, laterally extensive sheets and veins, up to several metres thick. Only the larger bodies are depicted on the map.

Relations between Lithologies

There is some evidence that at any rate some members of the Leucocratic Augen Gneiss Group are intrusive into the Amphibolite Group. The contact between the leucocratic augen gneiss and the banded gneiss, however, appears to be tectonic, although it may originally have been intrusive. Certainly this group as a whole appears to have rather discordant contacts with the other lithological units.

The leucogranites are demonstrably intrusive into all other rock types, and blocks of other lithologies occur within them. At all observed contacts between the Biotite Augen Gneiss Group and the overlying lithologies, a thin leucogranite occurs. In the neighborhood of the contact, the augen gneiss appears considerably more leucocratic and sheared than elsewhere. In general, the contact appears fairly concordant with the foliation of the biotite augen gneiss on the scale of an exposure, although it may well have been originally discordant. Where the compositional banding of the banded gneiss is folded, it is seen to be discordant to the contact.

Structure

General: For the purposes of structural description the area may be conveniently subdivided into two sub-areas which are more or less structurally

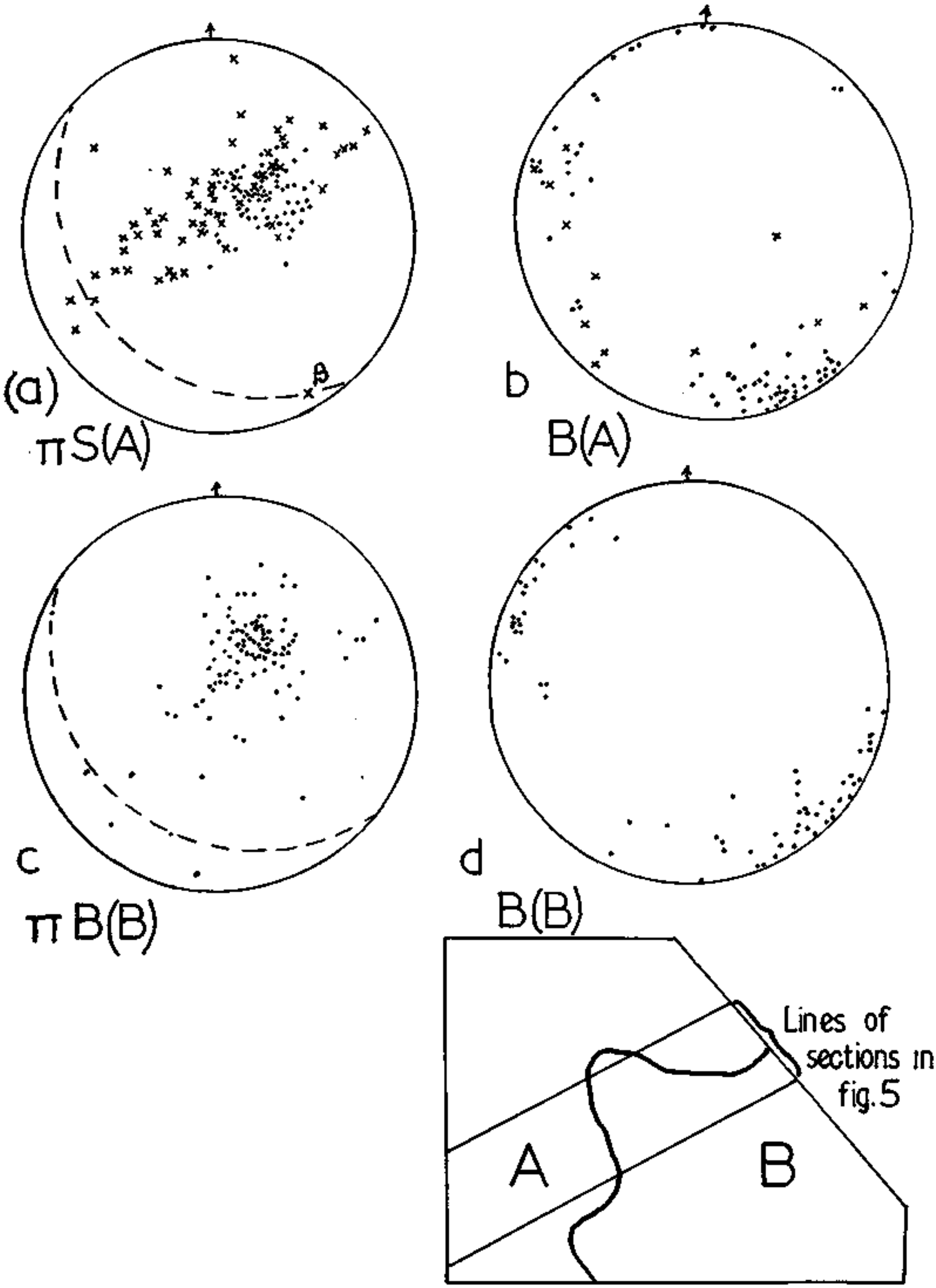

Fig. 3. Equal-area stereographic projections (lower hemisphere) of structural observations (a) 124 poles to foliation in sub-area (A); x = pole to S′, · = pole to S″ (b) 83 lineations and fold axes from Sub-area (A); x = axes of early isolines, · = mineral lineations and buckle axes c) 113 poles to foliation in Sub-area (B) (d) 66 lineations and fold axes from sub-area (B). The small map shows the limits of the two sub-areas and the positions of the cross-sections in Fig. 5. Correction-in (c), for π B read π S.

homogeneous within themselves, but between which there are significant differences. These sub-areas are designated (A) and (B) and their extent is shown in Fig. 3. Sub-area (B) corresponds largely to the area of outcrop of the Biotite Augen Gneiss Group, while sub-area (A) is predominantly occupied by other lithologies.

Sub-area (A): Most of the rocks in the area exhibit one or more foliations. In the banded lithologies of sub-area (A), the most prominent foliation is the compositional banding. Within this foliation there occur the hinges of isoclinal folds with axial planes parallel to the banding. The hinges of these folds appear to have been separated from their limbs by shearing parallel to the plane of the foliation. Where complete isoclines are observed, the amplitude/wave length ratio is greater than 6-1. In a few exposures, these isoclines are seen to be refolded by the buckle folds described below (Fig. 4).

The occurrence of the isoclines as refolded, rootless folds parallel to the banding of the gneiss suggests that the principal foliation of the banded lithologies may have developed from the sheared out limbs of these early isoclines, whose hinges have been largely destroyed during its production (e. g., BALK, 1936). The foliation formed in this way is here designated S_1.

Within the Leucocratic Augen Gneiss Group of sub-area (A), the foliation is defined mainly by the orientation of the micas. Rare folds are defined by augen-rich and augen-poor layers, within which the mica may have rotated and recrystallized to define an axial plane foliation. These folds are flattened buckles or concentric folds with amplitude-wavelength ratios less than 2-1. The augen are often reoriented parallel to the axial plane foliation, so that at many outcrops only one, apparently unfolded, foliation is observed.

Fig. 4. Early isoclines refolded in the core of a later buckle fold (drawn from a photograph).

Within the banded lithologies too, the foliation is frequently folded into buckles. Here the buckles tend to be flattened to a greater degree, and are frequently sub-isoclinal. In biotite-rich rocks, the mica is recrystallized parallel to the axial surfaces and thin leucocratic bands may be sheared out to give a new axial plane foliation, a foliation developed in association with the buckles in this way is here termed S_2. The buckles are the dominant structural feature on a mesoscopic scale. Within the banded lithologies, folds of similar style may occur adjacent to buckled horizons. This is probably due to inhomogeneous plastic strain within the less competent layers induced by the buckling of adjacent more competent layers (RAMSAY, 1962). The buckles themselves are frequently flattened, exhibiting thickened hinges and thinned or boudinaged limbs.

In several exposures, the buckle folds are deformed by later flexures. These have angular hinges, near horizontal axes and inclined axial planes. At a station immediately north-east of the Rieckentörl, banded gneisses, folded in a series of flat lying buckles, have been abruptly rotated through 90° about a WNW striking axis. The vertical limb extends approximately 2 metres, after which it is rotated into its original orientation suggesting that these flexures may resemble large-scale kink bands (knickung). A south-west dipping strain-slip cleavage produced by wrinkling of the axial plane foliation of the buckles may develop in association with this "mega-kinking."

In the discussion of the foliation attitudes which follows, where rocks exhibit only one foliation it is designated S'; where two foliations are observed in the same rock the earlier is designated S' and the later S". Both these terms are used without any genetic implication. Such a convention is useful where the origin of the foliation is uncertain as discussed below.

An equal-area plot of poles to foliation (π-poles) measured in sub-area (A) is shown in Fig. 3 a. The poles to S' define a great circle about a NW-SE, sub-horizontal axis, whereas the poles to S" cluster about a maximum representing a shallow, SW dipping plane. The axis of the S' girdle lies within this plane and correlates with the concentration of buckle axes shown in Fig. 3 b, dipping at approximately 10° SE.

The structural features of sub-area (A) may be summarized as:

a) Isoclinal folds, largely destroyed in the production of the compositional banding, S_1, in the banded lithologies: axial directions are not well established.

b) Buckle folding about sub-horizontal NW-SE axes, folding S_1 and locally producing a new mineral foliation, S_2, parallel to the axial planes.

c) Flexuring of the buckles on sub-horizontal E-W axes.

Sub-Area (B): In this sub-area which comprises largely augen gneiss, only one foliation is commonly observed; this is defined by the orientation of mica flakes. Folds defined by augen-rich and augen-poor layers are concentric buckles, with NW-SE trending axes. The mica foliation appears to be parallel to the axial planes of these folds. In Fig. 3 c, poles to the foliation in sub-area (B) are plotted. Very rarely are two foliations recognized, and the points cluster around a maximum coincident with the S" maximum for sub-area (A) (Fig. 3 a). This supports the field conclusion that for the augen gneiss in sub-area (B), $S' = S_2$ i. e., it is

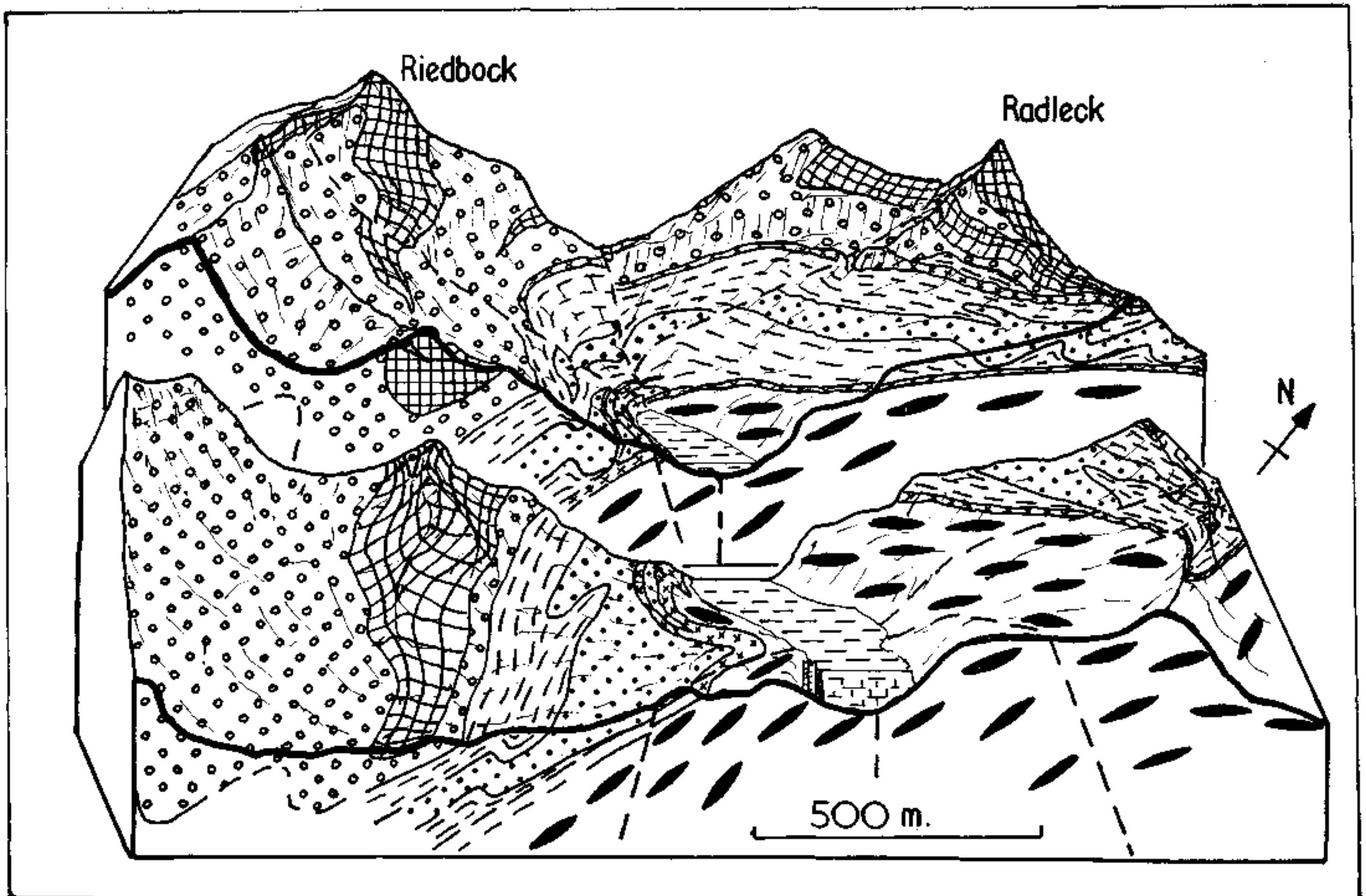

Fig. 5. Interpretative block diagram of the map area; ornament as in Fig. 2; section lines shown in Fig. 3.

parallel to the axial plane foliation of the buckle folds. On the other hand, in sub-area (A), S′ may in different places represent S_1 or S_2, while S″ everywhere corresponds to S_2.

Lineations and fold axes from sub-area (B) are plotted in Fig. 3 d, and exhibit a similar distribution to those in Fig. 3 b. In both plots of lineations, the points tend to spread along a great circle coincident with the axial plane deduced from the π-pole diagrams. The scatter of the buckle axes within their axial planes may be due to differential flattening perpendicular to this plane (RAMSEY, 1962) or to variable attitudes of S_1 prior to buckling. S_1 is parallel to S_2 over a large part of the area, reflecting the sub-isoclinal character of the buckles. As the early isoclines are tightly compressed within S_1, their axes also show a marked scatter within S_2.

Large scale structures and structural history

The block diagram (Fig. 5) shows the inferred large scale structure of the area. Tunnel and surface observations, both from this area and from adjacent areas, suggest that the Biotite Augen Gneiss Group forms a dome shaped mass of fairly complex internal structure, of which only the SW part is observed in the area of the map. Within the area of the augen gneiss outcrop (sub-area B) the foliation varies from a SSW direction of dip in the SE corner, to a WNW direction on the NW margin. The angle of dip also varies within the area, as is seen from the scatter of points in Fig. 3 c. To the south, outside the area mapped, the dip of the foliation changes to S and even SSE in direction, whereas to the NE, the direction of dip is NW to N. It is suggested that the contact between the Biotite Augen Gneiss Group and the overlying lithologies was formed during the phase of deformation responsible for S_2, and was subsequently domed by later movements. The principal structure in the overlying rocks is the syncline of leucocratic augen gneiss on the west flank of the dome (Fig. 6). This structure has a NW-SE trend and is associated with a strong development of minor buckle folds about a similar axis. The axial plane of the structure dips to the WSW as do the axial planes of the buckles. This NW-SE axis is therefore important on all scales within the area under discussion. A NW-SE axis appears to be fairly prominent in the eastern part of the Tauern-Window as a whole, and as it is also recorded in the Mesozoic Schieferhülle (EXNER, 1954; 1957; 1964), it is presumably of Alpine age. The earlier structures observed within the banded lithologies may belong to an earlier Alpine phase, or they may have originated during an older, possibly Variscan, orogeny.

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Die Metamorphose des NE-Randes des Kernes der Böhmischen Masse

Dušan Nemec *)

Mit 4 Abbildungen

Abstract

Along the NE border of the core of the Bohemian Massif, three distinct zones differing from each other by their grade of metamorphism may be distinquished, viz., the Svratka anticline corresponding by its mineral assemblages to the sillimanite-almandine-muscovite subfacies (it contains moreover some relic assemblages of the lower-grade metamorphism), 2. the deeply metamorphosed Moldanubicum showing mineral assemblages of the sillimanite-almandine-orthoclase subfacies of the Barrovian-type facies series and subordinately those of the sillimanite-cordierite-orthoclase-almandine subfacies of the Abukuma-type facies series, 3. the transitional zone inserted as a well defined broad stretch between both zones mentioned above. It contains assemblages of the sillimanite-almandine-muscovite subfacies which are in the process of conversion to the assemblages of the sillimanite-almandine-muscovite subfacies (according to the equation: Sillimanite + K-feldspar + Water → Muscovite + Quartz). The transition zone mentioned may be considered for the most part as belonging to the Moldanubicum which is in stage of accomodation to the lower-grade metamorphism of the nearby anticline of Svratka.

Zusammenfassung

Durch petrographische Untersuchungen am NE-Rande des Kernes der Böhmischen Masse konnten drei Zonen von verschiedenem Metamorphosegrade unterschieden werden. Es sind: 1. Die Antikline von Svratka, deren Metamorphose meist der Sillimanit-Almandin-Muskowit-Subfazies entspricht. Sie enthält noch reliktische Assoziationen niedrigerer Subfazien. 2. Das stärker metamorphosierte Moldanubikum mit Assoziationen der Sillimanit-Almandin-Orthoklas-Subfazies der Fazienserie vom Barrov-Typus und untergeordnet denjenigen der Sillimanit-Cordierit-Orthoklas-Almandin-Subfazies der Fazienserie vom Abukuma-Typus. 3. Die Übergangszone, die sich als ein gut definierbarer Streifen zwischen die beiden vorangehenden Zonen einschaltet. Zwar zeigt sie die Assoziationen der Sillimanit-Almandin-Orthoklas-Subfazies, diese sind aber offensichtlich unbeständig und wandeln sich in diejenigen der Sillimanit-Almandin-Muskowit-Subfazies um (in den pelitischen Assoziationen ist die Sillimanit-Umwandlung gemäß der Gleichung Sillimanit + Kalifeldspat + H_2O → Muskowit + Quarz im Gange). Diese Zone kann für einen Teil des Moldanubikums gehalten werden, der sich dem niedrigeren Metamorphosegrade der angrenzenden Antiklinale von Svratka rückläufig anpaßt.

Einleitung

Der ganze NE-Rand des Kernes der Böhmischen Masse wurde zuerst für eine einzige geologische Einheit (das Moldanubikum) gehalten, wenn auch schon früh

*) Adresse des Verfassers: Geologický průzkum, Jihlava, Jiráskova 2.