The Genesis of the Dobra and Krumau Complexes of the Kamp Valley in the Lower Austrian Waldviertel*)

With 3 figures and 3 tables

(Part 2: Mineralogy and Petrography)

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Abstract

The mineralogy and petrography of the Dobra- and Krumau-rock-complexes are studied in detail. The zircons of the different gneissic varieties are investigated. The genesis of the different rock types is discussed; the clear ortho-origin for the Dobra (Spitzer) gneisses is declined. The parent rock of these gneisses is suggested to be a sediment derived in large part from pyroclastic-rich sources with or without graywackes, very often interlayered with considerable submarine acidic flows, intercalated with limestones, from which the newly detected marbles are derived. The regularly intercalated amphibolites are suggested to be formed from simultaneous intercalations of thin basic flows and sills. The Krumau complex is believed to be of clear para-origin, representing a regionally metamorphosed series of marine argillaceous, calcareous and arenaceous sediments, from which the para-gneisses, schists, marbles and quartzites were formed. The basic volcanic activity continued to the east to be responsible for the amphibolite bands intercalated in this complex.

Introduction

This second part represents the mineralogic and petrographic studies of the Dobra- and Krumau complexes (Spitzer gneisses and para-rock series) after KHAFFAGY (1970). The first part (KHAFFAGY, 1970) represents the geological and structural studies, while the third part (KHAFFAGY & SCHROLL, in press) will represent the geochemical studies of the same rocks.

The samples studied (200) represent the different rock types and varieties in a west-east cross-section through the area. Samples numbered 1 to 100 were collected from the Dobra-complex till the Genitzbach area including the contact zone; those with numbers 100 and above belong to the Krumau-complex till the eastern contact with the Gföhler gneiss body.

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1. Petrography of the Gneisses

On the basis of about 75 modal analyses it can be stated, that nearly all the gneisses of the area studied are mainly composed of plagioclase (oligoclas and andesine), quartz and potash feldspars (mainly orthoclase). The relative abundance of each of them differs according to the locality and gneiss type. Besides these three main constituents other minerals occur, sometimes also as main constituents as biotite, muscovite, sillimanite and augite. Accessories include garnet, sphene, hornblende, chlorite, tourmaline, apatite, iron oxides, allanite, zircon and calcite. As already previously indicated (part 1, KHAFFAGY, 1970), the gneisses could be classified according to their field occurences to two main groups; it is also possible to classify them into two main types.

Type I: includes the typical Dobra-gneisses, represented by samples No. 1, 3, 20, 24, 30, 36, 45, 51, 53, 60, 61, 73, 74, 80, 84, 85, 86, 87, 89, 96 and 99. This type represents the subvarieties of the Dobra-gneisses with the field names: biotite-bearing, biotite-free, banded and augengneisses. This type can be further subdivided to two other subdivisions, according to the knaf/plag (alkali feldspar/plagioclase) ratio:

Type IA: represents the gneisses with knaf/plag-ratio of more than 1, and includes mainly the augen gneiss variety; to this type belong the samples No. 3, 45, 61, 80, 84 and 99.

Type IB: represents the gneisses, in which the knaf/plag-ratio is less than 1, and includes the other three subvarieties represented by samples No. 1, 20, 24, 30, 36, 51, 53, 60, 73, 74, 85, 86, 87, 89 and 96.

Type II: includes the paragneisses, occuring in both complexes, it is further classified into two subdivisions according to their field occurrence:

Type IIA: represents the paragneisses of the Dobra-complex, to which the following samples belong: 14, 17, 26, 27, 31, 34, 37, 43, 44, 52, 56, 67, 83, 92, 93 and 95.

Type IIB: represents the paragneisses of the Krumau-complex. The samples belonging to it are: 100, 103, 113, 114, 115, 116, 117, 118, 119, 121, 124, 125, 127, 134, 135, 139, 140, 142, 145, 148, 154, 168, 170, 180, 186, 188, 191, 192 and 195.

The main compositional differences between the two types can be summarised as follows:

1. The quartz content in type I shows almost similar values ranging between 30 and 40%, with a mean value of 32.4% (33.0% for I A and 31.8% for I B); in type II, it shows a wider range from 2% (sample 17) to 50% (sample 34); highly quartzitic gneiss No. 83 has 69% quartz; the mean value of quartz in type II is higher than that in type I, being 37.25% (39.5% for II A and 35% for II B).

2. The absolute values and the relative abundance of both types of feldspars, show significant differences in both main types as well as in their subvarieties. The mean values of knaf show gradual decrease in types I A, I B, II A and II B, being 37%, 20%, 15.3%, and 16% respectively. A similar relation is also indicated by the knaf/plag ratios of these types, being 1.42, 0.47, 0.43, and 0.90 respectively. The amounts of plagioclases are behaving nearly in a contrary manner, with the exception, that Type I A, which represents the augen-gneiss-varietis, has a remarkable low plagioclase content (26.1%). This trend follows I B, II A, II B and I A, with the sequence 42.8%, 36%, 34.8% and 26.1%.

It is to be considered, that the values of the feldspars, in the individual samples show relative constancy in types I A and I B, when compared with types II A and II B. It is also remarkable that the augen-gneisses senso strictu occur only in the Dobra-complex. If any augen-variety does occur in the Krumau-complex, the augen are of plagioclase and not of knaf (near the contact to the Gföhler gneisses as in samples 188, 191 and 195).

3. Concerning the type, amount and distribution of the occuring micas, it is found that the most flourishing mica is the reddish brown biotite variety. Besides, muscovite is also occuring in considerable amounts. The biotite with its both varieties (reddish brown and greenish brown), is the only mica, occuring in the gneisses I A and I B, with an amount, very rarely exceeding 5% of the rock composition. The greenish brown variety is practically restricted to the samples 73, 80, 85, 87, and 89. On the other hand, both types of mica, the reddish brown biotite and the muscovite do occur, either separately or together, in the paratypes II A and II B, with amounts always exceeding 5% and very often reaching 20% of the rock composition.

4. Sillimanite shows particular restriction to the paragneisses of types II A and II B, occuring in both complexes. Its amount varies considerably, as it occurs in some samples only as accessory, while it reaches high values in others (36% in sample 17). Intermediate amounts are recorded with special predominance opposite to the Schloteinbach area and around Krumau/Kamp till Thurnberg Sperre.

5. Augite and diopside are practically restricted to the gneisses of the Krumau-complex (II B). Diopside occurs in a more restricted area between the Genitzbach and Krumau (samples 117, 118, 119 and 121 with amounts of 6%, 2.5%, 5% and 12% respectively). The augite is much more widely occuring in the Krumau gneisses and acquires higher values, reaching 40%, as in sample 115. Both pyroxenes do occur together in different proportions, as in samples 118, 119 and 121.

6. Amphiboles in the gneisses are encountered only as accessories and are restricted to type II B. Only samples 114 and 117 were found to contain 9.5% hornblende and 2.5% tremolite respectively.

7. Garnet is an ubiquitous mineral, as it occurs nearly in all the gneisses sometimes as accessory and as main constituent. It increases gradually in the Krumau-complex towards the Gföhler gneiss contact. In some garnetiferous mica schists it reaches aprecciable amounts, as in sample 118 with 19% garnet.

8. Titanite is like garnet, an ubiquitous accessory, but of wider distribution in all types of gneisses. Its amount is seldom 1%, except in three cases (158, 180 and 195) where it acquires 4%, 1.5% and 1.5% respectively. It shows in this respect some parallelism to both augite and garnet, as it also flourishes in the Krumau-complex, specially near the contact to the Gföhler gneiss.

9. The mineral tourmaline is only detected as accessory in the Krumau gneisses, it increases also in distribution to the east, starting by sample 95 near the Genitzbach. It reaches 1% and 2% in samples 116 and 170 respectively.

10. The mineral chlorite is always occuring as a parallel partner to biotite, being almost in all cases its alteration product. It is an accessory, but sometimes it reaches values from 3% to 18%, specially in type II (44, 56, 74, 86, 92, 115, 139 and 159).

The specific properties of the gneisses minerals

Quartz: The quartz occurs always in the form of xenoblastic grains, which differ considerably in their grain size. In the fine-grained varieties it ranges from 0.2 to 0.8 mm., while in the medium and coarse-grained varieties it reaches 3 to 8 mm. in diameter respectively. However, the most abundant grain size is that of the medium-grained varieties, which mostly ranges between 2.5 and 4.5 mm. In some varieties it occurs in the form of porphyroblasts; sometimes also as embedded finer grains in the ground mass. In varieties representing the predominant types, the quartz occurs in the form of xenoblastic grains mostly in a segregation crystallisation with other light-coloured minerals and shows a preferable allignment in the s-plane of the rock, thus enhancing the gneissose structure.

It is almost always deformed, showing undulose extinction from weak to strong. Some of these strongly deformed quartzes do not show any more the typical uniaxial character, it is sometimes pseudouniaxial to clearly biaxial with a 2 V ranging from 5—7°. Generally the mineral is obviuosly fresh and includes very often other minerals specially undeformed grains of biotite, and very rarely zircons (samples 43 and 52) and sillimanite, as in sample 26. Pores with liquid inclusions are not rare.

Plagioclase: The mean values of the plagioclases in the different types vary from 26.1% in type I A, to 34.8% in type II B, to 36.0% in type II A and 42.8% in type I B. The relative amount of the plagioclases in the gneisses is always exceeding those of the knaf, except only in type I A (the augen gneiss varieties of the Dobra-complex) where the ratio knaf/plag is more than 1.42. If the plagioclase content of the individual samples of each type is considered, it is noticed that the increase of the plagioclase content comes mostly on the expence of the knaf, due to the relative constancy of the quartz content together with other constituents (except in some mica schists and augite gneisses). The plagioclases vary from oligoclase (in types I A and I B) to oligoclase, oligoandesine and andesine (in types II A and II B). Anorthite content higher than 50% are extremely rare. The high values of 40—48% An were only observed in augite-bearing gneisses. The plagioclases occur almost always as xenoblastic grains forming with other minerals the main tissue of the rock. They occur sometimes as disseminated grains in the groundmass of the augen varieties, as well as crystallised segregations with other light constituents in the form of fine bands, alternating with other bands, richer in dark constituents. In rare cases, they occur in the form of porphyroblasts, which disturb the gneissosity of the rock (37, 48, 154, 188 and 192). In the fine-grained varieties they acquire a grain size, ranging from 0.2 to 1.0 mm., while in the medium — to coarse-grained varieties they vary from 1.0 to 3 mm. and from 3 to 5 mm. respectively. In some porphyritic varieties they can reach 9 mm. in diameter.

The reverse zoning of the plagioclases is frequent in type I with a core ranging in An content from 20 to 25% and a rim ranging between 25 and 30% (samples 1, 24, 45, 53 and 60). Less frequent is this zoning in Type II (samples 27, 44, 100 and 186). The aplitic, gneissic varieties do not show any zoning-structure of their plagioclases.

Polysynthetic twinning is almost always occuring in all the plagioclases of the studied gneisses, mainly after the albite-law. In some plagioclases, especially those of the porphyritic gneisses at the east end of the area, the twin lamellae are often bent at their ends indicating post crystalline deformation. It happens also in some zoned plagioclases, that the twinning is only restricted to the rim of the zone.

The majority of the plagioclases show a considerable degree of alteration, mainly sericitisation. The degree of alteration varies from one locality to the other, without any definite trend, except, that it is in type I of a lower degree and less predominant, than in type II. Also the aplitic varieties show relatively fresh plagioclases, while in some samples, especially those of type II, complete alteration and sericitisation of the feldspars is recorded, sometimes to an extent, where the differentiation between plagioclase and knaf becomes impossible (14, 17, 43, 44, 56, 86, 127 and 133).

Besides the fine inclusions of sericite in the altered samples, the plagioclases include also fine inclusions of other minerals. Some of these inclusions, especially biotite, exhibit an alignment parallel to the twin lamellae. In few cases the plagioclase contains grains of allanite, which produced radial cracks around them (87, 88 and 95).

The antiperthitic tecture is observed often in the plagioclases of the studied gneisses of both complexes. It occures in the form of clots and/or spindles of knaf in the plagioclase crystals, the spindles sometimes acquire a parallel alignment to the twin lamellae. This texture is relatively more frequent in type I than in type II. The aplitic varieties do not have antiperthetic texture, instead some perthitic intergrowths may occur. The myrmekitic texture occures more often than the antiperthitic and shows an equal predominance in both types of the gneisses.

Alkalifeldspars: These show a wide range of grain size, content, and distribution in the gneisses of the studied area. They occur as minor constituents in the gneisses of type II A, and as accessories in type II B (with some few exceptions), but comprise one of the main constituents in types I A and I B. In type I A they always exceed the plagioclases, while they are of comparatively less abundance in type I B, where the accompanying plagioclase predominates.

The main type of knaf is the orthoclase, which is sometimes perthitic. Near orthoclase, occurences of microcline are also recorded, especially in the highly aplitic varieties of both gneiss types, where it is the main alkalifeldspar occuring with weak cross-hatching twinning. In the aplitic varieties microline is the only knaf occuring, which is very fresh and sharply cross-hatched. Therefore we think, that such microcline occurences are local and secondarily recrystallised from the original orthoclase, wherever the temperature conditions favoured its recrystallisation.

The $2\,V_X$ measurements range from -50° to -72° according to the type of knaf measured. The extinction angle perpendicular to (010) is almost always 0° or with small deviations of 1°—3°, while that parallel to (010) ranges between 5° to 8°.

The orthoclase is often twinned after the Carlsbad law, especially the porphyroblasts. Less common is the twinning after the Baveno law. Generally the alkalifeldspars show a degree of alteration, which corresponds to that of the accompanying plagioclase. Normally they are kaolinised, with dusty appearance and rarely, in the highly altered varieties it is so sericitised, that differentiation between both feldspars is impossible.

As a further proof a the type of alkalifeldspar occuring and as an attempt to get some genetical indications, the or-content, as well as the degree of obliquity of the knaf were investigated by X-ray diffraction techniques.

The obliquity of knaf, which is defined as the degree of departure from monoclinic to triclinic symmetry, was determined after the method of GOLDSMITH & LAVES (1954 b) through the equation

$$\Delta = 12.5\ d(1\bar{3}1)\ - d(131).$$

The obliquity is considered to be a direct measure of the statistical order-disorder distribution of the Al/Si atoms in the knaf unit cell. For $\Delta = 0$ the knaf is disordered and is monoclinic in symmetry (orthoclase), while for $\Delta = 1$ it is in complete order and is triclinic (microcline). MAC

KENZIE (1952, 1954) indicated, that the difference in $2\,\Theta$ between $(1\bar{3}0)$ and (130) reflections can be also considered as an expression of obliquity. It varies between 0.83° to 0.00° from monoclinic to triclinic symmetry respectively. However great care must be taken, in correlating these measurements with the degree of order, as it is certain, that the Na content can affect the $130-1\bar{3}0$ peak separation (MAC KENZIE, 1954).

The or-content of both the unmixed phase and the homogenised phase (after dry heating of the sampls to 1050° for 48 hours) was determined following the method of ORVILLE (1958) through the equation:

$$Y = 166{,}39 - 92{,}31\,X.$$

Where Y is the or-content for the monoclinic phase, and

$$X = 2\,\Theta\,(20\bar{1})_{knaf} - 2\,\Theta\,(101)_{KBrO3}$$

For the triclinic phase the following correction must be introduced:

$$X_{mon.} = X_{tric.} + 0.015.$$

The samples Nos. 80 (Type I A), 53, 74 (Type I B) and 31 (Type II A) were subjected to these studies, the results of which are shown by Fig. 1 and Table 1. The knaf in all the samples (except 53) proved to exhibit a highly disordered distribution of their Al/Si atoms, hence acquiring the least degree of obliquity, i. e a domination of the orthoclase phase. It is clear that the (130) as well as the (131) orthoclase reflection peaks of these samples are well developed in the range around 23.40° and 29.74° respectively (technical corrections must be considered). The corresponding separate reflections of the microcline (130), $(1\bar{3}0)$ and (131), $(1\bar{3}1)$ when present, should appear at 23.14°, 24.04° and 29.36°, 30.16° respectively.

The sample 53 develops very badly such reflections which are neither typical for the triclinic nor for the monoclinic phases. The obliquity primarily estimated from these underdeveloped peaks ranges around 0.86. Cases similar to this were given by GOLDSMITH & LAVES (1954 b), MAC KENZIE (1954), RICHTER (1965) and DA COSTA (1967), where it is explained by the simultaneous occurence of both monoclinic and triclinic phases in the same morphology in the form of sub X-ray twinning and/or the occurance of microscopic to submicroscopic islands of both symmetries. MAC KENZIE, ibid., added, that different possibilities can occur, so that all gradations between the two extreme phases are possible. Consequently, the degree of development and sharpness of the peaks can be taken as a direct indication for the relative abundance for one phase over the other. Accordingly it can be concluded that sample 53 represents a predomination of the triclinic phase over the monoclinic phase.

It is here worth mentioning, that HEIER (1957) indicated, that the knaf in the higher amphibolite facies, as well as in the granulite facies is a perthite with optical and X-ray monoclinic symmetry (there are indica-

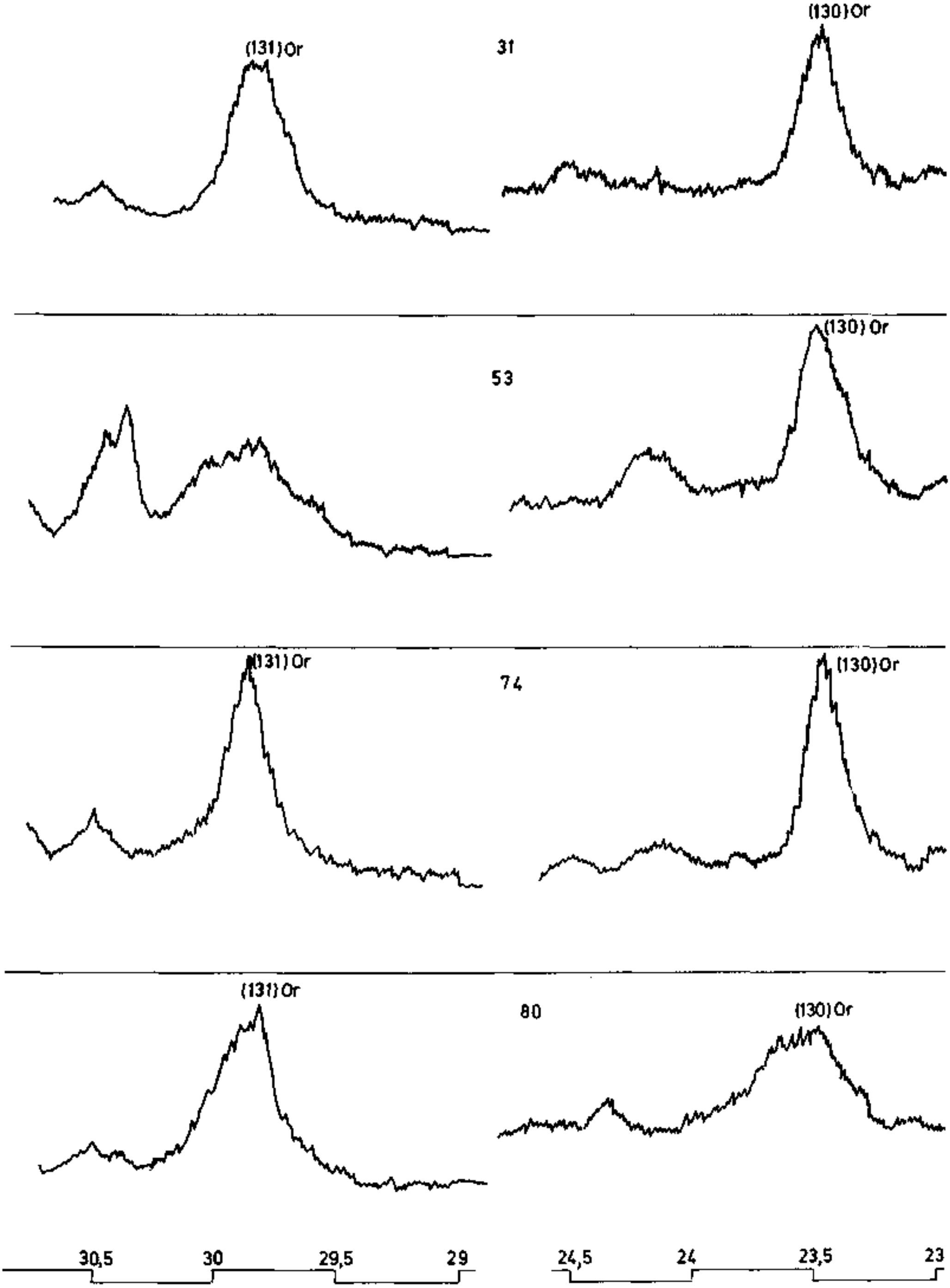

Fig. 1. The development of the peaks (131) and (130) in the unmixed and homogenised phases of the studied knaf samples.

tions for small deviations from monoclinic symmetry). A relation between obliquity and 2 V_X was indicated by HEIER (1961), as both of them increase parallel to each other. But in our case, where the studied Knaf of the orthoclase samples (Table 1) should acquire 2 V_X values near to each other, as they indicate similar degree of disorder, the differences in the 2 V_X are so big that such a relation does not exist. Similar cases were also indicated by MARFUNIN (1961) and H. G. SCHARBERT (1964), where it was explained by the fact, that X-ray data are not only dependant on the degree of order, but also on the sub-X-ray twinning, while the 2Vx is only dependant on the degree of order. On this basis the samples 31 and 74 can represent a highly disordered phase, while 53 and 80 must be having a sub X-ray twinning; then they would fall in the field of the "unbalanced twins" after MARFUNIN (1962).

Table 1.

Sample	Or% unmixed	Or% homogenised	2Vx°
31	88.72	87.00	51—58
53	93.93	86.31	62—67
74	87.14	79.85	53—60
80	89.77	86.08	

Concerning the orthoclase content of the unmixed and the homogenised phases no significant differences are detected. This is actually expected due to the low albite content, which is a reflection to the relative restriction of the perthitic structure.

Micas and Chlorites: Biotite and muscovite are the two mica types, occuring in the gneisses and schists of the studied area. Chlorite occurs mostly as accessory and mainly as an alteration product of biotite, garnet or sphene. The micas acquire a wide range of grain size from 0.2 mm, in the aplitic, mica-poor varieties (where the biotite is relatively fresh) to 6 mm long crystals, in the mica schists of both complexes. The most common grain size ranges between 1 and 3 mm.

In the Dobra gneisses both mica types are occuring. Actually type I (A and B) contains only biotite, while type II (A and B) can have biotite and/or muscovite.

In the typical Dobra Gneisses (I A and I B) the biotite content ranges normally around 5% of the total rock composition, mostly without any muscovite, which seldom occurs as accessory. In the other types II A and II B the biotite and/or the muscovite contents can be as much as 20 to 25% (samples 49, 95, 100, 117, 120, 170, and 180). In the mica schists the mica content can reach 60% (samples 46, 116, 132, 137, and 149).

Biotite occurs in the form of tabular crystals, which are always arranged parallel to the schistosity planes; in rare cases there are biotites crossing this direction. The most common biotite is pleochroic from x = light yellow to y = z = reddish brown. Less often the biotite acquires different colours and pleochroism mainly of the following varieties:

1. those, pleochroic from colourless or very light yellow to reddish brown, are represented by the samples 116, 118, 119, 120, 125, and 148; this biotite occurrence is often intergrown with muscovite laths.

2. those, pleochroic from brown to dark reddish brown (sometimes almost black), as in samples 93, 113, 145, 186, and 188.

3. those, pleochroic from light brownish green to dark green (sometimes also black); this is restricted to the samples 61, 73, 80, 84, 85, 87, and 89 of the Dobra-complex.

These biotites are altered mainly to chlorite with different degrees of alterations. In some highly altered varieties of types II A and II B the biotite is almost completely altered into chlorite, which still reserves laths of biotite, parallel to its cleavage that survived alteration. In others, which are less altered, the chlorites are found aligned parallel to the biotite cleavage, sometimes in optical continuity with them. Iron ores are often released as a result of this alteration and are mostly arranged in spots between chlorite and biotite. Chlorite is mainly of the pennine variety and seldom clinochlore. An other alteration product of biotite is sillimanite in the sillimanite-bearing varieties, as in samples 14, 26, 27, 31, 33, 37, and 168; only in sample 20 alteration to sericite is recorded. Pleochroic haloes around zircon, sphene and rutile inclusions are very frequent.

Biotite often has suffered post-crystallisation deformation and in some mica schists it is nicely microfolded, sometimes to be seen by the naked eye.

M u s c o v i t e is less abundant than biotite, being practically restricted in its occurence as a main constituent in types II A and II B; it shows some parallelism to the sillimanite in the sillimanite-bearing gneisses and schists; it is more frequent in type II B than type II A, with frequences from 5% to 22%, as in samples 95, 96, 127, 135, 140, and 170; in the muscovite schist No. 132 a muscovite content of 45% was observed.

The muscovite shows its normal optical properties, except in some samples of both types II A and II B, where it appears to be pseudouniaxial or with very small 2V angle, which never exceeds 7° (samples 52, 132, 140, and 149). It is quite possible that these muscovites are of the 3T or 2Ml polymorphs or even a mixture of both of them.

S i l l i m a n i t e: Sillimanite is the index mineral, if it occures in considerable amounts, the para-character of the gneisses is indicated. Therefore its occurrence is practically restricted to the Types II A and II B of the studied gneisses; in samples 17, 27, 33, 44, of the type II A it acquires higher frequencies, as 36%, 5.5%, 8% and 9.5% respectively; in other samples of the same type it ranges around 4% and in some others it occurs only as accessory. In type II B it is of a wider distribution allover the area, as it occurs in samples 118, 120, 140, 154 and 168 with amounts of 18%, 8%, 31%, 14% and 30% respectively.

The sillimanite occurs mostly as acicular aggregates, arranged parallel to the schistosity planes of the rocks. They often show post-crystallisation deformation, being sometimes microfolded. Some of the sillimanite is the alteration product of biotite, when it occurs in the form of sheaves; sometimes it reserves some biotite laths, which survived the alteration.

Another occurence of sillimanite is in the form of colorless prismatic crystals, arranged with their c-axes parallel to the s-planes, observed only in two samples, Nos. 186 and 195.

The sillimanite is always accompanied by muscovite.

P y r o x e n e s : Pyroxenes in the gneisses studied are practically restricted to the Krumau-complex. They are mainly augite and in relatively seldom cases diopside, which sometimes accompanies augite in the same rock. The diopside shows a special predominance in the area between the Genitzbach and Krumau in samples 115, 117, 118, 119 and 121 with 40%, 6%, 2.5%, 5% and 12% respectively; in the two samples 118 and 119 it is accompanied by augite as accessory and with 35% respectively.

The augite occurs as main constituent in the augite gneisses, which occur mainly at the contact with the marbles of the Krumau-complex. Examples for these gneisses are given by the samples 119, 139, 148 and 191 with amounts of 35%, 15%, 35% and 28% augite respectively. In other gneisses of the same complex it occurs as an accessory with frequencies ranging around 5%. It ranges in grain size from 0.4 mm. in the fine grained varieties up to 7 mm. in the coarse-grained varieties; intermediate grain sizes are also occuring. In the gneiss No. 119 the augite occurs in the form of porphyroblasts with an average diameter of 5 mm., which include other minerals, especially biotite. The predominance of augite gives the rock a faint greenish, sometimes also greyish colour.

It is almost colourless to very light green in colour showing no pleochroism. The z-angle C ranges between 45° and 48° in most of the cases with $2V_z$ 58° to 61°, with relatively low birefringence. The diopside is always colourless with a z-angle C from 37° to 40° and $2V_z$ ranging from 58° to 60°.

A diopside-salite band (35 cm. thick) was found at the contact with a dolomitic marble layer near Krumau, which is identical to another salite band occuring in the Topnetzbachgraben, detected by EXNER (1953). It is composed of prismatic crystals, about 3 cm. long and 1 cm. thick. They are milky white in colour and are according to EXNER (1953) the product of reactions of siliceous solutions with the host carbonate rock.

O t h e r M i n e r a l s : Other minerals occurring in the gneisses and schists as accessories are garnet, sphene, tourmaline, allanite, apatite, ores and zircon. Occurences of hornblende were recorded in the mica-hornblend schist No. 48 of the Dobra Complex with 18%, and in the Krumau Complex in sampels 100, 103 and 114 with amounts of 5%, 1.5%, and 9.5% respectively.

Garnet was recorded as a poor accessory in the Dobra gneisses, as in samples 20, 46, 52, 53, 56, 73, 74, 80, 84, 85, 89, 92, and 95. It occurs as idiomorphic crystals, sometimes rounded and ranging in grain size from 0.5 mm. to 0.9 mm.; it is often colourless and seldom light rosy in color, showing slight alteration to chlorite.

In the Krumau gneisses and schists, the garnet is of wider distribution. Moreover, it is one of the main constituents of the garnetiferous mica schists 118, 180, 186, and 95. In these schists it occurs in the form of big porphyroblasts, which distrub the schistosity of the rock, as they can attain a dimension of 7—8 mm. It is almost rather light rosy or rosy brown in colour, sometimes very sligthly anisotropic. Some crystals are riddled with inclusions of other minerals, as quartz and biotite and are slightly altered to chlorite.

Sphene is an ubiquitous accessory mineral in the majority of the gneisses and schists of both complexes, which never exceeds 0.5% except in some gneiss varieties of the Krumau-complex in the contact zone to the Gföhler Gneiss (159, 180, 195) with 4%, 1.5% and 1.5% respectively. In these three gneisses sphene occurs in the form of aggregates and clots of prismatic crystals, arranged with their c-axes parallel to the s-planes. Some of these crystals are zoned, some others are simply twinned.

Zircons: From the literature quoted before, about the Spitzer Gneisses and the Para-rock series, it is evident, that the work so far carried out, did not bring a satisfactory solution for the problem of their genesis and their relation to each other. It is also clear that no work was done on the accessory minerals as an additional tool to investigate the evolution of these gneisses and to participate in throwing some light on the problems of their petrogenesis.

The following zircon features are the mostly quoted: 1. habitus and terminal faces, 2. degree of rounding and corrosion, 3. elongation-frequencies, 4. color, zoning and inclusions and 5. growth trends of zircon crops.

The term "Abrasion Index" was firstly introduced by Allen (1944) to represent the percentage of zircon crystals in a given rock, that show no evidence of rounding. However, Eckelmann & Kulp (1956) noticed, that this terminology is unsatisfactory, as it indirectly suggests a meaning, contrary to that intended by the term. Therefore, they suggested the term "Rounding Index" to represent the percentage of crystals showing any signs of roundness. On the basis of this rounding index, they were able to differentiate between three types of granitic gneisses of igneous-(ortho)-origin and seven others of sedimentary-(para)-origin. Poldervaart (1956) suggested, that a low rounding index of zircons is a strong evidence for their ortho-origin.

Also the elongation-frequency and length frequency curves of zircons in collaboration with their rounding index were very often used. Poldervaart & Backström (1949) indicated that ortho gneisses have normally maximum elongation frequency above 2.0, while para gneisses have a value below 2.0. In most cases in which this maximum is below

2.0, nearly all the zircons show rounded terminations and the majority of the grains are well rounded.

Other properties like colour and inclusions can be quite helpful if they are conspiceous and common, specially for comparison and correlation purposes.

Zircon growth curves (Reduced Major Axis)

This technique is applied as it was firstly adopted by LARSEN & POLDERVAART (1957) in their attempt to differentiate between the Bald Mountain tonalites, Anthony Lake granodiorites and later intrusions.

Samples Studied and Techniques of Separation

For this study, 6 samples were subjected to statistical analysis. 5 samples of them are from the Dobra-complex, and the sixth is from the Krumau-complex. Sample No. 1 is an aplitic Dobra Gneiss variety, No. 2 is an augen gneiss variety, 3 and 4 are from the normal granitic Dobra gneiss, while the fifth is a sillimanite-bearing para gneiss intercalation in the Dobra gneiss. The sample No. 6 is also a sillimanite-bearing para gneiss, occuring in the Krumau-complex. The statistics for the first three samples were friendly offered by G. DESHPANDE (personal communication).

The sieved fraction of the crushed sample was carefully decanted with water and dried before being subjected to heavy liquid separation, using firstly tetrabromoethane (sp. gr. 2.90). The heavy concentrate obtained was washed by alcohol, dried, contaminations of biotite and other ore minerals were isolated, using a FRANZ isodynamic separator. The last concentration of the heavy mineral zircon was prepared by further separation using the Clarici solution (sp. gr. 4.2).

In this procedure attention should be paid to a common mistake, which often happens during the separation of zircons. This is the attempt to separate the biotite and other minerals of relatively higher magnetic susceptibility using the magnetic separator, before subjecting the sieved samples to heavy liquid separation. This seams actually logic; as, by getting rid of the magnetic fraction, the bulk volume will be greatly reduced, especially in biotite-rich rocks thus facilitating the heavy liquid separation which should follow. But it happens that, through this sequence of separation, the zircon escapes the fraction in which it is expected, that is the nonmagnetic light coloured fraction with quartz and feldspars, in spite of its pronounced low magnetic susceptibility. If such a nonmagnetic fraction is subjected to heavy liquid separation, practically no single zircon crystal will be gained. On the contrary, if the heavy liquid is firstly used to get rid mostly of the light fraction, then the magnetic separator to eliminate the magnetic fraction, an appropriate concentrate of zircon can be satisfactorilly obtained, by also using the Clarici solution.

As a result of our investigations the specific features of the different zircon crops are given in Tables 2 and 3. The figures 2 and 3 show their elongation frequencies and their RMAs respectively, which are discussed together with the other properties hereafter.

The zircons of these gneisses occur in the form of two significantly different types:

Type A: this is the type characterised by a high degree of roundness; its concentration in a gneiss variety gives rise to its "Rounding Index". The term "Rounding Index" is used here in the sense of ECKELMANN & KULP (1956), expressing the total percentage of the zircons, showing any degree of roundness. This Type A, occurs in the form of prismatic bipyramidal crystals with relatively simple form-combinations like [110], [111], sometimes combined with steeper bipyramids like [331] and very seldom recognised [100]. However the crystal forms were not easily recognised, due to the high degree of roundness and corrosion. Sometimes the crystals are highly corroded to an extent, so that they show extra-ordinary forms. A considerable proportion of this type is light coloured, from pale brown to pale yellowish brown; darker colors are very seldom; however, some dark brownish red crystals were also recorded.

Outgrowths and overgrowths are relatively seldom, not exceeding 11% in sample 6. Inclusions, in the form of fine needles and/or irregular, sometimes also globular forms of ores and other minerals, are not very rare. They are often difficult to identify, due to their extreme small size; zoning is absolutely absent.

Type B: This is relatively more idiomorphic than type A. The crystal faces and forms show better development, a relatively high proportion of them is euhedral with the prisms [110], [101] and the bipyramides [111], [321] and sometimes also [331] in different combinations. The crystalls are generally slimmer than in type A, seldom coloured,

Table 2. Statistics of the specific features of zircons.

samples	1	2	3	4	5	6
strongly rounded %	10	9	18	15	70.5	85.5
subrounded %	38	47	37	36	23.5	13
rounding index	48	56	55	51	94	98.5
angular zircons %	52	42	54	49	6	1.5
out- and overgrowths %	15	7	26	14	10.5	11
zoned zircons %	21.77	14	25	23	—	—
RMAs Statistics:						
a	0.3696	0.3641	0.3293	0.3105	0.4948	0.5388
σ a	0.0148	0.0282	0.0174	0.0155	0.0268	0.0290
x mm.	0.1441	0.0999	0.1075	0.1589	0.1605	0.1466
y mm.	0.0521	0.0343	0.0383	0.0614	0.0787	0.0738
Sx mm.	0.0447	0.0332	0.0395	0.0373	0.0381	0.0348
Sy mm.	0.0164	0.0120	0.0129	0.0120	0.0188	0.0187
r	0.8739	0.9556	0.7719	0.7305	0.6672	0.6749
Dd	15.7	31.6	24.5	16.79	16.19	20.05
a°	20 15	19 50	18 15	18 10	26 20	28 20

Table 3. Statistical comparison values of the zircon crops.

sample pairs	Za	Zp	$\overline{Zx}$	$\overline{Zy}$
1 and 2	0.26	0.2724	9.68	10.735
1 and 3	1.81	1.94	7.5	8.114
1 and 4	2.2336			
1 and 5	4.09			
1 and 6	4.2835			
2 and 3	0.97	0.1654	1.785	0.402
2 and 4	0.4516	1.581	15.510	20.846
2 and 5	3.4293			
2 and 6	4.380			
3 and 4	0.4313	0.8193	12.28	17.073
3 and 5	5.1718			
3 and 6	6.1982			
4 and 5	2.73			
4 and 6	1.965			
5 and 6	1.1139	1.1197	0.3821	1.5776

being mostly colourless. Some of them are even water clear. Zoning in this type is frequent, reaching sometimes 25% as in sample 3. Zoning becomes more distinct, when the crystal lies with its lenghth parallel to the vibration direction of the polarizer. The zones follow the crystal outlines and increase sometimes in order from margin to core, which may be due to the increase in thickness or birefringence in this direction. Inclusions are common, either opaque of irregular shapes, or transparent in the form of fine needles with no special arrangement; some smaller zircons are often included.

Outgrowths and overgrowths are also more often in this type than in type A. They occur in the form of prismatic protrusions or cap-like overgrowths.

Genetical Indications

The zircon type "A", which is proved to be of pure sedimentary origin (ALLEN, 1944; POLDERVAART & BACKSTRÖM, 1949; ECKELMANN & KULP, 1956; POLDERVAART, 1956; KHAFFAGY 1964, and others) occurs alone up to 100% in the two sillimanite-bearing gneisses of the Dobra gneiss and the Krumau series; it also occurs in considerable proportions in the other Dobra gneiss varieties reaching sometimes 56% in the Augen Gneiss variety.

On the other hand, the zircon type "B", which according to literature appears to be of magmatic origin, occurs in equal abundance with type "A" in the Dobra gneiss varieties.

Considering the elongation-frequency distributions of these zircons, new data can be added; for the two sillimanite bearing gneisses, the maximum elongation-frequency lies between 1.5 and 2.0, being around 60% in both of them; besides this, about 10% of both zircon crops show elongations below 1.5.

For the other Dobra gneiss varieties, the maximum elongation frequency lies between 2.5 and 3.0. Still there is a considerable proportion

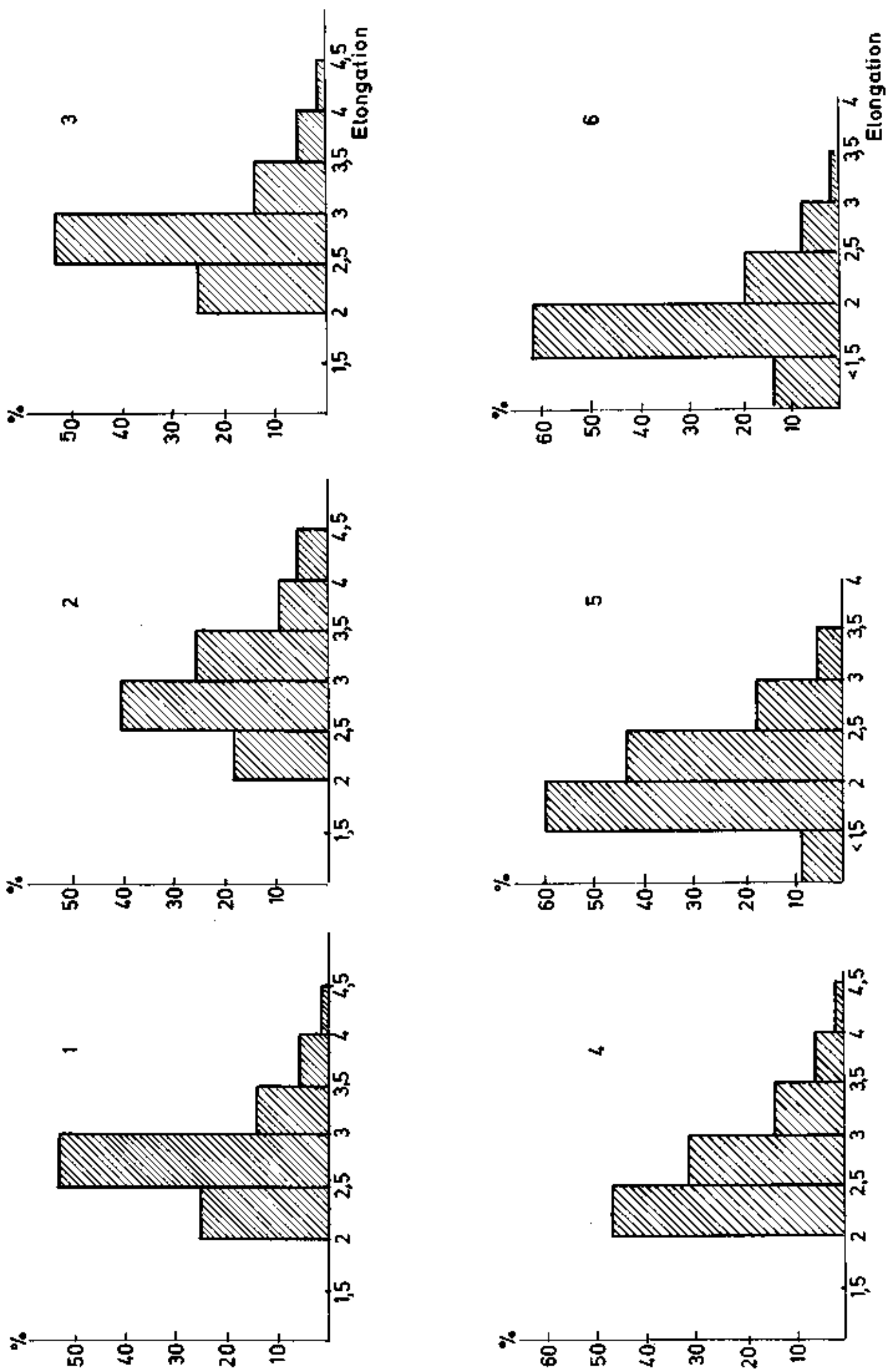

Fig. 2. The elongation frequencies of the zircon crops.

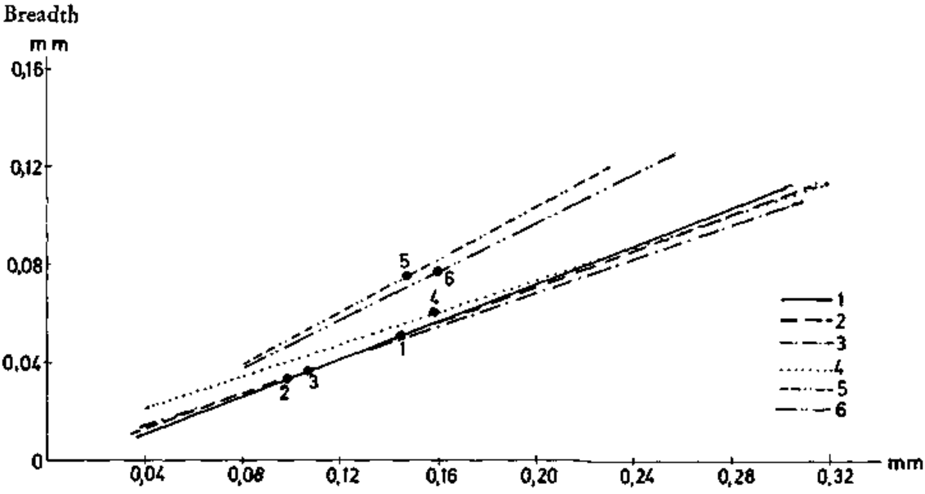

Fig. 3. The RMAs of the zircon crops.

of each variety, which has its elongation below 2.5. Also the RMAs-study separates very sharply between the two types of zircon crops. However, a glance to Table 3 where the different factors are compared on a statistical basis, shows, that the differences in slope between each of the two sillimanite-bearing gneisses and each of the Dobra gneiss varieties are, as expected, considered real. It is also clear that even between the Dobra gneisses themselves no complete harmony is recorded, concerning these differences. The difference in slope between 1 and 6 is considered real. Also, excluding the sample-pair 2 and 3, the other pairs of samples 1 and 2, 1 and 3, 2 and 6 and 3 and 6, are showing real differences in joint means Zx & Zy reaching sometimes very high values.

Considering these observations in connection with a discussion of the genetic problem of these rocks the following conclusions are submitted:

A. the definite sedimentary origin of the two sillimanite bearing gneisses, the one of the Dobra gneiss body and the second of the para-rock series is confirmed by:

1. the occurence of zircon type "A" in absolute majority in both of them;

2. the extreme "Rounding Index" of their zircon crops reaching 94% and 98.5% respectively.

3. the maximum elongation-frequency of their zircons lies between 1.5 and 2.0, being around 60% for both of them, and the occurance of about 10% of their zircons with elongations below 1.5.

A para-origin might be extrapolated for the other gneissic intercalations in the Dobra gneiss body, which are also sillimanite-bearing and/or mica-rich.

The occurrence of marble bands and calc-silicate rocks, together with these sillimanite-bearing gneisses in the Dobra gneiss body adds to the final proof, that their parent rock must have contained sedimentary material, and must have undergone sedimentary processes. This supports the idea of the existance of some sort of connection between the Dobra gneiss and the para-rock series, which was primarily indicated by the gradual transition along their contacts in the field.

B. concerning the other varieties of the typical Dobra gneiss body, the following conclusions are submitted:

1. the occurence of the zircon type "A" in nearly equal abundance with type "B" in these gneisses gives the impression, that the typical Dobra gneiss itself must have contained some kind of para- or sedimentary-material (from which type "A" was produced).

At the same time it must have also contained some kind of magmatic material, from which type "B" was derived. However the degree of this intermixing is not the same throughout the whole body.

2. the elongation-frequency maxima, being between 2,5 and 3,0 with percentages ranging from 40—50%, supports the just mentioned idea, that a high proportion of these zircons must have originated in a magmatic environment. On the other hand, if their considerable "Rounding Index" is taken into consideration, one could conclude, that even these zircons might have undergone at least one cycle of sedimentation, through which this rounding took place. Another explanation might consider the intermixing of this material with other sedimentary material, which contained the rounded and the subrounded zircons.

3. the relative harmony between the RMAs of these varieties, specially in the values of Za and Zp, indicates the existance of an intimate relation between them, having nearly the same origin and undergoing the same mode of formation. However, the two delicate tests Zx an Zy yielding very high values, up to 20,8 point strongly in the opposit direction. This can be only explained on the basis of the heterogenity and intermixing of different fource material of the Dobra gneisses in different proportions, thus giving rise to these different features.

From the foregoing discussion, it will be unappropriate to consider the Dobra gneisses (Spitzer gneisses) as typical O r t h o g n e i s s, as it always has been considered. It seems proven to be the metamorphic product of a heterogeneous mixture of O r t h o - and P a r a -materials. Also its relation to the para-rock series cannot be easily neglected.

2. Petrography of the Amphibolites

The amphibolites occuring in both complexes, are mostly hornblend-andesine rocks, associated with quartz, whose amount does not exceed 6%. It normally ranges between 2% and 3%, otherwise it is a negligible accessory. Other minerals are biotite, titanite, garnet, chlorite, apatite, ores and zircon. The Dobra amphibolites are more biotite- and titanite-bearing, than those of the Krumau-amphibolites, which are more garnetiferous especially at the contact with the Gföhler Gneiss.

On the basis of 37 modal analyses the amphibolites can be classified into the following main types: —

T y p e I: Includes the biotite-bearing amphibolites, represented by the samples 7, 11, 47, 58, 63, 75, 79, 81, 88, 101, and 107. According to the biotite content of these amphibolites two subgroups can be recognised:

T y p e I A: with a biotite content less than 15%; this includes the samples 4, 11, 47, 58, 63, 75, 81, 88, 107 and 129;

T y p e I B: covers the biotite-rich amphibolites with biotite contents ranging from 15% to 32%, forming a minor group of intercalations, represented by the samples 7, 18, 79 and 101.

T y p e I I: Includes the biotite-free amphibolites; it is the major type, occuring in both complexes. These are practically biotite-free or in very rare cases biotite occurs as traces of a minor accessory. This type is represented by samples 29, 40, 54, 57, 59, 102, 122, 126, 131, 157, 166, 167, 171, 172, 173, 177, 182, 189, 184, 187, 185 and 190; from these samples only 131, 157, 166, 167 and 171 are having biotite in negligible amounts.

Concerning the relative abundance of the two main constituents hornblende and plagioclase, some of the amphibolites show nearly an equal abundance, as in samples 11, 63, 88, 101 and 107 of Type I and samples 54, 129, 157, 173, 182, 185, 189 and 190 of Type II, ranging in their amounts around 40% of the total rock composition. Otherwise,the hornblende predominates the plagioclase, except in the two samples 11 of Type I and 157 of Type II, where the plagioclase slightly predominates the hornblende. In samples 4, 7, 18, 47, 58, 75, 81, 79, of Type I, and 29, 40, 57, 59, 102, 122, 126, 131, 166, 167, 171, 172, and 184 of Type II the hornblende predominates the plagioclase. Where its increase is almost always on the expence of the plagioclase. In the majority of the samples this excess in hornblende ranges from 20% to 30%. Greater differences of about 50—60% in amount are also detected as f. i. in samples 4, 7, 81, of Type I and 59, 102, 126, 131 and 184 of Type II.

Titanite and biotite show a certain parallelism in their occurence, being especially frequent in the Dobra amphibolites of Type I, where they are of less importance in the injection zone of the Gföhler Gneiss. Garnet occurres in detectable amounts only in the amphibolites at the contact zone to the Gföhler Gneiss, otherwise it occurs as a negligible accessory, except in the case of the two samples 102 and 107, where it acquires the amounts 2% and 3% respectively.

The amphibolites are almost fine-grained, mostly having a linear orientation of the hornblende prisms together with biotite (in biotite-bearing varieties) parallel to the s-planes, thus producing perfect schistose structure, which shows a complete concordance to that of the enclosing rocks. However some equigranular varieties, e. g. samples 29, 40 and 177 are obviously granoblastic, while samples 47, 57, 59 and 126 show a partial granoblastic structure. Coarse-grained amphibolites with hornblende prisms reaching sometimes about 1 cm in length are rare, except at the contacts of some aplitic injections. An example for this is sample 63, which is relatively rich in biotite (9%) and sphene (4%).

The hornblende, occuring in our amphibolites has a grainsize, normally ranging from 0,9—1,2 mm and is of the typically common green hornblende, pleochroic from light yellowish green to olive green in the majority of samples. Other samples of this hornblende are either lighter greenish or even brownish colours are not seldom. The amphibolites containing the typical green hornblende type are 4, 7, 11, 18, 101, 102, 107, 122, 182, and 185. Nearly all of this green hornblende is associated with dark brown biotite, pleochroic from light yellowish brown to dark brown, if the sample is biotite-bearing. Other amphibolites contain the brown variety of hornblende, which is pleochroic from light greenish brown to dark brown, associated with the previously mentioned brown biotite variety, they are represented by the samples 63, 173, 184, and 187.

Others with light green hornblende, pleochroic from light yellowish-green to light green, proved always to be accompanied by a light brown biotite variety. Examples of this type are the samples 47, 81, 131, 157, 166, 167, 171, 173, 177, 189, and 190.

Samples 57 and 59 (dyke- and sill-like occurances in the Dobra Complex) and the sample 126 (an occurence in the Krumau Complex) contain an almost colourless hornblende variety, pleochroic from nearly colourless to very light green, with z/C of 14,5° (in other hornblende varieties z/C ranges between 16—19°). These three samples are biotite-free.

Next to the hornblende and biotite the amphibolites include finer grains of other rock constituents, especially quartz, sphene, ores and zircons.

The zircons and sphenes are almost arranged with their c-axes parallel to the schistosity producing pleochroic haloes around them. Chlorites of the clinochlor and pennine types are the alteration product of both biotite and hornblende.

The plagioclases occur mostly in the form of xenomorphic grains, ranging in size from 0,6—0,9 mm. Greater grain sizes are relatively seldom and are only recorded at the contact zone with the Gföhler Gneiss, where they can reach 2 cm in diameter. They exhibit a wide range of An-content, ranging from 18—45%. Reverse zoning is frequent, nearly in all amphibolites, with a core ranging from 18—25 An % and a rim of 26—45 An %. They are polysynthetically twinned, mainly after the albite and pericline laws. In some plagioclases of the injected zones occurences of crystals with non-twinned cores are recorded, where the twinrims are generally bent. Completely individuals are frequent and occur everywhere.

The plagioclases are normally highly altered into sericite, except those of the aplitic injections, which appear to be relatively more fresh. Antiperthitic texture is very rare, observed only in the two samples 63 and 75. Inclusions of other minerals are often recorded, mainly hornblende, biotite, sphene and quartz.

The garnet seems to be preferable restricted to the amphibolites of the Krumau Complex, occuring only in samples 102, 107, 157, 166, 167, 171, 172, 173, 179, 184, and 185. However it shows special flourishing at the contact to the Gföhler Gneiss, thus developing the garnet-amphibolite varieties No. 166, 167, 171, 173, 184, and 185. Its amount ranges from 3% to 8% in the form of porphyroblasts of the almandine type, reaching a grain size of 7 mm, thus disturbing the schistosity of the rock. They are riddled with inclusions of other rock components. Some of them are irregularly cracked and are altered along these cracks into chlorite (mainly pennine). The garnet in the Dobra amphibolites is quite negligible, only occuring in the two samples 40 and 63 as a minor accessory.

The titanite on the other hand, shows its preferable occurence in the amphibolites of the Dobra-complex in samples 4, 11, 54, 63, 75, 79, 81 and 88. It ranges in amount from 2% to 10% and occurs in the form of idiomorphic sphenoidal crystals, which are almost always arranged with their c-axes parallel to the schistosity of the rock. Its occurence in the amphibolites of the Krumau-complex is relatively rare, being restricted to those at the contact with the Gföhler Gneiss, reaching sometimes 3.5%, sample 187. In the samples 102 and 107 with amounts of 2.5% and 2% respectively it occurs in the form of clot aggregates. It is sometimes altered into chlorite and replaced by ilmenite, especially in its core. The titanite is generally dark brown in colour, slightly pleochroic. In one sample (45) it is almost black.

Other accessory minerals as apatite and ores are ubiquitous and show a homogeneous distribution in the amphibolites of the whole area.

3. Petrography of the Marbles

Marbles occur in both complexes, they abound around Krumau till Thurnberg. However, the detection of the marble occurences in the Dobra-complex furnishes a good clue to the genetical problem, which so far remained puzzling and confusing for a long time.

Generally, our marbles are dolomite and/or calcite marbles, sometimes diopsidic, tremolitic, phlogopitic, or siliceous. Feldspathic marbles are rare except in the eastern contact zone of the Krumau-complex.

The samples Nos. 28, 32, 35, 38, 39, 68, and 82 were collected and investigated as typical for the marbles of the Dobra-complex (opposite to the Schloteinbachmündung, Franzen, Kamprohrbrücke and Schoerlberg); from the Krumau-complex the samples Nos. 108, 110, 111, 128, 136, 146, 152, 153, 156, 162, 163, 165, and 181 were studied, representative for the main varieties of this complex.

Our marbles are mostly fine- to medium-grained, ranging in diameter from 1—2 mm. Some occurences are also coarse-grained, reaching 4—5 mm. in diameter as in samples 28, 35, 110, and 136. They mainly consist of a mosaic of equal carbonate grains with lamellar twinning, closely packed and very often bent, which must be due to deformation.

Carbonate crystals are the main constituents of all the marbles, sometimes the only constituting mineral with few accessories. They may reach 95% of the total rock composition, as in samples 28, 110, 111, 136, 152, 162, and 165. Their percentages in other varieties, especially the siliceous No. 35, the tremolitic No. 82, and the diopsidic Nos. 38, 39, 68, 146, 163, and 181 range between 55% and 89%, according to the proportions of the other minerals.

An attempt was made to get an idea about the degree of dolomitisation in these marbles; they were subjected to X-ray diffraction method and a comparison of the peaks of the two reflections at 29.5° of the mineral calcite and 30.96° of the mineral dolomite was made. The results point to a relatively higher degree of dolomitisation of the marbles of the Dobra-complex, than those of the Krumau-complex, as indicated in Table 4.

Table 4. Degree of dolomitisation of the studied marbles as relatively indicated by X-ray diffraction method.

Sample No.	28	32	35	38	39	68	82	108	110	111
100% dolomite	×									×
dolomite calcite		×				×	×			
calcite dolomite				×	×			×		
100% calcite			×						×	

Sample No.	128	136	146	152	153	156	162	163	165	181
100% dolomite	×	×								
dolomite calcite										×
calcite dolomite										
100% calcite			×	×	×	×	×	×	×	

The origin of the dolomitic component of these marbles is less clear. However, the occurrence of the pure calcitic marbles of the Krumau-complex cannot be due to a "dedolomitisation" processes, since there is no appreciable concentration of minerals like tremolite, anthophyllite or talc, which could explain the refixation of the abstracted magnesia. Hence the other possibility of dolomitisation of actually calcitic marbles is more acceptable. Whether the dolomitic to partially dolomitic marbles were of primary syngenetic origin, or due to secondary dolomitisation processes, which should have taken place through the course of metamorphism presumably by Mg bearing solutions, remains purely speculative. It is also to be indicated, that no specific relation could be found, between the colour of the marbles and their degree of dolomisation. PINGER (1950) and ENGEL & ENGEL (1953), stated repeatedly, that the Frankline marbles and the marbles of northwest Adirondacks are predominently calcitic white, in colour, while local areas of dolomite are grey to dark grey. Our marbles, cover white as well as grey calcite- or dolomite-marbles.

The dolomitic and calcitic nature of the samples 128 and 163 was formerly detected by the U-stage measurements of the angle between the c-axes and the $(01\overline{1}2)$, for dolomite it is 62.5° and for calcite it is 26°.

Diopside occurs in samples 38, 39, 108, 136, 146, 162, and 181 in different proportions from accessory to amounts ranging from 10% to 30%. In the samples 39, 68, 146, and 181 it occurs with amounts of 30%, 29%, 10%, and 16% respectively, in the form of euhedral poikilitic crystals sometimes cracked, here calcite crystallises along these cracks; it is almost colourless with z/c from 39—40°.

Tremolite occurs in the sample No. 82 in considerable proportion of about 20% in the form of prismatic, colourless crystals, arranged parallel to the lineation of the rock; it occurs also in the two samples 128 and 136 as a minor accessory.

Phlogopite is recorded in all the studied samples (except 28, 35, 82, 128, and 181). In sample 38 it reaches an amount of 5%; in all the others its amount does not exceed 3%; also it was recorded in some of them as a minor accessory.

Graphite occurs in some marbles around Krumau, especially in those at the contact to the graphitic schists. Some of these marbles have a banded nature, graphite rich bands alternating with carbonate bands. The graphite is almost always accompanied by pyrite, in the form of euhedral crystals sometimes reaching 2 mm. in diameter.

Graphite was detected also in one marble variety (No. 35) occurring in the Dobra-complex opposite to the Schloteinbach mouth.

Forsterite altered into serpentine gives the marble variety No. 32 of the Drobra-complex a greenish spotted appearance; it is detected in considerable amount reaching about 15% of the rock compositon.

Quartz occurs as accessory mineral nearly in all marbles in the form of xenomorphic grains, which do not show the undulose nature. In the siliceous varieties 35 and 181 it occurs in amounts of 24% and 10% respectively.

Other accessories are muscovite, apatite, haematite, magnetite, and titanite. The last was detected only in the samples 153, 162, 163, 165, and 181. Zircon is observed in one sample No. 68 included in quartz.

4. Discussions and Conclusions

a) Degree and type of Metamorphism

The bulk of the metamorphic rocks, belonging to both complexes exhibit mineral assemblages of the almandine-amphibolite facies formed by regional metamorphism. According to TURNER & VERHOOGEN (1960), our mineral assemblages fall under the sillimanite zone of the almandine-amphibolite facies. According to WINKLER (1965), they fit mostly in the Barrovian almandine amphibolite facies, specifically into the sillimanite-almandine-orthoclase subfacies. The surviving of some muscovites of our gneisses and schists can be, according to WINKLER (1965), due to the highly pelitic nature of the parent rocks and/or the PT conditions of the sillimanite almandine orthoclase subfacies were not completely attained to transfer the whole muscovite present to sillimanite. He further adds that under high pressures more than 4000 bars (may reach 6 Kb), where almandine is generated instead of cordierite, 700° C would be surpassed so that muscovite may become unstable. For the parent rocks of such mineral assemblages, rocks as pelites, marls, shales, graywackes, sandstones, siliceous carbonates, and basic rocks can be taken into consideration.

Garnet is an ubiquitous wide-spread mineral throughout, and many of the gneisses are sillimanitic to highly sillimanitic. Also biotitic, muscovitic gneisses and biotitic amphibolites prevail in many localities. Most of these rocks are garnetiferous especially at the contact to the Gföhler gneisses, where the degree of metamorphism appears to have reached its apex. However, almost all the mineral assemblages of the paragneisses of both complexes appear to have been evolved in conjunction with extensive injections and soaking of the metasediments by magmatic fluids. Mainly alkali-siliceous liquids, locally aluminium-bearing, with iron and magnesium were introduced, from which reactions with the metasediments biotite, garnet and sillimanite were formed. They also clearly resulted in modifications in types and amounts of the occuring feldspars. Moreover the original composition of the metasediments involved in these interactions, undoubtedly varied appreciably at various parts of the sequence, and from place to place in the series, thus resulting in the diverse varieties mentioned before.

The amphibolites allover the area dominantly hornblende-andesine rocks with either biotite and/or clinopyroxenes as components. Titaniferrous and garnetiferrous varieties are recorded in the Dobra- and Krumau-complexes respectively and at the contact to the Gföhler Gneiss.

Most of the marbles contain diopside and tremolite. Only one variety contains forsterite, which does not seam to fit (as the case of muscovite) into this subfacies. This may suggest, that the rocks of this area lie in the transitional zone between the two subfacies.

The ubiquity of the assemblage quartz, biotite, oligoclase in the gneisses, as the oldest visible metamorphic assemblage is noteworthy. There are no clearly defined anticedent or relictminerals, suggesting a preceeding stage or step of lower grade of metamorphism. The chlorite as well as some of the sericite, recorded as minor constituents are products of superimposed retrograde metamorphism, which is only locally conspicuous. Thus the biotite is largely altered to chlorite, and the plagioclase are highly sericitised. Similar alteration to chlorite are also recorded for other minerals like hornblende, garnet and sphene.

b) Origin of the metasediments

The rocks of undoubted para-origin, occurring in the area, are the paragneisses, schists (Types II A and II B), marbles and quartzites. Concerning their origin, there ist no contradiction between the previous authors, who dealed with the area. It is considered, that the distinctly layered form of the paragneisses, quartzites and marbles of the Krumau-complex furnishes the first clue to their metasedimentary origin. They represent thus a series of marine sediments, originally laid down as alternating layers of shales, limestones, and sandstones, from which the gneisses and schists, marbles and quartzites were transformed, in the course of metamorphism. Before metamorphism, the rock may have been anything ranging from impure shales and sandstones to calcareous layers. Apparently here are important indications for sedimentary sequences commonly formed in fairly stable shelf environments, contrary to types formed on crustal segments of marked instability and appreciable local relief. These environment appears to have been marine, but with differences from place to place. An example is the marble-rich series around Krumau, which seems to have deposited in a large persistently negative, although not highly unstable basin. These thick, uniformly layered marbles and the associating quartzites lie stratified in the gneisses, are conformable with them.

These relations are in accordance with a concept, according which the gneisses are derived from shales or argillaceous sandstones, which themselves are the products of moderate to intensive residual weathering and good sorting. However the inferred premetamorphic features of the gneisses hardly point to a distinct type or origin of the parent sediment.

The pyritic and graphitic schist, undoubtedly has evolved from an argillaceous and somewhat calcareous sandstones, which may have contained much of the iron and sulphur combined in pyrite as sedimentary or diagenetic constituent.

c) Origin of the Amphibolites

Concerning our amphibolites, from the foregoing studies of the geology, distribution and petrology combined with their geochemical investigations, our basic conclusion is, that both the amphibolites of the Dobra- and Krumau-complexes might have the same parent rock, as no genetical differences between them are existing. The classification of the occuring amphibolites in both complexes into two types I and II, does not give an indication for any genetical differences, simply because:

1. the occurrence of both types in the Dobra- as well as in the Krumau-complex;

2. the equal distribution of both types all over the area;

3. the differences in these types concern mainly the occurrence or absence of some minerals as biotite, garnet and sphene, which can be due

to local changes in the degree of metamorphism (PT conditions), assimilation of parts of the country rock, or even due to post-metamorphic factors e. g. the case of the injected zone at the contact of the Gföhler gneiss.

It is worth mentioning to indicate that an ortho-occurrence of amphibolites can be taken into consideration, to which would belong the single dyke-like body of the Dobra-complex and related varieties previously discussed. These amphibolites are characterised by complete absence of biotite, the occurrence of the nearly colourless hornblende variety, which obviously predominates the plagioclase in amount, together with their granoblastic character.

Field observations and laboratory investigations, seem to suggest, that our amphibolites both of the thin sheet- and of the thick formation type, interlayering the gneiss complexes, have been emplaced, where they acquired their present composition during metamorphism; therefore they are either:

1. stretched and smeared-out fragments of basaltic flows, sills or dykes; or,

2. metamorphic differentiates derived from a sequence of basic fronts of mafic metasomatites.

Concerning the concept of the metamorphic differentiates, as a process contributing to or largely responsible for the formation of the amphibolites, it is possible, that the mafic elements, which are supposed to be expelled from the gneisses during metamorphism, have been selectively concentrated along certain bedding foliations and stratigraphic zones to form amphibolites. This hypothesis, if acceptable in our case, could be only as faint possibility considered for the thin amphibolite occurrences of the Dobra-complex, but certainly not for the thick formations of the para-series of the Krumau-complex.

This is on account of the minimum thickness of the amphibolites of the Dobra complex and also on account of their relatively smaller abundance (about 10% only), if compared with the enclosing gneisses. Here, the amount of the leached mafic elements from the gneisses could be sufficient to contribute in the formation of these thin amphibolites. On the other hand, the amphibolites in the Krumau-complex are nearly as abundant as the gneisses and they acquire bigger thicknesses reaching 200 m sometimes, which makes this hypothesis absolutely unrealistic. Even for the Dobra amphibolite sheets these metamorphic differentiation hypothesis is also rejected, as definite transitions between amphibolites and gneisses were not observed.

The above considerations lead to the conclusion, that the amphibolites allover the area have been derived from basaltic parent rocks. These could have been emplaced in the form of basaltic flows, sills, or as complex intrusive and extrusive types. These forms of occurrence might explain the thin sheets of amphibolites in the Dobra-complex, which could have been thinned and stretched by plastic flow of the rock sequences during the metamorphism. Usually in case of such basaltic flows or sills, complementary dykes and dyke-like occurrences are to be expected, which are lacking in our amphibolites except one single case of the Dobra-complex (KHAFFAGY, 1970). ENGEL & ENGEL (1965) and others (BOWN & ENGEL, 1956, and ENGEL, 1949) dealing with similar cases attributed this lack in dykes to tectonic processes, such as shearing out and rotation of fragments of the dykes into near conformity with metamorphically induced foliations.

The ortho-origin of the amphibolites may be inferred from:

1. the very sharp contacts of the amphibolites with the enclosing gneisses;

2. the common nature and the way of occurrence of the amphibolites in both complexes;

3. the consistenly fine-grained and the relatively more schistose margins of the thick bands and of the thin sheets of amphibolites, which may represent chill zones.

4. the discordant relation of the amphibolite occurrence in the Dobra-complex opposite to the Ruine Dobra.

5. the regular increase in abundance, frequency and thickness of the amphibolites from the Dobra towards the Krumau-complex.

As already indicated, the Krumau-complex is but the western limb of a regional syncline, whose eastern limb lies symmetrically east of the Gföhler gneiss. The volcanic center should thus have been situated somewhere under the Gföhler gneiss body. This position should have caused the basaltic flows, necessary for the formation of the amphibolites in the syncline. The fact that the Dobra-complet must be relatively older than (being underlying) the Krumau-complex suggests, that the thin amphibolite sheets intercalating it, represent the first eruptive pulses of this volcanic activity. These basaltic pulses should have been flown over long distances due to the high mobility of the basaltic magmas, which presumably helped in thinning these sheets. This volcanism should have been continued in the form of surface and/or subsurface eruptions; over different periods gradually increasing in intensity; it reached its apex with the eruption of the last basalts that correspond to the thick amphibolite bands of the Krumau-complex.

d) Origin of the Dobra Gneisses

The origin of the Dobra gneisses (Spitzer Gneis) is one of these interesting problems, that become the pivot for discussions, whenever the geology of the Austrian Waldviertel is concerned. This is perhaps due to the apparent contradictions between the ortho-origin suggested for these gneisses and their geologic and petrographic relations previously discussed. This ortho-origin was suggested mainly on account of the (granitic?) appearance and composition of some of the constituting gneiss varieties of this complex; which kind of ortho-origin and how it was formed, was no further explained.

EXNER (1953), in an attempt to pave the road to an approach to this problem, gave the following suggestions for the different possibilities for the modes of origin of these gneisses:

1. that the Spitzer gneiss is a magmatic intrusion in the neighbouring para-rock series;

2. that the Spitzer gneisses are but a granitised part of the para-rock series; or

3. that the para-rock series have been deposited over the Spitzer gneisses, here they have been later on folded together and been deformed through the same orogeny.

It is the author's opinion, that any origin suggested for the Dobra gneisses, should satisfactorily explain the following geologic and petrographic features:

1. the petrography and chemical composition of the different gneiss varieties;

2. their geochemical characteristics and the probable existence of an ortho-gneiss variety, together with typical sillimanite-, muscovite- and biotite-rich para-gneiss varieties;

3. the characteristics of their zircons, that lead to the final conclusion, that "The Dobra gneisses proved to be the metamorphic product of a heterogeneous mixture of ortho- and para-materials";

4. the coexisting intercalations of undisturbed amphibolites, with definite sharp contacts; besides, they are concordant with the enclosing gneisses and simultaneously folded with them;

5. the frequent occurrences of considerable marble bands, surrounded by typical paragneisses and schists, that follow the general trend of both Dobra- and Krumau-complexes.

6. the intimate geologic relation between the Krumau-complex and the Dobra-complex demonstrated by the gradual transition between them and the great similarity in the geologic trends and structures.

The mineral assemblage of our gneisses is composed of quartz, oligoclase-andesine and biotite, commonly accompanied by accessory sphene, muscovite, chlorite, apatite, (garnet and sillimanite) magnetite and zircon. The properties of the dominant minerals are remarkably constant, except in the case of biotite, where the greenish variety is observed only in some gneiss varieties near the contact zone with the Krumau-complex (samples 73, 80, 85, and 89). TILLY (1926), HARKER (1932), GILLULY (1936), AMBROSE (1936) and ENGEL & ENGEL (1960) noted, that the evolution of first greenish then brown biotite in successively more highly metamorphosed graywackes, is a gradual product during the dynamothermal "regional" metamorphism. Also SUGY (1935) described a reddish brown and a greenish brown biotite in metasediments and migmatites of north eastern Japan. He noted that the reddish biotite is the more highly metamorphosed facies with oligoclase and some garnet, where a mutual relation of metasediments and granitic components were instrumental in the evolution of the reddish biotite as well as garnet and sillimanite. Commonly the change in colour of metamorphic biotites from greenish brown to reddish brown is thought to reflect an increase in FeO.

The chemical analyses represented by Table 5 are remarkably similar in many aspects. However a main difference can be noticed concerning the values of the alkalies; while the Na_2O values of the authors analyses are 5.5% and 4.7%, that of the third analysis represented by EXNER (1953) is only 2.84%; also the K_2O values show a reverse relation being 1.85% and 1.58% for the first two and 5.84% for the third. This might be due to the fact that the analysed sample of EXNER is an augen gneiss variety (it is as such described by him) rich in Knaf augen. This naturally results in a remarkable difference in the Na_2O/K_2O ratios being 2.97 in the first two and only 0.59 in the third.

The question arises now whether the ratio Na_2O/K_2O may reflect a large scale abstraction of K_2O from the normal gneiss (Type I B) which should have been fixed in the form of Knaf augen in Type I A, or conversely the addition of soda after diagenesis and/or during metamorphism.

Table 5.

	1	2	3	4	5	6	7	8	9	10	11
SiO_2	71.38	72.43	71.90	72.31	66.82	71.72	69.69	65.95	64.20	75.50	70.72
Al_2O_3	15.98	15.55	15.76	14.69	18.83	13.23	13.53	13.58	14.10	11.40	12.79
FeO	1.85	1.16	1.50	1.47	2.87	3.58		4.18			1.25
Fe_2O_3	0.49	0.81	0.65	0.66	2.58	0.30	0.74	1.94	1.00	2.40	0.22
MnO	0.06	0.03	0.04	0.04			0.10				0.73
TiO_2	0.29	0.25	0.27	0.24		0.35	0.40	0.55	0.50		0.26
CaO	1.97	2.53	2.25	1.99	2.76	1.80	2.00	3.10	3.50	1.60	1.20
MgO	0.66	0.54	0.60	0.53	0.67	1.81	1.95	1.88	2.90	0.10	0.34
Na_2O_2	5.50	4.70	5.10	4.35	2.11	2.72	4.21	3.73	3.40	2.00	3.80
K_2O	1.85	1.58	1.64	3.09	1.34	1.29	1.71	2.01	2.00	5.60	3.50
H_2O-	0.10	0.12	0.11	0.13		0.15	0.62		0.10		1.52
					2.13			3.13		0.60	
H_2O+	0.42	0.45	0.43	0.63		2.53	2.08		2.10		2.75
	100.55	100.15	100.3	100.13							99.08

1, 2 and 3. The analysed samples by KHAFFAGY with their avarage respectively.
4. The avarage of the three analysed Dobra gneisses.
5. Avarage of five graywackes, Balclutha, New Zealand (TURNER & VERHOOGEN, 1960).
6. Avarage of three graywackes (TALIAFERRO, 1943).
7. Fresh Franciscan graywackes (TURNER & VERHOOGEN, 1960).
8. Avarage of two analyses of graywackes, Marlborough, New Zealand (after J. HENDERSON, 1934/35).
9. Avarage of 11 graywackes of widely separated age and locality (after PETTIJOHN, 1957).

10. The avarage Arkose compositions (After PETTIJOHN, 1957).
11. Avarage of 20 lithoidal welded and unwelded tuffs, rhyolitic and latitic flows (after H. R. CORNWALL, 1962).

It would seem possible, to conclude that the parent rock of the gneisses was a sediment derived in large proportions from sources rich in pyrolastics with or without graywackes, very often interlayered with considerable submarine acidic flows. The environment of deposition might have been exposed to some interrupting tectonical phases, involving also the deposition of limestones, from which marbles may have been produced.

The wohle series was simultaneously and regularly intercalated by thin basic flows and sills, responsible for the amphibolite formation, which possibly had its source in the east.

After the Dobra complex had been formed in this manner, gradual changes in the basin of deposition should have taken place, preparing for the deposition of the typical sedimentary facies, that covered the complex and from which the Krumau complex should have been derived (the pararock series). The varying nature of the paragneisses and schists, marbles and quartzites, which form this complex with its rapid lithological changes are infered to unstable conditions of deposition, under which great varieties of sediments rapidly, sometimes as intercalations must have been deposited. Sediments that could be responsible for the formation of this great variety of pararocks, could have been argillaceous sandstones, clays, marls, arkoses and pure sandstones, together with limestones, possibly intercalating each other.

The flourishing of amphibolites with their gradual increase in thickness towards east indicates, that the basic volcanic activities were not interrupted, but increased in intensity and frequency, thus producing more thick and more frequent flows and falls of basic material, which simultaneously interlayered the sedimentary sequence.

Both complexes, the Dobra-complex and the Krumau-complex will after deposition have undergone simultaneously the same events of regional metamorphism with the same degree of folding and deformation, through one and the same orogeny. This resulted in the major folding of them in the form of the now existing major syncline, whose western limb is represented by the Krumau-complex. The eastern limb of this major syncline exists east of the Gföhler gneiss body, which is supposed to be emplaced along its main axis.

That the Spitzer gneisses do not outcrop in the eastern limb of the Krumau-complex, may suggest, that this syncline is not symmetric or that the Spitzer gneisses are tapering and thinning out under the Krumau-complex in this direction.

Later on the Rastenberger pluton should have been emplaced at the western end of the Dobra-complex (Spitzer Gneisses) thus leading to the present state of the area studied.

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