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THE OCCURRENCE OF LOW PRESSURE METAMORPHISM IN THE PRECAMBRIAN OF THE MIDDLE-EAST AND NORTH EAST AFRICA

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ABSTRACT

The occurrence of metamorphic minerals, like andalusite and cordierite indicating formation under low pressures, is described from the Elat area in Israel and the Sinai Precambrian. The study of the timing of metamorphism with regard to folding phases has shown that the metamorphism is progressive in time. The possibility that the Precambrian of the Arabian shield belongs to a Hercynotype orogenic belt is discussed.

METAMORPHISM IN THE ELAT BLOCK ISRAEL

The Elat block forms part of the Precambrian in the southernmost extremity of Israel; it is bordered to the east by the Dead Sea Rift and the Gulf of Aqaba, to the west by a narrow slice of Precambrian rocks referred to as the Rhoded block which on its western side is overlain by a sequence of Cambrian Nubian sandstones and younger Mesozoic sediments. Southwards, the Elat area extends uninterruptedly as a more or less narrow belt parallel to the Gulf of Aqaba into the Precambrian rocks of the Sinai Peninsula.

The Elat block is characterized in particular by the abundance of high-grade regionally metamorphosed pelitic sediments, acid and intermediate intrusives and to a lesser extent metamorphosed basic igneous rocks. Migmatites and gneisses which do occur in the Rhoded area become more abundant in the Sinai portion of the Elat area, generally at the expense of pelitic schists. The structural and metamorphic history of these rocks and the chronological succession of events is complex, showing polyphase folding and plurifacial metamorphism. In spite of the fact that the structural and metamorphic history of these rocks are strongly interwoven, it is nevertheless not the purpose of this paper to discuss these aspects of the geology in detail. On the other hand, it is the intention of the writers to make a general statement and preliminary description of the widespread occurrence of porphyroblastic minerals, indicative of metamorphism under low pressures in this area and in some adjoining areas in Arabia and Sinai.

At least four distinct phases of folding can be identified in the area, each characterized by its own style, trend and associated planar and linear structures. Porphyroblasts of garnet, staurolite, andalusite, and cordierite began to grow mainly during the interkinematic period between the first and second phase and reached their maximum growth during the second period of folding. Garnets began to grow already during the first phase, and the youngest cordierites crystallized between the third and fourth phase of folding.

Recrystallization continued at least until the end of the third phase, as shown by polygonal arcs of micas in microfolds, whereas all fourth phase microfolds show deformed micas in the foldhinges. The microstructural history of the rocks was unraveled by comparing the internal schistosity of the porphyro-

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blasts with the external schistosity of the matrix (see Z w a r t, 1963).

Four distinct succeeding zones of metamorphism have been identified in the pelitic schists:

1) Biotite zone, characterized by the occurrence of biotite and muscovite, without aluminium silicates.
2) Garnet zone.
3) Staurolite zone, with accessory garnet.
4) Cordierite zone, with accessory andalusite, staurolite and garnet.

A fifth andalusite zone may be present, but the andalusite isograd was not clearly defined due to the narrowness of the metamorphic zones in this area. Fibrous sillimanite is locally present, but it can generally be related to late kinematic intrusive granites.

The metamorphism is plurifacial (D e R o e v e r and N i j h u i s, 1964) as the rocks clearly have gone through a number of successive facies or subfacies. This could be deduced from relics or inclusions of certain minerals in other minerals. For example unaltered garnet may occur in staurolite; staurolite and garnet may be included in cordierite. As the reverse relation has not been found one may conclude that the metamorphism was progressive, and that the higher grade minerals were formed later than the lower grade ones, except for a late retrograde metamorphism which took place mainly in the cordierite zone. Here perfect pseudomorphs of chlorite and muscovite after cordierite and staurolite are abundant.

The general trend of the isograds is WNW-ESE and this corresponds roughly with the trend of the regional axial plane foliation, S_1. However, the cordierite zone, lying beyond the cordierite isograd, is parallel to the trace of the axial plane of a major F_2 fold in the area. Apparently this second phase of folding may have some relation with the shape of the thermal dome and the distribution of the regional metamorphic zoning.

The following features of the metamorphism of the Elat block are of importance:

1) Because of the thinness of the metamorphic zones of the highest facies (200-300 metres) a high temperature gradient probably was present.
2) Granites are abundant whereas mafic and ultramafic rocks are rare or absent.
3) Migmatic rocks are present in a narrow aureole accompanying the early synkinematic granites.
4) The nature of the plurifacial metamorphism indicates a rise of temperature during the metamorphic period.

There are several similarities between the metamorphism in the Elat area and in the Pyrenees described by Z w a r t (1963). The Pyrenean low pressure metamorphism is found, according to this author, in large parts of the Hercynian orogenic belt of Europe. These relations have led to the distinction of Hercynotype orogens, which are particularly important in the Precambrian. In view of the presence of low pressure metamorphism in the Elat area, one may consider that this area forms part of a Hercynotype orogenic belt. For this reason our survey of metamorphic rocks has been extended to a larger part of the Arabian shield.

OCCURRENCES OF LOW PRESSURE MINERALS IN THE PRECAMBRIAN OF SINAI AND EGYPT

The presence of minerals indicative of low pressure metamorphism like andalusite and cordierite is reported by S c h ü r m a n n (1966, p. 74-77, 201-206) from the central and northern part of the Eastern Desert of Egypt and in the southeastern part of the Sinai Peninsula from the Wadi Kyd region. These findings can be attributed to the reconnaissance mapping of Hume and Barron during the late part of the 19th and early 20th century. These minerals occur in the Shadli series of metasediments. The first author had the opportunity to study the geology of these and related rocks in the Sinai Peninsula in some detail, and following additional discoveries of major occurrences of these porphyroblasts arrived at conclusions which differ somewhat from the classical concepts of Schürmann and others.

The so-called Shadli series in Sinai recognized by the first author, consists of a thick section of metasedimentary and metavolcanic rocks which were metamorphosed in the greenschist and amphibolite facies. Metamorphosed quartzites, semipelites and marble with calc-silicates are most abundant in the Wadi Feirran-Solaf region; high grade pelitic schists, amphibolites, slaty and phyllitic metavolcanics, pyroclastics and meta-conglomerates (possibly equivalent

to the Dokhan series showing coeval folding and metamorphism with the Shadli series) in the Wadi Kyd region, and metamorphosed acid and basic flows, ignimbrites, phyllites, quartzites and slates are characteristic of the Wadi Sa'al-Zrara region (newly discovered metamorphic belt) in the northernmost portion of the Sinai Precambrian (fig. 1). The Sinai metamorphics can therefore be subdivided into three principal regions or belts each with its own particular lithological and structural characteristics. The most widespread and best exposed Wadi Kyd region exhibits also the best and most extensive exposures of porphyroblastic minerals typical for low pressure metamorphism.

Based on recent geological mapping of the mentioned areas the first author came to the following, in part preliminary, conclusions.

The Shadli rocks overlie a highly metamorphosed (katazonal) basement complex of acid and intermediate gneisses, migmatitites, anatectic diorites and gneissified lower portions of the Shadli series, all of which are generally referred to as the Mitiq series. The contact between the supracrustal Shadli and infracrustal Mitiq series generally consists of a zone of migmatization, anatexis, and where exposed, of progressive metamorphism.

Following the first metamorphism of the basement rocks, the supracrustal series were deposited unconformably on an already existing metamorphic basement (now represented as highly tectonized relicts and metamorphic pebbles of an older generation in metaconglomerates in the supracrustals. Subsequent magmatic activity followed by regional metamorphism, reactivation and remobilization obliterated any unconformity present.

The latest penetrative structures are contemporaneous in all the rocks present, and furthermore at least two additional phases of folding have affected both the infra- and supracrustal series simultaneously.

It is of particular interest to note here that at least part of the so-called basement (or "fundamental") Mitiq orthogneisses show intrusive relationships with the Shadli rocks, a fact questioned by Hume and rejected by Schürmann. This fact may have some direct bearing on erratic radiometric ages in this area and in Egypt.

In the Wadi Kyd region of southeastern Sinai, the general transition from the upper segments of the supracrustal to the lower segments near the migmatite front consists of slaty and phyllitic metavolcanics, to a conspicuous section of garnet, staurolite and andalusite phyllites and schists, cordierite-andalusite schists with or without garnet, then across a strongly tectonized and gneissified zone into the infrastructure. The alumino-silicates form crystals locally more than 10 cm long with some beds containing up to 40% of these porphyroblasts. The cordierites and andalusites show a strongly linear arrangement with the lineation parallel to the regional strike. In some beds, however, the andalusites and cordierites have been rotated so that their long axes define rather clearly a new lineation which transects the main regional trend. Many of the andalusites and some of the cordierites and staurolites show clearly synkinematic growth as evidenced by s-shaped trails of inclusions. Multiphase growth can be seen in certain zoned andalusites and staurolites.

Similar to the Elat area, the metamorphism here is also plurifacial and progressive, with abundant, probably stable relicts of garnet in andalusite and andalusite in cordierite.

Retrograde metamorphism into the greenschist facies is conspicuous, but particularly so along certain major N-S trending faults which can generally be related to the Red Sea Rift movements (small grabens containing Lower Cambrian to Cretaceous sedimentary relicts are situated in these faults). In this area, all the andalusites as well as the cordierites have been completely altered to quartz, feldspar and muscovite.

CONTACT METAMORPHISM

There is no increase in the occurrence of porphyroblasts close to granite intrusions, in fact the most extensive cordierite and andalusite beds near the Wadi Kyd region, are rather far removed from any intrusive rocks (in the order of 15 km). On the other hand some cordierite with rare sillimanite-bearing beds were found close to synkinematic granite plutons and these may perhaps be attributed to contact metamorphism.

In this case, incipiently crystallized porphyroblasts of cordierite and retrograde pseudomorphs of quartz-mica clusters after cordierite have been found in low grade phyllites and hornfelses rather far removed from the transition into the infrastructure. These porphyroblasts sometimes show an irregular hornfelsic internal schistosity, but most often the internal

schistosity is planar, showing that some of these grew in already finely schistose rocks. The external schistosity shows coarser crystalline, occasionally porphyroblastic biotites, which are occasionally deflected around rotated crystals of cordierite.

These cordierites show certain contact metamorphic characteristics. Static growth is evident and lower grade minerals like andalusite, staurolite and garnet, which are present in the zone of progressive regional metamorphism, are absent. As the higher grade minerals were formed independently and without the growth of lower grade ones there is no evidence of progressive metamorphism here. Contact metasomatic sillimanite is sometimes present together with cordierite.

In summary therefore, the supracrustal series (Shadli) shows extensive development of aluminium-silicates which in major part must be attributed to regional metamorphism and not, as has been reported, due to contact metamorphism by young Gattarian intrusives.

Contact and regional metamorphism in this area produced similar metamorphic facies series although in the contact rocks garnet and andalusite have not been found.

Similar occurrences of low pressure alumino-silicates reported from the Eastern Desert of Egypt may show the same or similar histories, but as these were not examined no definite statement can be made at this stage.

Like in the Elat area, granites are by far the predominant rock type in the Sinai Precambrian. Ultramafic rocks are rare with the exception of two conspicuous serpentine belts in the central and southern Eastern Desert of Egypt. Kyanite has not been found and in contrast to the Elat rocks staurolite is rare, almandine garnets are present but not widespread, and cordierite and andalusite are the most abundant aluminium-silicates. It therefore seems that the Sinai metamorphics formed at somewhat higher temperature and lower operating pressures than the rocks of the Elat area. The general grade of metamorphism in the Sinai supracrustals is also somewhat lower with rocks with a phyllitic matrix predominant and coarsely crystalline biotite schists only locally present near the katazone transition area.

AGE OF METAMORPHISM

A detailed analysis related to the problems of the age of metamorphism in the above portion of the Arabo-Nubian Massif is beyond the scope and purpose of this paper; therefore only a brief discussion with regard to the many problems involved is made. Although our mapping of the Sinai Precambrian is at an advanced stage the detailed structural, petrographic and petrochemical studies are at an early stage of preparation and radiometric dating has as yet not begun. As such, definite commitments with regard to the age of metamorphism in this area can not be made at this stage of the work.

Extensive and somewhat detailed correlations between the Precambrian rocks of Egypt, Sinai and Elat with those of Arabia and southeast Africa have been made by Schürmann, Brown and Jackson and others (see S c h ü r m a n n, 1961 and 1966; B r o w n and J a c k s o n, 1960). The prevalent opinion is that the Precambrian rocks of the Red Sea area are all part of the Arabian Shield which builds the youngest consolidated rim around the old African cratonic areas, and the three massifs, Arabo-Nubian, Arabian-Somali, and the Sabean-Block should be considered as one entity (S c h ü r m a n n, 1961).

ISOTOPIC AGE DETERMINATIONS IN THE PRECAMBRIAN OF EGYPT AND SINAI

A somewhat detailed discussion of the radiometric age results and list of dates may be found in S c h ü r m a n n (1966). The following facts stand out:

K-Ar ages range between 356-666 m.y. whereas Sr-Rb ages range between 524-590 m.y. In general it may be said that most of the ages, except where locally showing a large spread, are concordant and show an average age of 550 m.y. for most of the specimens obtained in Egypt and Sinai. On the other hand, certain formations equivalent to the Mitiq and Shadli in Saudi Arabia show a mean age of about 1000 m.y. A discordance of up to 500 m.y. therefore exists especially with regard to the oldest formations (assuming that correlations across the Red Sea into S. Arabia are valid).

The mean age of 550 m.y. is equivalent to the Middle Cambrian whereas the youngest ages are as low as Middle Devonian. These ages can of course be

immediately rejected since the Lower Cambrian transgression has been clearly demonstrated both in Elat and Sinai; furthermore no orogenic movements as such followed this transgression.

It must be concluded therefore that from the present state of our knowledge of the radiometric ages from the Precambrian of Egypt and Sinai, these may not be used as a means of correlating this orogenic belt with those of the late orogens in the north, central and east Africa, especially so, since the Cambrian is not identified in east Africa.

The Rb-Sr ages of Brown in Saudi Arabia (in S c h ü r m a n n, 1966, p. 213) especially the rare 800 to 1050 m.y. ages must be considered as being much more representative of the age of metamorphism of this orogen. This view has been presented by S c h ü r m a n n (1966, p. 217) where he states that he believes that the Shadli series has an age of about 1000 m.y. and that the rocks with an age of 550 m.y. represent young Precambrian rocks rejuvenated during the Lower Cambrian epeirogeny.

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