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On the occurrence and genesis of mud zircon in the radioactive psammitic gneiss of Wadi Nugrus, Eastern Desert, Egypt

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ABSTRACT

A unique type of zircon occurs in the radioactive part of the psammitic gneiss which is the basal unit of the metamorphic rock succession in the Wadi Nugrus area, Eastern Desert of Egypt. This radioactive part is enriched in Zr, Nb, Sn and Pb and depleted in Ti, in comparison to the non-radioactive part of the rock. This enrichment is due to metasomatic alteration which acted on the rock and led to the concentration of the relatively rare elements in the upper part.

Zircon particles in the radioactive part show pronounced increase in grain size, overgrowth, outgrowth, crystal aggregation and multiple growth. These features resulted from the addition of zirconium transported by the metasomatising agents from the underlying part of the rock, on to both the pre-existing zircon and the newly formed crystals. The most abundant habit of zircon shows well-developed bipyramidal faces at the expense of the prismatic faces which are generally reduced or absent.

In contrast, zircon in the non-radioactive gneiss (lower part) is of the prismatic bipyramidal type but is corroded and bleached, reflecting the effect of dissolution by the metasomatising agents. This indicates that zircon was leached out from this part of the rock and added to the upper part by the rising metasomatic agents. The bearing of this study on the genesis of the psammitic gneiss is discussed.

INTRODUCTION

The geology and geochemistry of the psammitic gneiss of Wadi Nugrus were studied by Hassan (1964, 1973). This gneiss forms the base unit of the metamorphic rock succession in the area. This succession is formed (from bottom upwards) of psammitic gneiss, schist and hornblend gneiss. They form a north-west trending anticline. Psammitic gneiss occupies the core of this fold structure, and was drilled perpendicular to the foliation to a depth of about 167 m below wadi level without reaching its bottom.

The psammitic gneiss is mainly composed of quartz, K-feldspar (orthoclase, microcline and perthite) and oligoclase with variable amounts of biotite. The rock is characterised by a large number of accessory minerals including zircon, thorite, fluorite, apatite, magnetite, hematite and opaque sulphides. The zircon can reach up to 0·2% of the rock (Hassan 1964; El-Gemmizi 1979). The uppermost 50 m of this gneiss has abnormally high content of Zr, Nb, Sn and Pb as well as abnormally low content of

Ti (Hassan 1973). It also produces a pronounced radioactive anomaly (Krs *et al.* 1973). The high content of zirconium is correlated with the presence of the strong radioactivity of the gneiss (Hassan, personal communication).

El-Gemmizi (1979) found that zircon constitutes one of the major accessory minerals in a composite sample of the gneiss. He also noticed great variation in the nature and habit of the zircon which could not be explained because of the composite nature of the sample. The present paper reports on the occurrence of the various types of zircon and other accessory minerals in gneiss. It constitutes part of a more comprehensive study of all the accessory minerals, based on several systematic samples which represent both the radioactive and non-radioactive parts of gneiss.

HEAVY MINERALS IN THE PSAMMITIC GNEISS

A composite sample from each of the radioactive and the non-radioactive parts of the psammitic gneiss was obtained for the estimation of the heavy minerals content. Crushing followed by wet-tabling as well as magnetic and electrostatic techniques of mineral separation were used to obtain pure mineral fraction.

In the radioactive gneiss, zircon, thorium-bearing minerals, columbite and fluorite are the major heavy minerals, while magnetite, cassiterite, garnet, some sulphides, apatite, kasolite and hydrated iron oxides are the minor components. On the other hand, in the non-radioactive gneiss, magnetite and pyrite are the major heavy minerals while zircon, garnet and apatite are the minor components. Zircon as well as some other accessory minerals show significant differences in habit and other characteristics between both types of the psammitic gneiss.

Zircon in the radioactive gneiss

The distinctive feature of zircon in this rock is its habit. The most common habit is the bipyramidal form combined with extremely short prisms which are absent in most cases. The crystals are, therefore, invariably short and more or less equidimensional and possess square cross sections. They are commonly pale to deep brown in colour and generally opaque, although some are sub-translucent. The surfaces of the crystals are generally rough and dull. Some crystals developed basal pinacoid forms (Plate 1, A&B).

Single well-formed crystals show three crystal forms which may be combined in one crystal or may be separated. In all of them, the intercept on the two crystallographic axes is shorter than the two horizontal axes. The first crystal form is the bipyramidal {hhl}, the second and third are the first- and second-order prisms (Plate 1, C&D). In some crystals the faces and edges show slight curvature, especially the pyramidal faces (Plate 1, E). Indentation and inward embayment of the faces are also common. Due to the unequal growth of the crystal faces, several variations of this habit are present. The inequality of the pyramidal faces may make the crystals appear flattened (Plate 1, F) or elongated with rectangular cross (Plate 1, B). The presence of second-order prisms with different dimensions together with variation of the pyramidal faces and very short first-order prisms yield various crystal shapes (Plate 1, D). This characteristic form was first called mud zircon by Williams *et al.* (1956).

Single grains of the mud zircon usually show in most cases secondary growths, multiple growth and fused aggregations. A crystal may show one or more outgrowths

A B C D E F

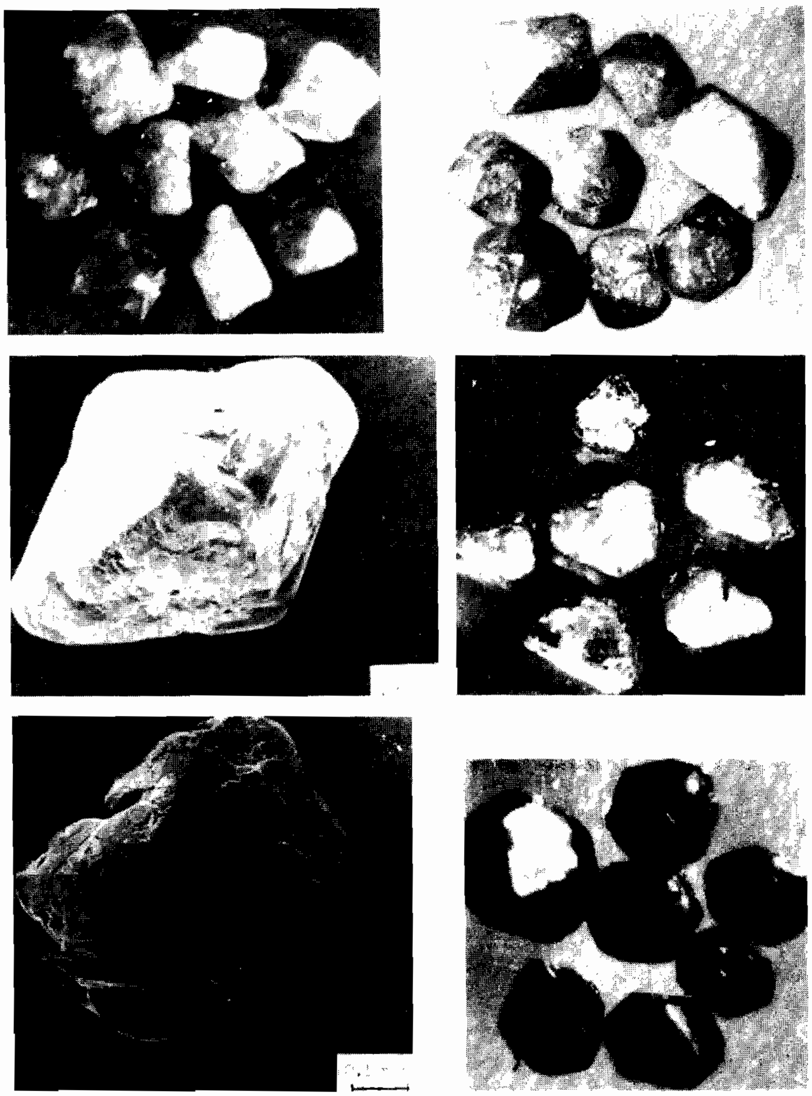

Plate 1. (A) Mud zircon crystals with equal pyramidal faces; some have basal pinacoid forms (lower left-hand corner) × 50. (B) Mud zircon crystals with various pyramidal faces, thus yielding equidimensional (highest), rectangular (the extreme right hand) and other crystals × 50. (C) SEM image of a zircon crystal with bipyramidal tetrahedron {hhl} and second-order prism. (D) Mud zircon crystals with various second-order prisms; some have a very short first-order prism (the two in the lower left-hand corner) × 50. (E) SEM image showing the curved edges of the pyramidal faces and the inward embayment of the faces. (F) Flattened mud zircon × 50.

which may be minute or big (Plate 2, A). On the other hand, overgrowth gives the crystals ill-defined outlines and surfaces (Plate 2, C). Fused aggregation yields non-defined shapes, while in some cases aggregation produces the characteristic habit (Plate 2, D). A grain of mud zircon may be composed of two crystals grown together simulating twinning (Plate 2, E).

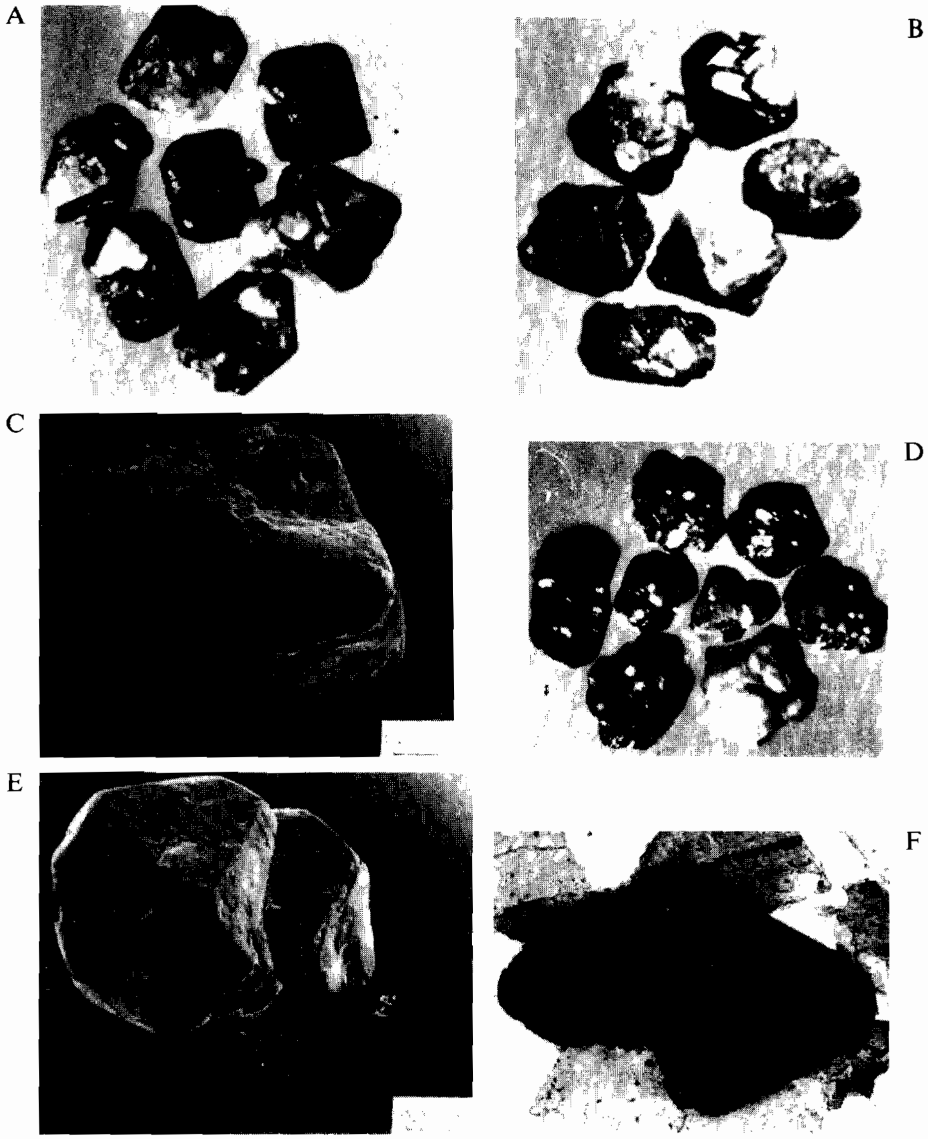

Plate 2. (A) Mud zircon grains with various outgrowths; some of them are lighter in colour than the parent zircon × 50. (B) Mud zircon crystals with various modes of overgrowths on the pyramidal faces × 50. (C) SEM image of mud zircon crystal with multiple pyramidal terminations. (D) Fused aggregations of mud zircon × 50. (E) SEM image showing a zircon grain with double growth of two mud zircon crystals. (F) Thin section image of a mud zircon with one of the pyramidal faces missing. P.P. × 200.

In thin section, mud zircon appears dull greyish brown in colour. Commonly, a crystal may show a well-developed euhederal shape except that one of the pyramidal faces is missing (Plate 2, F). Most grains are zoned due to overgrowth especially in their outer parts (Plate 3, A). Sieve texture is developed in some zircon crystals due to inclusions of other minerals like feldspar and biotite (Plate 3, B).

Plate 3. (A) Thin section image of a zircon crystal with well-developed pyramidal faces and much reduced prismatic faces. Note the inclusions and zoning. P.P. × 500. (B) Thin-section image of a mud zircon crystal with poikilitic texture. The inclusions are biotite (grey) and quartz (white). P.P. × 300. (C) Various modes of columbite inclusions in mud zircon, some being entirely black due to the condensed minute inclusions of columbite × 50.

Inclusions of columbite seem to be the most common type in mud zircon. Several modes of this inclusion were detected (Plate 3, C). It may be single minute or big or numerous minute in a zonal distribution pattern especially in the outer zone, causing a black colouration of the zircon grain. In polished section, columbite inclusions in zircon were identified as white coloured irregular bodies in a grey background of zircon (Plate 4, A). The same peculiar habit of zircon was recorded by Mockie (1931) in

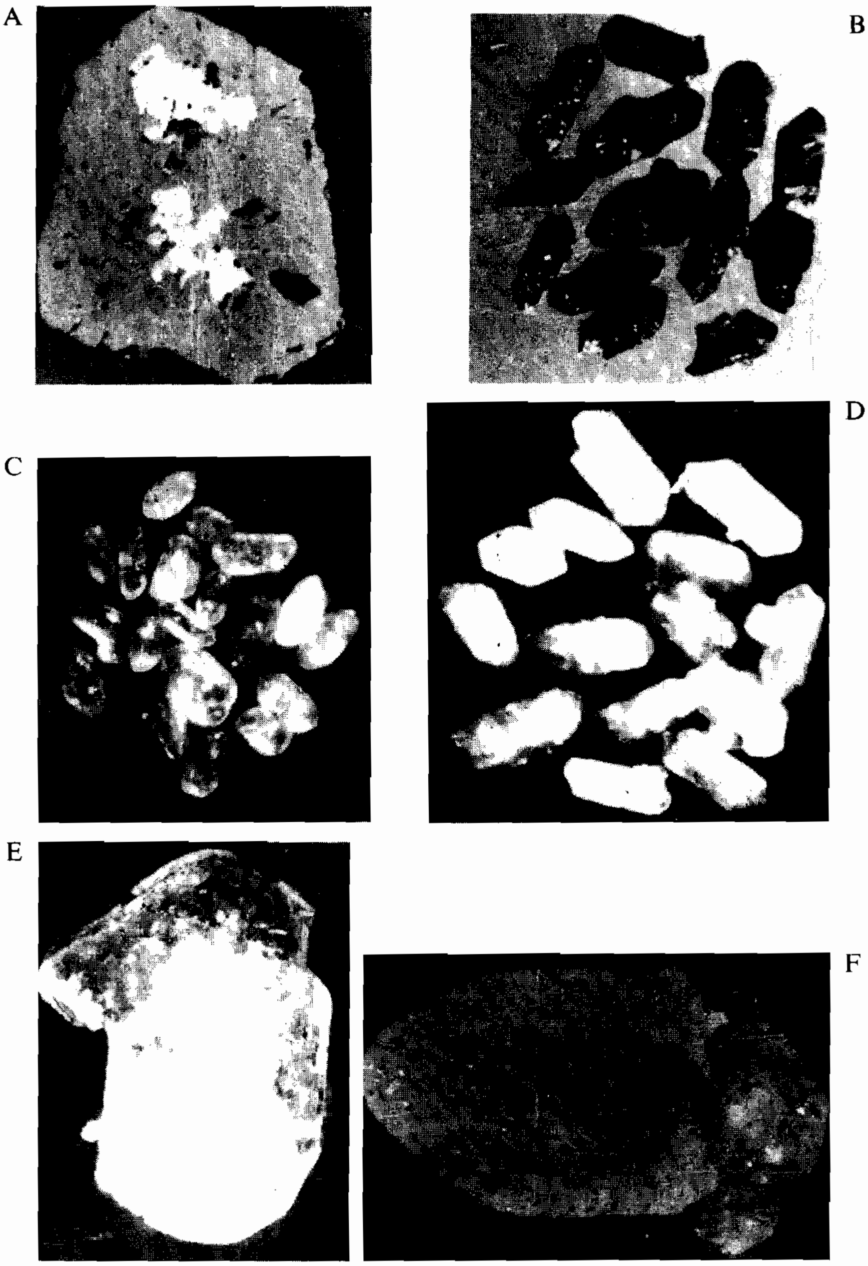

Plate 4. (A) Polished surface image of a zircon crystal with interior irregular columbite inclusions. R.L. × 200. (B) Recrystallised zircon with small outgrowth; some zircon grains are corroded × 75. (C) Detrital zircon × 75. (D) Corroded and bleached recrystallised and detrital zircon × 75. (E) Early stage of formation of mud zircon from a detrital zircon by addition of new zircon materials on the pyramidal faces × 200. (F) Early stage of replacement of a detrital zircon grain by numerous mud crystals × 200.

Scotland granite and by Williams *et al.* (1956) in the Jos Plateau (Buruku Complex) of Nigeria.

In addition to the mud zircon which constitutes about 97% of the zircon in the radioactive psammitic gneiss, the recrystallised and detrital zircon forms the other 3%. The last two forms are very similar to the zircon in the non-radioactive gneiss.

Zircon in the non-radioactive gneiss

In the lower non-radioactive part of the gneiss, zircon is mainly of the detrital and recrystallised types (Plate 4, B&C). No mud zircon has been observed in this gneiss. The most distinctive feature of these zircons is the pale greyish-pink colour and the low lustre, as well as the extensive corroded and bleached appearance of the grains (Plate 4, B&D). They are commonly free from inclusions and other features exhibited by the mud zircon in the upper part of the psammitic gneiss except a few outgrowths characterising zircon in metamorphic rocks (Butterfield 1936; Poldervaart 1950; Chowdhary 1971; Bowes *et al.*, 1976).

GENESIS OF THE MUD ZIRCON

The general morphological character of zircon can be used as evidence of the origin of the host rock, whether igneous, detrital, metamorphic or metasomatic (Trueman 1912; Butterfield 1936; Poldervaart 1950; Wyatt 1954; Poldervaart & Ecklemann 1955; Verpyke 1961; Dalziel 1963; Chowdhary 1971; Augustithis 1973; Jocelyn & Pidgeon 1974; Bowes *et al.* 1976). The present investigation indicates that zircon in the radioactive gneiss has a much larger grain size and occurs in greater abundance (up to 15 times) as compared to non-radioactive gneiss. The mud zircon is confined to the radioactive psammatic gneiss, while the non-radioactive gneiss contains the recrystallised (metamorphic) and detrital types of zircon. Furthermore, the radioactive gneiss contains a very small amount of very fine-grained detrital and fine-grained recrystallised types of zircon. These features suggest that mud zircon was formed by the metasomatic processes in the radioactive psammitic gneiss.

The excellent positive correlation of mud zircon with signs of metasomatic alteration in the psammitic gneiss is a strong supporting evidence (Hassan 1973). Although this mode of occurrence of zircon is somewhat rare, it was reported by some authors (Mockie 1931; Williams *et al.* 1956). This zircon was formed mainly by dispersed nucleations and growth in the solid state, resulting in zonal and sieve textures. In a few cases, pre-existing minute zircon crystals in the rock acted as nuclei for the newly formed mud type by addition of new materials to the pyramidal faces (Plate 4, E).

The great abundance of zircon as well as the very high value of zirconium in the radioactive gneiss (more than 300 p.p.m. (Hassan 1973)) indicate that zirconium was introduced into the rock during metasomatism. The occurrence of the corroded zircon in the deep non-radioactive gneiss may provide evidence that zirconium was transported by the rising metasomatising agents which partially dissolved the materials upwards until they were trapped by the overlying schist. The continuous supply of zirconium by the rising metasomatising agents to the upper part led to the crystallisation of the mud zircon followed by the formation of further growth features.

Some mud zircon was formed by the addition of zircon materials to the detrital nuclei or by replacing them (Plate 4, F).

It seems that the crystallisation of zircon by replacement in the solid rock resulted in the form of the mud habit rather than the normal one. Trueman (1912) suggests that the crystallisation of minerals in solid conditions yields a marked development of the faces which have the strongest crystallisation forces. This indicates that the pyramidal faces of zircon are the strongest of all, followed by the second-order prisms and finally the first-order prisms.

CONCLUSION

The present study contributes to the solution of the controversy about the origin of the psammitic gneiss of the Wadi Nugrus–Wadi Sikait area. There were three main views concerning the origin of this rock: it is a localised intrusive granite (Basta & Zaki 1961), a psammitic gneiss with a 50 m thick granite sill at its top (Bugrov *et al.* 1973), or a psammitic gneiss which was metasomatised by emanations from a deep-seated granitic intrusion (Hassan 1973). It has been shown here that:

(1) The whole rock (radioactive and non-radioactive) is a metamorphosed clastic sedimentary unit as indicated by the presence of detrital zircon in both types of the rock.
(2) Zirconium metasomatism has taken place by removal from the lower part of the psammitic gneiss and addition to the upper part without contribution from outside sources.

Abdel Monem & Hurley (1979) dated zircons from the psammitic gneiss of the same locality by U/Pb method and reported a concordia of 1·77 B.Y. They concluded that this is the probable age of the crustal block that supplied the detritus which formed the original sediments. They also gave evidence for notable hydrothermal activity and mineralisation which probably affected the U/Pb systems in zircon. Hashad *et al.* (1981) dated the last hydrothermal event affecting this gneiss to be 600 M.Y. The disturbance of the U/Pb systems in zircons indicates that zircon was opened during the hydrothermal event which supports zirconium metasomatism (Abdel Monem, personal communication).

An interesting outcome of this study is that detrital zircon can withstand the processes of metamorphism and metasomatism of the Egyptian gneisses. Thus, it can be used as a means to differentiate between ortho- and para-gneisses, which is an important tool in solving some problems in the Egyptian Basement, e.g. Meatiq and Hafafit gneisses.

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تواجد الزركون (المد) في صخور النيس الرملي المشع بمنطقة وادي نجروس بالصحراء الشرقية بمصر

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خلاصة

يوجد نوع من الزركون في صخور النيس الرملي المشع ويساهم في درجة النشاط الاشعاعي للصخر . وقد تكون هذا النوع من الزركون نتيجة للتحول الميتاسوماتي الذي تعرض له الصخر الحاوي ، وتشير الدلائل إلى ان نسبة تواجد هذا النوع من الزركون في الجزء العلوي (المشع) من الصخر أعلى بكثير من نسبة تواجده في الجزء السفلي (غير المشع) وان معظم الزركون في الجزء السفلي من النوع العادي ، وقد تعرض للاذابة ونقص حجمه نتيجة لذلك . ولظروف خاصة فان هذا النوع من الزركون (المد) كون بلورات ذات أوجه هرمية جيدة النمو وأوجه منشورية صغيرة أو غير موجودة .

وتدل هذه الدراسة على ان خواص معدن الزركون في الصخور المتحولة يمكن ان تؤخذ كأحد الدلائل الهامة لمعرفة أصل هذه الصخور وما اذا كانت قد تعرضت للتحول الميتاسوماتي .