ZIRCONS AS PROVENANCE INDICATORS

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Abstract

Study of a Scottish granite intruded into Moine "granulites" showed that although most of the granite was magmatic, there was considerable granitization near the contact in some areas. Examination of accessory zircon showed that in the granite it is idiomorphic and in the Moine it is well-rounded. Furthermore zircon from contaminated granite is very elongated, and zircon from granitized Moine is recrystallized and idiomorphic, but quite distinct from that in the granite. It is suggested that this technique may have wider uses in similar studies.

Introduction

In a recent examination of a granitic intrusion and the associated contact relations, a statistical study of the form of zircon provided clear confirmatory evidence of the extent of granitization of the contact rocks adjacent to the instrusion, although the behavior of zircon in this instance, under both regional and thermal metamorphism, was not entirely in agreement with the findings of others (Poldervaart and Von Backstrom, 1950).

The Monadhliath granite,* situated in the Grampian Highlands of Scotland about twenty miles South of Inverness, is approximately circular and covers an area of about thirty-two square miles, and all the evidence indicates that it is mainly a normal intrusive magmatic granite. It is remarkably uniform mineralogically—a quartz-monzonite in which orthoclase is usually slightly more abundant than plagioclase (oligoclase), and biotite is the only ferromagnesian constituent; neither hornblende nor muscovite were found. The texture is usually coarse and non-porphyritic, but finer porphyritic and aplitic types are common in some areas.

The granite cuts metamorphic rocks of the Moine series, which are mainly a monotonous succession of typical Moine "granulites"—uniform massive rocks showing little or no banding or segregation of dark and light constituents. The granulites consist essentially of quartz, orthoclase, oligoclase or andesine, and some biotite. Pelitic schists, found in some areas, frequently contain much garnet, staurolite and sillimanite, and belong to the sillimanite zone (Barrow, 1893); and there are also a few quartzite bands.

Adjacent to the contact the Moines have been recrystallized, with the formation of andalusite and cordierite in the pelitic types; and many transgressive veins and apophyses from the granite cut this contact

* The area will be described in detail in a forthcoming paper.

region. Sometimes extensive granitization accompanies this veining, producing augen-gneisses, banded gneisses, or "granite-looking rocks," depending on the original composition.

The intrusion contains some inclusions of diorite and granodiorite showing varying degrees of modification by the enclosing granite, which is itself contaminated in their vicinity, but contamination of granite by Moine, or inclusion of Moine xenoliths in granite, is very rare—this circumstance is confined to some of the granite apophyses in the Moine near the margin of the granite.

Normal granite and granitized Moine can usually be differentiated with reasonable certainty, but it was thought that a statistical study of the form and elongation of the zircon in these rocks might supply an additional criterion for differentiating between similar-looking types of different origin, since zircon behaves as a highly refractory mineral under conditions of normal metamorphism. Accordingly it was thought that zircon from granitized Moine might show features characteristic of zircon from sediments, in which case it would probably be distinct from zircon in the granite. The refractory behavior of zircon is well known (Harker, 1932, pp. 12, 71), and zircon has been shown to retain a detrital form even in quartzite which has undergone intense thermal metamorphism and metasomatism (Reynolds, 1936), and in rocks which have been subjected to conditions of strong regional metamorphism (Poldervaart and von Backstrom, 1950; McLachlan, 1951). However there is abundant evidence that zircon does not always behave as a refractory mineral; for instance, in the Kakamas area of South Africa Poldervaart and von Backstrom (1950) show that zircon has recrystallized during ultrametamorphism. Again there are several records of authigenic outgrowths on zircon in unmetamorphosed sandstones (Butterfield, 1936; Smithson, 1937; Bond, 1948), and zircon has also been recorded as a pneumatolytic mineral, produced in limestones near the contact with a granite intrusion (Gillson, 1925). Thus much care must be observed in determining the origin of rocks from the form or habit of their zircon.

The possibility that an examination of the zircon would assist in differentiating rock types of different origin was tested by separating the heavy minerals from a variety of rocks and studying the zircon statistically. All the rocks examined contained zircon, sphene and iron ore and garnet and, less commonly, monazite were present in some types. The long axis of each crystal of zircon, and an axis perpendicular to this, were measured with a micrometer eyepiece (in well-rounded crystals the long axis is not necessarily the *c*-axis), and the elongation of each crystal was calculated; error in measurement is about 0.002 mm. Breakage of crystals during crushing constituted a source of error, but broken crystals were easily recognized, were generally those with an elongation greater than 3, and never formed more than about 5% of the zircons present.

The results were represented by plotting the elongation of 200 zircons from each rock on a histogram, and assemblages of different origin could be distinguished easily on these graphs. This method of representation is independent of the size of the grains, but assemblages of similar origin gave similar histograms, even though the average size of the grains varied greatly from rock to rock. As this method only serves to distinguish short zircons (typical of rounded grains from sediments) from long zircons

TABLE 1. TYPE OF ZIRCON

Type	Habit	Nature of faces	Zoning	Color	Alteration
Sedimentary	Well rounded No faces present	—	Absent	Clear. Usually colorless	Fresh
Igneous	Idiomorphic; dominant forms: {110}, {111}; small {100}, {311}; rare {101}	Rather dull and pitted	Usually present	Cloudy. Colorless or pale mauve	Metamict zones common, often with reddish stain
Contamination	Idiomorphic; very long. Dominant forms: {110}, {111}; others rare	Smooth	Usually present	Usually clear and colorless	Usually fresh
Recrystallized	Idiomorphic; dominant forms: {100}, {110}, {311}; small {331}, {111}, {101}; rare {001}	Perfectly smooth and brilliant	Absent	Clear. Usually colorless	Fresh

(typical of idiomorphic grains from igneous rocks), it must be used with caution, since:

(1). In many sediments the majority of zircons are idiomorphic, so would give a histogram of "igneous" type.

(2). In some igneous rocks the zircons may be very short, although they are idiomorphic—this is the case particularly if {001} is present, or if the prism zone is short and the pyramidal faces are rather flat; a histogram for such assemblages would be similar to one for well-rounded grains.

Because of these difficulties a careful examination of the appearance of the grains must accompany a statistical study of the elongation of zircon. In the present study it was found that zircon from different rocks could be divided into four types, which are named according to their typical environment (Table 1).

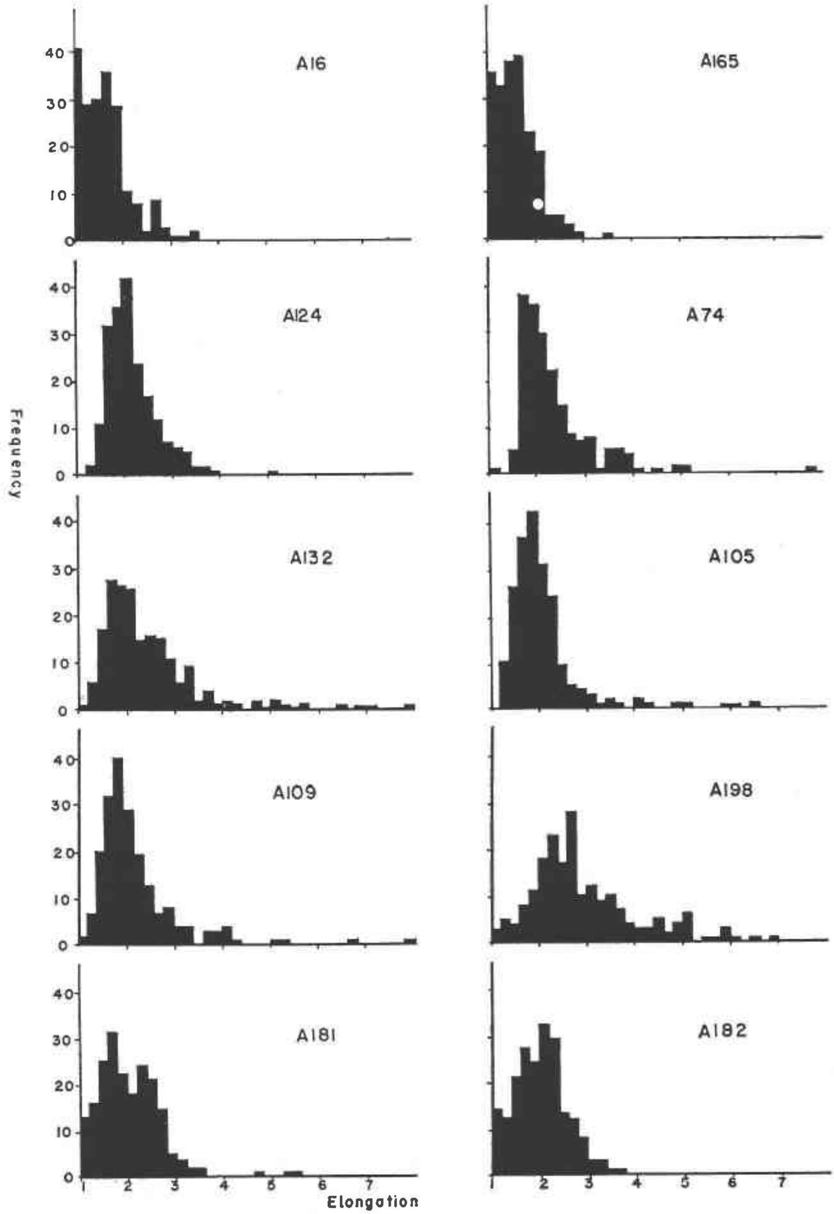

Fig. 1. Frequency-elongation histograms of zircons.

Results

Zircon was examined from typical Moine types; granite and aplite; xenoliths; contaminated granite; and granitized Moine. The zircon from each of these types showed differences as follows:

Moine schists

Zircon from a typical Moine "granulite" (*A16*)* and a fairly pure quartzite (*A165*) was examined. All the zircon was of "sedimentary" type, and the histograms (Fig. 1) show the very high degree of rounding; the only essential difference between the two assemblages is the size of the grains, for in the quartzite they are 0.06–0.35 mm. long, and in the granulite they are 0.02–0.14 mm. The larger grains in the quartzite are to be expected in a rock which was probably much coarser-grained originally.

An interesting feature is the high degree of rounding of small crystals, since none showed any trace of crystal faces. It is a general observation that grains below a certain size are not effectively rounded by water action, and Hutton (1952) found that crystals smaller than about 60 microns show little if any rounding when they occur in beach sands, so the high degree of rounding in the present case would seem to be due to some factor other than corrasion in water. If this high degree of rounding is a primary feature, it may be due to extensive wind transportation, or possibly the zircon originally crystallized as well-rounded grains; however, the absence of any grains showing crystal faces makes the latter suggestion unlikely. Other possibilities would be either solution or mechanical granulation during metamorphism. Solution seems unlikely, and in the few other areas of intensely metamorphosed sediments where zircon has been studied a mixed assemblage of rounded and idiomorphic crystals is found; and if the rounding were to be attributed to some mechanical cause, then some traces of broken crystals or partially crushed augen would be expected; these were not observed. Accordingly, wind transportation is believed to be the prime factor in the formation of these rocks.

Granitic types

Zircon was examined from a typical coarse granite (*A124*) and from a porphyritic aplite (*A74*). In both instances zircon was of "igneous" type, and the histograms for the two assemblages are very similar—each shows 55% of the zircon with an elongation between 1.6 and 2.2, but the aplite has a slightly higher proportion of stumpy crystals within

* Specimen numbers are field numbers of material in the collection of the Department of Mineralogy and Petrology, University of Cambridge.

this range. The only significant difference between the two assemblages is that the zircon from the granite is generally rather larger than that from the aplite, though the actual range in size is similar for both assemblages (0.035–0.35 mm.).

Contaminated granites

Zircon was examined from two contaminated granites; one of these (*A109*) has been contaminated by adjacent xenoliths of more basic material, and as a result is richer in biotite and plagioclase than is the normal granite; the second (*A198*) is a granite vein in the Moines, which contains many small xenoliths of Moine rocks, and has incorporated some material from them.

The first example (*A109*) has a zircon assemblage composed mainly of normal "igneous" zircons, with a smaller number of "contamination" zircons, transitional types between typical "igneous" and "contamination" zircons being common. This assemblage is clearly shown in the histogram (Fig. 1) which is similar to that for zircon from the normal granite, except for the larger number of elongated crystals—6% of the crystals have an elongation in excess of 3.8, whereas only 0.5% occur in this region in the normal granite.

The zircon from the vein in the Moine shows a more complex assemblage. About 20% of the crystals are of "sedimentary" type, and the remainder are of "igneous" and "contamination" types, including many transitional between the last two. As a result, the histogram is more complex, and here the proportion of elongated zircons is even higher—20% have an elongation in excess of 3.8. The "sedimentary" zircons are identical with those from the Moines, and are probably due to actual incorporation of Moine schist in the granite, the zircon persisting unchanged. The elongated zircons are of interest—the evidence indicates that very elongated zircon is produced only in granite which has been contaminated, and they supply some evidence of the degree of crystallization of the granite at the time contamination took place. These elongated crystals are commonly zoned, and the zoning is always concentric, so the first-formed portions of the crystals were also elongated. Since zircon is one of the first minerals to start crystallizing, this suggests that at the time the granite was intruded as veins into the Moines, and incorporated some material from them, it was largely or entirely liquid.

Xenoliths

Zircon from two large cognate xenoliths was examined. One of these (*A132*) is granodiorite, the other (*A105*) is an albitized biotite-tonalite, and both are veined by contaminated granite. In each of these, zircon is mainly of "igneous" type, but there is a little material of "contamination" type, probably from the veins of contaminated granite. This is reflected in the histograms, which are similar to those for the granite except for the presence of a few elongated crystals. The only other way the zircon from these rocks differs from that in the granite is that the crystals in the xenoliths are rather smaller, the usual size being 0.02–0.2 mm.

Granitized Moine

Zircon from two examples of granitized Moine was examined. One of these (*A181*) is a "granite-looking" rock derived from a rather leucocratic granulite; the other (*A182*) is a coarse micaceous augen-gneiss derived from a pelitic schist. The zircon assemblages in these rocks are complex; the "granite-looking" rock contains a few "igneous" zircons, probably from granite veins which are abundant in the area, and are present in the specimen; the majority of the other crystals in both rocks are of "recrystallized" type, and there are also some which appear to be typical "sedimentary" zircons. These "sedimentary" zircons, however, if examined in detail, show unusual features; in transmitted light they appear to be well-rounded, but under reflected light they are seen to be bounded by numerous small irregularly-developed crystals faces, and from crystals of this type there is every transition to typical "recrystallized" zircons. The process of recrystallization must be solution of material from some parts of a crystal and deposition on others, so that a rounded grain is gradually converted to a perfectly idiomorphic crystal in which no trace of the original form can be detected. Breakdown of one large detrital grain to give an aggregate of smaller grains, such as Poldervaart and von Backstrom (1950) found at Kakamas, is very rare here, but instead this gradual change from a rounded grain to an idiomorphic crystal is the usual process. The average size of the recrystallized zircon is about the same as that of zircon in the original Moine from which these rocks were derived, and this appears to suggest that no material has been subtracted or added to the zircons during recrystallization.

Summary

The zircon assemblages from the normal igneous types, contaminated igneous rocks, Moine schists, and granitized Moines, are quite distinct, and comparison of the different assemblages was found very useful in confirming the difference between normal granite and granitized schists. A similar comparative study may give useful results in other areas.

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