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Informal Report

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Q. 314
UC-11

Reporting Date: July 1976

Issued: July 1976

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by

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CONTRACT W-7405-ENG. 36

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Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161
Price: Printed Copy \$3.50 Microfiche \$2.25

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MORPHOLOGY OF ZIRCONS FROM PRECAMBRIAN ROCKS

PENETRATED BY GEOTHERMAL TEST HOLE GT-2

by

R. A. Heimlich

ABSTRACT

Analysis of zircons separated from nine samples of Precambrian rocks in the interval 786 to 2902 m, along geothermal test hole GT-2, reveals the presence of large percentages of light-colored as well as some dark brown grains in each sample. A majority of the zircons in all samples are rounded or subrounded, and a large number in all but two samples exhibit overgrowths. Some zircons from all samples possess extinction angles, many exhibit zoning, and a small percentage show truncated zoning.

Zircon mean lengths and mean widths fall within narrow ranges. Mean elongations cluster near 2.0, typically, and elongation histograms are primarily bimodal. Reduced major axes vary in position, length, and slope.

Collectively, the mean elongations, rounding index, euhedrism, overgrowths, extinction angles, truncated zoning, and reduced major axis data suggest that these zircons are detrital in nature. Thus the rocks in which they occur are inferred to be paragneisses.

I. INTRODUCTION

Because of their ubiquitous occurrence in a wide variety of rocks, great resistance to chemical and thermal alteration, and utility in radiometric age studies, zircons have been employed as petrogenic indicators in numerous studies of igneous, metamorphic, and sedimentary rocks. It was the purpose of this study to make a detailed analysis of the morphology and other physical characteristics of zircons from Precambrian rocks cored from geothermal test hole GT-2, with the objective of applying this information to the question of the origin of these rocks.

Material provided for the study consisted of nine core samples spanning roughly 1931 m, from a depth of 786 m (about 55 m below the Pennsylvanian-Precambrian contact) to a depth of 2902 m. With the exception of two samples that were only a few meters apart, the samples were spaced about 168 to 738 m from one another. Based on megascopic examination

of cuttings, Purtymun, West, and Pettitt¹ classified these rocks as granite or granodiorite, with the exception of Sample 6153 which they described as biotite-hornblende schist. They indicated that core examination showed the presence of a slight gneissosity in the granitic rocks. In a subsequent report by Pettitt², a core log for these rocks shows most of them as gneissic granites.

II. ZIRCON SEPARATION AND ANALYSIS PROCEDURES

The samples (approximately 600 g each) were subjected to crushing, pulverizing, and sieving. All powder which passed through an 80-mesh sieve was then processed by means of tetrabromoethane, and magnetite was removed from the resulting concentrate by hand magnet. This was followed by runs with the Frantz magnetic separator. The nonmagnetic concentrate resulting from this procedure was subjected to a second heavy-liquid separation using methylene iodide. Several samples were then subjected to a 1-h treatment

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with aqua regia to remove pyrite. All of the final zircon concentrate was mounted on glass slides using Hyrax as the mounting medium.

For each sample, 200 unbroken grains were studied microscopically under 250X magnification. Those selected for study were grains visible in the microscope field at equal intervals along traverses equally spaced across the slide. Length and width measurements were punched onto computer cards and processed statistically by use of a FORTRAN IV computer program.

III. GENERAL CHARACTERISTICS OF THE ZIRCONS

Although a majority of the zircons are colorless or pale yellow, each sample includes some which are medium brown in color (Table I). Most of the lighter colored grains are exceptionally clear, whereas the brown zircons are commonly cloudy.

Nonopaque inclusions are relatively common in the zircons from all the samples (Table I). Most are long, colorless prisms terminated by the basal pinacoid; they appear to be apatite. Other rounded, elongated or subcircular inclusions with extreme relief and birefringence appear to be zircon. Like the apatite inclusions these are typically randomly

oriented, with their long axis rarely parallel to the long axis of the zircon grain which encloses them. In addition to small bubbles which occur in a very few of the zircons, opaque inclusions characterize some zircons from all the samples. Although typically anhedral, some of the opaque grains are diamond-shaped suggesting that they are magnetite. Sample 9521 is unique with respect to the very high percentage of inclusions in its zircons. However, these zircons are also notable for their clarity and lack of color.

A majority of the zircons in all samples (75 to 98.5%) are rounded or subrounded (Table I). Small percentages are subhedral and a very few are euhedral; i.e., their original terminal crystal faces are present and meet the prism faces at more or less sharp angles. Euhedral and subhedral crystals consist of the basic tetragonal prism terminated by the dipyrmaid or several dipyramids of different slope. Examples of these habits and degrees of euhedrism and rounding are illustrated in Figs. 1 through 10 for all the samples.

With the exception of Samples 7102 and 9521, a majority of the zircons exhibit partial or complete

TABLE I

GENERAL CHARACTERISTICS OF THE ZIRCONS^a

	Sample Number								
	2580	3151-1	3151-7	3698	4283	4896	6153	7102	9521
Color									
Colorless	7.5	64.0	33.5	52.5	14.5	75.5	44.0	37.5	86.5
Yellow	85.5	24.5	59.5	43.0	84.0	20.5	30.0	46.0	9.5
Brown	7.0	11.5	7.0	4.5	1.5	4.0	26.0	16.5	4.0
Inclusions									
Opaque	4.5	3.5	8.5	3.5	3.5	3.5	4.5	2.5	5.5
Nonopaque	33.0	40.0	41.5	52.0	40.5	62.0	35.5	32.5	92.0
Fluid	1.0	0.5	0.5	0.5	0.0	3.5	0.0	0.0	0.0
Euhedrism									
Euhedral	0.5	0.0	0.5	1.0	1.5	4.0	0.0	0.0	0.0
Subhedral	20.5	1.5	5.5	20.0	14.0	21.0	5.5	7.5	8.0
Subrounded	58.5	81.0	72.0	70.5	77.0	68.0	87.0	78.0	80.0
Rounded	20.5	17.5	22.0	8.5	7.5	7.0	7.5	14.5	12.0
Overgrowths									
Partial	61.0	58.5	42.0	64.0	55.0	72.0	80.0	12.0	10.0
Complete	14.0	7.5	2.5	6.0	3.0	2.0	7.5	3.5	7.0

^aAll values given as percentages of total (200) grains studied.

Fig. 1. Sample 2580. Representative zircons including dark, subrounded grain with partial overgrowth (100X).

Fig. 3. Sample 3151-7. Representative rounded, subrounded, and subhedral zircons (100X).

Fig. 2. Sample 3151-1. Representative dark and light, subhedral and subrounded zircons (100X).

Fig. 4. Sample 3698. Representative rounded and subrounded, colorless zircons (100X).

Fig. 5. Sample 4283. Representative subrounded and subhedral, small zircons (100X).

Fig. 7. Sample 6154. Representative subrounded and rounded zircons, several with partial overgrowths (100X).

Fig. 6. Sample 4896. Representative subhedral and subrounded, colorless zircons containing inclusions (100X).

Fig. 8. Sample 7102. Large subrounded zircon with euhedral, zoned overgrowth (100X).

Fig. 9. Sample 7102. Fractured, subrounded zircon with euhedral overgrowth, and other representative zircons (100X).

overgrowths, the former being the most common (Table I). Outgrowths are virtually lacking on these zircons. Typically colorless or yellow, the overgrowths occur on both colorless or colored grains. Commonly thin (less than one-half the width of the core crystal), the overgrowths are inclusion-free and may be zoned or unzoned. Most possess subhedral or euhedral outlines and many are truncated by the basal pinacoid. Examples are illustrated in Figs. 1, 7, 8, and 9.

IV. EXTINCTION ANGLES AND ZONING

When formed initially by crystallization from igneous melts, zircon crystals lack extinction angles because of coincidence of the C-crystallographic axis with the axis of maximum elongation. However, an extinction angle may characterize some percentage of the original zircons, ultimately, because of subsequent grain breakage (at an acute angle to the C-axis) during sedimentary transport of the weathered igneous rock. Thus, extinction angles are of petrogenic significance with respect to metamorphic rocks.

All of the rocks sampled contain some zircons (8 to 16.5%) with extinction angles (Table II). Although the value of the extinction angle varies

Fig. 10. Sample 9521. Representative euhedral, subhedral, and subrounded zircons, one with apatite inclusions and several zoned (100X).

widely for zircons from a single sample, the average extinction angle falls between 5.70 and 8.90.

Also of petrogenic significance is the presence or absence of zircons exhibiting truncated zoning. A relatively large percentage of zircons in all the samples exhibit zoning (Table II), either strongly or moderately well developed. Moderate zoning includes grains possessing faint, discontinuous lamellae, or few lamellae, or zoning in only part of the grain (typically absent in the central portion). A maximum of 2.5% of the zircons exhibit zoning truncated by the grain boundary.

V. DIMENSIONAL CHARACTERISTICS

With respect to dimensional characteristics of zircons from the nine samples, mean length (0.06 to 0.10 mm) and mean width (0.03 to 0.05 mm) vary little (Figs. 11 and 12), particularly the latter. Zircons from Samples 3151-7 and 4283 are smaller than those from the other samples. Zircons from Samples 3151-1 and 3698 have bimodal length histograms. In most samples, the smaller grains are the yellow zircons whereas the larger grains are the colorless or brown varieties. Mean elongations (Table III) are

Fig. 11. Zircon length histograms.

Fig. 12. Zircon width histograms.

TABLE II

EXTINCTION AND ZONING CHARACTERISTICS OF THE ZIRCONS

	Sample Number								
	2580	3151-1	3151-7	3698	4283	4896	6153	7102	9521
Presence of an extinction angle ^a	15.5	8.0	16.5	8.5	6.0	6.0	8.0	10.0	9.0
Average of extinction angle	8.9°	7.3°	7.9°	5.4°	6.6°	6.3°	5.7°	7.2°	5.7°
Range of extinction angle	2-23°	4-16°	2-22°	3-14°	2-16°	2-17°	2-11°	2-12°	2-10°
Presence of zoning ^a	31.5	23.5	17.5	24.0	34.5	40.0	23.5	16.5	7.5
Strong zoning	54.2	16.3	30.0	27.9	36.9	31.3	34.9	15.2	0.0
Moderate zoning	45.8	83.7	70.0	72.1	63.1	68.7	65.1	84.8	100.0
Presence of truncated zoning ^a	2.0	2.0	2.5	2.5	2.0	0.0	2.0	0.0	0.5

^aPercentage of total (200) grains studied.

TABLE III

STATISTICAL PARAMETERS OF THE ZIRCONS

	Sample Number								
	2580	3151-1	3151-7	3698	4283	4896	6153	7102	9521
Mean length (mm)	0.0911	0.0969	0.0707	0.1015	0.0616	0.0911	0.1034	0.0921	0.1017
Mean width (mm)	0.0425	0.0433	0.0383	0.0486	0.0308	0.0402	0.0508	0.0474	0.0432
Mean elongation	2.2674	2.3071	1.8688	2.1392	2.1038	2.3464	2.0776	1.9845	2.5015
Mean volume	0.0002	0.0002	0.0001	0.0003	0.0001	0.0002	0.0003	0.0003	0.0002
Standard deviation of length	0.0288	0.0287	0.0205	0.0382	0.0189	0.0301	0.0351	0.0320	0.0380
Standard deviation of width	0.0129	0.0121	0.0094	0.0145	0.0099	0.0118	0.0160	0.0144	0.0132
Correlation coefficient	0.3840	0.6147	0.6726	0.6068	0.5602	0.5679	0.7220	0.6788	0.5446
Slope of RMA	24°	23°	24.5°	21°	27.5°	21.5°	24.5°	24°	19°

TABLE IV

INTERPRETATION OF ZIRCON DATA COMPARED AGAINST PETROGENIC CRITERIA

	Sample Number								
	2580	3151-1	3151-7	3698	4283	4896	6153	7102	9521
Mean elongation	IG? ^a	IG?	SED	SED?	SED?	IG?	SED?	SED	IG?
Founding index	SED ^b	SED	SED	SED	SED	SED	SED	SED	SED
Amount of euhedral crystals	SED	SED	SED	SED	SED	SED	SED	SED	SED
Amount of overgrowths	SED	SED	SED	SED	SED	SED	SED	IG	IG
Extinction angle	SED	SED	SED	SED	SED	SED	SED	SED	SED
Truncated zoning	SED	SED	SED	SED	SED	IG	SED	IG	SED
RMA projection	IG?	IG	IG?	SED	IG?	SED	SED	SED	SED

^aIG--igneous (or metaigneous).

^bSED--metasedimentary.

generally close to 2.0, ranging from 1.87 to 2.35 with the exception of one (Sample 9521) at 2.50. The elongation histograms (Fig. 13) are right-skewed and typically bimodal.

Reduced major axes (RMA) are shown for the zircons in Fig. 14. In terms of position and slope, the RMA for zircons from Sample 4283 is distinctly different from those for the other eight samples. However, the remaining samples also exhibit RMA variability, particularly in length and position and, to some extent, in slope. Reduced major axes for Samples 4283, 3151-7, 2580, and 3151-1 project very close to the origin of the plot; in fact, Sample 3151-1 RMA projects directly through the origin.

VI. DISCUSSION

A fundamental question concerning the rocks cored by GT-2 involves the extent to which they are igneous or metamorphic in origin. The preponderance of evidence generated by this zircon study suggests that the nine samples are metamorphic rocks, probably metasedimentary gneisses for the most part. Because each zircon criterion is no more than a generalization, seven criteria are listed in Table IV and the samples are compared against each criterion to determine if

a distinct igneous or metasedimentary tendency is indicated.

Poldervaart³ showed that zircons from most intrusive granitic rocks have mean elongations exceeding 2.0 (typically 2.0 to 3.0). On the contrary, those for zircons from sedimentary rocks are typically less than 2.0.^{3,4} Zircon mean elongations for five of the samples in this study are near 2.0 or below, suggesting a sedimentary parentage. The maximum value is 2.5 for Sample 9521, which may be igneous based on this criterion. Three other samples are less obviously igneous.

Relative to the rounding index, or the percentage of zircons exhibiting any sign of rounding,⁵ all the samples are metasedimentary in nature since their zircons are dominantly subrounded or rounded. By the same token, the very low percentages of angular, euhedral zircons in each sample (Table I) suggest a sedimentary parentage for these rocks.^{3,6}

With the exception of Samples 7102 and 9521, overgrowths are characteristic of the zircons in most of the samples. Because this phenomenon is prevalent in metamorphic-metasomatic rocks,⁷⁻⁹ it may be inferred, in conjunction with the sedimentary

Fig. 13. Zircon elongation histograms.

Fig. 14. Zircon reduced major axes.

parentage data presented above, that seven of these samples are metasedimentary in origin.

Further support for this interpretation is provided by the extinction angle and truncated zoning data. A modest but distinct percentage of zircons from all the samples exhibit extinction angles comparable to those found in zircons from sedimentary rocks⁴ and from metasedimentary gneisses.^{10,11} Similarly, all but two of the samples contain a small percentage of zircons which exhibit truncated zoning such as that found in a typical clastic sedimentary rock.⁴ Extinction angles and truncated zoning are atypical of zircons from igneous rocks but ought to be characteristic of transported, detrital zircons.

Finally, the reduced major axis for Sample 3141-1 is the only one which projects through the origin of the plot, indicating that these zircons are self-nucleated,¹² a feature typical of igneous zircons. To a lesser extent, this is true of the RMA for zircons from three other samples, but clearly not the case for those from the remaining five samples (Table IV) which are judged to be metasedimentary. If all nine samples are considered as representing a single rock unit, then the overall variability of the RMA would suggest a metasedimentary origin for this rock. The bimodality of the elongation histograms would tend to support this interpretation as well.

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