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ZIRCONS OF THE WHITE MOUNTAIN MAGMA SERIES: BELKNAP MOUNTAIN COMPLEX

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ABSTRACT

Zircon populations from several intrusive members of the White Mountain Magma Series were studied in terms of dimensions, elongation, complexity of single crystal morphology, color and variety of forms within a single population. In gabbro and diorite zircons are subhedral or anhedral. Euhedral crystals appear in the monzodiorite state and form an increasing larger percentage as the host rock becomes more silicic. Mean elongation of euhedral populations is constant throughout the series. Parameters such as color, single crystal morphology and elongation variance vary continuously with host rock composition. Population characteristics are most probably related to the length of the crystallization period of each population.

INTRODUCTION

Many studies have been made for the purpose of describing morphological and dimensional characteristics of zircons from various igneous rock types. These studies, in many cases, have shown that zircons from a particular rock type have several distinctive characteristics. This would indicate that zircons might be of help in establishing petrogenetic relationships where other methods are inconclusive. Studies by Spotts (1962), Alper and Poldervaart (1957), and Larsen and Poldervaart (1961) have shown that zircon data can be used as supporting evidence for establishing genetic relationships between geographically separated, but chemically related igneous rocks.

This study is concerned with the variability of zircon populations through a wide range of rock types of the White Mountain Magma Series. The purpose was to determine if changes in such zircon characteristics as morphology and dimensions could be related to the progressive differentiation of the comagmatic series.

Seven different members of the White Mountain Magma Series were sampled in the Belknap Moutain area of New Hampshire. The comagmatic origin of the series has been demonstrated by several investigators, *e.g.*, Billings (1928), Chapman and Williams (1936), Modell (1936), and Quinn (1944).

The Belknap Mountain area was selected as the sampling site because a wide spectrum of rock types representative of the White Mountain Magma Series are present within a small area. The nature of the rocks present have been described fully by Modell (1936).

Zircon characteristics such as habit, color, zoning and inclusions were determined. When present, length-breadth ratios of euhedral crystals were measured.

Geologic Setting

The Belknap Mountain area is one of seven localities where the White Mountain Magma Series is exposed in New Hampshire. The rocks include comagmatic extrusives and intrusives, with compositions ranging from gabbro to granite. From oldest to youngest, the rocks include the Moat Volcanics, Gilford Gabbro, Endicott Diorite, Ames Monzodiorite, Gilmantown Monzodiorite, Belknap Syenite, three varieties of quartz syenite, Conway Granite, and the Rowe Vent Agglomerate, an extrusive breccia (Modell, 1936). Each intrusive lithology is homogeneous and distinct. The units are bounded by sharp, well-defined contacts, indicating that each rock type was formed at depth and intruded separately Figure 1 is a geologic map of the area with sample locations indicated.

Formation of the White Mountain Series is believed to be due to a combination of progressive crystal fractionation and assimilation of highly siliceous rocks. Quinn (1944) states that a simple subtraction of material by fractional crystallization of basaltic material is not quantitatively capable of producing all the rock types of the White Mountain Series. Fractional crystallization is considered to be the dominant process up to the syenite stage; however, at that point addition of siliceous material is required to produce the quartz syenites and granite. Chemical analyses of several rock types are available in Modell (1936).

Methods

Zircon populations were separated by the procedures outlined by Hall and Eckelmann (1961). Zircon characteristics such as color, nature of inclusions, and zoning were noted. Where a doubly terminated euhedral crystal was found, its length and breadth were measured. Zircons in the Gilford Gabbro and Endicott Diorite are anhedral and subhedral, and were not measured. Similarly, the Belknap Syenite contained only fragments of exceedingly large zircons (>1mm) and mean length-breadth data were not obtained. The euhedral zircons are mainly prismatic and are terminated by either bipyramids $\{101\}$, pinacoids $\{001\}$ or a combination of these forms (mixed). The relative abundances of these three termination types were noted for each population containing euhedral zircons.

Results

Mean lengths, breadths, and elongations of the populations measured are listed in Table 1. The dimensions of the crystals are relatively similar

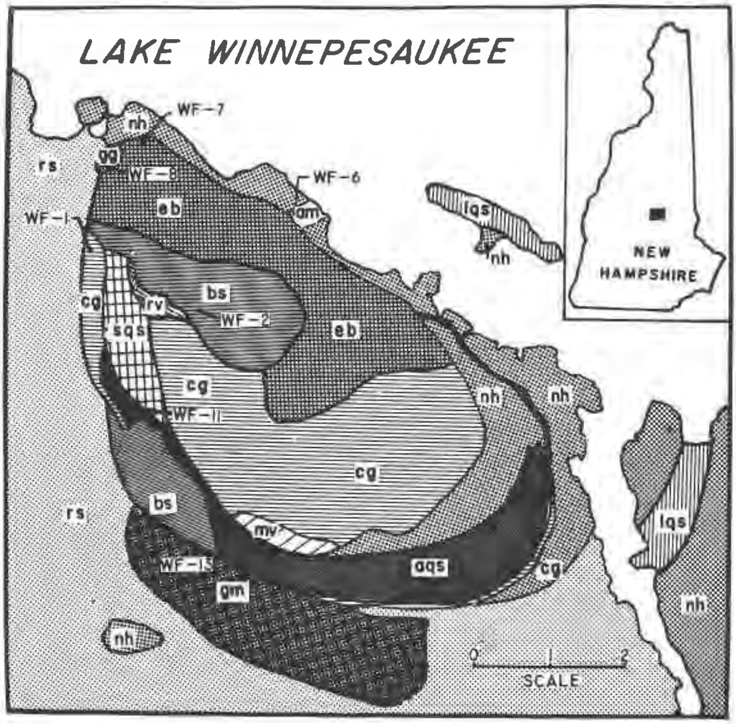


FIG. 1. Geologic map of Belknap Mountains area with sample location noted (after Modell, 1936). Explanation of symbols, arranged from youngest to oldest: rv = Rowe Vent Agglomerate, cg = Conway Granite, aqs = Albany Quartz Syenite, lqs = Lake Quartz Syenite, sqs = Sawyer Quartz Syenite, bs = Belknap Syenite, gm = Gilmantown Monzodiorite, am = Ames Monzodiorite, eb Brecciated Endicott Diorite, gg = Gilford Gabbro, mv = Moat Volcanics, nh = New Hampshire Magma Series, rs = Rockingham Schist.

TABLE 1. DIMENSIONAL DATA FOR ZIRCON POPULATIONS WHITE MOUNTAIN MAGMA SERIES, NEW HAMPSHIRE

Sample	$\bar{x}$(mm)	$\bar{y}$(mm)	Sx(mm)	Sy(mm)	$\bar{x}/\bar{y}$(mm)	Sx/y	r
Granite	0.1155	0.0585	0.0349	0.0154	1.982	0.372	0.7941
Quartz Syenite	.1323	.0674	.0438	.0226	2.037	.512	.6195
Gilmantown Monzodiorite	.0974	.0434	.0348	.0109	2.139	.803	.4295
Ames Monzodiorite	.1114	.0603	.0316	.0159	1.963	.857	.1778

$\bar{x}$ = mean length; $\bar{y}$ = mean width; Sx = standard deviation of length; Sy = standard deviation of width; $\bar{x}/\bar{y}$ = mean elongation; Sx/y = standard deviation of elongation; r = correlation coefficient; N = 200.

throughout the series and do not vary systematically from one rock type to another. Mean elongation values for the zircon populations of the monzodiorites, quartz syenite and granite are identical, *i.e.* the differences between sample averages were not large enough to be statistically significant. Although mean elongations are the same between populations, the variance of elongation values changes regularly between populations (Table 1). A large variance indicates a wide variety of crystal habits in the population, while a low variance represents a fairly uniform array of crystal shapes. The elongation variance data indicate that populations in rocks of intermediate silica content contain a wide variety of crystal shapes and those of the more siliceous rocks become progressively more uniform in morphology.

A continuous variation is also seen in the measure of correlation between the length-breadth dimensions of euhedral zircons (r). The population of the Ames Monzodiorite has a correlation coefficient of 0.1778, indicating almost complete non-linearity of length-breadth dimensions. Correlation between these variables increases systematically to the Conway Granite population where a strong linear trend is quite apparent ($r=0.7941$). Thus, some aspects of the dimensional data indicate variations which can be correlated to the progressive differentiation of the White Mountain Magma Series. Descriptions of other population characteristics such as frequency of termination type, color, zoning and inclusions are given in Table 2. Representative zircon morphologies of the monzodiorite and syenite stages are shown in Figures 2 and 3 respectively.

The progressive increase of zircons terminated by bipyramids can be correlated to a corresponding increase of zoned crystals. Zoning patterns show that the basal pinacoid is eliminated by crystal growth. The observed color changes are probably due to progressively higher uranium and thorium contents.

The observed morphological changes between populations listed in Table 2 also occur between size fractions within a single population. Abundances of termination types, presence of $\{211\}$ faces, and abundances of colored crystals are given in Table 3 for the 400, 170, and 120 mesh fractions of the Albany Quartz Syenite. Specimens exhibiting representative morphology of the 400 and 170 mesh fractions are shown in Figures 4a and 4b respectively. The smaller crystals generally are colorless, unzoned and often exhibit the $\{211\}$ form. Larger crystals are distinctly zoned, generally they are colored and frequency of the $\{211\}$ form is much lower. If it is assumed that the 120–170 mesh zoned crystals are the result of growth from smaller crystals, similar in morphology to those in the 400 fraction, then crystal growth clearly tends to modify

TABLE 2. SUMMARY OF ZIRCON POPULATION CHARACTERISTICS, WHITE MOUNTAIN MAGMA SERIES

Rock type	Termination type (% of euhedral population)			Color	Zoning	Inclusions	Remarks
	Bipyramidal	Pinacoidal	Mixed				
Gilford Gabbro				Clear	None	None	<1% euhedral zircons
Endicott Diorite				Clear	Occasional fine zoning	Few bubbles	<1% euhedral, some development of prism faces, cigar-shaped crystals characteristic.
Ames Monzodiorite	18	37	45	<10% colored	Majority of crystals faintly zoned	Rod-shaped, clear inclusions parallel to crystal faces	50% euhedral, 40% subhedral, <10% anhedral; high index pyramidal faces common
Gilmantown Monzodiorite	33	30	37	>50% crystals light tan, occasional dark brown crystal	All crystals zoned, zones clearly defined	Rod-shaped, spherical clear	Frequency of high index pyramidal faces somewhat lower than Ames Monzodiorite population
Albany Quartz Syenite	47	21	32	>80% crystals dark brown remainder tannish	All crystals coarsely zoned	Sphene, opaques, rod-shaped	>90% population euhedral
Conway Granite	67	10	23	All crystals colored dark tan to dark brown	Coarse zoning	Opaques	Slightly corroded outlines common; occasional apatite overgrowths.

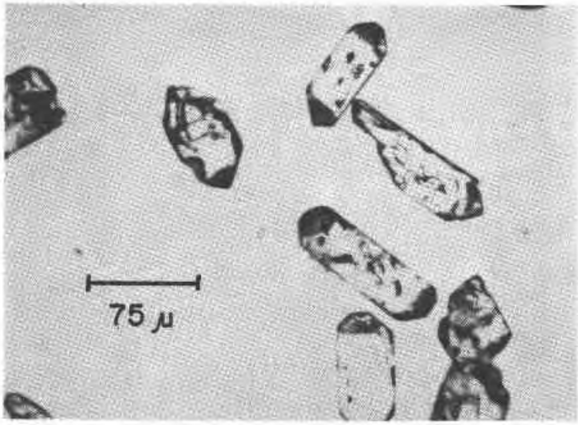


FIG. 2. Typical zircons of the Ames Monzodiorite showing the presence of {211} faces. All grains are colorless and are unzoned.

crystal morphology. Addition of material as outlined by zoning patterns eliminates basal pinacoids and high index faces.

DISCUSSION

Clearly, the trend of zircon populations, from a population consisting of highly variable crystal shapes to a morphologically simple and uniform one, can be correlated to the stage of differentiation. This variation is probably dependent on the length of the crystallization period of each population. The observed variation within a single population strongly indicates that crystal growth produces uniform crystal shapes. Therefore, a morphologically complex population, such as those of the monzo-

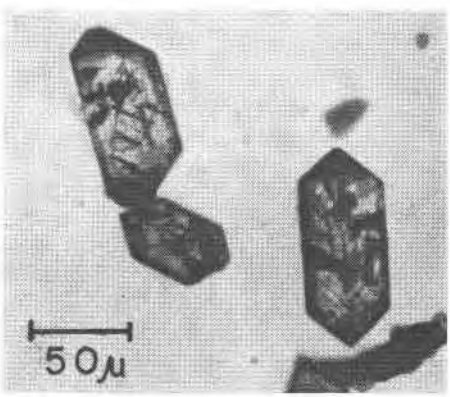


FIG. 3. Zircons characteristic of the Albany Quartz Syenite. The majority of crystals are dark brown in color and are zoned.

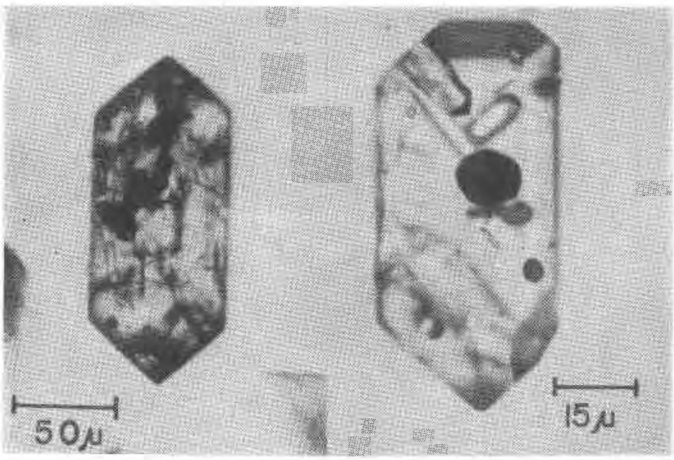
TABLE 3. MORPHOLOGICAL DATA OF SIZE FRACTIONS OF ALBANY QUARTZ SYENITE[a]

Mesh fraction	Termination type			Colored	{211} Present
	Pyramidal	Mixed	Pinacoidal		
80–120	46	36	18	67	39
120–170	40	39	21	54	43
170–400	24	48	28	42	75

[a] Numbers refer to percentage of the euhedral population showing the particular parameter.

diorites, may result from a short crystallization period, whereby modification of early, complex crystal forms by continued growth could not occur. The increasingly uniform populations of the granite and syenite stages may be the products of a comparatively long crystallization period. The preponderance of a simple termination type of zoned crystals in these populations, strongly suggests that modification of crystal form did occur. It should be noted that onset of zircon crystallization may not be synchronous with the onset of host rock crystallization. Similarly no estimates of the length of the zircon crystallization period as compared to the crystallization time of the host rock can be made.

Poldervaart (1956), Alper and Poldervaart (1957), and Larsen and



(b) (a)

FIG. 4. Contrasting morphologies in the Albany Quartz Syenite population. (a) Grain shape found only in the 170–400 size fraction. Note the {211} face. A very faint zoning may be seen. (b) Zircon characteristic of the >170 size fraction. The crystal is strongly zoned and is bounded by simple prismatic and pyramidal faces

Poldervaart (1957) conclude that zircon crystallized early in calc-alkaline rocks. They feel that a dimensionally and morphologically uniform zircon population could be produced only during a limited time interval during which the magmatic environment is uniform. Poldervaart (1956) states that such a uniform environment exists only at the onset of rock crystallization. Gottfried *et al.* (1959) and Gottfried and Waring (1964) however, find a progressive increase in the uranium, thorium and hafnium contents of zircon from a comagmatic sequence of rocks from the Southern California Batholith. They attribute this variation to the continuous formation of zircon during the crystallization of magma. The systematic variations in zircon populations of this study suggest that zircon crystallized over progressively longer periods as differentiation proceeded, but do not alone indicate if the crystallization period was continuous. If crystallization of zircon were continuous through the differentiation sequence, a regular increase in zircon size would be expected. The crystals do not show such a variation, thus suggesting that each population began crystallizing after the host magma was removed from the main magma chamber. The relative similarity of sizes between different populations suggests that, in gross terms, the number of nuclei and the amount of zirconium in each melt was approximately the same for each rock type.

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