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A QUANTITATIVE PETROGRAPHIC STUDY OF DOLERITE IN THE DEEP RIVER BASIN, NORTH CAROLINA

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ABSTRACT

Dolerite samples were collected from 41 dikes and 7 sheet-like bodies in the Deep River Triassic basin, North Carolina in order to perform a quantitative petrographic study.

Mineral proportions are highly variable from one intrusion to another, and within individual bodies. Olivine averages 15–20%, but ranges from 0–54%, thus indicating a larger variation and higher average content compared to dolerite from other areas. Other major primary minerals include augite, plagioclase, and micropegmatite. Texture varies from xenomorphic granular, to sub-ophitic, to ophitic, to idiomorphic granular. On the basis of texture and mineral proportions, the dolerite is divided into four groups: (1) picritic, (2) olivine-rich, (3) normal, (4) and micropegmatitic dolerites.

Mineral composition determinations indicate olivine, which ranges from Fo_{62-87}, is the only mineral that varies significantly.

Dikes from which more than one sample were taken indicate the center has a higher olivine content and is richer in magnesium than the marginal zone. This might be best explained by the tapping-off of various parts of a basaltic magma mass which had undergone partial crystallization with local concentrations of early crystals.

INTRODUCTION AND GENERAL GEOLOGY

Dolerite samples were collected from the Deep River Triassic basin which is centrally located within the state of North Carolina (Fig. 1). On the basis of physiography and structure, the Deep River basin has been divided into three parts: the northern part is the Durham sub-basin; the central part is the Sanford sub-basin; and the southern part is the Wadesboro sub-basin. In this study, only the Durham and Sanford sub-basins were examined.

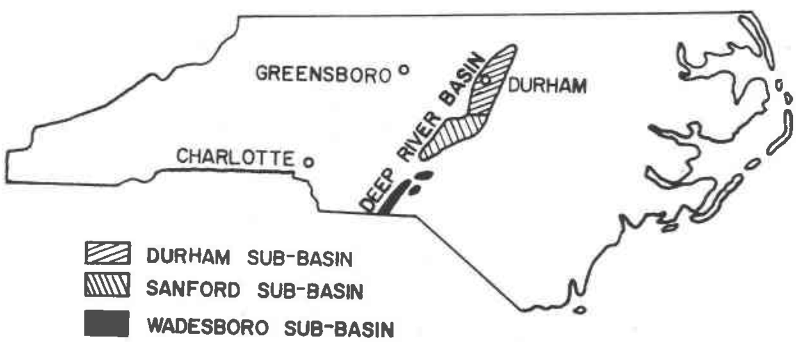

FIG. 1. Index map showing the location of the Deep River basin within the state of North Carolina.

The Deep River basin is structurally and stratigraphically similar to the numerous Triassic basins located discontinuously from Nova Scotia to South Carolina. The Triassic rocks in the basin were intruded, probably near the end of the Triassic period, by mafic igneous rocks in the form of dikes and sheet-like bodies. Dikes range in length from a few feet to more than seven miles, and are as narrow as a fraction of an inch and as wide as 300 feet. A zone of darkened, baked sediments is nearly always present near dike contacts. The widths of these zones are extremely variable, probably depending in part on the composition of the sediments intruded.

The major trend of dolerite dikes along the Atlantic seaboard changes systematically: from Alabama to North Carolina, the trend is NW.; in southern Virginia it changes to NNW.; across Maryland and into New England, the trend is NE. (King). The Deep River basin dikes show a systematic, local variation within this major trend. In the southern part of the basin, the trend is N. 25° to 40° W.; to the north, the trend is more northerly until a nearly north-south trend is attained near Creedmoor, N. C.

Dikes appear to have been formed by upwelling magma which mainly followed joints and cross faults. Most dikes are fairly straight, continuous, and parallel except where abundant longitudinal faults occur. The dip of most dikes is nearly vertical, but several have been observed to dip as low as 25°.

Sheet-like bodies occur mainly in thin-bedded, fissile shales where the magma has spread either laterally or obliquely across the beds. Because these bodies are in part conformable to the bedding, but sometimes exhibit a cross-cutting character, they are not true sills. Most sheet-like bodies are only local in areal extent and appear to be of moderate thickness.

Procedure

The major part of the field work involving sample collections was done in the spring and summer of 1962. Samples from a total of 41 dikes and 7 sheet-like bodies were collected. In the case of dikes, a sample was generally taken only from the center of the body. Two well-exposed dikes were sampled both at the contact and at the center in order to compare the marginal zone with the central part. Interpretations of sheet-like bodies are limited because in all cases the top portion has been removed by erosion, and generally the lower contact is not exposed.

Fifty-two thin-sections were obtained from the collected samples, and from these, modal analysis using the pointcounting technique were made. The identity change number was sufficiently high to necessitate only one section from a sample; the limit of error is probably $\pm 2\%$ (Chayes).

Techniques used for the determination of mineral compositions for each of the major minerals are as follows:

Olivine. A four axis universal stage was used to measure axial angles, and the orientation was plotted on a Wulff stereographic net; in thin-sections where the crystals had the proper orientation, direct measurements were taken. Accuracy is estimated to be $\pm 2°$. Magnesium-iron ratios were then determined from $2\,V_\gamma$ values using the curve by Poldervaart (1950).

Augite. All axial angles for augite were measured directly with the universal stage. The refractive index, γ, was determined by standard oil immersion techniques. Curves published by Hess (1949) were used in determining augite compositions.

Plagioclase. The composition of plagioclase was determined by two methods. The first technique used was the Michel-Lévy extinction method with aid of the universal stage. Because of the frequent complex twinning of the plagioclase and the rarity of simple albite twins in thin-section, the method is difficult to use and has a comparatively large limit of error ($\pm 3°$).

The second and best technique used was an oil immersion method determining γ by use of cleavage flakes lying parallel to (001). Accuracy of refractive index measurements is estimated to be $\pm .002$. A curve by Tsuboi (1923) which is a plot of anorthite content against refractive index, was used to determine the calcium-sodium ratio.

Petrography

The dolerite rocks are quite variable in color, texture, and mineral proportions. Minerals present are grouped as shown below.

Primary minerals: olivine, augite, plagioclase, intergrown quartz and orthoclase forming micropegmatite, opaque minerals (ilmenite, magnetite, pyrite), and apatite.

Secondary minerals: biotite, chlorite, sericite, magnetite, antigorite, a clay-like mineral (kaolinite?), and an iddingsite-like mineral.

The texture of the dolerite varies from xenomorphic granular, to sub-ophitic, to ophitic, to idiomorphic granular. Generally, the true ophitic texture is limited to those rocks having a small grain size and a low olivine content. In rocks of larger grain size, the texture is sub-ophitic, and with a high olivine content and a coarser grain size, the texture is xenomorphic granular. Rocks containing more than 2% micropegmatite have an idiomorphic granular texture; long, euhedral crystals of augite lie parallel to slender plagioclase blades, and micropegmatite fills in interstices.

The largest crystals observed were augite crystals which average 3.3 mm in length; however, some blades of augite in one sheet-like body attain a length of 7.0 mm. Some plagioclase crystals are as much as 4.0 mm long, but most are less than 3.0 mm. Crystals of olivine are highly variable in size, averaging 1.5 mm across, but in the center of one dike (NC-30A), they are as much as 4.0 mm in diameter.

In some thin-sections, subhedral to anhedral olivine crystals completely enclose euhedral magnetite and lath-shaped plagioclase blades. Narrow reaction rims surround the olivine in some cases. Olivine is commonly altered to antigorite or a reddish-brown iddingsite-like mineral.

Augite, in thin-sections containing micropegmatite, is euhedral to subhedral, and is commonly twinned. In the presence of olivine, augite is untwinned, and is irregular and anhedral, filling the interstices between olivine and plagioclase. Alteration products of augite include biotite, chlorite, and an opaque mineral, probably magnetite.

Plagioclase in all thin-sections is complexly twinned. Recognizable twins include simple albite, Carlsbad, combination of Carlsbad-albite, pericline, and a more complex type of twin which was not determined. Normal oscillatory zoning does occur in the plagioclase, but it is not common, and the change in extinction angle from the core to the edge was observed to be always less than 3°. Small clusters of plagioclase commonly have a radiating pattern. Locally, plagioclase is altered to sericite or a clay-like mineral.

Modal Variation

Modal analysis of 52 thin-sections reveal a wide range of mineral proportions. The modal variation is illustrated by use of a triangular plot having end points of plagioclase, pyroxene, olivine, and micropegmatite (Fig. 2).

Mineral proportions for most samples fall within the following ranges; plagioclase 45–65%, augite 15–40%, olivine, when present, 5–25%, and micropegmatite, when present, 4–25%. Never was more than 1% micropegmatite observed to be present in an olivine-bearing dolerite.

For this study of dolerite rocks, the following classification, based largely on mineral proportions and texture, was used (Table 1).

1. Picritic dolerite: At least 50% of the rock is composed of olivine. Plagioclase comprises approximately one-third of the dolerite, and augite less than one-tenth. Micropegmatite is absent. The texture is xenomorphic granular.

2. Olivine-rich dolerite: Plagioclase generally comprises more than 50% of the constituents, and augite makes up one-fifth to one-third of the rock. Olivine ranges from 16–50%. Micropegmatite is absent. The texture is mainly sub-ophitic, but the more olivine rich rocks have a xenomorphic granular texture.

3. Normal dolerite: Olivine forms 0–15% of the rock, while plagioclase generally makes

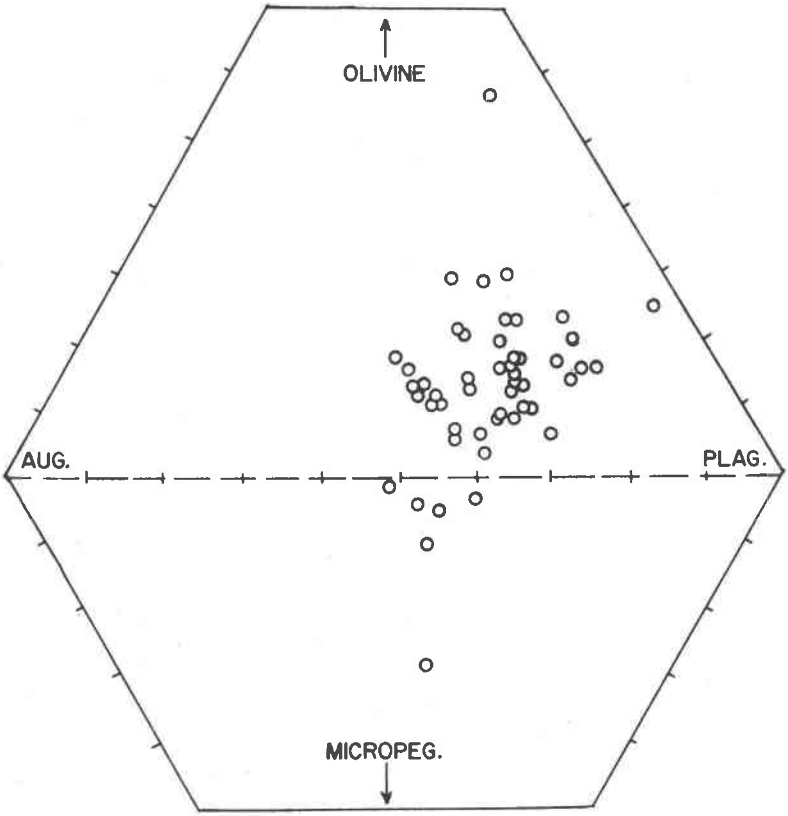

FIG. 2. Plot showing variation in percentage of major minerals.

up 50% or more of the constituents. Interstitial augite, which in many cases completely surrounds euhedral plagioclase, comprises one-fourth to two-fifths of the rock. Trace amounts of micropegmatite may be present. The texture varies from sub-ophitic to ophitic.

4. Micropegmatitic dolerite: Plagioclase and augite crystals are present in nearly equal proportions and commonly parallel each other. Interstitial micropegmatite is present in significant amounts. Olivine is absent. The texture is mainly idiomorphic granular.

No distinct difference in mineralogy between dikes and sheet-like bodies is apparent from the modal analysis data. The only intrusion which could be called picritic dolerite is a dike; otherwise both dikes and sheet-like bodies are randomly distributed throughout the above classification.

OPTICAL DATA

Optical studies were made of 24 samples which represent all the major dolerite types. The complete data are shown in Table 2, and the arithmetic means of the major groups are given in Table 1.

Although the anorthite content of plagioclase varies from An_{58} to An_{72}, these limiting values are rarely attained. For most specimens, the anorthite content is near An_{64}, regardless of dolerite type (Table 1). In general, any change in plagioclase composition appears to be so small that it falls within the margin of error.

Augite in the picritic, olivine-rich, and normal types of dolerite has a nearly constant composition, although slight variations within each group are present. A significant decrease of calcium and an increase of magnesium in the augite was observed for the micropegmatitic dolerite group (Table 2).

Magnesium-iron ratios of olivine are highly variable, but no consistent change is apparent between the dolerite types. An increase of magnesium in olivine is generally accompanied by a smaller increase of magnesium in augite (Fig. 3).

An interesting observation is the change of optical properties across a dike. Both olivine and augite are more magnesium-rich in the center than at the contact of a dike. For example, thin-sections within 3 feet of the contacts of two dikes (NC-30B and DU-7) were compared with sections

TABLE 1. AVERAGE MODES AND AVERAGE MINERAL COMPOSITIONS FOR THE FOUR DOLERITE TYPES

Dolerite Group		Picritic dol.	Olivine-rich dol.		Normal dol.		Micropeg. dol.	
Number of samples		1	14		31		6	
			Range	Mean	Range	Mean	Range	Mean
Modal Data	olivine	54%	16–28	20%	2–15	10%	—	—%
	plagio.	34	39–70	53	41–67	55	37–56	47
	augite	10	5–41	24	16–47	32	30–49	40
	micropeg.	—	—	—	0–1	tr.	1–27	9
	opaques	2	2–4	3	1–6	3	3–6	4
Average Mineral Composition	plagio. (An)	66	65		62		64	
	augite Wo:En:Fs	39:52:9	39:45:16		40:47:13		35:58:7	
	olivine (Fo)	84	77		77		—	
augite:plagio. ratio		18:60	27:60		35:60		51:60	
average specific gravity		3.15	2.98		2.98		2.93	

taken near the centers of the respective dikes (NC-30A and DU-8). Magnesium in augite apparently increases as much as 10% from the contact to the center, and the fosterite content of olivine may increase more than 10% (Table 2). It is important to note that the volume per cent of olivine for the above two dikes increases as much as 33% from the con-

TABLE 2. OPTICAL DATA AND MINERAL COMPOSITIONS

Specimen	Plagioclase		Augite			Olivine		Spec. Grav.
	γ	An	γ	$2V_\gamma$	Wo:En:Fs	$2V_\gamma$	Fo	
Picritic dolerite								
NC-30A	1.569	66	1.702	49	39:52:9	92	84	3.15
Olivine-rich dolerite								
DU-6	1.572	72	1.702	51	38:52:10	94	79	3.00
NC-35	1.568	64	1.716	46	38:42:20	99	68	2.95
DU-8	1.569	66	1.702	47	38:52:10	90	87	3.02
NC-30B	1.572	72	1.708	48	40:46:14	97	73	3.01
CB-49	1.568	64	1.712	52	43:42:15	95	77	2.98
CB-41	1.567	62	1.712	49	40:44:16	97	73	2.97
Normal dolerite								
CB-28	1.566	60	—	45	36:40:24	93	81	2.96
CB-23	1.567	62	1.705	49	40:49:11	90	87	2.96
CB-32	1.565	58	1.722	48	39:37:24	102	62	2.95
CB-16	1.566	60	1.706	49	39:53:8	92	84	3.01
CB-17	1.566	60	—	—	—	—	—	—
DU-9	1.566	60	1.702	48	39:52:9	90	87	3.01
CB-19	1.569	66	1.708	48	40:46:14	91	85	3.03
H-1	1.566	60	1.703	48	39:51:10	94	79	2.94
DU-4	1.569	66	1.710	49	40:45:15	98	71	2.98
DU-7	1.567	62	1.714	48	40:42:18	95	77	2.97
NC-19A	1.566	60	1.708	49	40:46:14	99	68	3.05
NC-19B	1.569	66	1.710	49	40:45:15	99	68	2.97
CB-18	1.567	62	1.714	49	40:42:18	93	81	2.92
Micropeg. dolerite								
NC-37	1.566	60	1.690	47	34:61:5	—	—	2.94
JY-1B	1.570	68	1.702	44	35:54:11	—	—	2.95
CB-26	1.571	70	1.702	48	39:52:9	—	—	2.94
NC-31	1.567	62	1.694	45	35:58:7	—	—	2.95
CB-11	1.566	60	1.686	43	31:66:3	—	—	2.86

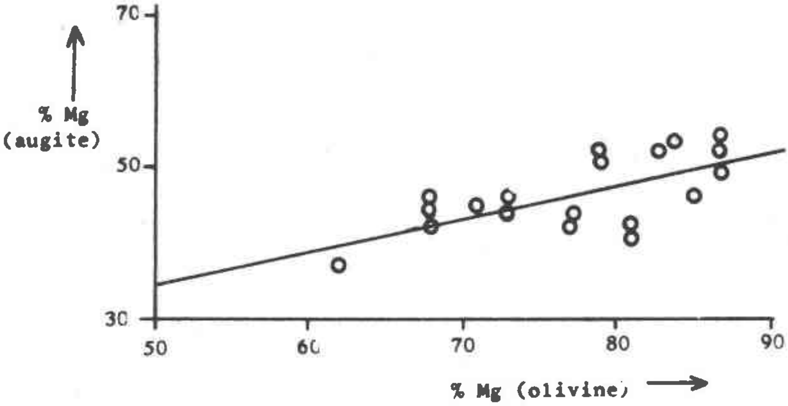

FIG. 3. Plot of Mg in augite against Mg in olivine.

tact to the center. The anorthite content of plagioclase does not appear to change beyond the margin of error across a dike. The data are not conclusive, however, because only two dikes were examined both at the contact and at the center.

No distinct variation between sheet-like bodies and dikes is apparent from the optical data.

Chemical Composition

Chemical compositions for the various dolerite groups, and for the central and contact areas of dikes were computed from the modes and mineral compositions (Table 3). The computed values are considered to

TABLE 3. ESTIMATED CHEMICAL COMPOSITIONS, CALCULATED FROM MODAL AND OPTICAL DATA FOR THE DOLERITE GROUPS (MEAN VALUES)

	1	2	3	4	5	6
SiO_2	42.9	45.6	46.9	49.2	44.9	45.2
Al_2O_3	9.8	16.1	17.3	16.8	12.8	17.6
Fe_2O_3	2.4	4.5	5.0	6.5	3.1	5.7
FeO	10.2	7.0	5.8	5.0	6.6	6.7
MgO	27.4	13.5	9.5	5.5	22.4	10.4
CaO	6.2	11.4	13.3	14.5	8.7	12.4
Na_2O	1.2	1.9	2.2	1.8	1.5	2.0
K_2O	—	—	—	0.7	—	—

1. Picritic dolerite
2. Olivine dolerite
3. Normal dolerite
4. Micropegmatitic dolerite
5. Mean dike center
6. Mean dike contact

be fairly reliable because the margin of error in modal determinations is low and because the approximate mineral compositions are known from the optical data.

Silica content is below 50% for each of the groups. A slight silica enrichment plus an increase in Al_2O_3 and Fe_2O_3 accompanies a decrease in olivine content. FeO and MgO decrease with decreasing olivine content.

In comparison to average, normal dolerite compositions (Nockolds, 1954), the following features appear regarding the chemical composition of the Deep River basin dolerite: low in silica and alkali oxides, low in ferrous iron, and high in ferric iron, alumina, magnesia, and lime.

A comparison of the calculated chemical compositions at the center and at the contact of two dikes indicates a strong increase of MgO toward the center (Table 3). Alumina, ferric iron, and lime increase toward the contact while SiO_2, FeO, and the alkalies remain nearly constant.

Discussion of Variations

The most significant variation revealed by this study is the wide range of mineral proportions from one intrusion to another. These varying mineral proportions do not appear to be correlated with specific locations in the basin; instead, the change is irregular throughout the entire area. For example, a specimen (NC-30A) from one dike contains 54% olivine, but the highest olivine content observed in neighboring dikes is 14%. Likewise, a specimen (CB-11) containing 27% micropegmatite was found to occur in an area where other intrusions contain as much as 18% olivine. A high percentage of olivine is more prevalent in dikes of large width, although some small dikes, mostly those intersecting larger ones, do have rather large amounts of olivine.

The change in mineral composition from one intrusion to another is generally small. The only significant change beyond the margin of error appears to be olivine. Olivine was observed to vary from Fo_{87} to Fo_{62} from one intrusion to another.

Within individual intrusions, the major variations seem to be an increase in the volume per cent of olivine, plus an increase in the fosterite content towards the center. For example, specimen NC-30A (Table 2), which is from the center of a dike 60 feet wide, has 54% olivine with composition Fo_{84}; specimen NC-30B, taken three feet from the contact of the same dike, contains 21% olivine with composition Fo_{73}. The composition of augite and plagioclase does not change appreciably across this dike. The data are not conclusive, however, since not all dikes were sampled both at the contact and at the center. Additional work is currently being conducted at the University of North Carolina on selected dikes in the Deep River basin, in an effort to solve the problem of zoned dikes.

Because of the insignificant changes in mineral composition, it is probable that little, if any, differentiation resulting in large mineral compositional variations took place after intrusion. Since most of the bodies examined are of relatively small width or thickness, significant differentiation would not be expected. Most of the intrusions probably cooled before extensive crystal fractionation was able to occur.

The petrogenesis problem, therefore, is mainly one of varying mineral proportions, rather than varying mineral compositions. This might be best explained by the intrusion of a basaltic magma mass which had undergone partial crystallization at depth with local concentrations of early crystals, especially olivine.

Certain parts of the magma mass could have been tapped-off during the time of dike intrusion. If so, different rock types would result depending on the part of the magma mass tapped, and on the particular stage at which the magma body had crystallized. Tapping-off of an olivine enriched zone would lead to a more basic rock type such as picritic dolerite. Micropegmatitic dolerite could be produced by the tapping-off of the late-stage liquid produced near the latter part of crystallization in the main magma mass, whereas intermediate dolerite types would be produced by the tapping-off of intermediate fractions. The more magnesium-rich pyroxene in the micropegmatitic dolerite may be explained by the fact that olivine is absent; hence all magnesium present will occur in the pyroxene.

Bowen (1928), authors of the Mull Memoir, and others have suggested that in basaltic and ultrabasic dikes, the intrusion of a fluent basic magma may be necessary before the inflow of more basic material. This would be true not because the more basic liquid was more viscous, but because it was already partly crystallized. The initial liquid magma would be able to flow freely into almost any fissure, while the latter, partially crystallized, more basic material could intrude only the larger fissures. In large dikes, the more basic material may have swept out the initial, fluent basaltic magma in the centers of these dikes. The result would be a dike with a large amount of olivine having a higher fosterite content at the center than at the contact.

Interstitial liquid swept away by the intrusion of the partially crystallized material might be squeezed upward into narrower parts of the same fissures, or into intersecting ones. The result would be a less basic rock, represented by micropegmatitic dolerite.

Small fissures through which only the initial fluent liquid could penetrate would result in a rock largely composed of augite, plagioclase, and a small amount of olivine, *i.e.*, normal dolerite.

Comparison with Other Triassic Areas

Dolerite of the Deep River Triassic basin differs in several ways from dolerite of other eastern United States Triassic basins. Average dolerite in the Deep River basin normally contains 15–20% olivine which is a substantially larger amount compared to dolerite in other basins. Stose and Lewis (1916), for example, mention that their most olivine-rich dolerite in Pennsylvania consisted of only 10% olivine. Roberts (1928), in a discussion of Virginia dolerite, cites olivine only as an accessory mineral, and olivine in dolerite from the Georgia Piedmont occurs in irregular but generally small amounts (Lester and Allen, 1950). Walker (1940), in his description of the Palisade dolerite, found a maximum of 25.5% olivine in the dolerite from the olivine-rich layer, whereas zones of certain dikes in the Deep River basin contain more than 50% olivine.

The usual texture of the rock is coarser than average dolerite from other areas, although coarse varieties exhibiting a granitic texture like those reported from parts of Pennsylvania (Stose and Lewis, 1916) and Virginia are not present. Moreover, no pegmatitic nor albitic dolerite was observed.

The Deep River basin dolerite shows less variation in mineral composition of minerals than dolerite from most other Triassic regions. This lack of differentiation might be due in part to the usually smaller size of most intrusions in the Deep River basin which resulted in cooling before extensive differentiation was able to occur. Although Deep River dolerite bodies are usually small, the number of individual bodies appears to be greater than in most other areas.

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