ART. XLI.—*Intrusive Granites and Associated Metamorphic Sediments in Southwestern Rhode Island*; by G. F. LOUGHLIN.

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INTRODUCTION.

Studies in southeastern Connecticut and southwestern Rhode Island have convinced the writer that all the granites in this area are parts of one composite batholith, and that this batholith is not of pre-Cambrian age, but is intrusive into rocks that have been mapped as Carboniferous. A detailed report on the southeastern Connecticut portion was completed about two years ago, and is awaiting publication by the United States Geological Survey.*

The present paper expresses the results of reconnaissance work from the Connecticut-Rhode Island boundary eastward to the vicinity of Narragansett Basin and of more detailed study along the western border of the Basin—here designated the Kingstown area.

Bibliography.—The granites of the area studied have been mentioned in a few publications, but their ages and structural relations have seldom received close attention, especially at critical points. C. T. Jackson, in 1840, mapped the granite as "Primary"† and the sediments of the Narragansett Basin as "transition graywackes" derived from the Primary. In 1899, Shaler, Woodworth, and Foerste published "The Geology of the Narragansett Basin, R. I."‡ Shaler and Foerste, who worked in the area under discussion, gave little attention to the granites bordering the Basin. They regarded them as Algonkian and distinct from the pegmatite dikes that cut the Carboniferous strata of the Basin. The latest geological map of North America§ represents the granite as pre-Cambrian.

* Contributions to Geology of Eastern Connecticut.

† Geol. and Agricult. Surv. of the State of R. I., 1840.

‡ U. S. Geol. Surv., Mon. XXXIII, 1899.

§ Bailey Willis, Geol. Map of No. America, 1906.

B. K. Emerson and J. H. Perry* in 1907 described and mapped the formations along the western border of the Narragansett Basin. The southern end of their area overlaps the northeast corner of the area here discussed, but no contacts are there exposed. They also mapped the granite as pre-Cambrian (fig. 1 of this paper).

Résumé of Evidence in S. E. Connecticut.

As the writer's work here described has been essentially a continuation of his studies in southeastern Connecticut, a summarized statement of the character and relations of the granite and adjacent metamorphic sediments in that area is here given to serve as a basis for correlation.† A portion, also, of the map is copied (fig. 1, west of long. $71^{\circ} 45'$ and north of lat. $41^{\circ} 25'$).

The metamorphic sedimentaries shown in the map are a quartzite (Plainfield quartz-schist) and a more extensive quartz-biotite-schist, more or less feldspathic (part of the Putnam gneiss series). These, and closely related metamorphics not shown in the map are characterized by the general predominance of plagioclase wherever feldspar is present. The composition of the plagioclase ranges from Ab_3An_1 to Ab_1An_3 . They are possibly of Carboniferous age.

The granite—Sterling granite series—mostly of pink color and gneissoid structure, includes three varieties: normal biotite-granite, porphyritic biotite-granite, and alaskite. The alaskite is known to cut the other two varieties, but all gradations in composition and texture appear. All the varieties are intrusive into the sedimentary series. Pegmatite and aplite, in sheets and dikes, cut the granite series, and are abundant in the metamorphic sediments. The granite series is characterized by a well-developed microcline, in some cases microperthitic, white oligoclase, or albite, and some quartz.

The relation of the micro-textures of the granites to regional metamorphism has been treated at some length in the original paper, with the conclusion that the normal and porphyritic types were intruded and crystallized while the disturbing forces were most active, and that the alaskite became solid during the waning stage of regional movement. This relation, if the sedimentary series includes Carboniferous rocks, correlates the time of metamorphism and intrusion with that of the Appalachian Revolution. The question of age will be further considered towards the end of this paper.

* The Green Schists and Associated Granites and Porphyries of Rhode Island, U. S. G. S. Bull. 311, 1907.

† By permission of the Director of the U. S. Geol. Survey.

Evidence at Westerly and Niantic, R. I.

The writer during the past six years has made several visits to the Westerly, R. I., granite quarry district along the southern part of the Connecticut boundary, and one visit to the neighboring and similar district of Niantic, R. I. (fig. 1) He finds at these places the above summarized evidence duplicated and supplemented by a later intrusion—that of the Westerly granite. Metamorphic sediments here appear only as isolated inclusions in granite. Both the sediments and the Sterling granite series are cut by dikes of the fine-grained Westerly granite (quartz-monzonite according to Dale).^{*} The latter rock has the same mineralogic characters as the Sterling granite, differing only in containing a higher percentage of plagioclase. Its contact phase and apophyses are medium-grained to pegmatitic, and cannot be distinguished in the specimen from the Sterling granite series. The contacts of the Westerly with the Sterling granite are sharp, but the close petrographic resemblance between the two rocks and the absence of any evidence indicative of widely different age favor the interpretation that the Westerly granite is not a type independent of the Sterling granite series, but the latest exposed phase of the same batholith.

Reconnaissance Eastward to the Kingstown Area.

Two reconnaissance traverses have been made across southwestern Rhode Island, one extending from the southeastern Connecticut area eastward to Wickford Junction, the other from Hope Valley southward to Niantic and thence eastward, in a zigzag course, to Wakefield (fig. 1). The outcrops visited are plotted on the map. Those along the first, or northern, traverse are identical in character with the normal gneissoid Sterling granite, save one outcrop of the porphyritic type a mile west of Millville. The normal type is disintegrated to a considerable extent, a characteristic feature in parts of southeastern Connecticut, and some outcrops are completely reduced to a coarsely granular soil to a depth of six feet or more.

Short veins of pegmatite and pegmatitic quartz, from less than an inch to one foot in width, are commonly present, most of them cutting across the schistosity of the granite. One small dike of fine-grained granite, similar to the Westerly type, was noted on the southward sloping ridge $1\frac{1}{2}$ miles east of Pine Hill. No inclusions of the metamorphic sediments were found.

A glance at the map will show that no outcrops were found along the eastern three miles of the traverse; but over 99 per

^{*} Dale, T. N., *The Chief Commercial Granites of Mass., N. H. and R. I. Bull.* U. S. G. S., No. 354, 1908, pp. 190 et seq. The reader is referred to this Bulletin for structural and petrographic details.

cent of the abundant boulders in these three miles, and in fact along the whole traverse, are of the normal gneissoid Sterling granite, and it is the writer's experience that the majority of boulders in southern New England are of strictly local origin. The granite therefore is believed to be continuous from the Connecticut boundary to the edge of the Narragansett Basin, $1\frac{1}{2}$ miles west of Wickford Junction, but the relations there between the granite and the rocks of the Basin are concealed by drift.

The eastern part of this traverse overlaps a small part of the area mapped by Emerson and Perry as a southward continuation of the pre-Cambrian Northbridge gneiss of Massachusetts. The thorough concealment of all contact relations renders it impossible at this point to choose between the conclusion of the authors cited and that of the writer. Evidence supporting the writer's views will be presented in the description of the Kingstown area.

Evidence along the southern traverse is not quite so inconclusive as that just presented. The granite outcrops are all of the Sterling types, chiefly the normal and to some extent the porphyritic. Two small dikes of the Westerly type were noted; one a mile south of Plainfield, the other on the summit of Shumukanug Hill. No outcrops were found along the eastern six miles of the traverse, but here again practically all the boulders are of the Sterling granite.

Exposed inclusions of the metamorphic sediments are very scarce and only one deserves mention. This one lies in the road on the hill a mile west of Worden's Pond (see map, fig. 1). Its texture is pseudo-porphyrific with flattened, lens-shaped pebbles of quartz-schist, but the matrix is identical in color and texture with the quartz-biotite schist exposed in southeastern Connecticut and at Westerly. It is also similar to the most severely metamorphosed conglomerate in the Kingstown area. It is cut by a narrow pegmatite dike of the Sterling (or Westerly) type. This evidence though limited proves that the age relations found in Connecticut and at Westerly exist as far east as Worden's Pond.

The Kingstown Area.

The limits of the Kingstown area are shown in fig. 2. It includes the west boundary of the Narragansett Basin sediments from Hamilton southward, and has yielded decisive evidence for determining the relative ages of the rocks in question. The area was studied and mapped in detail by Messrs. Y. S. Bonillas and V. M. Frey under the writer's direction.* The

* MS. thesis No. 340, 1908, Min. Dept. Mass. Inst. Tech., Boston, Mass.

FIG. 1.

FIG. 1. Geologic map of S. W. Rhode Island and S. E. Connecticut. Detailed mapping is expressed only in the eastern and western portions of the area. Only outcrops seen by the writer are shown in the central portion, which is believed to consist essentially of the Sterling granite.

writer has not visited every outcrop in the area, but has studied the continuous exposures along the shore of the Bay, and all the exposed granite contacts, and has examined thin sections of the several rock types represented.

Granite.—The various granite exposures include types identical in texture, mineral composition, and structural relations with the several members of the Sterling series (including the Westerly granite). These types and their relations to one another are perfectly shown in the continuous granite ledge which extends along the shore of the Bay from Narragansett Pier for two miles southward. There is, in addition to the types previously mentioned, a pegmatitic muscovite granite which, as will be shown presently, is a contact phase of the Sterling batholith, and is transitional into those pegmatites which were previously interpreted as post-Carboniferous.* Muscovite variations are present in the areas previously described, but only in the Kingstown area are they conspicuous and important. The feldspars of the muscovite granite are the same in character and composition as those of the other types. Schist inclusions are found in all the granite types.

Normal and porphyritic Sterling granite, moderately to highly gneissoid, are the prevailing types in the Kingstown area. They comprise the body of the two-mile exposure along the shore, and are exposed to the north on Rose, McSparren, and Hammond Hills. Exposures are few at intervening points, but are of the same types of granite. Small pegmatite dikes, more or less muscovitic, are of common occurrence. The northern part of this area also overlaps the southern limits of the area previously mapped as pre-Cambrian (see p. 448); but here again, owing to the general lack of local evidence, it is impossible to choose between the differing interpretations. Weathered schist inclusions are found on McSparren Hill, but the presence of these alone is not convincing evidence.

Definite evidence, however, is afforded east of Wakefield, at the bend of Indian Run, in an exposed contact with quartz-biotite schist, the metamorphic sediments of the Narragansett Basin. The granite a short distance from the contact is red, distinctly gneissoid, and irregularly porphyritic. Both its megascopic and microscopic characters are identical with those of the Sterling granite types of Connecticut. As the contact is approached, the gneissoid character is obscure or absent, and pegmatitic segregations are numerous. Distinct dikes of pegmatite are also present, cutting the granite. The adjacent schist is penetrated by many pegmatitic apophyses, most of which follow the foliation planes.

A mile eastward, along the southeast slope of Tower Hill,

* U. S. G. S. Mon. XXXIII, p. 377.

FIG. 2.

FIG. 2. Detailed geologic map and sections of parts of North and South Kingstown, R. I., along the western border of the Narragansett Basin. Boundaries actually exposed or definitely located are represented by solid lines; indefinite boundaries by dotted lines. The dotted lines in the sections indicate the unexposed surfaces of bed rock.

are excellent exposures of granite apophyses following and cutting across the foliation of the schist. The apophyses are medium-grained to pegmatitic, slightly to highly muscovitic, and of red to white color. The white color is more pronounced in the more highly muscovitic rock. The pegmatitic and muscovitic characters are best developed in the large dikes (fig. 2), which cut approximately at right angles to the foliation of the schists. These dikes, or large apophyses, are exposed at intervals along Tower Hill towards Bridgetown.

Excavations in a graphitic bed of the schist, between one and two miles south of Bridgetown, have exposed pegmatite dikes and associated quartz veins. The graphitic rock is also cut by small, branching, fibrous veins composed chiefly of sillimanite, quartz, and muscovite. These veins are believed to be genetically associated with the pegmatite, but no careful study has yet been given them in connection with the problem under discussion.

Similar, and even more convincing, evidence is found along the shore of the Bay from Little Neck northward to Hazzard's quarry. The muscovitic granite with schist inclusions is the prevailing rock on Little and Boston Necks. It is increasingly muscovitic and pegmatitic as the contact with the schists is approached. At Watson's Pier schist, cut by many large dikes of the granite and pegmatite, is the prevailing rock. Large pegmatite dikes are numerous along the coast as far as the north end of the Bonnet, and outcrop at intervals as far north as Saunderstown. From this point northward, pegmatite dikes are scarce, and the northernmost exposure seen is at Hazard's quarry. Here is a small dike consisting chiefly of quartz with a little feldspar and practically no mica. A few quartz veins with rare feldspar crystals, exposed near the summit of Barber's Heights, are the northernmost pegmatitic exposures found. The evidence in the Kingstown area, therefore, appears conclusive that the granites bordering the metamorphosed Narragansett Basin sediments are members of the Sterling batholith and are intrusive into the schists. Petrographic study proves that the pegmatite dikes on Tower Hill and along the shore of the Bay are not independent intrusions, but apophyses from Sterling batholith, tending to grade into quartz veins as the distance from the batholith increases. Evidence in the whole area studied has proved that the granites of southwest Rhode Island, south of the Washington Co.-Kent Co. boundary (fig. 1) are not of pre-Cambrian age as previously supposed, but belong to the Sterling batholith, the youngest formation (including the Westerly granite dikes) of the area.

Time of Intrusion.—The details of metamorphism in the

Kingstown area have not been exhaustively studied, but it is very evident, from the field work done, that vertical dips and the most complete recrystallization of the sediments are found where granitic intrusions are most abundant. There seems, then, no reason for doubting that in the Kingstown area, as well as in southeastern Connecticut, the granite intrusion accompanied metamorphism and folding. As the Kingstown sediments have been determined to be of Carboniferous age,* the time of granite intrusion and folding may be correlated with the Appalachian Revolution.

The Kingstown Sediments.—As the Kingstown sediments have heretofore been regarded as resting unconformably upon the granite, a study of their composition is necessary for a complete solution of the problem here considered, and as a check on the conclusions already reached. Detailed descriptions of outcrops have been made by Foerste,† and only petrographic evidence is considered here.

The sediments comprise chiefly an alternating series of light to dark gray arkose, conglomerate and phyllite beds, with at least one highly graphitic bed. Metamorphism effects are everywhere distinct, varying from moderate around Hamilton, the northernmost point studied, to extreme in close proximity to granite contacts. In the latter case traces of elastic structure are nearly, or quite, obliterated, and the rocks are typical gray gneisses and schists, penetrated by the reddish granite.

The pebbles of the less metamorphosed conglomerate comprise quartzite, quartz-sericite schist, black very fine-grained slaty schist, vein-quartz, felsite-porphyry, a fine even-grained granite. The granite pebbles, which do not resemble the Sterling or Westerly granite, will be separately described below. In the highly metamorphosed conglomerate, the pebbles appear as flattened lenses and even linear streaks. Only the less severely mashed are clearly recognizable. The arkose and the matrix of conglomerate consist of quartz, feldspar, biotite, and muscovite in varying amounts. The most metamorphosed exposures present the same general megascopic characters and variations as the quartz-biotite schist of southeastern Connecticut. Thin sections prove the feldspars to be mostly plagioclase with a few of poorly defined microperthite and, possibly, of orthoclase. Not a feldspar grain was noted with the well-developed microcline twinning so characteristic of the feldspar in the Sterling and Westerly granite, save in the one instance, 1¼ miles south of Narragansett Pier, of a schist inclusion which is thoroughly injected with dikelets and stringers from the granite.

* Mon. XXXIII, U. S. G. S., plate xxxi.

† Op. cit., pp. 215 et seq.

Granite Pebbles.—The granite pebbles in the conglomerate are light gray to pink, fine even-grained to sub-porphyrific, and consist of finely intergrown quartz and feldspar with a little biotite and muscovite. Three thin sections were studied; one of a pebble from an outcrop $1\frac{1}{2}$ miles west of Wickford Junction (fig. 1), one from an outcrop $\frac{1}{4}$ mile southeast of Hamilton, and one from a boulder south of McSparren Hill. The three thin sections present the same characters. The texture is conspicuously micrographic. The primary minerals are plagioclase and micropertlite in about equal amounts, quartz, biotite, and the usual minor accessories; the chief secondary minerals are muscovite, replacing feldspars, and chlorite replacing biotite. The micropertlite is the same type as that noted in the arkose and conglomerate matrix. The plagioclase mostly corresponds to oligoclase-andesine, though some grains appear more basic. These characters suffice to point out the decided lack of resemblance to the Sterling granite.

Derivation and Correlation of the Kingstown Sediments.—The composition of the Kingstown sediments thus verifies the conclusions already stated, and no evidence whatever remains to indicate that the Sterling granite is not the younger rock. The Kingstown sediments were derived from a series of quartzites and black slaty schists, felsite-porphry, and igneous rocks containing considerable plagioclase. The plagioclase may come wholly or in part from the fine-grained granite and possibly in part from more basic igneous rocks, no pebbles of which have yet been found. None of these rocks are found within the area studied, but they may be represented in the Cambrian formations and the granite-porphyrries to the north.*

The general similarity in mineral composition between the Kingstown sediments and the quartz-biotite schists of the southeastern Connecticut and the Westerly-Niantic, R. I., districts favors the correlation of these rocks as parts of one extensive formation. Fossil evidence in the areas studied is wholly lacking, but structural and petrographic evidence favors this provisional conclusion.

Summary.

The principal conclusions reached in this paper are as follows:

1. The Westerly granite is closely related to the Sterling granite in general character and mineral composition, and is considered the latest exposed phase of the Sterling batholith.
2. The Sterling granite batholith is continuous from eastern Connecticut to Narragansett Bay, R. I., and includes granite formerly thought to be pre-Cambrian. There are no

* Emerson and Perry, op. cit., pl. 1.

pre-Cambrian rocks in Rhode Island south of the Washington Co.-Kent Co. boundary.

3. The Sterling granite batholith is intrusive into all the sediments with which it is in contact, including the Kingstown sediments of the Narragansett Basin, and its intrusion accompanied metamorphism and folding.

4. Since the Kingstown sediments are said to be of Carboniferous age, the time of the granite intrusion, metamorphism and folding may be correlated with that of the Appalachian Revolution.

5. The Kingstown series were derived principally from metamorphic rocks of possible Cambrian age, from felsite-porphry, fine-grained micrographic granite, and possibly more basic igneous rocks.

6. In the absence of fossil evidence, structural and petrographic data favor provisional correlation of the Kingstown sediments with the quartz-biotite schists found in southeastern Connecticut and at Westerly and Niantic, R. I.

Massachusetts Institute of Technology.