

## METAMORPHIC DEVELOPMENT OF THE EASTERN PART OF THE CRAWFORD NOTCH QUADRANGLE, NEW HAMPSHIRE

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The Crawford Notch quadrangle is situated in the White Mountains of central New Hampshire. The rocks in the quadrangle are of two major types: (1) metamorphic and plutonic rocks of Devonian age and (2) mildly alkaline igneous rocks of probable Mississippian age. This paper is concerned with the evolution of the Devonian metamorphic and plutonic rocks.

### LITHOLOGY

*Terminology.*—The term “granitic” material is used in a megascopic descriptive sense to refer to light-colored granitic-looking rock contained in gneiss and schist. The terms granite, quartz monzonite, granodiorite, and quartz diorite are used purely in a descriptive sense to designate essentially massive granular rocks which have mineralogic compositions according to the classification of Johannsen (1939). None of these terms have genetic connotations.

*General features.*—The Devonian rocks consist mainly of gneiss and schist of the Littleton formation which contain about 50 percent of intermixed “granitic” material. A small amount of fine-grained gneiss and lime-silicate granulite is locally interbedded in the gneiss and schist.

Also in the area are three bodies of quartz monzonite each approximately two miles across.

*Littleton formation.*—The bulk of the Littleton formation consists of medium-grained biotite-muscovite gneiss which contains approximately an equal amount of “granitic” material in lenses, bands, and small irregular bodies. Locally, the amount of “granitic” material ranges from a few percent to almost 90 percent. It is predominantly concordant in rocks which contain less than 50 percent. Much is discordant in rocks which contain more than 50 percent. The mineralogic composition of the average gneiss is given in column 1 of table 1. The mineralogic composition of the “granitic” material is like that of column 3 of table 1.

Six areas of schist which range from approximately one-half to two square miles occur in the gneiss in the northeastern quarter of the quadrangle. The typical schist is medium-grained muscovite-biotite-chlorite schist and is spangled with porphyroblasts of muscovite approximately 0.5 to 1 cm. across. Most of the schist contains approximately 50 percent “granitic” material similar to that in the gneiss. In many areas the schist occurs as fragments ranging from an inch to many feet across. A body of schist in the northeast corner of the quadrangle and a small projection of schist from a large area in the Mt. Washington quadrangle to the north are the only large areas of schist which contain

TABLE 1.—APPROXIMATE MODES OF METAMORPHIC AND PLUTONIC ROCKS, CRAWFORD NOTCH QUADRANGLE, N. H.

	1	2	3	4	5	6	7	8
Biotite.....	20	10	..	30	..	..	30	3
Muscovite.....	20	40	20	20	..	..	..	2
Quartz.....	35	15	50	20	..	25	30	30
Plagioclase.....	20	15	25	20	30	25	20	33
Perthite.....	..	..	5	..	..	..	..	30
Chlorite.....	5	20	..	10	..	..	..	2
Sillimanite.....	tr	tr	..	..	..	..	..	tr
"Orthoclase".....	..	..	..	..	40	30	..	..
Actinolite.....	..	..	..	..	20	..	10	..
Diopside.....	..	..	..	..	10	20	..	..
Garnet.....	..	..	..	..	..	..	10	..
Percent of anorthite in plagioclase.....	20	20	20	20	50	60	80	20

1. Average mode of gneiss.
2. Average mode of schist.
3. Average mode of "granitic" material in schist.
4. Fine-grained thin-bedded gneiss, railroad cut, Crawford Notch.
5. Actinolite-diopside granulite, central part of Crawford Notch quadrangle.
6. Diopside-actionolite granulite, central part of Crawford Notch quadrangle.
7. Biotite-actinolite-garnet granulite, east edge of Crawford Notch quadrangle.
8. Average mode of quartz monzonite.

practically no "granitic" material. An average mode of the schist is given in column 2 of table 1. An average mode of "granitic" material in schist is given in column 3 in table 1.

Lenses and groups of beds of fine-grained gneiss and lime-silicate granulite which range from a few inches to tens of feet thick are scattered through the gneiss and schist. The bedding is almost undeformed in most places, and in many places resembles the bedding of varved clay. The composition differs greatly in different beds. Some of the most typical compositions are shown in columns 4 to 7 in table 1. Much of

the fine-grained gneiss and lime-silicate granulite occurs in broken fragments and slabs, ranging from a few inches to tens of feet across, in gneiss and schist containing 50 percent "granitic" material.

*Quartz monzonite.*—Rocks included under the term quartz monzonite actually range in composition from sodic quartz diorite to granite. The structure ranges from gneissose to massive. The average rock is slightly foliated biotite-muscovite quartz monzonite. An average mode is given in column 8 of table 1.

Much of the quartz monzonite occurs in dikes and irregular small bodies in the Littleton formation. It is similar in appearance to the predominantly concordant "granitic" material in the Littleton formation. The distinction between the quartz monzonite and the "granitic" material is arbitrary and is based chiefly on structural relations. The quartz monzonite is predominantly discordant and occurs in larger bodies than the "granitic" material.

The quartz monzonite occurs in only three bodies large enough to map geologically. The contacts are gradational into the gneiss and schist of the Littleton formation. An interesting relationship exists between the size and composition of the bodies of quartz monzonite. In general, the small bodies are quartz dioritic or granodioritic in composition, whereas the larger bodies approach a true granitic composition.

## STRUCTURE

Only a brief and generalized account will be given of the structural features. The rocks are greatly and irregularly contorted and the detailed structural relations are not easily discernable because of their

TABLE 2.—CHEMICAL ANALYSES OF DEVONIAN METAMORPHIC AND PLUTONIC ROCKS IN NEW HAMPSHIRE

	1	2	3	4	5	6	7	8
SiO <sub>2</sub> .....	58.92	58.14	61.40	56.23	66.68	62.87	63.5	68.8
TiO <sub>2</sub> .....	0.93	0.65	0.92	1.11	0.87	0.92	0.9	0.4
Al <sub>2</sub> O <sub>3</sub> .....	18.55	21.00	19.04	23.15	18.17	17.43	17.6	15.9
Fe <sub>2</sub> O <sub>3</sub> .....	0.94	0.33	0.63	1.17	0.90	0.55	0.9	0.5
FeO.....	6.63	6.32	6.90	6.94	4.98	6.67	6.5	4.0
MnO.....	0.08	0.06	0.07	0.12	Tr.	0.23	Tr.	Tr.
MgO.....	3.24	3.41	2.10	2.21	1.42	2.71	2.5	1.2
CaO.....	0.48	0.32	0.90	0.26	0.76	0.59	0.7	1.5
Na <sub>2</sub> O.....	1.49	1.10	1.30	1.14	0.74	1.71	1.7	2.9
K <sub>2</sub> O.....	3.74	3.85	3.74	4.53	2.89	4.08	4.0	4.2
H <sub>2</sub> O+.....	3.90	4.47	2.89	2.75	1.75	2.10	2.0	0.6
H <sub>2</sub> O.....	0.11	n.d.	0.06	0.09	0.40	0.08		
CO <sub>2</sub> .....	0.25	0.00	0.01	0.01	0.00	0.02		
P <sub>2</sub> O <sub>5</sub> .....	0.14	0.00	0.08	0.18	Tr.	0.11		
S.....	0.17	0.09	0.08	0.02	0.05	0.04		
ZrO <sub>2</sub> .....	n.d.	0.04	n.d.	n.d.	n.d.	n.d.		
C.....	n.d.	n.d.	n.d.	n.d.	0.29	n.d.		
O-S corr....	-0.06	.....	-0.03	.....	.....	-0.02		
Total...	99.51	99.78	100.09	99.90	99.90	100.09	100.0	100.0

1. Slate, Littleton formation, Littleton quadrangle (Billings, 1941, p. 902).
2. Slate, Littleton formation, Littleton quadrangle (Billings, 1937, p. 556).
3. Fine-grained pseudo-andalusite schist, Littleton formation, high-grade zone, Mt. Washington quadrangle (Billings, 1941, p. 902).
4. Coarse pseudo-andalusite schist, Littleton formation, high-grade zone, Mt. Washington quadrangle (Billings, 1941, p. 902).
5. Sillimanite schist, Littleton formation, high-grade zone, Franconia quadrangle (Billings, 1938).
6. Banded gneiss, composed of approximately equal amounts of dark and light bands, Littleton formation, Mt. Washington quadrangle (Billings, 1941, p. 902).
7. Approximate average composition of gneiss and schist in the Littleton formation, Crawford Notch quadrangle. Calculated from the average mode.
8. Approximate average composition of quartz monzonite in the Crawford Notch quadrangle. Calculated from the average mode.

complexity and irregularity, the intense metamorphism, and the lack of outcrops in many critical places. Most of the major folds probably trend approximately northeast-southwest. Minor folds rarely show systematic relations to one another or to major folds. Irregular minor folds are particularly conspicuous in areas of gneiss and schist which contain abundant "granitic" material.

Much of the quartz monzonite oc-

curs in irregular discordant bodies which are less than 50 feet across. It is so abundant in most of the gneiss and schist that it cuts these highly contorted rocks into extremely coarse breccias with blocks ranging from an inch to several hundred feet across.

The large bodies of quartz monzonite are irregularly shaped, essentially cross-cutting and gradational into the surrounding gneiss and schist. The foliation of the quartz monzonite and the foliation of the abundant bands of gneiss and schist within the quartz monzonite are essentially parallel to that of the surrounding gneiss and schist.

#### METAMORPHISM

*Original nature of the Littleton formation.*—Local preservation of sedimentary bedding, the chemical composition, and correlation with rocks of unmistakable sedimentary origin in the Littleton-Moosilauke area indicate that the gneiss, schist,

fine-grained gneiss and lime-silicate granulite originally were sediments. Lithologic correlation and comparison of the chemical composition of the high-grade metamorphic rocks in the Crawford Notch area with those of the low-grade shales and slates in the Littleton quadrangle indicate that the original sediments in the Crawford Notch region were predominantly shales and sandy shales. Analyses and calculated analyses of such rocks may be compared in table 2. The mineralogic compositions of the fine-grained gneiss and lime-silicate granulite (table 1) indicate that small amounts of impure sandstone, arkose, and dolomite were interbedded with the shale.

*Stage of recrystallization.*—The first major change during metamorphism of the shaly sediments probably was simple recrystallization with essentially no differential movement of chemical constituents over distances greater than a few millimeters. The resulting products were schist and gneiss which probably contained no intermixed "granitic" material. Although most of the recrystallized rocks were subsequently greatly modified, local remnants have survived. The rocks were recrystallized in response to increase in temperature and pressure, particularly differential pressure. The generally coarse grain-size and the widespread occurrence of sillimanite indicate that high-grade conditions were reached throughout most of the quadrangle.

*Stage of reconstitution.*—Throughout most of the quadrangle simple recrystallization was followed by a stage of reconstitution which involved widespread movement of material. The resulting product was gneiss and schist containing abun-

dant intermixed "granitic" material. Movement of material is clearly indicated by the occurrence of all stages of destruction of the original sedimentary features which survived the stage of recrystallization. Furthermore, all steps in the regrouping of constituents into light and dark bands can be observed. Although movement of material was widespread the similarity in composition (table 2) of the reconstituted rocks and the original and recrystallized rocks indicates that the distance of movement of the individual constituents probably was less than a few feet or tens of feet.

The reconstitution of the schist and gneiss into rocks with segregated dark and light bands is believed to have taken place by a process of metamorphic differentiation essentially like that proposed by Eskola (1932). The process depends chiefly upon the greater solubility of the light-colored minerals and a tendency for the constituents of such minerals to collect and crystallize along the foliation. Metamorphic differentiation was favored by continuation and increase in temperature conditions from the preceding stage of recrystallization. The movement of constituents in metamorphic differentiation probably was chiefly in solution by flow and diffusion through inter-granular and larger spaces. Solid diffusion through crystal structures probably was not important because the larger atoms or ions such as K, Na, and Ca apparently moved as easily as the smaller Fe, Mg, and Al atoms.

*Stage of metasomatism.*—A stage involving differential movement of material followed the stage of reconstitution and resulted in the formation of the typically discordant quartz monzonite. The stages prob-

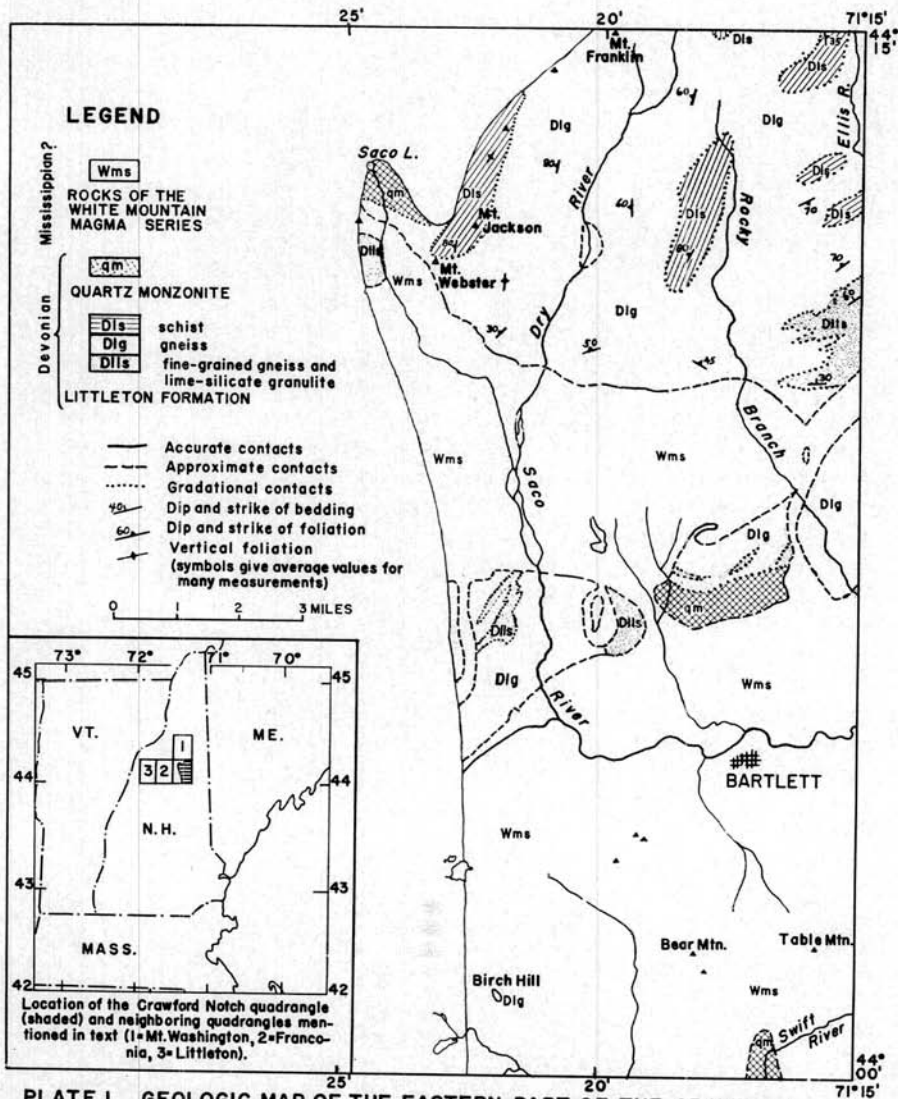


PLATE I. GEOLOGIC MAP OF THE EASTERN PART OF THE CRAWFORD NOTCH QUADRANGLE, N.H.

ably were transitional because complete gradation exists between the composition and structural occurrence of the "granitic" material in gneiss and schist and those of the quartz monzonite.

Comparison of the composition of the average quartz monzonite with that of the older rocks (table 2) indicates an introduction of CaO, Na<sub>2</sub>O, K<sub>2</sub>O, and SiO<sub>2</sub> and a removal of FeO, MgO, and Al<sub>2</sub>O<sub>3</sub>. The differential movement of material causing the changes in composition probably was aided by widespread fracturing of the previously formed rocks which allowed easier movement of material over distances of many feet. The formation of the large bodies of quartz monzonite may have been favored by localized extreme fracturing. Intermediate steps in the formation of the larger bodies are apparent in many places.

Metasomatism or intrusion of melts appear to be the major alternative mechanisms for the production of the quartz monzonite. Metaso-

matism by solutions contributing CaO, Na<sub>2</sub>O, K<sub>2</sub>O and SiO<sub>2</sub> and removing FeO, MgO, and Al<sub>2</sub>O<sub>3</sub> is believed to be the most probable mechanism because of abundant evidence of replacement and because of the large amount of heat necessary to produce a silicate melt.

*Retrograde stage.*—The preceding stages produced under conditions of increasing temperature and pressure were followed in many places by changes apparently in response to conditions of decreasing intensity. The changes were similar to those in many other areas. The most conspicuous were chloritization of biotite and sericitization of sillimanite, andalusite, and plagioclase.

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