American Journal of Science

TRACE ELEMENTS IN ROCKS OF THE OLIVERIAN MAGMA SERIES OF NEW HAMPSHIRE.

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ABSTRACT. Spectrographic analyses of 21 specimens from an intrusive body in west-central New Hampshire were prepared. The igneous mass belongs to the Oliverian magma series and is considered to be of late Devonian age. Though ranging from quartz diorite to granite, all petrographic types are gradational and, in most respects, are remarkably similar.

Earlier studies have led to the conclusion that the mass crystallized originally as a potash-poor granodiorite with quartz diorite locally developed (border facies). The granite and quartz monzonite are considered to have developed as a result of the introduction of microcline commonly as large metacrysts.

Spectrographic analyses also show a remarkable similarity in the various rock types and a marked uniformity of distribution of trace elements throughout the body. This is in harmony with the original theory of petrogenesis offered for this pluton.

PURPOSE OF THE STUDY.

THE geologic mapping of western New Hampshire has revealed four distinct magma series (Billings, 1937, p. 469-470). Within the past 15 years very extensive and detailed work on these intrusive rocks has been done by numerous persons which shows that each magma series is characterized by its own mineralogy, petrology, and mode of intrusion.

In some instances, however, it is difficult to distinguish these magma series or groups within series, thereby impeding the correlation of certain igneous rock bodies. The present study was initiated to determine whether spectrographic work would reveal differences in the micro-chemistry of the rocks comparable with those differences in mineralogy and petrography.

Since the writers are somewhat more familiar with the Oliverian magma series and have at hand a representative collection from one of its larger and more diversified bodies, they
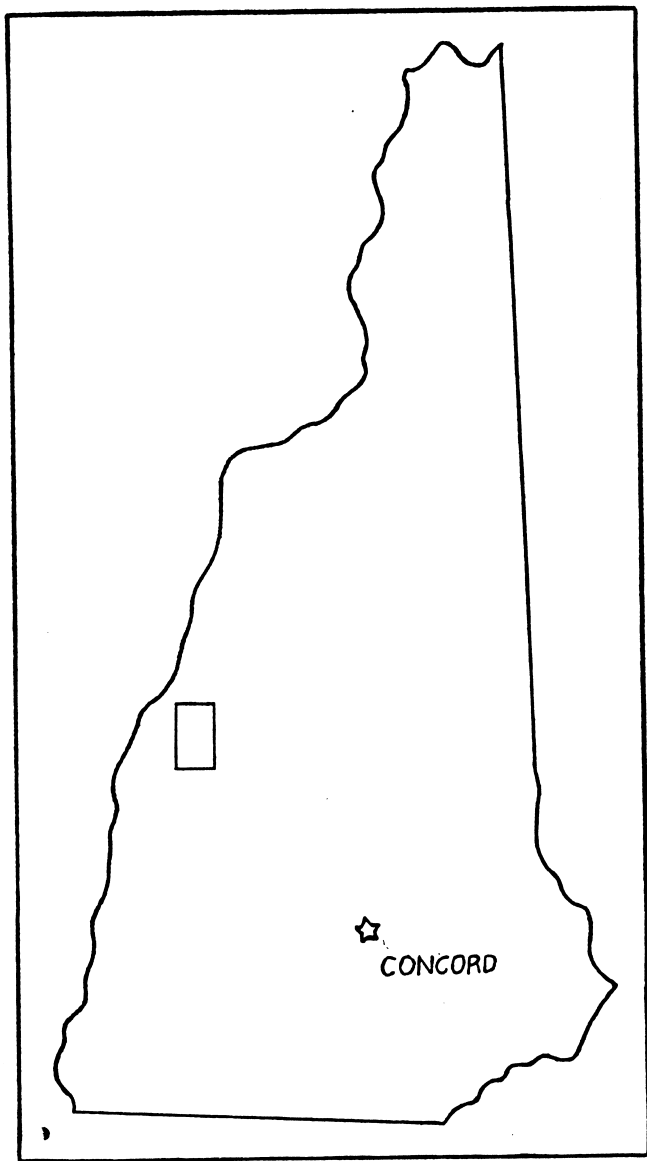

Fig. 1. Index Map.
Showing location of the Mascoma dome in west-central New Hampshire.

chose this series as the first to be studied. It was anticipated that these studies would reveal the more abundant of the trace elements present, and that a set of "index" or "key" elements might be determined for each group within the series as well as for each petrographic type within a group.

The first analyses of the Oliverian magma series were made of 21 representative specimens selected from the Mascoma group which constitutes the core of the Mascoma dome in west-central New Hampshire (Fig. 1).

NATURE OF THE MASCOMA GROUP.

Structure. The Oliverian magma series in western New Hampshire consists of a series of intrusive rocks of late (?) Devonian age which occur in domical bodies in metamorphic rocks. The Mascoma dome (Fig. 2) furnishes a typical example of this plutonic series, and its relation to the surrounding metamorphic rocks and is the one chosen for this study. An igneous core (the Mascoma group) surrounded by concentric belts of outwardly dipping metamorphic rocks conveys a simplified picture of the more complicated structure shown in Figure 3. The Ammonoosuc volcanics (Upper Ordovician (?)) constitute the innermost belt and are composed chiefly of amphibolites. The Clough formation (Lower or Middle Silurian) forms the next outer belt but mainly on the west flank of the dome. Here the formation is composed of quartzite, quartz conglomerate, and mica schist. Beyond the Clough formation, on the west flank of the dome, is a wide belt of mica schists of the Littleton formation (Lower Devonian). Between the Clough and Littleton formations, at the north end of the dome, is a narrow belt of the Fitch formation (Middle Silurian) composed of mica schists and lime-silicate granulite. At the south end the Mascoma group comes in contact with the Bethlehem gneiss (Late Devonian). Figure 3 shows the striking parallelism between the foliation of the plutonic core and the bedding and foliation in the surrounding metamorphic rocks.

Petrography. The Mascoma group consists of fine-grained to medium-grained granitic rocks which range in color from white to gray. A foliation is detectable in nearly all specimens due to parallel arrangement of small flakes of biotite. This foliation is believed (Chapman, 1939, p. 155-7) to be
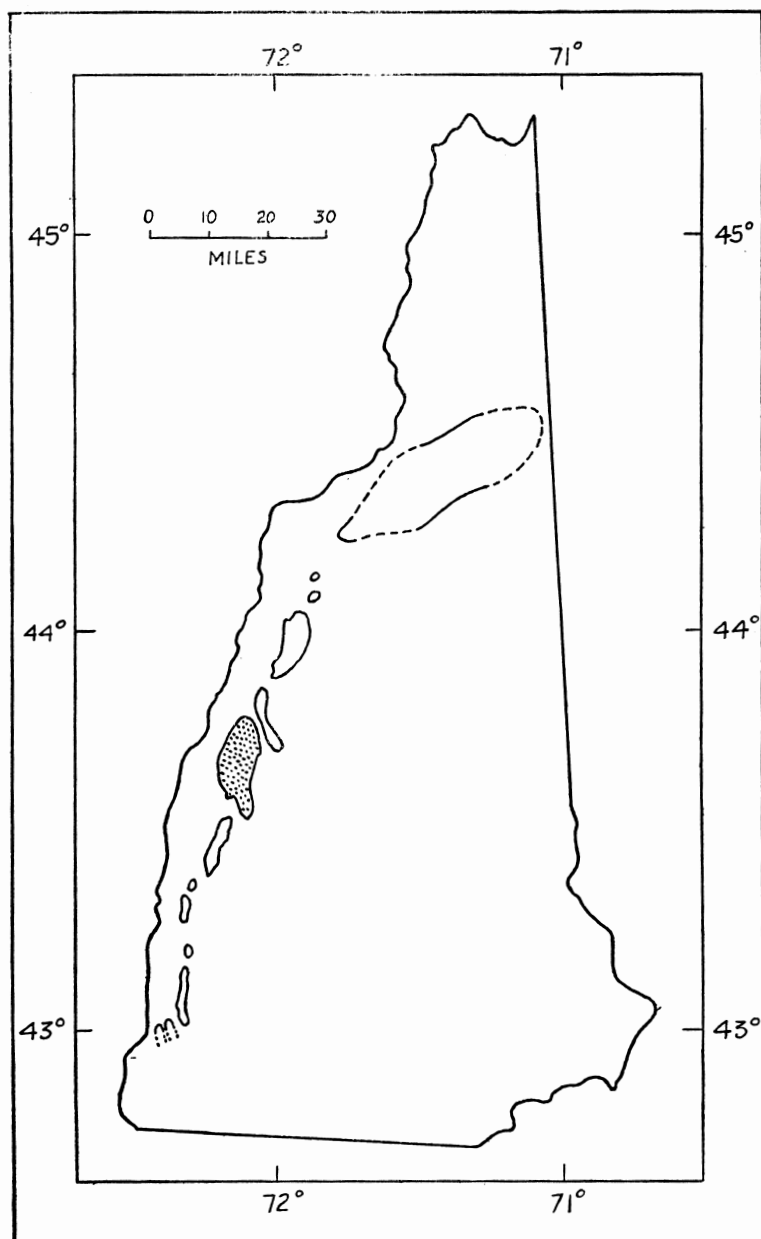
Fig. 2. Distribution of the Oliverian Magma Series.
The Mascoma dome is indicated by stippling.

partly primary and partly secondary. In thin section the tex-
ture is typically granoblastic, and large, granulated quartz
crystals (probably phenocrysts) are common in many speci-
mens. Potash feldspar is locally abundant in large crystals
giving the rock a light gray to pink color and a subporphy-
ritic appearance. The senior writer (Chapman, 1939, p. 167-
70) has shown, however, that these large feldspar crystals are
not phenocrysts but are metacrysts which replaced the rock
subsequent to its consolidation.

Petrographically the group ranges from quartz diorite
through granodiorite and quartz monzonite to granite. The
areal distribution of these various types, as determined by
field and laboratory studies, is shown in Figure 3. It will be
seen that granodiorite is the predominating type and that
quartz diorite is more or less confined to the borders of the
pluton; quartz monzonite and granite make up the west-cen-
tral portion of the body.

The petrography of the rock types, save for relative per-
centages of the major constituents, is remarkably similar.
Quartz constitutes from 20 to 45 per cent of the rock and is
generally more abundant in the quartz diorite than in the
granite. Plagioclase is universally present in amounts rang-
ing from 17 to 66 per cent. Nearly all of it is oligoclase whose
composition ranges from An_{13} to An_{30}. Microcline composes
from 0 to 50 per cent of the rock. Where present in large
quantity, it occurs both as large metacrysts and as fine-
grained, interstitial material. Where present in smaller
amount it is usually interstitial. The metacrysts range up to
two centimeters in length and occasionally are composed of
microcline perthite. Myrmekite, replacing potash feldspar,
constitutes as much as 10 per cent of some specimens. Biotite
is in olive-green flakes 0.1 to 2.0 millimeters long, and in some
specimens it constitutes 10 per cent of the rock. Accessory
minerals and alteration products, occurring usually in trace
amounts, are apatite, sphene, zircon, magnetite, ilmenite,
pyrite, rutile, hornblende, garnet, allanite, epidote, muscovite,
sericite, and chlorite.

In order to correlate more closely the petrography and
spectrochemistry of these rocks, a detailed petrographic
description of each analyzed specimen will now be given. The
geographical distribution of these specimens within the group
is shown by the numbered locations in Figure 3.
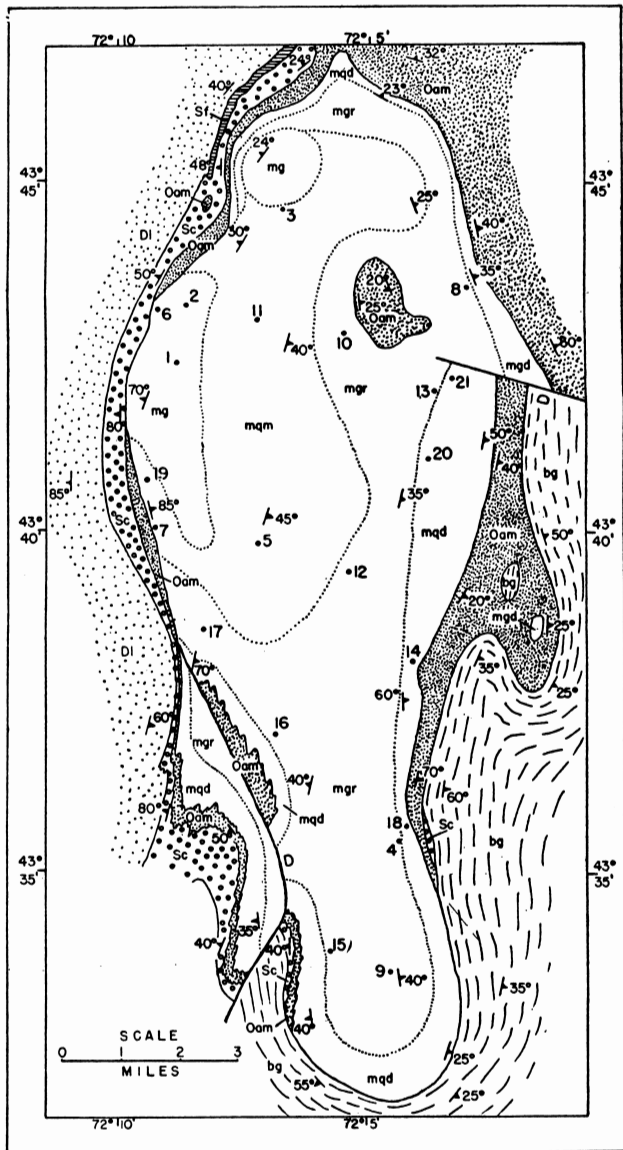
Fig. 3. Geologic Map of the Mascoma Dome.
(After C. A. Chapman and J. B. Hadley.)
bg   = Bethlehem gneiss (Late Devonian)
       Mascoma group (Late Devonian)
mg   = granite
mqm = quartz monzonite
mgr = granodiorite
mqd = quartz diorite
Dl   = Littleton formation (Lower Devonian)
Sf   = Fitch formation (Middle Silurian)
Sc   = Clough formation (Middle or Lower Silurian)
Oam = Ammonoosuc volcanics (Upper Ordovician ?)
Dip and strike symbols indicate foliation or schistosity.
Numbered points refer to specimen localities discussed in the text.

1. Fine-grained, gneissoid granite from near road, $4\frac{1}{2}$ miles north of the village of Enfield. Granoblastic, porphyritic.

   Quartz ....27%, same granulated phenocrysts
   Microcline ....50%, no metacrysts in thin section
   Oligoclase (An$_{23}$) ....20%, slight zoning
   Biotite .... 3%, olive green, some chloritized
   Sphene, magnetite, zircon, apatite, epidote, muscovite, and sericite ....trace

2. Fine-grained, gneissoid granite from summit of South Peak on Moose Mountain, $5\frac{1}{2}$ miles north of the village of Enfield. Granoblastic, porphyritic.

   Quartz 33%,
   Microcline ....44%, mainly as perthite metacrysts
   Oligoclase (An$_{15}$) 20%,
   Biotite .... 3%, olive green, largely chloritized
   Sphene, magnetite, zircon, apatite, myrmekite, epidote, muscovite, and sericite ....trace

3. Fine-grained, gneissoid quartz monzonite from near road, $1\frac{1}{2}$ miles northeast of North Peak of Moose Mountain. (North Peak is $6\frac{1}{2}$ miles north of the village of Enfield.) Granoblastic, porphyritic.

   Quartz 25%
   Microcline ....47%, mostly in metacrysts
   Oligoclase (An$_{20}$) 17%
   Myrmekite (oligoclase) ..... 8%, mostly replacing microcline
   Biotite .... 3%, olive green, some chloritized
   Sphene, magnetite, zircon, apatite, epidote, muscovite, and sericite ....trace

4. Fine-grained, gneissoid quartz monzonite from near road, $2\frac{1}{2}$ miles due east of the village of Enfield Center. Granoblastic.

   Quartz 25%
   Microcline 40%
   Oligoclase (An$_{20}$) 33%
   Biotite .... 2%, olive green, very slightly chloritized
   Sphene, magnetite, zircon, apatite, and sericite ....trace

5. Medium-grained, gneissoid quartz monzonite from near road, $2\frac{1}{2}$ miles northeast of the village of Enfield. Granoblastic, porphyritic.

   Quartz 25%
   Microcline ....30%, mostly in metacrysts
   Oligoclase (An$_{25}$) 30%
   Myrmekite (oligoclase) .....10%, mostly replacing microcline
   Biotite .... 4%, olive green, some chloritized
   Epidote and Allanite 1%
   Sphene, magnetite, zircon, apatite, muscovite, and sericite ....trace

6. Fine-grained, gneissoid quartz monzonite from near contact, about $\frac{3}{8}$ mile west of the summit of South Peak on Moose Mountain. Granoblastic, porphyritic.

   Quartz 19%
   Microcline perthite ....25%, much in metacrysts of perthite

Oligoclase-andesine (An$_{30}$) ..45%
Biotite .... 5%, olive green, very slightly chloritized
Muscovite .... 5%, in large flakes
Epidote 1%
Sphene, zircon, apatite, pyrite, and allanite ....trace

7 Fine-grained, gneissoid quartz monzonite from the base of Moose Mountain, 2½ miles north-northwest of the village of Enfield. Granoblastic, porphyritic.

Quartz ....25%, some granulated phenocrysts
Microcline 25%
Oligoclase (An$_{15}$) 45%
Biotite .... 4%, olive green, slightly chloritized
Epidote 1%
Sphene, magnetite, apatite, and muscovite ....trace

8. Fine-grained, gneissoid granodiorite from the ridge, 3 miles north of the village of Canaan Center. Granoblastic.

Quartz ....35%, several granulated phenocrysts
Microcline 20%
Oligoclase (An$_{20}$) 43%
Biotite .... 2%, olive green, some chloritized
Sphene, magnetite, zircon, apatite, allanite, muscovite, and
    sericite ....trace

9. Medium-grained, gneissoid granodiorite from the hill, 2½ miles southeast of the village of Enfield Center. Granoblastic.

Quartz 35%
Microcline 17%
Oligoclase (An$_{20}$) 45%
Myrmekite (oligoclase) ..... 1%, mostly replacing microcline
Biotite .... 2%, olive green, very slightly chloritized
Sphene, magnetite, zircon, garnet, epidote, muscovite, and
    sericite ....trace

10. Medium-grained, gneissoid granodiorite from the knoll, 3 miles northwest of the village of Canaan Center. Granoblastic, subporphyritic.

Quartz ....35%, several granulated phenocrysts
Microcline ....15%, a few small metacrysts
Oligoclase (An$_{27}$) 39%
Myrmekite (oligoclase) .... 1%, mostly replacing microcline
Biotite .... 8%, olive green, very slightly chloritized
Epidote 2%
Sphene, magnetite, zircon, apatite, and sericite ....trace

11. Fine-grained to medium-grained, gneissoid granodiorite from near road, 1¼ miles east-southeast of South Peak on Moose Mountain. Granoblastic, subporphyritic.

Quartz ....27%, several granulated phenocrysts
Microcline ....15%, a few metacrysts
Oligoclase (An$_{25}$) ....40%, zoned
Myrmekite(oligoclase) ...... 1%, mostly replacing microcline

Biotite ....10%, olive green, very slightly chloritized

Epidote 7%

Sphene, zircon, apatite, allanite, and sericite ....trace

12. Medium-grained, gneissoid granodiorite from the hill, about $2\frac{1}{4}$ miles southwest of the village of Canaan Center. Granoblastic.

Quartz 38%

Microcline 15%

Oligoclase (An_{17}) 45%

Biotite .... 2%, olive green, slightly chloritized

Sphene, magnetite, zircon, epidote, allanite, muscovite, and sericite ....trace

13. Medium-grained, gneissoid granodiorite from about $1\frac{1}{2}$ miles north-northwest of the village of Canaan Center. Granoblastic.

Quartz 35%

Microcline ....15%, interstitial

Oligoclase (An_{25}) 45%

Biotite .... 4%, olive green, very slightly chloritized

Sphene, magnetite, zircon, apatite, epidote, allanite, muscovite, and sericite ....trace

14. Fine-grained to medium-grained, gneissoid granodiorite from near road, $2\frac{3}{4}$ miles west-southwest of the village of Canaan. Granoblastic, subporphyritic.

Quartz ....35%, some granulated phenocrysts

Microcline 9%

Oligoclase (An_{25}) 50%

Biotite .... 4%, red-brown, somewhat chloritized

Muscovite .... 1%, in large flakes

Garnet 1%

Sphene, magnetite, zircon, apatite, pyrite, and sericite ....trace

15. Medium-grained, gneissoid granodiorite from the knoll, $1\frac{3}{4}$ miles south-southeast of the village of Enfield Center. Granoblastic.

Quartz 40%

Microcline 7%

Oligoclase (An_{20}) 49%

Myrmekite (oligoclase) ...... 1%, mostly replacing microcline

Biotite .... 3%, olive green, slightly chloritized

Sphene, magnetite, zircon, epidote, allanite, garnet, and sericite ..trace

16. Fine-grained to medium-grained, gneissoid granodiorite from the hill, $2\frac{1}{4}$ miles southwest of the village of Enfield. Granoblastic.

Quartz 37%

Microcline 5%

Oligoclase (An_{25}) 55%

Biotite .... 3%, olive green, very slightly chloritized

Sphene, zircon, apatite, pyrite, epidote, allanite, and sericite ....trace

17. Fine-grained, gneissoid granodiorite from just north of the village of Enfield. Granoblastic.

Quartz 25%
Microcline 5%
Oligoclase (An$_{22}$) 65%
Biotite .... 4%, olive green
Sphene, zircon, apatite, epidote. and allanite ....trace

18. Fine-grained, gneissoid quartz diorite from near road, 2½ miles west of the village of Enfield Center (¼ mile north of specimen 4). Granoblastic.

Quartz 32%
Oligoclase (An$_{28}$) ....63%, zoned
Biotite .... 5%, olive green, slightly chloritized
Magnetite, zircon, apatite, epidote, and sericite ....trace

19. Fine-grained, gneissoid quartz diorite from base of Moose Mountain, 3 miles north-northwest of the village of Enfield. Granoblastic to schistose.

Quartz 27%
Oligoclase-andesine (An$_{30}$) ..62%
Biotite .... 5%, olive green
Epidote 6%
Sphene, zircon, apatite, and pyrite ....trace

20. Medium-grained, gneissoid quartz diorite from about ⅝ mile northwest of the village of Canaan Center. Granoblastic, subporphyritic.

Quartz ....40%, a few granulated phenocrysts
Oligoclase-andesine (An$_{30}$) ..56%
Biotite .... 2%, olive green, somewhat chloritized
Hornblende .... 1%, blue-green
Epidote 1%
Sphene, apatite, allanite, and sericite ....trace

21. Fine-grained, gneissoid quartz diorite from the hill, 1¾ miles north of the village of Canaan Center. Granoblastic.

Quartz 45%
Oligoclase-andesine (An$_{30}$) ..53%, zoned
Biotite .... 2%, olive green, somewhat chloritized
Sphene, magnetite, zircon, apatite, epidote, allanite, muscovite, and sericite ....trace

SPECTROGRAPHIC ANALYSIS.

Preparation of Samples. Samples for spectrographic study were prepared from hand specimens, care being taken to obtain representative material. These were crushed to about 20 mesh and the original 100 gram sample reduced to about 1.5 grams by the quartering method. These smaller samples were then finely pulverized in an agate mortar and stored in small glass phials until ready for use.

Method. The instrument used was the Bausch and Lomb Large Littrow Quartz Spectrograph. Arc excitation of the

powdered sample was employed at 220 volts D. C. with an electrode gap of 2-3 millimeters. The slit width was adjusted to about 0.03 millimeters and the positions used were numbers 3 and 5 giving ranges of 2900-4500Å and 2500-3400Å respectively. The electrodes were made of National Carbon Company's specially pure 3/16-inch carbon rod, the cathodes having a concave cup of about 5 millimeters depth, the anodes having a convex surface about 5 millimeters high; both were 34-40 millimeters in length. An iron spectrum was placed at the top of each plate for purposes of comparison, to be mentioned later. Each sample was exposed for 90 seconds. The iron spectrum was produced by using spectroscopically pure iron electrodes and exposing for 10 seconds.

Preliminary qualitative analysis was made by projecting the plates upon a calibrated iron spectrum and master chart bearing the more persistent lines of most of the elements known. In this manner, lines on the plate could be identified by comparison with those on the chart. The spectral ranges employed did not contain usable lines of several elements that would have been desirable for study, notable among which are lithium and boron. Other desirable lines were either obscured by sensitive lines of major elements, were too diffuse, or were obscured by cyanogen bands. Some of these are rubidium, cesium, rare earths, and a few of the heavier elements.

The densities of the various lines in the rock spectra were then determined by use of the Gaertner densitometer. Since the density of the lines varies logarithmically with the quantity of elements present, it was possible to give to the qualitative work a semi-quantitative aspect. Since no attempt was made to prepare or examine standard mixtures of these minor elements, it is not possible to assign an absolute percentage value to any particular density; the density readings can be considered as only relative. They can be used only for comparing an element in one sample with the same element in another sample. It must be emphasized that no inter-comparison of elements can be made, as the sensitiveness of the various elements varies widely.

Table I gives the minor elements detected in the samples, together with the spectral lines found most satisfactory for their identification. In the case of most of these elements two or more lines were detected and their densities determined. In

general, the denser lines were selected as the more satisfactory;
however, the relative densities were so similar that any one
line would serve equally well as representing that element

TABLE I.

Spectral Lines of the Minor Elements.

Element	Spectral Line or Lines in Angstroms
Be	2650.95
Sr	4215.52, 4967.92
Ba	4934.09
Ge	2740.43
Pb	2833.07
Ti	3088.3, 3385.95, 3387.84
Zr	3241.05, 2700.14
V	3053.38, 2962.78, 2943.20
Cr	3014.76, 3014.92
Mo	2816.15
Mn	2949.21, 2933.06
Ni	3064.63
Ru	2568.76
Rh	2703.72, 2671.04
Ir	2694.22, 2673.60
Pt	2646.89
Cd	3252.55, 2712.6

Results of Spectrographic Analysis. Table II is a list of
the 21 specimens referred to in the previous sections and the
densities of lines given by certain minor elements contained
in the rocks. It seems preferable to use the letters A = absent,
L = light, M = medium, H = heavy, and VH = very heavy,
instead of referring to such quantitative terms as trace, small,
medium, large, etc. Nevertheless, the relative density of a
line is a rough measure of the relative quantity of an element
present in the specimen. It was not intended to identify all
the trace elements in these samples but rather to select only
those with more easily identifiable lines. Many elements are
difficult to identify because very few of their lines are suf-
ficiently intense to record photographically. Hence, absence
of an element from the table does not necessarily indicate its
absence from the sample. Again, it must be emphasized that
one can only quantitatively compare an element in one sample
with that same element in another. No intercomparison of
unlike elements can be made.

TABLE II.

Spectographic Analyses of Rocks of the Mascoma Group, New Hampshire.

	Be	Mg	Sr	Ba	Cd	Ge	Pb	Ti	Zr	V	Cr	Mo	Mn	Ni	Ru	Rh	Ir	Pt
Granite																		
1	M	M	H	M	M	M	M	M	M	M	M	M	M	L	M	M	M	M
2	M	M	VH	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
Quartz monzonite																		
3	M	M	VH	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
4	M	M	L	M	M	H	M	M	M	M	M	M	M	A	M	M	M	M
5	M	M	VH	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
6	M	M	L	M	M	H	H	H	M	M	M	M	M	A	M	M	M	M
7	M	M	VH	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
Granodiorite																		
8	M	M	H	M	M	M	M	L	M	M	M	M	M	L	M	M	M	M
9	M	M	L	M	M	M	M	L	M	M	M	M	M	A	M	M	M	M
10	M	M	H	M	M	M	M	M	M	M	M	M	H	L	M	M	M	M
11	M	M	H	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
12	M	M	H	M	M	M	M	M	M	M	M	M	M	L	M	M	M	M
13	M	M	VH	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
14	H	H	L	M	H	H	H	H	H	M	M	H	H	A	H	H	H	M
15	M	M	L	M	M	M	M	M	M	M	M	M	M	A	M	M	M	M
16	M	M	L	M	M	M	M	M	M	M	M	M	M	A	M	M	M	M
17	M	M	L	M	M	M	M	M	M	M	M	M	M	A	M	M	M	M
Quartz diorite																		
18	M	M	L	M	M	M	M	M	M	M	M	M	M	A	M	M	M	M
19	M	M	VH	M	M	M	M	H	M	M	M	M	M	M	M	M	M	M
20	M	M	H	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
21	M	M	L	H	M	M	M	M	M	M	M	M	H	A	M	M	M	M

Note: Density of spectographic lines is indicated by symbols:
A = absent, L = light, M = medium, H = heavy, and VH = very heavy.

TABLE III.

Major Elements in Granitic Rocks.

Element	Group	Valence	Ionic Radius*
Si	IV	4	0.39Å
Al	III	3	0.57
Fe	VIII	3	0.67
Fe	VIII	2	0.83
Mg	II	2	0.78
Ca	II	2	1.06
Na	I	1	0.98
K	I	1	1.33

* Values of ionic radii are taken from: Goldschmidt (1927).

GEOCHEMICAL RELATIONS.

General Principles. Before considering the geological significance of the spectographic results, it seems advisable to consider briefly certain well established principles of crystal chemistry and geochemistry insofar as they are concerned with the distribution of minor elements in minerals and rocks.

A list of the major elements, excluding oxygen, found in granitic rocks is given in Table III together with their group numbers in the periodic system, their valences, and their ionic radii. A similar listing is given in Table IV for the trace elements determined in the present study.

TABLE IV.

Minor Elements Identified in Rocks of the Mascoma Group.

Element	Group	Valence	Ionic Radius*
Be	II	2	0.34Å
Sr	II	2	1.27
Ba	II	2	1.43
Ge	IV	4	0.44
Pb	IV	4	1.32
Ti	IVB	4	0.64
Zr	IVB	4	0.87
V	VB	5	0.75
		4	0.61
Cr	VIB	3	0.65
Mo	VIB	2	0.68
Mn	VIIB	2	0.91
Ni	VIII	2	0.78
Ru	VIII	4	0.65
Rh	VIII	4	0.65
Ir	VIII	4	0.66
Pt	VIII	4	0.55
Cd	IIB	2	1.03

* Values of ionic radii are taken from: Goldschmidt (1927).

The SiO_4 tetrahedron is the fundamental unit of silicate structures. This group consists of a small silicon atom surrounded by four much larger oxygen atoms. The numerous types of silicate structures are formed by different arrangements of these fundamental units. Thus the SiO_4 groups may form rings, chains, sheets, three dimensional networks, or exist separately.

Within certain limits, as can be seen from their ionic radii, trivalent aluminum may replace tetravalent silicon in the silicates. In such a case, however, an unbalanced charge is left and this is usually neutralized by the addition of a sodium or potassium ion. The amount of substitution of aluminum for silicon helps to explain the additional cations in a silicate,

because ions, other than sodium and potassium, may be taken up to balance the charge difference.

In addition to the charge balance phenomenon between silicon and aluminum, other factors influence the minor element content of a silicate. These include the substitution of one element for another and various defect structure phenomena. The most important is the substitution mechanism. It is generally recognized that the substituting and replaced ions must have similar chemical, physical, and geometrical properties. Generally ionic size is the most important factor, with ionic type exhibiting a secondary influence. In some instances, the chemical similarity acts as a stronger influencing factor than do ionic radii. In the case of sodium and potassium this phenomenon is illustrated by the frequent replacement of one of these elements by the other. In this instance a considerable difference in ionic radii is to be noted.

The Geochemistry of the Mascoma Group. Of the Group II elements, beryllium, probably octahedral when in trace amounts, is thought to replace octahedral magnesium. Barium and strontium, with properties similar to those of calcium, probably replace the latter. The similarity in ionic radii between potassium and barium indicates that the latter may replace the former. This relation has been observed in many instances.

In Group IV, germanium is probably octahedral when present in small amounts, resembling titanium more than silicon. One school of thought believes that germanium replaces ferric iron and does not enter into the silica tetrahedra. Lead may replace potassium according to ionic radii considerations and this replacement has been observed.

Titanium and zirconium, of the Group IVb elements, are present. It is now generally considered that these elements replace ferric iron instead of silicon as formerly believed. It is interesting to note the marked difference in ionic radii of titanium and zirconium as compared with silicon.

Vanadium is known to replace ferric iron in many instances and this is the most likely explanation of its presence in these rocks. Chromium and molybdenum are also found accompanying ferric iron and, hence, they probably also replace ferric ions.

Manganese, nickel, magnesium, and ferrous iron are all interchangeable. Hence, manganese and nickel are believed to substitute for magnesium and ferrous iron.

The platinum metals (Ru, Rh, Ir, and Pt) are in the same periodic group and have ionic radii comparable with ferric iron; hence, it is probable that they have replaced the latter.

The relation of cadmium in these minerals is questionable, and the writers prefer not to advance an opinion.

The probable relations between the various elements present in the rocks of the Mascoma group are summarized in Table V.

TABLE V.

Replacement Agents.

Displaced element	Replacing element
K	Ba
Ca	Sr, Ba
Mg	Be, Mn, Ni
Fe (ferrous)	Mn, Ni
Fe (ferric)	V, Cr. Mo, Ru, Rh, Ir, Pt, Ge, Ti, Zr
Si	Al
(?)	Cd

From these relationships, it seems logical to assume that the trace elements may be localized in the more abundant minerals as follows:

1) barium replacing potassium in microcline; 2) barium and strontium replacing calcium in oligoclase; 3) the trace elements replacing magnesium and iron may concentrate principally in biotite. Perhaps most of the zirconium is confined to zircon, much of the titanium to sphene, and possibly some of the other minor constituent minerals carry small amounts of the trace elements.

CONCLUSIONS.

A study of Table II reveals a marked uniformity in the intensity of any one line, save for strontium, among the various samples, indicating a similar uniformity in the quantity of the elements represented by that line. There are no marked qualitative differences between samples. The variation within petrographic types is as great as any variation between them. There are, for example, no outstanding differences between the quartz monzonites and quartz diorites. As far as trace elements are concerned, therefore, the whole Mascoma group is remarkably uniform. Any differences are insufficient to indicate reliably types within, or subdivisions of, the group itself.

Strontium is the only element shown to be extremely variable. In general, it is more abundant in the rocks richer in

potash feldspar, but there are several exceptions to this. Barium is remarkably uniform. The variation in iridium, as shown by the Gaertner densitometer readings, is very consistent with that of platinum and the same may be said of ruthenium and rhodium. This would be expected from the chemical similarity of these metals (platinum group).

These spectographic data, therefore, check well with the petrographic studies. The petrographic types of the Mascoma group are not in themselves very different; the microcline content is the major variable. This marked petrographic similarity may be noted from the detailed description of the specimens already given.

The senior writer (Chapman, 1939, p. 166-70) has previously suggested that the rocks of the Mascoma group were derived from a potash-poor granodiorite magma which assimilated small amounts of Ammonoosuc volcanics locally. From this slightly heterogeneous magma were crystallized the quartz diorite border facies and the granodiorite core. At some later date, potash-rich solutions were introduced to develop microcline, thereby changing some of the solid granodiorite and quartz diorite to the quartz monzonite and granite (Fig. 3). Such an interpretation, which was developed as a result of petrographic studies, seems quite in harmony with the results of the spectrographic analyses.

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