A STUDY OF THE SALT SPRINGS ROAD PERIDOTITE DIKE IN SYRACUSE, NEW YORK

James E. Maynard and Louis W. Ploger, *Syracuse University, Syracuse, New York.*

Contents

Abstract

The Salt Springs Road dike occurs near the intersection of Salt Springs Road and East Genesee St., Syracuse, N. Y. It intrudes the nearly horizontal Camillus formation of the Silurian system as a steeply dipping dike approximately 51 inches wide. The dike now, largely altered, consists of small grains, small composite fragments and yellowish-green, friable masses that are occasionally porphyritic in appearance. Geologic, petrographic and chemical studies indicate that the material of the dike was formed from the weathering of a serpentine rock, which in turn resulted from the alteration of an igneous rock of the peridotite group.

The altered dike consists, primarily, of vermiculite with somewhat less serpentine. Magnetite, limonite, perovskite and clay minerals are relatively abundant in the altered material. In addition there are small quantities of olivine, phlogopite, apatite, quartz, carbonates, andesine and tremolite present. The relict minerals are small amounts of magnetite, perofskite, apatite, olivine and perhaps chromite.

From the chemical and petrographic data the unaltered rock is according to Johannsen's classification, a mica peridotite, class 4, order 1, family 5, (415).

Introduction

Slightly over 100 years ago the first igneous dike, now known as the Green Street dike, was discovered in Syracuse, N. Y., and reported by Vanuxem.[1] During this period a number of such dikes were discovered in central New York. One of these was exposed along Thompson Road just outside of the eastern city limits; it is now known as the Dewitt dike because of its occurrence at the Dewitt reservoir. A bibliography of the

[1] Vanuxem, Lardner, *Geological Survey of New York.* 3d an. Rept. of the Geol. Surv. of 3d Dist. (**1839**), 160 and 283.

geology and petrography of these dikes is given by Clark,[2] and by Hopkins.[3]

The most recent dike to be recorded[4] is the subject of this paper. It is known as the Salt Springs Road dike, and was brought to Ploger's attention in the Spring of 1921 by Arthur E. Brainerd then Professor of Geology at Syracuse University. A geologic study of the dike and the surrounding area was made at that time, and samples were collected for laboratory investigation. These have now been studied with the results here reported.

LOCATION OF THE DIKE

The Salt Springs Road dike was exposed during an excavation for a sewer along the north side of Salt Springs Road, Syracuse, N. Y., about
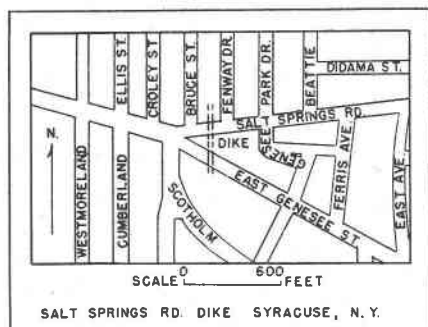

FIG. 1

midway between Bruce St. and Fenway Drive, and approximately 200 feet east of the intersection of Salt Springs Road and East Genesee St. A scanty exposure of what is thought to be the same dike was seen on a newly graded lawn, and along the sidewalk, on the north side of East Genesee St. directly south of the exposure on Salt Springs Road. No detailed examination of this location was feasible at the time, nor has it been since. These exposures are now covered by lawns, sidewalks, and pavements. The location of the dike is shown in Fig. 1.

[2] Clark, Burton W., The peridotite dikes of Onondaga County, New York. Masters Thesis, Syracuse University Library (**1908**).

[3] Hopkins, Thomas C., The Geology of the Syracuse Quadrangle: *New York State Museum, Bull.* **171**, 53–56 (1914).

[4] Maynard, James E., and Ploger, Louis W., An unrecorded altered peridotite dike in Syracuse, N. Y.: *Am. Mineral.*, **31** 200–201 (1946). Abstract.

GEOLOGY OF THE OCCURRENCE

The dike at Salt Springs Road is about 51 inches wide, and at the time of observation was exposed to a depth of slightly more than 5 feet. It was decomposed by weathering, almost completely disintegrated so as to consist of a yellowish-green earthy material made up dominantly of a mixture of sand-size particles and larger friable lumps. When pulverized with the fingers residual hard kernels were recovered from some of the lumps; a few of these were about as large as peas, the average being about 3 mm. in diameter. The rounded forms of the kernels resembled very closely those that are commonly found in igneous rocks that are undergoing weathering, and where all stages are represented from completely weathered material to fresh unaltered rock.

Examination of the larger residual fragments with a hand lens showed small greenish-brown rounded grains distributed throughout a finer grained matrix, producing a distinctly porphyritic-like appearance. The shape, arrangment and aspect of the grains strongly suggested serpentine pseudomorphs after original olivine phenocrysts.

The altered dike was penetrated by rootlets, up to one half inch thick, to the bottom of the exposure. This condition contrasted markedly with the complete failure of such roots to penetrate the country rock on either side of the dike.

The country rock is dominantly shaly limestone, and shale, and is referred to the lower member of the Camillus of the Salina group. The strata of this formation normally have a gentle dip in a southerly direction in this region. Within the first few feet adjacent to the dike on both the east and west sides, the pressure of the intrusion caused an appreciable dip of the strata away from the dike, with an angle reaching a maximum of 45° on the east side. The dike itself dips eastward at an angle of about 82°. An effect resembling slaty cleavage appears in the shale on the east side of the dike and closely adjacent to it, and was probably induced by the pressure of the intrusion.

A zone 8 to 10 inches wide on the west contact, and 10 to 12 inches on the east contact showed a whitish powdery surface that may have been produced by heat during the intrusion of the dike.

On the east side of the dike and in contact with its upper part is a deposit of Pleistocene conglomerate, occupying an erosional hollow to a depth of about 3 feet. To the west of the dike and sloping in the direction of Salt Springs Road, is a north-south hollow now partly occupied by fill. The origin of the hollows may have a bearing on when the weathering of the dike took place. Their position on either side of the dike at least suggests that the dike was relatively unweathered during the Pleistocene,

and, therefore, more resistant than the softer country rock on either side to erosion and to the thrusting action of the Pleistocene ice sheet advancing from the north-northwest. The data, however, are inadequate to draw definite conclusions, either as to when the depressions were formed or when the weathering of the dike took place. An east-west structure section across the dike is shown in Fig. 2.
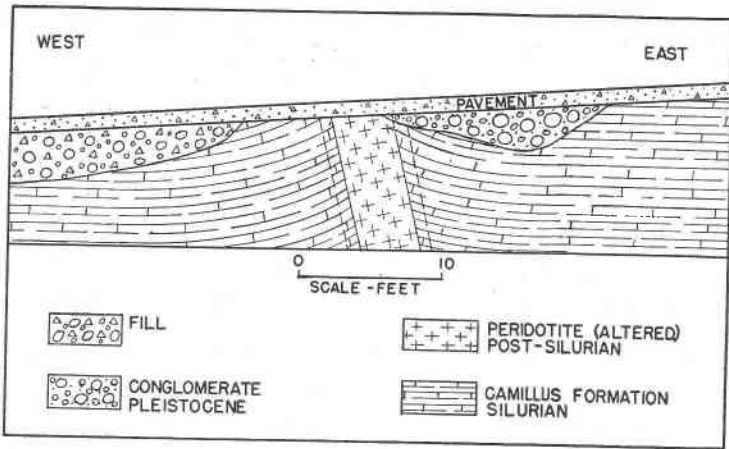

FIG. 2. Structure Section Through the Salt Springs Road Dike in Syracuse, N. Y.

PRELIMINARY TREATMENT

For the purpose of facilitating petrographic and mineralogic study, and to obtain information on the state of disintegration of the material, a large quantity was separated into fractions by sieving with a Tyler automatic "Ro-Tap" shaker. The weight percentages of the separates, according to the Wentworth grade scale, are given in Table 1.

TABLE 1. MECHANICAL ANALYSIS OF ALTERED ROCK

	Per Cent by Weight
Pebble, 64 to 4 mm.	3.5
Granule, 4 to 2 mm.	3.5
Very coarse sand, 2 to 1 mm.	4.9
Coarse sand, 1 to 0.5 mm.	8.4
Medium sand, 0.5 to 0.25 mm.	4.9
Fine sand, 0.25 to 0.125 mm.	27.5
Very fine sand, 0.125 to 0.062 mm.	19.2
Silt and clay, below 0.062 mm.	30.1
	100.0

The mechanical analysis shows very clearly that the rock is in an advanced stage of disintegration; approximately 75 per cent of it is finer than medium sand. Microscopic examination of the separates shows that all grades coarser than very fine sand consist dominantly of aggregates. The very fine sand and the grades below it consist dominantly of monomineralic grains. Many relatively hard and still coherent fragments of rock occur in the pebble and granule grades. Practically all of the composite grains in the larger grades are friable and can be disintegrated by rubbing with the fingers.

Petrography of the Residual Rock Fragments

Under the microscope many of the pebbles and granules show a well defined porphyritic texture. Most of the phenocrysts are serpentine, but they have the typical rounded and angular outlines of olivine; a few show residual cores of olivine; some are surrounded by rims of brown phlogopite. They average about 1.0 mm. in size, but occasionally an individual grain may reach 2.0 mm. Phenocrysts of phlogopite averaging 8 mm. in size are rare.

The groundmass is largely a fine-grained aggregation of vermiculite and serpentine. Iron oxides, both magnetite and limonite, and perofskite are prevalent. Apatite occurs in minor amounts. Part of the magnetite is automorphic which strongly suggests that at least some of it may be primary. Most of the perovskite and apatite are also automorphic and probably original constituents. Clay minerals, quartz, carbonates, and chromite were not identified in the groundmass of the fragments.

Volumetric measurements on many pebbles and granules gave: serpentine phenocrysts 32.0 per cent; groundmass 68.0 per cent. These values indicate that olivine constituted at least 34.0 per cent of the unweathered rock.

No satisfactory quantitative determinations could be made on the relative abundance of the various minerals in the groundmass. By inspection, vermiculite and serpentine appear to be present in about equal proportions and constitute three fourths of it; the balance is about equally distributed between magnetite, limonite, and perovskite.

The geologic studies together with the petrographic data show that the altered material now constituting the Salt Springs Road dike was formed from the weathering of a serpentine rock high in mica, and that this serpentine rock resulted from the alteration of a basic igneous rock of the peridotite group. The most important original minerals in the peridotite appear to have been olivine and phlogopite; the former has been largely altered to serpentine and iron oxides, the latter to vermiculite. Mag-

netite and perovskite are the most prevalent relict minerals now remaining, but there are also small amounts of apatite, phlogopite and olivine.

Mineralogy

The coarse fragments and the very fine sand size particles yielded the most satisfactory material for mineral studies. The minerals were studied, primarily, in oils, and all refractive index determinations were made by the immersion method.

Serpentine: Two types of serpentine are present. They probably are antigorite and serpophite. The antigorite occurs as a fine felt of pale green unorientated shreds with greenish yellow, first order, maximum interference colors. Its indices of refraction are: $N_\alpha = 1.550$; $N_\beta = 1.560$; $N_\gamma = 1.560$. These values are somewhat lower than those generally listed, and may be the result of a partial loss of MgO and a gain in H_2O because of weathering. On the other hand they may be normal values for antigorite, for Larsen and Berman[5] list figures that are even lower. Serpophite occurs as pale yellow, structureless, more or less oval masses with either none, or very low first order gray interference colors. Its indices of refraction vary between $N = 1.540$ and $N = 1.543$. The serpophite appears to correspond very closely with that described by Rogers and Kerr.[6]

The serpentine minerals are found as pseudomorphs after olivine, in irregular masses, or as individual flakes. Some of the pseudomorphs and irregular masses consist of rounded kernels of serpophite in a matrix of antigorite; others contain many inclusions of automorphic magnetite and perofskite; others show smears of yellowish-brown limonite, or contain varying amounts of fine powdery magnetite.

Vermiculite and Phlogopite: Pale yellowish-brown to pale greenish-brown vermiculite occurs as elongated flakes with ragged ends, or as automorphic to hypautomorphic pseudohexagonal crystals. The cleavage flakes have very weak birefringence and yield good negative interference figures; the axial angle varies from 0° to 8°. The average refractive indices are $N_\alpha = 1.520$; $N_\beta = 1.540$; $N_\gamma = 1.540$. The vermiculite is remarkably fresh in appearance, but in places many elongated needle-like crystals of apatite, or occasional crystals of perofskite are distributed throughout it. By count, vermiculite constitutes approximately 32.0 per cent of the very fine sand grade; this figure probably represents very closely the actual percentage of vermiculite in the unseparated material, for rough estimates on the other grades gave values that were similar.

[5] Larsen, Esper S., and Berman, Harry, The Microscopic Determination of the Non-opaque Minerals: *U. S. Geol. Surv., Bull.* **848,** 152 (1934).

[6] Rogers, Austin F., and Kerr, Paul F., Optical Mineralogy, 362 (**1942**).

Brown phlogopite occurs sparingly as pseudohexagonal plates up to 3.0 mm. in size. It is negative with an axial angle of 9°. Its average indices of refraction are: $N_\alpha = 1.530$; $N_\beta = 1.555$; $N_\gamma = 1.560$. Many of the phlogopite grains contain inclusions of automorphic apatite.

It is generally recognized that members of the biotite system may change to vermiculite on weathering by loss of alkalies and the addition of water.[7] All of the vermiculite in the dike rock is probably secondary after phlogopite, for many of the phlogopite flakes are bleached in appearance, and have abnormally low and variable indices of refraction, indicating that they are in different stages of alteration to vermiculite.

Olivine: Olivine occurs as very pale yellow, glassy grains that show a branching pattern of curved cracks and break with a conchoidal fracture. They average 1.31 by 0.85 mm. in size, with an occasional grain having a maximum dimension of 2.0 mm. The average indices of refraction are: $N_\alpha = 1.663$; $N_\beta = 1.678$; $N_\gamma = 1.698$. The optic angle is large; it is usually positive, but may be negative.

Considering the advanced state of alteration of the dike, the fresh and unweathered character of most of the olivine grains is remarkable, for there is no evidence of serpentinization or of the formation of secondary iron oxides, even along the abundant curved cracks. The only explanation that suggests itself is that the grains are the remnants of much larger olivine phenocrysts.

Practically all of the olivine, with the exception of highly altered relicts in the phenocrysts of the rock fragments, occurs in the coarse sand grade. Some of these relicts of olivine, because of their optically negative character, were mistaken for hypersthene in the preliminary study. By count, olivine constitutes approximately 5.0 per cent of the coarse sand grade; its volume in the altered dike is computed to be approximately 0.4 per cent.

Perovskite: Small honey-yellow crystals of perovskite with square cross-sections are abundant as inclusions in the serpentine, and somewhat less prevalent in the vermiculite and phlogopite. They vary between 0.03 and 0.005 mm. in size, show very high relief, and have an adamantine luster in reflected light. A few of the larger crystals have very faint interference colors. The automorphic character of the crystals and their occurrence as inclusions in the other minerals strongly indicates that they are primary constituents. They appear to be similar to those first identified and described by Williams,[8] and noted by Smyth,[9] Kemp,[10] and Clark[11] in their petrographic studies of the Syracuse dikes.

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[7] Winchell, Alexander N., Elements of Optical Mineralogy, Pt. II, 275 (**1933**).

[8] Williams, George H., On the serpentine (peridotite) occurring in the Onondaga Salt Groups at Syracuse, N. Y.: *Am. Jour. Sci.*, (3) **34**, 137–145 (1887).

Iron Oxides: Magnetite is present as small crystals, irregular grains, and fine powdery dust. Many of the automorphic crystals occur as inclusions in phlogopite and vermiculite and are undoubtedly primary. Much of the dust and many of the grains are probably secondary from the alteration of olivine, for they are very intimately mixed in with serpentine.

Yellowish-brown limonite occurs as smears and stains irregularly distributed over the surfaces of many of the other minerals, and intimately associated with serpentine. Just how much of it is secondary from the alteration of olivine, and how much has resulted from the weathering of magnetite is not known.

Clay minerals: Distributed throughout the smaller size are pale greenish to colorless microcrystalline aggregates, and extremely fine scale-like individual grains. They have indices of refraction that vary between $N = 1.48$ and $N = 1.52$. When disturbed in the oils they show flashes of a yellow interference color. No interference figures could be obtained from them. From the data assembled by Rogers and Kerr,[12] they are taken to be montmorillonite. The high moisture content in the chemical analysis is also suggestive of the behaviour of minerals in the montmorillonite group.

Apatite: Needle-like crystals of apatite, $N_\omega = 1.635$, were only noted in, or protruding from, fragments and crystals of vermiculite and phlogopite; they represent one of the few original rock constituents.

Chromite: A few small grains of an opaque brownish-black mineral with high index of refraction and submetallic luster in reflected light were taken to be chromite. Chromium in the chemical analysis also suggests this conclusion. The chromite is also probably a relict mineral.

Quartz: A few rounded grains of quartz were noted in the various sand sizes. These probably represent extraneous detrital material. In addition small particles of quartz rather irregular in outline were identified in the silt and clay grade. Some of these may be from disintegrated shale fragments picked up during intrusion of the dike; others may be secondary products produced by hydrothermal alteration or weathering of the original primary silicate minerals.

Andesine: A few angular grains of unweathered milk-white andesine ($Ab_{65}An_{35}$), with N_p on {001} and {010} cleavages averaging 1.546, were

[9] Smyth, C. H., Petrography of recently discovered dikes in Syracuse, N. Y.: *Am. Jour. Sci.*, (4) **14** 26–27 (1902).

[10] Kemp, J. F., A newly discovered dike at Dewitt, N. Y.: *Am. Jour. Sci.*, (3) **49**, 459 (1895).

[11] Clark, Burton W., *op. cit.*, 51.

[12] Rogers, Austin F. and Kerr, Paul F., *op. cit.*, 354.

found in the coarse sand and fine sand sizes. It may be one of the original constituents of the rock, but more probably because of its acid character, represents xenolithic material brought from below. Smyth[13] points out that inclusions, both Paleozoic and pre-Cambrian, are prevalent in the Syracuse dikes examined by him.

Tremolite: Three elongated transparent and colorless crystals of tremolite, that showed excellent amphibole cleavage when broken, were found in the 0.5 to 0.25 mm. particles. Careful search of the other sizes failed to yield more material. Index measurements gave: $N_\alpha = 1.600$; $N_\beta = 1.614$; $N_\gamma = 1.625$. Iddings[14] states that tremolite "occurs in serpentine associated with olivine and pyroxene as an alteration product, in peridotites, and in some gabbros." It is probable, therefore, that the tremolite is a secondary product from a pyroxene or related silicate that was originally present in the dike in very small amounts.

Carbonates: A small amount of carbonate, either calcite or dolomite, was detected in the ground mass of some of the rock fragments. Although Winchell[15] points out that the atmospheric weathering of olivine often results in the formation of calcite, showing the removal of magnesium and its replacement by calcium; it is probable that the carbonate is dolomite, for the total amount of calcium in the rock, as shown by the analysis, is relatively low, and most of this is required for perovskite and apatite.

Chemical Characteristics

A chemical analysis of the altered dike, with the exception of the determination for manganous oxide, was made by Dr. David S. Morton; the manganous oxide was determined by Dr. Joseph L. Neal. The analysis is given as no. 1 of Table 2. There are also tabulated for comparison analyses of three related peridotites, the average of a number of peridotite analyses, and an early analysis of one of the Syracuse serpentine rocks.

Table 2 shows that the analysis of the Salt Springs Road dike agrees rather closely with the analyses of the Kentucky and Arkansas dikes which contain rather large amounts of mica. The analysis also departs very little from that of the nearby Dewitt dike, which according to Kemp,[16] has much augite as well as mica in it. Furthermore, it does not deviate very much from the average of peridotite analyses as compiled by Grout.[17]

[13] Smyth, C. H., *op. cit.*, 29.

[14] Iddings, Joseph P., Rock Minerals, 354 (1906).

[15] Winchell, Alexander, N., *op. cit.* 190.

[16] Kemp, J. F., *op. cit.*, 458.

[17] Grout, Frank F., Kemp's Handbook of Rocks, 107 (1942).

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TABLE 2. CHEMICAL ANALYSES OF RELATED PERIDOTITES

	1	2	3	4	5	6
SiO_2	36.96	33.84	38.78	38.80	40.67	41.09
TiO_2	2.24	3.78	0.89	1.26		1.16
Al_2O_3	6.16	5.88	6.85	4.16	5.13	4.80
Fe_2O_3	10.60	7.04	8.83	n.d.	}8.12	3.96
FeO	2.33	5.16	1.99	8.33		7.12
MnO	0.03	0.16	n.d.	0.13		
MgO	21.30	22.96	26.34	25.98	32.61	32.25
CaO	3.04	9.46	3.88	8.63		4.42
Na_2O	0.25	0.33	0.78	0.17		0.49
K_2O	0.10	2.04	2.56	2.48		0.96
H_2O+	7.12	}7.50	7.85	6.93	}12.77	3.53
H_2O-	8.50		1.95	0.51		
P_2O_5	0.54	0.89		0.47		0.12
Cr_2O_3	0.33	0.18		0.20		
CO_2	0.74	0.43	0.14	2.95		
BaO	0.02	0.06		0.12		
SO_3	0.03					
S(Sulfide)	0.03					
Cl		0.05				
NiO		0.10		0.09		
	100.33	99.86	100.84	100.22	99.30	100.00

1. Mica-peridotite. Salt Springs Road dike, Syracuse, N. Y. Morton, analyst.

2. Mica-olivinite ("mica-peridotite"). Flanary dike, Crittenden Co., Ky. Hillebrand, analyst. Diller: *Am. Jour. Sci.*, (3) **44**, 288 (1892).

3. Pikeite ("augite-phlogopite-peridotite"). Pike Co., Ark. Brackett, analyst. Williams: *Geol. Surv. Ark.*, Rept. for 1890, II, 383 (**1891**).

4. Mica-augite-peridotite ("limburgite"). Dewitt dike, Syracuse, N. Y. Stokes, analyst. Kemp: *Am. Jour. Sci.*, (3) **49**, 461 (1895).

5. ("Ophiolite"). Syracuse, N. Y. Hunt, analyst. Hunt: *Am. Jour. Sci.*, (2) **26**, 237 (1858)

6. "Peridotites," average composition (mostly after Daly). Grout: Kemp's Handbook of Rocks, 107 (**1942**).

The low K_2O and high H_2O content of the Salt Springs Road material is to be expected because of the weathered and altered character of the dike. The change of phlogopite to vermiculite involves loss of K_2O, and the presence of clay minerals, either of extraneous or secondary origin, requires acquisition of water.

The chemical study verifies the geologic evidence as to the igneous origin of the material, and in conjunction with the petrographic data establishes the rock as a member of the peridotite group.

SPECIFIC GRAVITY

The specific gravity of the altered rock was determined by means of a

pyknometer, care being taken to remove all of the air by means of a vacuum pump. An average of 3 determinations gave a specific gravity of 2.70.

CALCULATIONS

For the purpose of classifying the dike on a quantitative and modal basis, the weight percentages of the known component minerals were calculated from the chemical analysis. The formulas and the average specific gravities of the minerals used in the calculations are chiefly from Dana.[18] The formula used for montmorillonite is taken from Rogers and Kerr,[19] and that for vermiculite is given by Gruner.[20] The values for the specific gravities of vermiculite and montmorillonite are taken from Winchell.[21] Calculations were made with a slide rule.

Vermiculite was used as the starting point in the calculations because the individual grains were identified readily and with accuracy. Its frequency percentage, 35.0 per cent, was obtained by counting the grains in the very fine sand grade. This value was taken to represent the relative proportions of vermiculite in the altered rock. This assumption undoubtedly involves some error, but it cannot be very great for approximately the same value was obtained from the disaggregated fine sand size. Knowing the average specific gravity for vermiculite and the specific gravity of the altered rock, the approximate weight percentage of vermiculite was calculated. The weight percentages of the different oxides in vermiculite were then determined from its chemical composition.

The molecular proportions of the other known minerals in the altered rock were calculated from the chemical analysis. All the K_2O was allotted to phlogopite. The excess of Al_2O_3 over that required for vermiculite and phlogopite was assigned to montmorillonite. All the CO_2 was assigned to dolomite. The balance of the MgO, after apportioning the dolomite, vermiculite and montmorillonite equivalents, was assigned to serpentine. All the TiO_2 was allotted to perovskite and all the P_2O_5 to apatite, the excess CaO being apportioned between dolomite and montmorillonite. All the Cr_2O_3 was assigned to chromite, the remaining FeO was assumed to be in magnetite. The excess Fe_2O_3 was assigned to limonite after allotting the equivalent required for vermiculite. The excess SiO_2 was assumed to be present as quartz. The weight percentages of the various minerals in the altered rock were calculated from their molecular equivalents. These values are shown in Table 3.

[18] Dana's Textbook of Mineralogy, William E. Ford (**1932**).

[19] Rogers, Austin F., and Kerr, Paul F., *op. cit.*, 359.

[20] Gruner, John W., The structures of vermiculite and their collapse by dehydration: *Am. Mineral.*, **19**, 560 (1934).

[21] Winchell, Alexander N., *op. cit.*, 434.

TABLE 3. MINERAL COMPOSITION OF THE ALTERED ROCK IN WEIGHT PERCENTAGES CALCULATED FROM CHEMICAL ANALYSIS AND PETROGRAPHIC DATA

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	K_2O	Na_2O	TiO_2	P_2O_5	Cr_2O_3	CO_2	H_2O	Sum	Adjusted
Serpentine	12.80				12.56			0.25					3.82	29.43	30.33
Vermiculite	11.54	4.46	1.39		7.71								6.27	31.37	32.23
Phlogopite	0.35	0.11			0.26		0.10						0.04	0.86	0.89
Magnetite			5.02	2.25										7.27	7.49
Limonite			4.19										.74	4.93	5.08
Perovskite						1.57			2.24					3.81	3.92
Chromite				0.08							0.33			.41	0.42
Apatite						0.71				0.54				1.25	1.29
Dolomite					0.34	0.56						0.74		1.64	1.69
Quartz	7.59													7.59	7.82
Clay Minerals*	4.68	1.59			0.43	0.20							1.69	8.59	8.84
Remainder													3.06	3.06	
	36.96	6.16	10.60	2.33	21.30	3.04	0.10	0.25	2.24	0.54	0.33	0.74	15.62	100.21	100.00

* Probably minerals of the montmorillonite division.

The results given in Table 3 must be considered only as approximations, for none of the assumptions can be considered as absolutely correct. They do, however, give a much more accurate picture of the quantitative mineralogic composition of the altered rock than can be obtained from the petrographic and chemical studies alone. The amounts of magnetite and serpentine are a little high, for small quantities of MgO and FeO are required for unaltered olivine. These errors, however, cannot be great for olivine constitutes less than 0.4 per cent of the altered rock. The amount of montmorillonite, also, may be somewhat too high for a small quantity of Al_2O_3 is required for andesine. The adjustment for H_2O is rather large, and may be caused by the variable and high water content of vermiculite and montmorillonite, as shown by the analyses of the former assembled by Gruner,[22] and of the latter assembled by Winchell.[23]

By means of the data assembled in Table 3 and the average specific gravities of the minerals, an estimated mode of the altered rock was calculated in volume percentages. It is tabulated together with the weight percentage mode in columns 1 and 2 of Table 4.

With the aid of certain assumptions, a very generalized mode of the fresh rock was calculated from the mode of the altered rock. The procedures used in the calculations and the assumptions made are as follows:

The relative proportion of olivine was calculated from the volume percentage of serpentine on the assumption that serpentine replaced olivine volume for volume. The relative proportion of phlogopite was found by combining the amount of phlogopite in the altered rock with the quantity of phlogopite calculated from the molecular equivalent of Al_2O_3 in vermiculite. The weight percentages of magnetite, perovskite, and apatite were taken to represent the relative amounts of these minerals in the fresh rock. The clay minerals were considered as impurities and omitted from the calculations. The relative proportions of the various original minerals were then recalculated to 100 per cent. The mode in volume percentages was then calculated from the weight percentages and average specific gravities of the minerals. The mode of the fresh rock, in volume and weight percentages, is given in columns 3 and 4 of Table 4.

The data assembled in Table 4 emphasize the highly altered character of the dike, and contrast rather well the secondary constituents with the primary minerals from which they were derived. Practically all the olivine has been changed to serpentine with the liberation of iron oxides,

[22] Gruner, John W., *op. cit.* 559 (**1934**).
[23] Winchell, Alexander, A., Montmorillonite: *Am. Mineral.*, **30,** 512 (1945).

TABLE 4. MODES OF ALTERED AND UNALTERED MICA-PERIDOTITE

	Altered Rock		Unaltered Rock	
	Weight percentages	Volume percentages	Weight percentages	Volume percentages
Serpentine	30.4	32.6		
Olivine	—	0.4	44.0	43.0
Vermiculite	32.2	35.0		
Phlogopite	0.9	1.0	43.0	48.0
Magnetite	7.5	4.0	8.0	5.0
Limonite	5.1	3.7		
Perovskite	3.9	2.6	4.0	3.0
Chromite	0.4	—	—	—
Apatite	1.3	1.1	1.0	1.0
Dolomite	1.7	1.6		
Quartz	7.8	8.2		
Clay*	8.8	9.8		
	100.0	100.0	100.0	100.0

* Probably montmorillonite.

and most of the phlogopite has been altered to vermiculite. The only relict minerals appear to be small amounts of olivine, magnetite, perovskite, phlogopite, apatite, and chromite.

GENERAL DISCUSSION AND CONCLUSIONS

The calculated mode, as represented in Table 4, places the unaltered rock in class 4, order 2, family 5 (425) of Johannsen's classification. Because of the assumptions necessary for the calculation of the mode, this conclusion is subject to some revision.

The value for magnetite, 5.0 per cent, just places the rock in order 2. This figure, however, is undoubtedly too high, for relative to the other minerals, it has undergone less loss during weathering. In addition all of the magnetite was assumed to be primary, whereas at least part of it came from the alteration of olivine. The total percentage of ores is, therefore, actually well under 5.0 per cent; consequently the rock should be placed in order 1.

In calculating the serpentine all of it was assumed to have replaced olivine volume for volume. On this basis the value for olivine may be somewhat high, for Harker[24] has shown that the change from olivine to serpentine may produce an increase in volume. On the other hand, any error of this kind is probably more than compensated for by the loss of

[24] Harker, Alfred, Petrology for Students, 81 (**1923**).

MgO from olivine or serpentine during weathering, for Goldich[25] and others have shown that there is a relatively high loss of this oxide during the weathering of basic rocks. The net result of these discrepancies is that the value for olivine should be somewhat higher; it does not appear from the available evidence that the olivine should be increased to the point where it would be necessary to place the rock in family 1. This possibility, however, should not be overlooked.

The modal values for perovskite, apatite, and probably chromite are also a little too large, for like magnetite, they suffered less loss relative to the other minerals during weathering. The figure for phlogopite probably involves the least error as it was calculated from Al_2O_3, a constituent that is normally considered constant during weathering. Omitting the clay minerals and quartz in determining the mode no doubt introduced some general errors, for some of them may have resulted from the alteration of primary or secondary silicates, or have formed from an original groundmass that at least, in part, may have consisted of glass. None of these discrepancies, however, are sufficiently great to change the class and order of the rock, and it is also doubtful if they have been great enough to change the family.

As a result of a preliminary study, the unaltered dike was thought to contain sufficient hypersthene to be classified as a hypersthene-phlogopite peridotite, and, therefore, it was placed tentatively in family 7 by the authors.[26] This assumption was based primarily on the erroneous conclusion that some of the highly altered relics of negative olivine in the serpentinized phenocrysts were hypersthene. Careful study of somewhat less altered material failed to confirm the presence of hypersthene; if present in the unaltered rock it probably occurs in only very minor amounts. Consequently, for reasons given in this paper, the rock should be placed in family 5, rather than in family 7.

From the data herein presented, it is concluded that the Salt Springs Road material is the alteration product of an igneous dike of the peridotite group, and until less weathered material is available for study, it should be classified according to Johannsen's classification as a mica peridotite, class 4, order 1, family 5 (415).

[25] Goldich, Samuel S., A study in rock weathering: *Jour. Geol.* **46**, 54 (**1938**).
[26] Maynard, James E., and Ploger, Louis W., *op. cit.*, 201 (**1946**).