Molecules (1).	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	K_2O	Na_2O	CO_2	H_2O	Corresponding percentage.	
Equivalent weight (2)	60	102	160	72	40	56	94	62	44	18		
Per cent in analysis of 15515 (3)	46.45	16.60	2.72	7.25	9.21	6.32	1.02	4.05	0.40	5.01	99.03	
(3) ÷ 2	0.774	0.163	0.017	0.101	0.230	0.113	0.011	0.065	0.009	0.278		
Feldspar											4.03 6.62 23.4	
Ab = Na_2O, Al_2O_3, 6 SiO_2, using all Na_2O	0.390	0.065						0.065				
	0.384	0.098									3.64 6.62 7.8	34.06% Ab
An = 2 CaO, 2 Al_2O_3, 4 SiO_2. Enough for Ab_2An_1, chap. VI. § 2.	0.130	0.065				0.065						52.13% Ab_2 An_1.
	0.254	0.033				0.048					1.03 1.12 1.32	18.07% An
K_2O, Al_2O_3, 2 SiO_2; may combine with Ol. molecule for biotite or with 4 SiO_2 for feldspar	0.022	0.011					0.011				1.58 2.24 1.32	3.47% requiring 2.6% SiO_2 to make orthoclase or any amount of olivine for biotite.
	0.232	0.022										
*FeO, Al_2O_3, SiO_2, using the remainder of Al_2O_3	0.022	0.022		0.022							1.22 2.72	5.14%
	0.210	0.000		0.079								
FeO, Fe_2O_3			0.017	0.017							2.668 1.92 5.76	3.94% Magnetite 15.49% augite.
				0.062								
CaO, MgO, 2 SiO_2; augite, diopside, using all Ca	0.096				0.048	0.048						10.35%
	0.114				0.182						7.28 5.46	
Balance so far as may be is 2 MgO, SiO_2	0.091				0.182							12.74%
Respectively 2 FeO, SiO_2	0.023 0.023										3.32 1.38	17.44% Olivine.
				0.046								4.70%
Excess of bases				0.016							1.15% FeO not accounted for.	

* Augite-fassaite molecule.

Molecules (1)	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	K_2O	Na_2O	CO_2	H_2O	Sum.	Sp. Wt.	Corresponding percentage.	
Equivalent weight (2)	60	102	160	72	40	56	94	62	44	18				
Per cent in analysis of S. 15523.	46.13	19.79	7.24	3.79	7.27	11.43	0.52	2.55	0.29	1.83	100.84	2 887		
(3) ÷ (2)	0.769	0.194	0.045	0.053	0.182	0.204	0.006	0.041	0.007	0.102				
Ab = Na_2O, Al_2O_3, 6 SiO_2, using all Na_2O	0.246	0.041						0.041					2.54 4.18 14.76	
	0.523	0.153											6.89 12.54 14.76	21.48 % Ab
An = 2 CaO, 2 Al_2O_3, 4 SiO_2, enough for Ab_2 An_3, chap. VI, §2	0.246	0.123				0.123								55.67 % feldspar Ab_2 An_3
	0.277	0.030				0.081							0.55 — 0.03 0.61 0.72	34.19 % An
K_2O, Al_2O_3, 2 SiO_2; may combine with 4 SiO_2 for feldspar or with olivine molecule for biotite	0.012	0.006					0.006							
	0.265	0.024											1.73 2.45 1.44	1.87 %. Query: In orthoclase or biotite molecule?
FeO, Al_2O_3, SiO_2; the augite fassaite molecule, using the remaining Al_2O_3	0.024	0.024		0.024										
	0.241			0.027									4.54 3.24 9.72	5.62 %
CaO, MgO. 2 SiO_2; the augite diopside molecule, using all remaining CaO	0.162				0.081	0.081								
	0.079				0.101								2.08 4.64	19.50 %
FeO, Fe_2O_3; magnetite, using all remaining FeO			0.029	0.029										
			0.016										0.64 2.56 0.96	6.72 % magnetite.
MgO. Fe_2O_3, SiO_2; augite molecules, using all remaining Fe_2O_3	0.016		0.016		0.016									
	0.063				0.085								3.44 2.58	4.16 % 27.28 % augite.
2 MgO, SiO_2: olivine molecule, using remaining MgO	0.043													
SiO_2 excess; in feldspar, or in converting olivine to augite	0.020				0.085									6.02 % olivine. 1 20 SiO_2 not accounted for.

With all allowances for interchange of bases and secondary alteration, the relative constancy in quantity by variability in chemical character of the feldspar, the increase in the augite and diminution of olivine as compared with 15515 are clearly indicated. See note. p. 148.

must not then be applied indiscriminately, but only to the Greenstone and to flows strictly comparable. As we have seen, it does apply fairly well to a large number of other flows among the Keweenaw beds and may thus be considered as characteristic of a standard type, so that variation from it points to abnormal chemical composition. Numerous instances of the smaller grain of the augite have been noted, from actual measurement, in the beds above the Greenstone.

§ 11. Other factors affecting grain.

We have mentioned that there are other factors affecting grain, just as there are other factors affecting the rate of solidification. But our investigations throw little light on them. We have no right to presume any great variation in pressure in the series which we have been studying. The sole exception which we have already mentioned, is that around certain amygdules the grain seems to be finer (Pl. VI, Ss. 15811 and 15008-15117). This can hardly be due to cooling, as the escape of heat into a small closed space like the bubble in which an amygdule is formed, can hardly be more rapid than elsewhere, but this finer grain may easily be supposed to be due to the escape of the gas that caused the bubble. Thus, too, we have around an amygdule in S. 15618, a zone with a trichitic texture of arborescent feldspar. Since, as we have already mentioned, the diffusion of gas follows in general the same laws as the diffusion of heat, and indeed is dependent upon it, our best chance of studying the varying effects of gas diffusion, would be if we could compare some flows which we knew were poured forth under a considerable depth of water, with those which we knew were subaerial. Even then we should probably find that the varying conductivity respectively of water and air was a more important factor. We have not this certainty concerning any of the flows here considered. It has occurred to me that the upper part of the series where sedimentaries are more abundant, and especially the beds around Chippewa Harbor, where the sedimentaries are fine grained sandstones, and seem to be penetrated by intrusive sills, were likely to have been deeper submarine eruptions. It would seem likely that in such a case a flow would be especially liable to be split while hot by a later flow, but that question must await farther investigation.

§ 12. Distinction between intrusive and effusive rocks.

The most important bearing of this discussion from a theoretical point of view is on the question as to the recognition of the abyssal or plutonic rocks as a separate group. It has often been denied that we can make any distinction between the more massive basic effusives and the deep seated intrusive, that is, plutonic or abyssal forms of the same chemical composition, while the marked difference between the equivalent more siliceous forms, the granites and rhyolites, is undeniable and generally accepted. But now in view of what we have seen, the question opens whether we may not seek characteristic differences, not merely in the appearance of diallage or augite, which is rather a phenomenon connected with metamorphism and of dynamic origin, but also in the character of the variation in grain. A rock may be looked on with equal justification as a geological unit, or as a mineralogical combination of certain minerals in a certain manner of texture, and according as we look at it our classification will differ, both classifications being equally justified, both having their place. But if we are to consider a rock as a geological unit, as a constituent of the earth's crust, then I presume no one will doubt that we must consider one single sheet of lava or igneous magma as one unit, and then we come to this characteristic difference between the effusives (in general) and the intrusives (in general),—that the former increase in size of grain from the margin clear to the middle, and the others have a more or less broad contact zone of uniform grain, while the deeper

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In the table on the preceding page the CO_2 and H_2O are neglected as secondary additions. The excess of bases in Sp. 15515, 1.15 per cent FeO not accounted for, points to a probable removal of part of the SiO_2 which has been replaced by the CO_2 and H_2O. It would be mathematically easy enough but not physically probable to assume that the iron was added to the augite so as to make a kalk-olivine. Or it is likely that somewhat too much An has been taken, as the determination, by the extinction angles, of ratio of Ab : An may easily be 10 per cent out. Finally, it is obvious by comparison with analysis of No. 15523, that the relative proportion of Fe_2O_3 : FeO is liable to variation which may be due to the character of the secondary alteration. Molecule (3) was very likely in the original glass with SiO_2, now removed. The FeO and MgO are interchangeable in (4) and (7), making a possible variation in percentage there. Query: Is the higher percentage of iron in the olivine in No. 15515 probable, or is it more likely that the iron was present as iron oxide and that the corresponding SiO_2 was used to make orthoclase?

seated intrusives, either because of the higher initial temperature of the molten rock itself or because of the higher temperature of the rock into which it was injected, would have no marginal zone of finer grain. Of course, here, as everywhere in nature, we have transitions. It is easy to conceive that flows near their source may be superheated when coming to rest, and to imagine intrusive sheets whose conditions of cooling will approximate to those of effusion. The real determining factors of a rock are not its geological surroundings, but the physical conditions consequent upon those surroundings. These physical conditions will, however, as a matter of fact be closely linked with certain geological surroundings, and whichever we use for our classification, the important thing is that we should be able to read from the present state of a rock the physical conditions of its formation, and hence the probable geological conditions that surrounded it at that time.

The practical question for Isle Royale is whether dikes (or intrusive sheets) do play the important role that they are imagined to by N. H. Winchell (Am. Geologist, 1895, p. 270). There is no doubt that at certain points on the north side of the island the Minong trap does resemble a dike, and in a reconnoissance such as Winchell made might readily be taken for such, and I do not wish to be understood as criticizing Prof. Winchell farther than to say that in a cursory glance at a region out of his particular realm of study he seems to have been mistaken. There are other arguments enough for the non-intrusive character of the Minong trap, but the argument on which we are now dwelling is one that applies equally to practically all the other basic sheets. Their grain increases clear up to the center. Now if we compare Lawson's studies of the intrusive sills and dikes of the opposite or "North Shore," which in all probability represent deeper seated forms of the same general magma, at any rate are very similar chemically (Bull. Minn. Geol. Survey, VIII, pp. 32, 36; Am. Geol., VII, 1891, p. 153 *et seq.*), we find it distinctly stated that there is a *rapid variation in grain for the first few feet from the contact, and then a central coarser belt of tolerably uniform grain.* In the Stop Island dike, for example, he has given the measurements and also distinctly stated that while the dike is 150 feet wide, the grain increases rapidly for the first four feet, then slowly to 15 feet, then there is hardly any perceptible change to the center. The pyroxene, according to his figures, actually diminishes in size (owing perhaps to the chemical differentiation which is the principal subject of his paper). It is easy to see that his statement and figures point to a curve of grain like those of Fig. 17, which are from similar dikes in the South Shore Huronian. It is then evident that the conditions of grain alone would suffice to indicate that the basic rocks of Isle Royale are superficial, and I venture to prophesy that it will prove widely true that *superficial basic rocks are characterized by an increase of grain to near the center, while deep seated basic rocks have a broad central zone of nearly uniform grain.*

It may also be noticed in this connection that Lawson finds the intrusive quartz porphyrites accompanying the basic sills to be granophyric, a form of structure closely akin to the ophitic, but which we have found on the island only in pebbles in conglomerates. It is not impossible that we have here the indication of a corresponding scale of textures for the acid rocks which we have failed to find on Isle Royale, where acid rocks are the exception (Cf. Ros. M. u. Pet. Mitth., XII, 1891, p. 379).

The bearing of the above remarks upon the controverted question of the effect and importance of the geological environment ("Ort") upon rocks is too obvious to need explanation. The only thing to be noticed is that it introduces a factor hitherto disregarded, the temperature at the end of motion, as an important one. It must also be remembered that the possession and loss of gas by diffusion follow the same laws as the possession and loss of the imponderable "caloric," while the possession of gas may greatly lower the temperature of solidification as glass.

CHAPTER VI.

PETROGRAPHY.

§ 1. Work of previous investigators.

Elsewhere and especially in the preceding chapter on the grain of rocks, I have given many facts of interest which are based on microscopic studies, but which in themselves required no knowledge of the technique of microscopic work for their understanding, and were of a broader interest in the results to which they led. In the present chapter I have gathered together those facts of interest which appeal solely to the professional student, and can neither be observed nor appreciated except by one who has had some acquaintance with the use of the petrographic microscope in the examination of rocks. The Keweenawan rocks have already been ably described in reports of the Survey and elsewhere by Pumpelly, Rominger, Wadsworth, Irving and others, and illustrated by Irving with a perfection that I cannot hope to surpass. It will not therefore be necessary for me to recapitulate my observations on over a thousand slides, but rather to summarize the more important observations. If, in the course of this resumé, I am led to lay undue emphasis on the points as to which I differ from my predecessors, it must be remembered that such is the inevitable result of coming afterward. It is useless to repeat again and again in extenso what has already been well said. But since their work was done methods and instruments have been greatly improved, and if in some respects a new and perhaps ampler material, and the application of the later methods enable me to correct or supplement their results, it is but natural that a prominence to such corrections should be given, which perhaps unduly exaggerates the importance of the observations, considered by themselves.

The chief works to which I shall have occasion to refer are:

Irving: Copper-Bearing Rocks of Lake Superior, Mon. V., U. S. G. S., 1883.

Wadsworth: Bull. Minn. Geol. Survey, II, 1887. Notes on the Iron and Copper Series of Lake Superior, Bull. Museum of Comparative Zoölogy, VII, 1880.

Pumpelly: Geol. Sur. Mich., I, Pt. II. Wis. Geol. Survey, III, Pt. II, pp. 27-49. Proc. Am. Acad., XIII, 1878, pp. 253-309.

Rominger: Geol. Sur. Mich., V, Pt. I.

Lawson: Bull. U. Cal., Geol. Dep., I, p. 30.

Rosenbusch: Mikroskopische Physiographie I, 1883, II, (2nd Ed.), 1887, (3rd Ed.), 1896, Stuttgart.

Grant, U. Sherman, 22d Annual Report Minn. Geol. Survey, 1894, Pt. IV.

I shall first give a resumé of the observations by minerals, then by textures, and then by rocks. Although this may involve some repetition, it will better bring out the various relations of the observations.

§ 2. Microscopic observations on minerals.

I refer to a table of the rock-forming minerals, published in the Am. Geologist (June, 1891) and thus save repetition of the various characters by which these minerals are commonly recognized, as unless otherwise mentioned they have the characters indicated in the table.

I have used with good effect Becke's method for determining refraction, especially in distinguishing between talc and sericite, *q. v.* As it does not appear to be yet much in use among American petrographers, I may be pardoned for giving a brief account of it, especially as the original paper is not easily accessible (Sitzungs-berichte der Kaiserlichen Akademie der Wissenschaften, Mathematische-Naturwissenschaftliche Classe, Band CII, Hefte vi u. vii, 1893, Juni u. Juli, Abth. 1, "Bestimmbarkeit der Gesteinsgemengtheile", Vienna, p. 360). "With a mean focus" (on a boundary between two minerals of different refraction, which is practically perpendicular to the line of vision) "both sections appear equally bright and the bounding plane appears as a hair line. If the tube of the microscope is raised, a bright line is developed near the border on the side of the more refractive mineral, which moves away from the border, becomes broader and vaguer as the tube is farther raised. If the tube is lowered the same appearance is developed on the less refractive side." Page 361. "If the two substances interlock, by focussing too high one appears to see the whole surface of the more refractive substance brighter."

"We must narrow the cone of illumination to the angle of total reflection, to get the best results" (that is, lower the condensor, but use above an objective of wide angle). Pages 361-2. "The phenomena are the more marked, the thinner the rock section. A considerable deviation of the boundary from being exactly in the line of vision is less disturbing to the phenomenon, if the less refractive mineral is on top." Page 363. "The differences of refraction can be made still more sensible if observations in oblique light are used," i. e., cut off half the cone of rays with your hand or a card, below the rock section; "more light will go into the objective from the side of the more refractive section that is turned away from (i. e. apparently toward) the light." Cf. also Exner, Archiv für Mikroscopische Anatomie, 28, 1895, p. 97.

In applying this method we must remember that we must study one index of refraction at a time, in birefractive minerals, and that is the index of refraction for light vibrating in the plane of polarization of the lower nicol. In one position talc will appear nearly as refractive as the surrounding serpentine, in another it will appear much less refractive.

We take up the minerals in order, by groups, beginning with the primary and more basic.

Olivine. The olivine is very rarely unaltered (Ss. 15807, 15827). It is generally evidently the oldest of the constituents, rarely showing a division into two generations (Ss. 15821, 15170). There seems to have been a tendency for floating grains of olivine to cluster together (Ss. 15461, 15404, 15391), which makes it hard to give the size of the individual grains, when all are altered. Generally speaking, they are larger in the less augitic rocks (the Ashbed diabases, etc.), though less numerous. (Cf. beds below No. X, 426 ft., down to the Greenstone.)

In the ophites, as described, the olivine is crowded between the patches in minute corroded grains. In the porphyrites the glomero-porphyritic olivine-plagioclase aggregate is significant of the tendency of the magma at an early stage to crystallize out in that form, rather than as augite.

The alteration to serpentine is usually well developed (Ss. 15649, 15837, yellow-green; 15636, 15096, 15089, 15179, oily). The reddish

alterations, or sometimes red with green centers (S. 15783), are also well exhibited. Figure 23, from specimen No. 15492, exhibits the exact character of the resultant pleochroism, concerning which the authorities either differ or are ambiguous.*

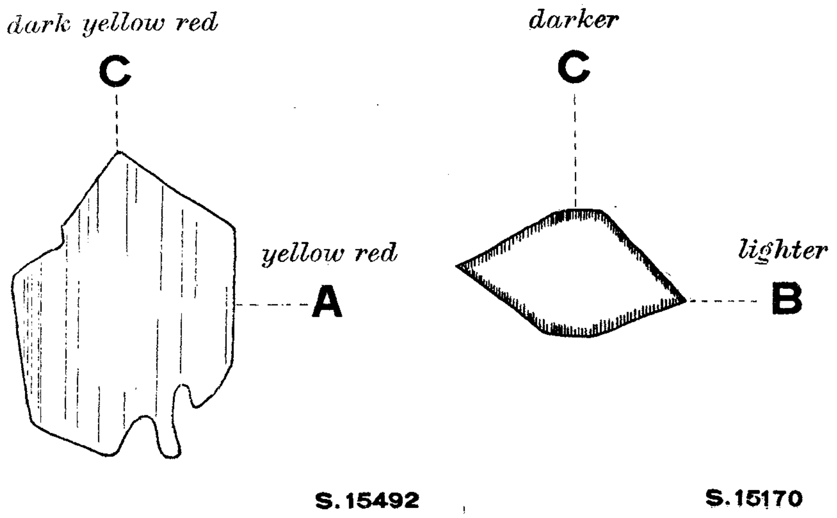

Fig. 23

Illustrates the pleochroism and optical characters of altered olivine phenocrysts.

This reddish alteration product agrees optically with Lawson's iddingsite, and I think that Lawson is right in considering the iron as largely a pigment of minute scales of hematite arranged parallel to a cleavage which is developed at the same time as the pleochroism (S. 15450). The nature of the alteration product seems to vary. Sometimes it appears to be distinctly a mica, either red (S. 15083, Cf. Rominger, *loc. cit.*, p. 114), or green (Ss. 15731. 15736, 15825). Again at times there is an alteration to talc, as reported by Julien (Ss. 15774, 15571), and again nothing but hematite seems to be left (Ss. 15243, 15083, 15090?). Iron oxide,

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* Geol. Sur., Mich. 1895, Rominger, V, Pt. I, pp. 114, 124; Rosenbusch, Mik. Phys., II, 1887, pp. 489, 512, 1896, p. 963; Lawson, Bull. U. Cal., Geol. Dep., I, p. 30, "Iddingsite." Irving, *loc. cit.*, p. 39. See also Fig. 29.

especially magnetite, also occurs in the process of serpentinization (S. 15089). All the above changes are quite natural for olivine, and there is good evidence that they all occur. "Iddingsite" seems to me but a half way house. I am inclined to believe that alterations to mica are especially frequent, compared with the frequency with which they are recognized.

In regard to the alteration to magnetite, while it is hard to distinguish the magnetite from the hematite when they occur together, magnetite does often occur but generally under such conditions, replacing the olivine in such a way, not strictly pseudomorphic, (S. 15493) *and yet taking its place* as an element in the texture, that it seems to be a primary or magmatic replacement, due to oxidation in the still fluid magma.

The reason why Irving reports no olivine from the Ashbed diabase group, and includes as olivine-free diabases many rocks which I should class as melaphyres, *e. g.*, Marvine's bed No. 87, is probably that his sections showed no fresh olivine, which as we have seen is not surprising, and he interpreted the pseudomorphs as augite. But the analysis, *loc. cit.*, p. 66, which is like ours of specimens Nos. 11515-15523, shows plainly enough with 5% of alkalies and 13% of FeO and MgO, and not enough SiO_2 for the anorthite ratio, that if the original rock has not been entirely altered in composition it must have contained olivine, as both oligoclase and augite would imply much higher percentages of SiO_2. And in fact I did not doubt before having any analysis made, nor do I think anyone of experience would doubt, that the pseudomorphs were after olivine.

Augite. When the augite is scarce, it is idiomorphic and colorless (Ss. 15531, 15328, etc.). When a little more abundant, it may appear in sheaflike or shredded forms (Ss. 15622, 15537, 15926). Around an amygdule it often has arborescent forms (S. 15618). When moderately abundant (Irving's "ordinary type diabase"), it is in granules (Ss. 15494, 15783) or in xenomorphic wedge shaped forms (Ss. 15393, 15841), dependent somewhat upon the nature of the accompanying plagioclase. It has evidently more tendency to be idiomorphic against the plagioclase, the less lime the latter has. Sometimes it seems just on the border line, patchy, and in part idiomorphic (S. 15349). Commonly, of course, it is poikilitic, enclosing the feldspar laths. To this variety of poikilism the term ophitic is applied. But even when the augite is thus ophitic, it is not, as is sometimes said, necessarily without form of its own. For example, in S. 15834 the poikilitic augite is in long prisms. A significant variation from the ordinary rules is in S. 15428, where the augite is extra coarse along a vein with amygdaloidal filling. In the doleritic type of structure it may be long and idiomorphic (octagonal prisms); so is the feldspar also (S. 15275). It occurs occasionally, but not so characteristically as the feldspar, in nests (Ss. 15148, 15784) and also in two sizes (S. 15784), the larger size however not apparently indicating any great break in the process of crystallization.

When the augite is more abundant the brownish tint is more marked, but I have not noticed the strongly pleochroic variety with violet hues that sometimes occurs.

The decomposition of the augite to chlorite, *q. v.*, is everywhere to be seen. Epidote prisms as an alteration product of augite are not infrequent (S. 15516). In contrast to the frequent mention of uralite after augite or primary hornblende, from other parts of the Keweenawan, I may say that I have found hornblende in any shape extremely rare. (S. 15534?).

Rounded granules of augite, quite fresh too, are often found in the basic sediments (S. 15043).

Feldspars. This group is well represented in its range from orthoclase (Or. = K_2O, Al_2O_3, $6SiO_2$) to albite (Ab. = Na_2O, Al_2O_3, $6SiO_2$) and nearly to anorthite (An. = $2CaO$, $2Al_2O_3$, $4SiO_2$) (S. 15666). The group of the soda-lime feldspars is of especial importance, and Plate V shows the chemical composition corresponding to various proportions of the constituent molecules. It also shows the method I have very generally used in the determination of the feldspars. As has been long known, the extinction angles of the feldspars depend very closely on the percentage of lime present. Pumpelly, even at the early date of his work, appreciated their importance and made good use of them, and Irving followed his methods (*loc. cit.* p. 39). While in general Pumpelly had caught the right idea, his method was deficient in that the distinction between positive and negative directions of extinction, *i. e.*, between those of greater and less refraction, was not noted, and the limit of extinction angles for anorthite was put too low. The farther development of the theory of the feldspar series by A. Michel Lévy, Schuster, Mallard, and others, is in all the petrographical text-books; I have used the statistical and other methods, and the diagrams already printed. The method which I have thought it worth while to illustrate by plate V, is one suggested by Lévy in his "Détermination des feldspaths", which is the best book yet published on the subject. This work enables one to determine the lime percentage in a single compound individual, and there is scarce a thin section but will furnish many such.

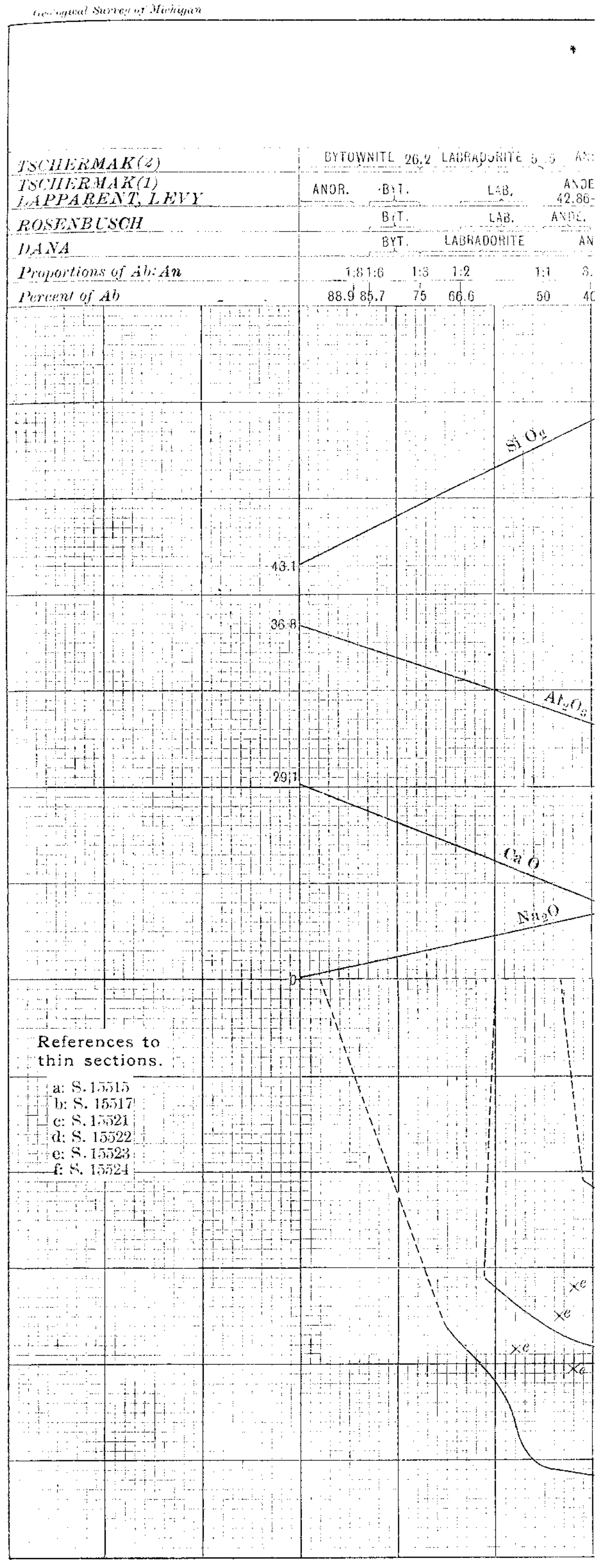
If we have four sets of feldspar lamellæ occurring as two compound individuals composed of albite lamellæ, which individuals stand in the relation of Karlsbad twins to each other, then when they are cut perpendicular to the lateral pinacoid (M) we shall have two sets of extinctions symmetrically arranged on each side of the dividing lines parallel to M. If these dividing lines are turned until they are at 45° to the plane of the nicols, the individual will appear to consist of but two parts, but there will be no position in which the whole compound individual will appear to be equally illuminated. Now it is possible to determine from Lévy's data, what the one set of extinctions will be if the other set are given, for the various species of feldspar produced by the various intermixtures of the albite and anorthite molecules. Hence we have plotted curves for the various feldspars, showing this connection, the value of the less extinction being taken as abscissa, and of the greater as ordinate. The results may be checked by the statistical method, or Michel Lévy gives a formula for the relative birefraction which may also be used as a check. Generally speaking, the set with the greater extinction angles have the less birefraction (Ss. 15499, 15523). We may also check up our observations of extinction by reading on the positions of equal illumination which are connected with the birefraction.

For example, take the Greenstone. In S. 15252 we have the following observations

Alb.	K.	*Alb.*
19°–19°	with	41°–
30°–28°	with	37°–
34°–24°	with	38°–
31°–23°	with	23°–
39°–34°	with	6°–2°
	S. 15254	
25°–27°	with	9°–4°

which indicate very plainly a curve for all the observations which are nearly symmetrical, between Ab_3 An_4 and An, really about Ab_1 An_2 and near the common formula for labradorite, Ab_2An_3. One big porphyritic crystal gives the higher values of 43°–43°.

In this way the statements scattered through this report were substantiated concerning the feldspars. Of course a good many readings were made on simple albite twins besides.



VARIATION OF CHEMICAL COMPOSITION

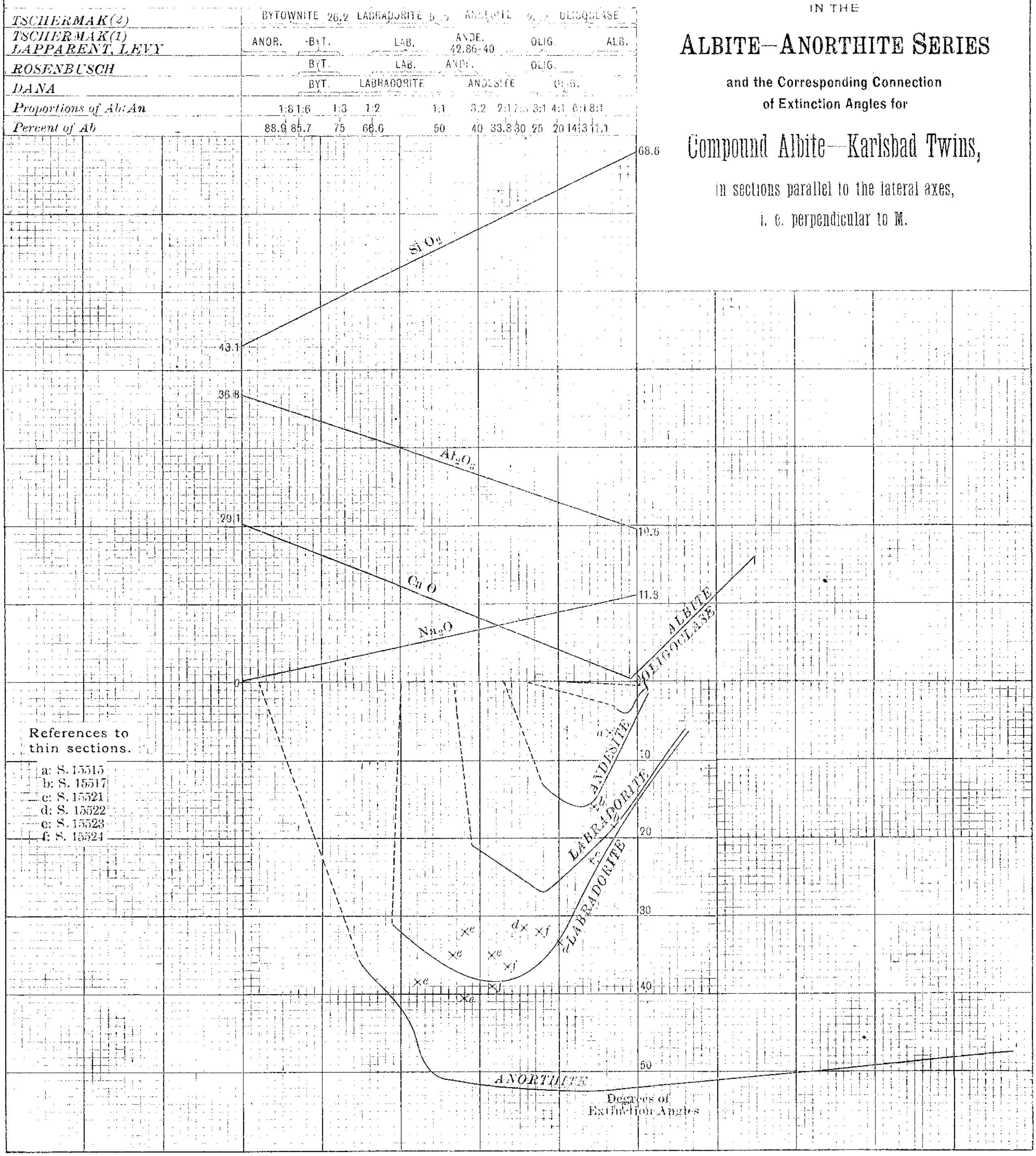
IN THE

ALBITE–ANORTHITE SERIES

and the Corresponding Connection
of Extinction Angles for

Compound Albite–Karlsbad Twins,

in sections parallel to the lateral axes,
i. e. perpendicular to M.



Orthoclase occurs rather rarely in a form that may be certainly identified. It occurs in large corroded phenocrysts in quartz porphyries and orthophyres, which are represented mainly in the conglomerates and tuffs (S. 15951). In S. 15955 it has a curious porous structure.

Triclinic and twinned crystals with very low extinction angles occur in connection with the orthoclase under the same circumstances, and occasionally appear to be anorthoclase (S. 15436), but I have not made sure that they are. They too are corroded very often (Ss. 15237, 15897). Besides occurring in the conglomerates they occur in the Huginnin porphyrite (drill hole No. XIV, S. 15816, etc.) and similar corrosion occurs in the Minong porphyrite (drill hole No. 1, Ss. 15046, 15052, Pl. VI, fig. 6, etc.). In these cases they are in size very distinct from the mass of the feldspars, and may be true intratelluric products, showing some signs of corrosion. Were it not for the character of its feldspar, the Huginnin porphyrite would be a type of labradorite porphyrite.

In the main occurrence of the oligoclase feldspar, it has a somewhat different character. Sometimes very clearly porphyritic, or at least subject to the accidents of motion, the feldspar as a whole is not divisible into sharply separate groups, but we have every gradation of size down to the smallest, showing that although the feldspar began to form before the flow came to rest, its formation continued thereafter. In such case we are very likely to have a glomero-porphyritic texture (Pl. VI, fig. 4), that is several of the larger feldspars are likely to be grown together in aggregates which it seems a stretch to ascribe even to the ineffable complexity of feldspar twins, though we can in favorable cases recognize the presence of the Manebach (S. 15578), the Baveno (Ss. 15537, 15801) and probably other laws. Even if the feldspars are now in twin position, the evidence at times is clear that they were formed separately, and clotted together. Zonally varying extinctions, indicating variation of chemical composition, are not uncommon (Ss. 15767, 15828), and sections parallel to the lateral pinacoid (010) M are especially instructive (Ss. 15361, 15784). Not always are the margins more albitic (Ss. 15328, 15329), but this is generally true.

In a number of flows which stand as connecting links between the Ashbed diabases or navites (below, § 3) and the ophites the feldspar often differs in character from the top to the bottom of the flow. The flow in drill hole No. X (Ss. 15514-15524), from which the analyses were made, is one such,—S. 15515 giving 4°-9°, with 3° extinction angles, etc.; S.

15517 giving 21°–16° with 3°, and 6°–5° with 16°, etc.; S. 15521 giving 6°–6° with 23°–23°; S. 15522 giving 11°–18° with 29°–34° and 33°–34° with 10° extinction; S. 15523 giving 24°–20° with 42°–39°, 24°–23° and 19°–18° with 37°–33°; 24°–20° with –32°, 28° with 40°–37°; and S. 15524 giving 14°–11° with 26°–38°, 20°–17° with 35°–43°, and 13°–20° with 36°–37°. These plotted on Plate V show a well marked variation from andesite down about to the feldspar of the Greenstone, the normal labradorite type. Other similar cases are the bed at the bottom of drill hole No. IX (Ss. 15454–15461), drill hole No. VIII (Ss. 15354–15364) and below, and drill hole No. IV (Ss. 15176–15183).

In the well marked ophites the feldspar is generally a normal labradorite and the extinctions rarely indicate a less proportion of An to Ab than 1 : 1. Occasionally a feldspar close to anorthite is indicated (S. 15609, 21°–30° with 45°–45°), as is the case toward the middle and bottom of the big flow at the top of drill hole No. XIV. Baveno twins are very common. When the crystals are flat tablets, owing to the development of (010) M, Baveno twins give cruciform sections which are common and characteristic. Some of the finer grained basic sediments are largely composed of labradorite sand (S. 15161).

Coming to the smaller feldspars, we find rarely indications of three periods of feldspar growth (S. 15441). Very commonly and uniformly at the margins of the flows there are indications of two periods, the younger feldspars being mere trichites, with a very strong tendency to protruding angles and edges, which give characteristic forked and hollow forms (S. 15572) and skeletal outlines (Pl. VI, figs. 1 and 5, Ss. 15300, 15368, 15334). These trichitic additions naturally use the porphyritic crystals for foundations (Plate VI, fig. 1, Ss. 15092, 15186). But the very flows so markedly porphyritic at the margin may show little or no trace of it at the center, showing that far from the margin the coming to rest produces no sudden change in the conditions of cooling and solidification. There are evidently two marked epochs of alteration in conditions of solidification in the history of the feldspars; one is when the change from internal to superficial conditions takes place,—the eruption,—the second when the cessation of motion takes place, or, as we may say, the beginning and end of eruption. It is often possible to distinguish the products of the three periods separated by these two epochs. Much of the feldspar appears to have been formed between them.

Glomero-porphyritic feldspar aggregates also occur in the various tuffs and conglomerates, in many cases like those of associated flows (S. 15431). Feldspar is also alluded to by Koch as a secondary mineral. I have not noticed it.

Quartz and the other forms of silica (SiO_2).

The most distinct primary forms of quartz are the phenocrysts in quartz porphyries, which have been so admirably illustrated by Irving, that little remains to add. I have met them at Isle Royale only in conglomerate pebbles (Ss. 15237, 15890, 15902, 15922, 15949, 15950) unless in S. 15998 there is a small exception. They are generally corroded.

Quartz occurs abundantly in poikilitic secondary patches, sometimes so replacing a fine grained porphyrite, that while in ordinary light the microlitic flow texture is perfectly plain, in polarized light it is entirely disguised. In all respects it corresponds to the micropoikilitic patches described by Miss Bascom (Journal of Geology, I, 1893, No. 8, p. 816), and is referred to by Irving (*loc. cit.*, pp. 113 and 114) and by Wadsworth as well. It is not quite clear however, from Irving's descriptions, whether he did not lump the micropoikilitic and micropegmatitic textures together, as secondary quartz (*l. c.*, p. 100), though he alludes (on page 113) to the characteristic difference, viz., that in the micropegmatite the feldspar with which the quartz is intergrown has continuous orientation as well as the quartz, while in the secondary poikilite, quartz embeds and surrounds or replaces whatever comes in its way with no regard to previous orientation. If we do make this sharp distinction, as we ought, between poikilitic quartz and pegmatitic quartz, then I must say that a large part of the quartz that Irving and Wadsworth consider secondary, namely that which is pegmatitic, I do not so consider. It seems to be the normal mode of solidification of the acid magma under certain circumstances. In other cases it is the mode in which the more basic rocks have, under conditions of intrusion, filled the last interstices, which would otherwise be miarolitic. (See my discussion of quartz diabases in Chapter X.)

In this connection it may be as well to speak of spherulites, though they may not be really quartz. Irving did not happen to see any. On Isle Royale they occur in the Minong porphyrite at McCargoe cove (S. 16082) and in the porphyry tuffs (Ss. 15902, 15922, 15949, 15950).

Quartz also occurs abundantly in amygdules with epidote, etc., (S. 15820) as has been already so carefully described in our reports by Pumpelly. In S. 15114 A, from above the Minong trap, there is a section of an agate, such as are characteristic of this bed.

This bed is quite chalcedonic (S. 15120) in parts. Chalcedony and chalcedonic quartz also occur commonly in the tuffs, very markedly in the last one toward the bottom of drill hole No. XVI, immediately above the porphyry. Chalcedonic dots, and white margins to the ash fragments are characteristic of this whole formation (Ss. 15986, 15982, Pl. VI, fig. 2, etc.). Chalcedony also appears to occur coating miarolitic cavities (S. 15499).

Amethyst occurs around the outlet of Siskowit Lake.

Iron ores and ferrites. The somewhat old fashioned term "ferrites" is not objectionable if one distinctly understands that ferrite does not mean any one mineral, but is a group name for translucent, red to yellow, hydrates or oxides of iron.

Magnetite occurs at times in coarse distinguishably octahedral grains (Ss. 15126, 15831–3, 15906–17, etc.), and more often in finer grains It most often occurs, however, with the serpentine or other pseudomorph of olivine in such relation that we may say they make a grain together, and it seems to have formed from the oxidation of the iron olivine. In the ophites, for example, it mostly occurs thus crowded with the olivine into the interstices of the olivine patches. As a fine dust it is universally distributed (S. 15174), more abundantly in the more basic rocks. Not evenly, however, for sometimes it gathers into spots around which there is a clearer halo (S. 15566), or gathers simply into blacker spots (S. 15123) and club shaped and branching aggregates (S. 15640, as illustrated by Rosenbusch, I, Pl. III, fig. 2), or, especially in the less augitic types, around their small pores makes a darker border (Plate VI, fig. 4, and S. 15117, the Minong porphyrite; Ss. 15811, 15950, 15951). In many such cases its primary nature is by no means certain. Where, as in S. 15960, it outlines a perlitic texture or structure, it is more certainly secondary.

Of the other iron oxides,—

Hematite occurs more rarely (S. 15008) in irregular skeletons (S. 15520) Cf. also S. 15380.

It occurs sometimes in the coarse doleritic spots in the form of flat plates (Ss. 15912, 15544), and elsewhere quite frequently, and also in red ferritic form, in connection with alteration, and in the more feldspathic rocks, in certain kinds of alteration. *Ilmenite* also occurs (S. 15455)

DESCRIPTION OF PLATE VI.

Photographs of Microscopic Thin Sections.

FIG. 1. S. 15417. Drill hole IX, 279 ft. (1,100 ft. total depth.) From the top of the "Ashbed." Illustrates chiefly vesicular and concave forms of ash. Contact with overlying porphyrite also shown. Nicols 15° from crossed: 15 diameters enlargement.

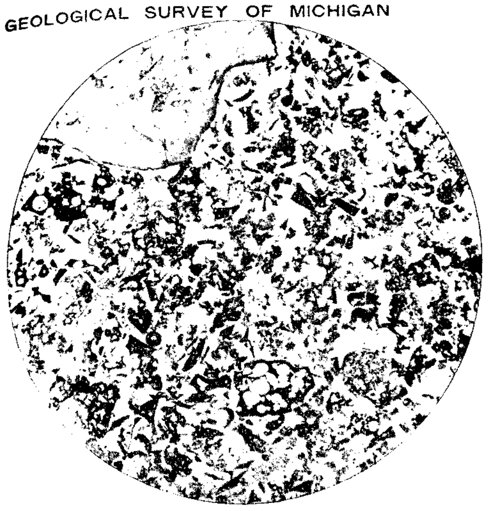
FIG. 2. S. 15982. Drill hole XVI. 891 ft. (6,160 ft. total depth.) From a tuff not far above the felsite. Illustrates the quartzose and chalcedonic dots, and agatoid margins of the fragments 9 mm from the lower left hand margin of figure. Neither feature comes out well in the process of reproduction. Nicols crossed; 23 diameters enlargement.

FIG. 3. S. 15493. Drill hole X, 225 ft. (621 ft. total depth.) From a melaphyre porphyrite, leaning toward an andesitic ophite. Illustrates doleritic texture—miarolitic cavities with chlorite coatings, wrapping around feldspar, e. g. 20 mm from bottom of figure; andesite feldspar with extinction *not* varying from center to margin of feldspar: xenomorphic augite also shown at lower right margin of figure. Nicols crossed; 18 diameters enlargement.

FIG. 4. S. 15438. Drill hole IX, 346 ft. (1162 ft. total depth.) From a typical navite or Tobin porphyrite. Illustrates glomeroporphyritic (oligoclase) feldspar, granules of idiomorphic augite in short square or round bright spots, hematite either original or replacing olivine. Type of navite texture. Nicols crossed; 17 diameters enlargement.

FIG. 5. S. 15811. Drill hole XIV, 370 ft. (5197 ft. total depth.) From the Huginnin porphyrite. Illustrates the finer grain of the feldspar (Ab_5 An_3) and its trichitic character around amygdules; 20 diameters enlargement.

FIG. 6. S. 15052. Drill hole I, 483 ft. (4103 ft. total depth.) Zone of interfusion of the Minong trap and the Minong porphyrite. Illustrates corroded labradorite (with glass enclosures; cf. Rosenbusch, Mik. Phys., 1892, I, Plate XXIV, Fig. 3), idiomorphic augite granules which are distinguished only by their greater refraction and do not stand out as well as in the photograph (one may be seen 2 mm from the top to left of the magnetite) and blotchy intermixture of coarser and finer textures; 20 diameters enlargement.

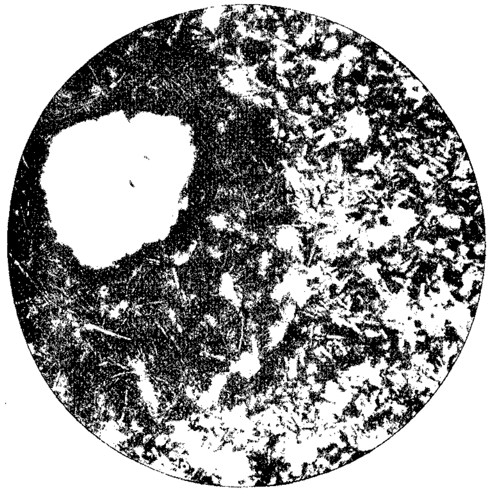


I

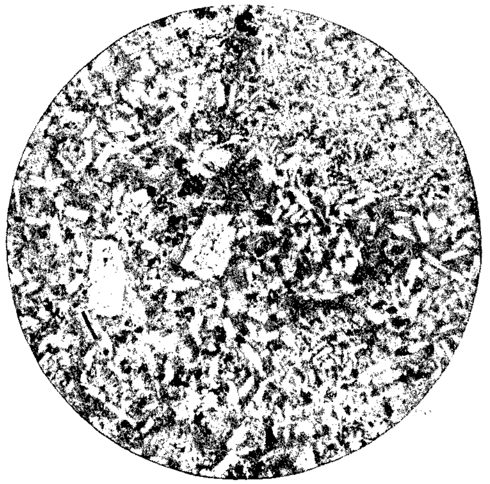
II

III

IV



V



VI

and also *leucoxene* (S. 15534), its alteration product. Whether the triangular outlines in S. 15520 indicate an original intergrowth of ilmenite and magnetite is not quite certain.

Ferritic discoloration, as described by previous authors, is widespread, giving to the sedimentary beds and to the red amygdaloids their characteristic red color; the amygdaloids at the bottom of a flow are more characteristically red in color than those at the top. The decomposition of the melaphyres seems sometimes to be accompanied by oxidation, and then ferrite is abundant. At other times the change is more of a pure hydration, and then ferrite may be wholly absent, being replaced by a magnetite dust, while chlorite and serpentine are abundant. In such secondary viridite, opaque trichites of decomposition occur (S. 15577).

Viridite. This somewhat old fashioned name (Vogelsang) is, nevertheless, a very convenient one for the secondary hydrous magnesian silicates of a green color described below, which probably form an isomorphic series like the feldspars. Their optical properties are certainly variable. I have discussed the optical properties of the group quite fully elsewhere, in connection with the quartz diabases. The process of alteration has been quite fully described by Pumpelly, and I have few facts to add, though some differences in interpretation to suggest.

Serpentine occurs as usual, and after olivine, *q. v.* At times it appears to approach bastite in its form, but I have never been able to convince myself that any enstatite was originally present (S. 15510).

Chlorite. There are two kinds of chlorite, which we may call delessite and chlorite, the former being the more birefractive and the more pronouncedly fibrous (S. 15332). They occur;—

(1) Lining amygdules,—generally delessite—

(2) Coating cavities of irregular shape but bounded by the idiomorphic crystals of the groundmass (Plate VI, fig. 3). These are taken by Pumpelly to be replacements either of augite or of some mesostasis (Irving, *l. c.*, p 65), though the idea that they might in some cases be the replacement of a pre-existing cavity, evidently occurred to him. When we study some of these cavities carefully, I think we shall be convinced that associated as they are with the general doleritic texture, and marked by a continuous band of delessite around their walls with its fibres perpendicular to the walls which band may be replaced by quartz or chalcedony, other filling material being various, they are the interstices which would necessarily be left in the process of cooling and complete

crystallization, and are akin to the miarolitic texture, and correspond to the micropegmatite interstices of the quartz diabases.

(3) Chlorite often occurs after augite also, of course; also as amygdaloidal filling, and, as Pumpelly describes, secondary after prehnite. "Chlorastrolite" seems to be a name applied to certain amygdules which have resisted weathering better than the matrix; in these amygdules the chatoyant effect produced by a fibrous chlorite rind is retained.

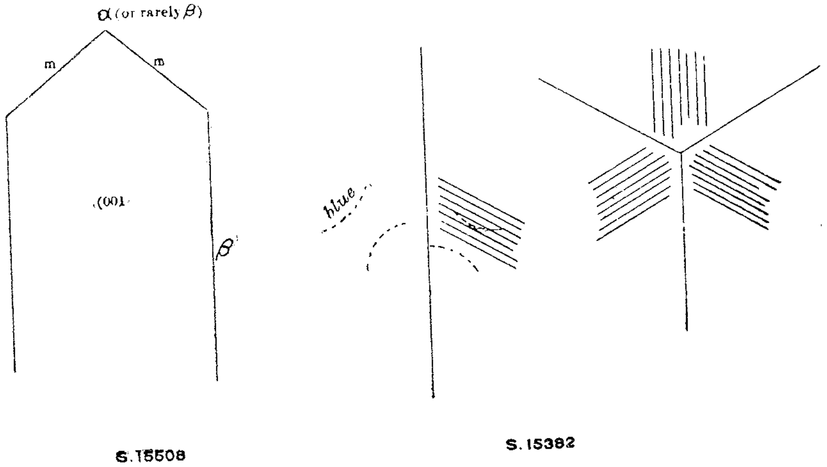


Fig. 24.

Illustrates the form, optical orientation, and some of the twinning phenomena of prehnite.

Prehnite. We class this with zeolites, from its association and behavior. It is the most abundant and characteristic replacement mineral, occurring in veins (S. 15521), in amygdules (S. 15508), and replacing the whole mass of the rock or the feldspar (S. 15508), with copper (Ss. 15149 and 15150) and quartz (S. 15820), with quartz and epidote (S. 15644), and with other zeolites (S. 15373). The order of occurrence has been carefully studied by Pumpelly. It differs in its characters from those indicated by its position in the table referred to, only in that +2V is likely to be small, and the dispersion is likely to vary even in the same slide. This is due to the oft described twinning (Neues Jahrbuch für Mineralogie, 1888, I, p. 91) which can often be recognized. In S. 15508 the prism m (110) and pinacoid b (010) can be recognized; Fig. 24 shows its optical orientation. The extinction of the principal zone, i. e., extension, is almost invariably negative, not always however. The pink prehnite does not appear as such in thin section (S. 15651), but S. 15149, which shows copper crystals under the microscope, shows a light flesh pink color to the naked eye.

Laumonite is well characterized, as indicated by its position in the table (Ss. 15453, 15352, 15087). At least two cleavages are distinct; a diagonal twinning (100) corresponds to that described, and bisects (110) the cleavage. A small −2V and large extinction are normal. Cleavage fragments, however, which have been for some time in the collection, show abnormally small extinction angles, which may be attributable to loss of water, or possibly to conversion to leonhardite. Other sections interesting for zeolites are Nos. 15373, 15303, and 15275.

Thompsonite is a very common zeolite on the island, but I have not happened to meet it in any of the sections examined by me (S. 15826?).

Analcite, which occurs frequently in the more feldspathic melaphyres, in distinct crystals in the incompletely filled amygdaloidal cavities, has also not been recognized under the microscope, but owing to its isotropic character and weak refraction it might easily be overlooked. A special test of the solubility and gelatinization of S. 15515, whose analysis indicated that it might have been present, was made with a negative result. As I remember, it occurs (Sp. 15289) more in the Ashbed diabase group, above the Greenstone, i. e., in the rocks that contain more soda, where it might be expected.

Apophyllite is mentioned by Koch, p. 188.

Whether the reddish yellow feldspathic mineral mentioned by him is really feldspar, as it may be, or possibly some undescribed zeolite, I dare not say.

Pectolite is also reported by Foster and Whitney (*loc. cit.*, p. 105).

Wollastonite has been described by Foster and Whitney (*loc. cit.*, p. 108) from Scovill Point.

Calcite is of course abundant, in amygdules, in replacement, and in veins. Section 15743 shows an interesting case of calcite between layers of peeled off clay, and it occurs very abundantly as a cement in the conglomerates (Ss. 15043, 15778). It is very commonly poikilitic (S. 15705), large secondary patches extinguishing all together. This produces a lustre mottling, which must not of course be confused with that of the augite. In general the calcite presents no features unusual in the Keweenawan rocks.

Aragonite. In one section, No. 15820, a mineral appears with —ex. 0°, strong birefraction, something like that of white mica, with moderate refraction in the direction of elongation, in the other a stronger refraction, stronger than that of chlorite in which it occurs, which could not be certainly determined, but agrees with aragonite.

Chlorastrolite (Jackson, 418; F. and W., II, 97; Hawes, Am. J. Sci. X, 1875, p. 24; Foote Am. Ass. Adv. Sci., 1872, p. 65).

The chlorastrolite question will probably be taken up later in a report devoted to mineralogy. Here I will only say that I agree with the view that it is not a mineral by itself, and hence it is no wonder that it has not been recognized as such by me in thin section.

Epidote. This mineral is abundant and well characterized. The ferriferous yellow and not the zoisitic varieties are best developed. It occurs in veins (S. 15[illegible]81), in the fragments of conglomerates (S. 15633), in amygdules (Ss. 15435, 15820), and is most often associated with quartz (Ss. 15820, 15435). It is often in sharply defined crystals.

Datolite, so far as noticed, is of the porcelain variety, of almost submicroscopic fine grain.

Copper seems to occur in minute cubes or octahedra, when it occurs in microscopic size. It occurs, when noticed in thin section, enclosed in prehnite (Ss. 15150, 15149). All the depths at which copper occurred are noted in the geological column.

Mica. The micaceous minerals replacing olivine have been already noted (also S. 15355). A sericitic mineral often occurs after feldspar.

Clay. The clay of the flucans (S. 15680) has almost no action on polarized light.

Apatite occurs as needles imbedded in quartz in the interstices of the dolerite (Ss. 15615, 15126), also occasionally in pebbles from the more acid rocks (S. 15586). The occurrence of apatite in the interstices parallels that in the quartz diabases.

Fluorite occurs in the porphyry tuff immediately above the porphyry at the bottom of the cross-section (Ss. 15972, 15976). The blue pigment is irregularly distributed and the cleavage is well marked. The color is really blue, rather than violet.

Amphibole is as rare in these rocks as it is prevalent in the Huronian rocks. However, in S. 15534, secondary actinolite needles appear to be present in a much altered porphyrite.

WEATHERED SURFACE OF OPHITE.

§ 3. Textures.

Among the textures worthy of mention are:

(a) Igneous central; *ophitic,* that is, with poikilitic augite enclosing idiomorphic feldspar with the lateral pinacoid and the direction of ă best developed. This is a variety of the general poikilitic texture, and is well illustrated in Rosenbusch (*loc. cit.*, II, Pl. II, fig. 3) and in Irving (*loc. cit.*, Pl. IX), and its weather surface by Pl. VII of this report. Olivine is crowded in corroded fragments in between the patches, and is associated with abundant magnetite.

(b) Igneous central; *doleritic* (Pl. VI, fig. 3). In this the feldspar and augite are more nearly of a size (S. 15493) and between them are interstices, which may of course at times be filled with glass or decomposition products of glass, but in typical cases the surrounding augite and feldspar are idiomorphic against these interstices, which are lined with a border of chlorite or chalcedony, and then filled in with chlorite, quartz, etc., and may be crossed with apatite needles (Ss. 15499, 15615, 15674. Cf. the apatite of Capo di Bove). In transition forms this may be combined with the ophitic texture (Ss. 15090, 15201) or with decomposed glass, etc , to produce the tholeyitic* texture or intersertal structure. (Rosenbusch, *loc. cit.*, 1896, II, 1072, and his Pl. IV, fig. 2.) Some of Irving's orthoclase gabbros seem to have a parallel texture.

(c) Igneous central: *navite* type (Pl. VI, fig. 4). The groundmass, so far as can be seen, is composed of idiomorphic feldspar laths of the oligoclase series, and a small amount of idiomorphic light colored augite. The feldspar occurs largely porphyritic, but not sharply separated from the groundmass. As a matter of fact, though not affecting the texture, in which they play no role, porphyritic olivines are large and few. Irving's Fig. 3 and Fig. 4, Pl. X, belong to this type, though neither is very characteristic. The one is decomposed, and the other does not show as much variation in the size of the feldspar as is common. The larger feldspars tend very strongly to gather together,—become "glomeroporphyritic" (S. 15438), while at the same time they do not lose their connection with the smaller feldspars. Rosenbusch's Pl. IV, fig. 2, might be taken to be a magnified view of a not very porphyritic part, while Fig. 3 would also be representative. This type can pass by increase of augite, toward the bottom of the flow, into the ophitic type,

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* The town of Tholey is commonly thus spelt in atlases, and it is much more in accord with the usage of the English language to spell tholeyitic rather than tholeiitic and slavishly follow the Germans who do not use y.

(S. 15513–15524); by growing finer and glassier, and more markedly porphyritic toward the margin, into the "microlitic" type (Lévy) or hyalopilitic type (Pl. VI, Fig. 5). These transitions may take place in the same flow. In comparing different flows we find generally, with decreasing augite or olivine, that the distinction between the younger and older crystals becomes sharper and sharper, as in the Huginnin porphyrite (Ss. 15811–15818) and in the Minong beds. Thus we have the pilotaxitic variety of the microlitic texture, somewhat like Irving's Fig. 2, Pl. X, which is however more hyalopilitic, according to description (Rosenbusch, *loc. cit.*, 1896, Pl. IV, fig. 1, Pl. V, fig. 2).

Coming now to the marginal textures, we have

(d) The *amygdaloidal* (Pl. VI, fig. 5), full of gas bubbles, more or less filled.

These bubbles are larger in the more augitic rocks, smaller and finer in the more feldspathic ones. Around the amygdules the grain becomes finer, (Ss. 15008, 15117, 15811); the feldspar assumes forked, skeletal and trichitic forms (S. 15572; Rosenbusch, *loc. cit.*, I, Pl. II, fig. 4); the augite may be arborescent, and the iron oxides gather or become more conspicuous. The foot wall amygdaloids seem more ferruginous than the top, and less amygdaloidal. Their amygdules are often long tubular amygdules, whose lower end is at right angles to the bottom of the bed.

(e) The general texture surrounding the amygdules is *microlitic* (Pl. VI, figs. 5 and 1, and generally more or less glassy, and flow lines may be obvious.

(f) Actual examples of a thoroughly glassy texture, *vitrophyric*, are usually confined to a few millimeters from the contact. It is in the basic rocks brown or yellow brown, and soon decomposes (Ss. 15366, 15106, 15110, 14748, 15566–15572, 15508, 15644).

Among the sedimentary rocks,

(g) The peculiar concave forms of *ash* are well illustrated in Pl. VI, figs. 1 and 2 (Ss. 15417, 15260, 15962, 15982, 15277). Sometimes the fragments are charged with epidote (S. 15633), sometimes coated with chalcedony, from the large amount of soluble SiO_2 that necessarily occurs in a glass deposit (S. 15962); often they are dotted with iron oxides.

§ 4. The rocks.

We give in the appended table a revised extract from the classification of the rocks according to Rosenbusch, which I published in the American Geologist, wherein are the types of igneous rocks found on Isle Royale. Of the divisions made by Irving we may mention,—

I. *Basic original rocks,*

A. Coarser grained rocks, the orthoclase-free diabase and gabbro, and olivine gabbro, so far as represented on the island, are by us included under doleritic and ophitic melaphyres. Among the above coarser grained rocks Irving includes the coarser part of the Greenstone, but as we interpret the beds, we cannot agree with his statement, page 69, that the coarse and fine kinds are not found grading into one another in any one bed. The true deep-seated rocks, the orthoclase gabbro, the hornblende gabbro, and the anorthosite seem to be unrepresented.

B. Fine grained basic rocks.

(1) The olivine-free diabases of the ordinary type. (Irving, *loc. cit.*, p. 61.) These are, as Irving says, the smaller flows, in which the change from marginal to central texture has not advanced enough to be characteristic. The feldspar is oligoclase. They are more or less altered, but I do not think there can be much doubt that they were originally olivinitic,—at any rate, that that was the case for the type bed, Marvine's bed No. 87, which has been analyzed (see end of Chap. IX; Irving, *loc. cit.*, p. 66). I class them therefore among the melaphyre porphyrites, as we class the latter, going back to Streng's word (N. J., 1877, p. 41), i. e., melaphyres close to the spilites. (See also Zirkel, Petrography, 1894, II, p. 701; Rosenbusch, *loc. cit.*, 1896, II, pp. 1061, 1064.) Fig. 3, of our Pl. VI illustrates a coarse form of the same family.

(2) Irving's second group (p. 68), the olivine diabases and melaphyres, are precisely our ophites, and Rosenbusch's olivine tholeyites. It should be remarked perhaps, that the degree of alteration which characterizes the rocks to which the term ophite was first applied, has nothing to do with the definition, as used by A. Michel Lévy. Fouqué and Lévy called a certain group of their artificially formed rocks ophites.

(3) In his third group, diabase porphyrite and Ashbed diabase Irving, as he himself recognizes, has rocks of widely different character, with SiO_2

ranging from 48% to 60%. We may subdivide this group into the following groups:

(a) The more pronounced porphyrites of the Ashbed diabase type, where the augite is scarce and idiomorphic, the olivine not very abundant, the feldspar oligoclase and more or less porphyritic, Pl. VI, fig. 4, there are, as Irving says, gradation forms from these rocks to his "ordinary diabases," i. e., according to my grouping they both belong to the same group of melaphyre porphyrites. As they are well developed on the north side of Tobin Harbor, we might call them the Tobin porphyrites. They are Rosenbusch's navites.

(b) The Huginnin porphyrite type, in which large oligoclase phenocrysts lie in a fine grained groundmass of alkaline feldspar, in which some orthoclase may be included (Pl. VI, fig. 5, Ss. 15811-15818). Olivine is not present. This is not a melaphyre at all, but an augite porphyrite, close to the "plagiophyres", and but for the character of the feldspar would be classed with the labradorite porphyrites

(c) Finally, a still less augitic group, in which the augite is present only, as we may say, as an accessory; orthoclase is almost certainly present, though not readily recognized, and spherulites may occur. The most important representative of this group is the Minong porphyrite, which falls under the felsite porphyrites, or felsophyrites, e. g., S. 15045 *et seq.,* from drill holes No. I and No. III. All these types may be recognized also in Irving's descriptions.

The remaining more acid types are present only in pebbles, so far as we know, except at the very bottom of our cross-section, where we have a red aphanitic felsite. Under

II. *Acid original rocks,*

Irving makes four divisions:

(1) Quartzless porphyry (p. 91), including only kinds with 60% to 70% SiO_2. The porphyritic crystals are orthoclase and oligoclase, the former prevailing. This type is abundantly represented in the conglomerates (Ss. 15550, 15555).

(2) Quartz porphyries and felsites (p. 95), the latter term applied to the kinds not evidently porphyritic. This includes both Rosenbusch's orthophyres and quartz porphyries. Both types are present in conglomerates quite abundantly (Ss. 15546, 15576, 15578, and at the bottom of our column is a felsite, S. 15986). Spherulites, which Irving did not happen to encounter, occur abundantly in conglomerate pebbles (Ss. 15578, 15579, etc.) and also occur in the Minong porphyrite (Sp. 16082). Quite a common type not emphasized by Irving, among the porphyries, is that of quartz porphyrite (S. 15579). Throughout the series it seems to me that oligoclase or albitic feldspars are quite abundant, but I cannot say that any proper keratophyres occur.

(3) The granitic porphyries, augite syenite and granitell of Irving (p. 112 and Plates XIV and XV) are granophyres and granophyrites. The difficulty which Irving found in naming them arises from the fact that he considered the quartz of the micropegmatite as secondary.* The descriptions and illustrations as given by Irving are very clear and accurate, whatever may be the interpretation put upon them. In this connection Bayley's work on Pigeon Point, Am. J. S. XXXV, 1888, p. 388, also XXXVII, 1889, p. 4, and XXXIX, 1890, p. 273, and Bull. U. S. G. S., No. 109; and Harker's work on the Carrock Fell (with whom I agree in general), Q. J. G. S., 51, 1895, p. 126, and 50, 1894, p. 311; and Grant's on augite soda granite, Am. Geol. XI, 1893, p. 384, and Pt. II of the 21st Ann. Report, Minn. Geol. Survey, 1892, dated 1894, should be consulted. Waiving the question of the anorthoclastic character of the feldspars, the name augite granophyrite will be applicable to most of these rocks. This group is on Isle Royale practically absent, and rare even in the conglomerates (S. 15481).

(4) Granite (p. 125) fails entirely, even in the conglomerates, so far as I have noticed, until we come to the pebbles of the recent gravels, but I do not intend to take up the petrography of the glacial deposits, except to state that a wide variety of rocks is represented in them. Irving's

III. *Conglomerates and sandstones* may be separated into the following not sharply distinguished classes:—

(1) Ash beds, properly so called, having the constituent fragments in the conchoidal forms of glass ash. These were not noticed by Irving but they do occur (Pl. VI, figs. 1 and 2, Ss. 15260, 15417, 15418, lowest tuff in drill holes No. XII and No. XVI and Ss. 15430-15432).

(2) Scoriaceous conglomerates. Irregular masses or bombs of amygdaloid together with the rough and irregular top of the underlying sheet are cemented together with a fine grained red matrix. This includes a

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*My views on the subject will be reserved for my discussion of the micropegmatite in diabases, in Chapter X.

portion of the so called "Ashbeds" and part of the scoriaceous amygdaloid beds.

(3) Conglomerates, having rounded pebbles of various kinds.

(4) Tuffs, having fragments mainly of one, probably contemporaneous rock, mingled with some ash.

(5) Sandstones, finer grained than the conglomerates, so that the nature of the constituent fragments is not apparent to the naked eye. If they are largely derived from basic rocks, and this is often the case, they are made up of granules of plagioclase, augite and the like, and may be called basic sandstones.

(6) Shales, still finer grained, so that the material is largely not rounded, having been carried by flotation. The material is much decomposed into clayey matter.

§ 5. Petrographic review of geological column.

We will now briefly review the geological column, for petrographic notes.

(0 ft.) in cross-section. In drill hole No. XI down to 389 ft. the trap beds are comparatively thin melaphyres, largely amygdaloidal, but at once showing the ophite type as soon as they become a little compact, the feldspar labradorite, the olivine in small granules (0.20 mm.). The associated conglomerates show quartz porphyry, orthophyre, oligoclase porphyrite, decomposed melaphyre (S. 15559) and spherulitic porphyry pebbles (S. 15591), often with a calcareous cement, and often, too, showing the secondary poikilism of quartz; also chalcedony (S. 15599). Sedimentary veins, "clasolites", occur, and glassy contacts are well represented. No. XI, 389-396 is an amygdaloidal melaphyre with low angled feldspar. It is altered and gives one of the best illustrations we have of secondary poikilitic quartz (S. 15659). Both these and the flow below, No XI, 396-457, show a tendency to two generations of feldspar and the lower (S. 15666) carries some porphyritic feldspar near anorthite.

Below this lower flow is a well marked basic sandstone, the porphyry fragments absent, but epidote, plagioclase, augite, etc., abundant.

The remainder of No. XI consists of small flows, mainly amygdaloids (spilites; feldspar from andesite, S. 15697, to anorthite, S. 15704).

The conglomerate, No. XI, 493-499, shows spherulitic poikilitic orthophyre, quartz porphyry, quartz porphyrite and ophite, pebbles.

Down to the conglomerate, No. X, 170-193, the succession of minor flows continues,—normal ophites when not amygdaloidal. The feldspar of the marginal amygdaloids gives lower extinction angles than the feldspar of the centers. Is this perhaps due to an elongate rather than to a tabular habit? The extinction angles of the center indicate labradorite near Ab_3An_4.

(567 ft) (589 ft.) No. X, 170-193. The pebbles of this conglomerate are like those of the conglomerates above, except that S. 15486, a glomero-porphyrite, seems to be a new type.

No. X, 193 306. This big flow is not lustre mottled, and most of the feldspar is Ab_5An_3, though in and near S. 15499, at 272 ft., it is more basic. The olivine is much larger than in the ophites above (up to 2 mm.). The distinction of this melaphyre porphyrite from the ophites is marked, but there is still a good deal of augite in it. (Pl. VI, fig. 3.)

The record is confused for the next 20 feet, but within the interval there is plainly an ophite with labradorite (S. 15507). Then beginning at 338 ft, or a little higher, and extending down to 415 ft., a flow comes, which has been analyzed (p. 145), like the melaphyre porphyrite just mentioned, but more basic at bottom and then somewhat poikilitic (S. 15522) and also doleritic (S. 15521), in the latter case with chloritic rinds around the feldspar.

(806 ft) (817 ft.) No. X, 415. This conglomerate contains only fragments with a microlitic texture; at top it is composed of small grains with a poikilitic calcite cement.

Underneath it we come to the Ashbed or navite type proper. The comparatively large olivines (1 mm.) continue. The feldspar is an andesite, in two distinct generations, the larger visible to the naked eye (1.4 mm. x 0.37 mm), the smaller not a third as large, the augite very small, as is shown in Fig. 19. The olivine, although large, is quite rare. The augite is in very minute light colored idiomorphic prisms. This bed occurs again at the top of No. IX, and here the underlying flows remain of the same type with somewhat varying amounts of augite, down to No. IX, 235. The flow below this, to 279 ft. has a somewhat poikilitic augite and an interesting case of a decomposed feldspar (S. 15415) with low extinction angles, surrounded by a fresher border with the extinction angles of labradorite. It is a reversion to the melaphyre porphyrite of more basic habit.

(1100 ft.) No. IX, 279. The underlying scoriaceous conglomerate has a genuine fine grained ash bed on top, as is shown in Pl. VI, fig. 1, S. 15417. The conglomerate is composed of amygdaloidal and microlitic fragments, with calcite. Underneath it we have repeated the cycle from a navite with very little augite (Pl. VI, fig. 4), and associated amygdaloids of the same character, to a more augitic melaphyre porphyrite in which the feldspar varies from andesite to labradorite, farther down. The same beds are repeated at the top of hole No. VIII, down to 273.

The beds from No. VIII, 196-377, show a return to the ophite type, only the upper one showing andesite feldspar,
(1526 ft.) the rest going back to labradorite.

No. VIII, 377. The succeeding bed, a sandstone,
(1567 ft.) considering its thickness, is notable for its fine grained character, only the lowest foot being conglomerate; it is mainly composed of rounded grains of augite, of microlitic porphyrites, etc.

Two more small amygdaloidal melaphyre porphyrites, with low angled feldspars, inconspicuous augite or olivine, and glomero-porphyritic feldspar,—overlying four feet of shale,—bring us to another navite, which might almost be classed under the augite porphyrites, rather than under the melaphyres, though there is no important change in its mineral composition from the other navites except that the olivine is even more scarce. A curious feature in the bed is an aggregate of iron ore with agatoid bands of varying lustre (S. 15380). About eight of these flows of varying size, marked by a peculiar type of amygdules and amygdule fillings, bring us down to No. VII, 221, where we have a big flow of the melaphyre porphyrite type, ophitic toward the bottom, however, and containing a more basic labradorite feldspar. Similar types succeed down to ———
(2035 ft.) from top of cross-section.

No. VI, 81, = No. VII, 430. Porphyry tuff. Ash and
(2045 ft.) sediment forms may be noticed, but the principal material of the bed is very uniform, being a quartz porphyry, with corroded quartz and oligoclase phenocrysts (S. 15237), not fluidal in texture, but with traces of perlitic texture (S. 15327). One fragment of microlitic porphyrite with quartz amygdules was noticed (S. 15242). This stratum, thin as it is, seems to be very widespread, for it is reported in the Peninsula and Tamarack mines. Does it represent the eruption which so interlarded the Beaver bay group with felsites, and produced the felsites of the Porcupine Mountains?

Beneath the tuff we have one small, and one large sheet of ophite, the Greenstone. The feldspar is throughout labradorite, the augite abundant, and the olivine and iron ores are abundant but small. There are also occasional big porphyritic crystals near anorthite.

(2310 ft.) No. VI, 363, the Allouez conglomerate, next below, shows beside the vesicular ash with altered glass fragments, i. e., pumice like those of Pl. VI, fig. 1, only porphyries with orthoclase and oligoclase phenocrysts. The sheets below for some distance belong all to the ophite family, though at times doleritic in texture. S. 15274 shows the poikilitic type well, the feldspar between the poikilitic augite patches being somewhat larger than that enclosed in them. The olivine is well marked.

S. 15275, from the same flow, shows the doleritic type. The augite is about half as large as in the ophitic type, in long octagonal prisms, while the feldspar is even larger than in S. 15274. The olivine is largely replaced by magnetite—rather coarser grained than the olivine which it replaces. Ophitic sheets continue with little variation down to No. II, 136. Thence we have a melaphyre porphyrite with more sharply defined olivine crystals, small augites, and a double generation
(2570 ft.) of feldspar. This bed is associated with sediment in an ill defined manner. Then follow more ophites (in S. 15082 the olivine is porphyritic), largely amygdaloidal, down to No. IV, 108 at which there is a foot or more of basic sand-

stone largely composed of labradorite. Under this sandstone is a melaphyre porphyrite with porphyritic low angled feldspars,—one of the phenocrysts in fact seems to be orthoclase —then another foot of basic sandstone, then a thick very ferruginous ophite with labradorite, rather more basic than usual. Then follow a number of small amygdaloids, not as ophitic for their size as, for example, those in hole No. XI.

No. IV, 245-263, is melaphyre porphyrite. Then we soon have a big well-marked ophite. Then two small ophites and one big one, all more feldspathic than usual. Hole V shows nothing but ophites and their amygdaloids. Hole 1 begins in feldspathic ophites, with their amygdaloids. S. 15008 shows an interesting illustration of a big amygdule, the coarse grain becoming porphyritic, and interstitial glass and hematite showing around it.

(4006 ft.) At No. I, 361½, there is a change in the character of the flows, the feldspar being low angled, the augite in occasional polysomatic grains.

Next underneath comes an ill defined series of amygdaloids and sediments, the amygdaloid being of the porphyrite type; the sediment, which is well marked at the bottom, contains beside augite and plagioclase grains, poikilitic quartz and quartz porphyry and agate.

(4068 ft.) Beneath this comes a bed which is practically unique. Augite is barely present and in minute granules. Olivine is not present at all. Occasionally large oligoclase phenocrysts (2 mm. x 1 mm.) occur in a very fine grained and ferruginous groundmass of minute feldspars (0.20 mm. x 0.03 mm.); the latter are all low angled and many of them unstriated. Instead of the ordinary amygdules, this bed has minute irregular pores with borders blacker than the rock in general. S. 15120 is quite chalcedonic. At the Minong mine what I take to be this same rock has spherulites. We may then fittingly call it an oligoclase felsophyrite, classing it among the porphyrites, having affinities to the keratophyres, to the labradorite porphyrites, and to the quartzless porphyries in different directions, and itself varying somewhat. It may evidently be derived from the navites by still farther eliminating the augitic matter. The sheet beneath is in the upper part very much like the porphyrite, and in fact the line between the two flows is not well defined. At the bottom it is an ophite, not very basic. The observations in the field show that the two sheets tongue into each other in a very complex fashion, only to be explained by supposing, either that the porphyrite is intrusive, which does not seem likely from its contact with the overlying sediment, or that the flows were practically contemporaneous, and a certain amount of mixture took place along the contact line. This seems all the more natural, because the more acid flow being lighter would readily float on top. This supposition will also explain the coarser and finer streaks and the apparently corroded plagioclase crystals in S. 15052 (Pl. VI, fig. 6). The characteristic thing about the ophite of the lower bed,—the Minong trap—is that the grain is not as coarse as one would expect if it followed the same law as the Greenstone, and there is very little olivine in it.

(4174 ft.) Next underneath comes a heavy bed of normal ophite, then a foot of sand, largely labradorite, then a number of smaller amygdaloidal ophites down to 463 feet. Then comes a rather feldspathic ophite with a nest of augite (S. 15148) which brings us to the bottom of drill hole No. III.

No. XIII down to 230 shows ophites, feldspathic, yet having a basic feldspar near anorthite (S. 15718), and a couple of seams of red sandstone composed chiefly of augite and plagioclase granules. Then from No. XIII, 230-252, is a melaphyre porphyrite, with low angled feldspar and but very little augite.

Next comes a big ophite which is poikilitic but quite feldspathic, so that it is characteristic that the augite is cut up by the feldspar into wedge shaped portions which over considerable patches have common orientation, but the feldspar is quite basic, which may account for the augite retaining its xenomorphic character, which usually becomes lost when the augite is in small quantity.

Underneath this comes another big ophite, with a not clearly indicated separation of the feldspar into two sizes.

Probably connected with this is the fact that the feldspar
extinction is frequently zonal, the zones having alternately
greater and less extinction (S. 15767). In the doleritic spots
the olivine is more abundant, and the feldspar not so much
enclosed in the augite (S. 15770). Under this at No. XIII,
447½, comes a melaphyre porphyrite with small granular
augite, occasionally porphyritic augite (S. 15775) and two not
sharply separated sizes of feldspar. The pseudomorphs after
olivine (?) are often like bastite. It is quite possible that they
replace pyroxene. This is quite a characteristic bed and drill
hole No. XIV begins in the same bed. The feldspar is quite
basic toward the bottom. The flow beneath, from No. XIV,
139-200, leans more to the ophites, being in part poikilitic (S.
15792), and showing traces of a double generation of feldspar.
Two feet more of basic sandstone bring us to a large and
(5194 ft.) typical ophite. Below this bed (drill hole No. XIV, 367) comes
in the Huginnin porphyrite, much like the Minong porphyrite
(5260 ft.) (Pl. VI, fig. 5). The augite is rather easier to recognize, in the
lower part only, however. The porphyritic phenocrysts are
very much more conspicuous, and are a striking feature of
the rock. The grain otherwise is given in Fig. 20, Chap V.
This porphyrite would be a typical labradorite porphyrite,
were not the feldspar oligoclase (Ab_4An_1).

Under this last bed is a little ash, and then a big ophite with olivine and feldspar nests. The feldspar in the poikilitic patches is much smaller than that outside. Fresh olivine occurs, but at the bottom of the flow it seems to be altered to magnetite, and (S. 15834) the ophitic augite is in long prisms.

Under this ophite at the top of drill hole No. XVI come a collection of feldspathic melaphyres, amygdaloidal and microlitic with porphyritic feldspar, with the augite xenomorphic, occasionally somewhat poikilitic, but showing no great tendency that way.

(5849 ft.) Then at No. XVI, 438, we seem to strike into another oligo-
clase porphyrite or a conglomerate made up of the pebbles
of the same, which passes into an indubitable conglomerate
with calcareous cement and some quartz porphyry pebbles.

Under this is a large and well marked ophite, with the usual more basic feldspar at the bottom,—also zonar and nested feldspar (S. 15912), showing doleritic as well as ophitic texture.

(5996 ft.) No. XVI, 611, conglomerate with pebbles containing quartz
(6003 ft.) phenocrysts, spherulites, etc.; under it is a melaphyre porphy-
rite with but little olivine, amygdaloidal and leaning toward
the Huginnin type. Below the latter there is apparently a
basic conglomerate with fragments of dark ferruginous, more
or less microlitic porphyrites, and a cement largely calcar-
eous; all the fragments are like the Huginnin porphyrite
but the phenocrysts are not so distinct.

At No. XVI, 697, is an ophite with labradorite.

(6155 ft.) Under this a porphyry tuff. Corroded feldspar (Ss. 15948,
15949, 15950, 15955, 15977, 15987); spherulites (Ss 15949,
15950, 15956, 15979); pores generally with dark borders and
various fillings (Ss. 15950, 15951, 15971); perlitic forms (Ss.
15960, 15983) are characteristic. Fluorite is significant (Ss.
15972–6). Toward the bottom glass ash fragments, some-
times outlined with white chalcedonic margins, are not
uncommon (S. 15982, Pl. VI, fig. 2); chalcedonic dots are
characteristic of the whole formation (S. 15983). This tuff
is very largely composed of fragments such as the underlying
rock might furnish, and frequently in the forms of concave
ash.

The remainder of the drill hole is in a red felsite with a secondary poikilitic groundmass in places, and very inconspicuous porphyritic crystals of corroded orthoclase and quartz.

CHAPTER VII.

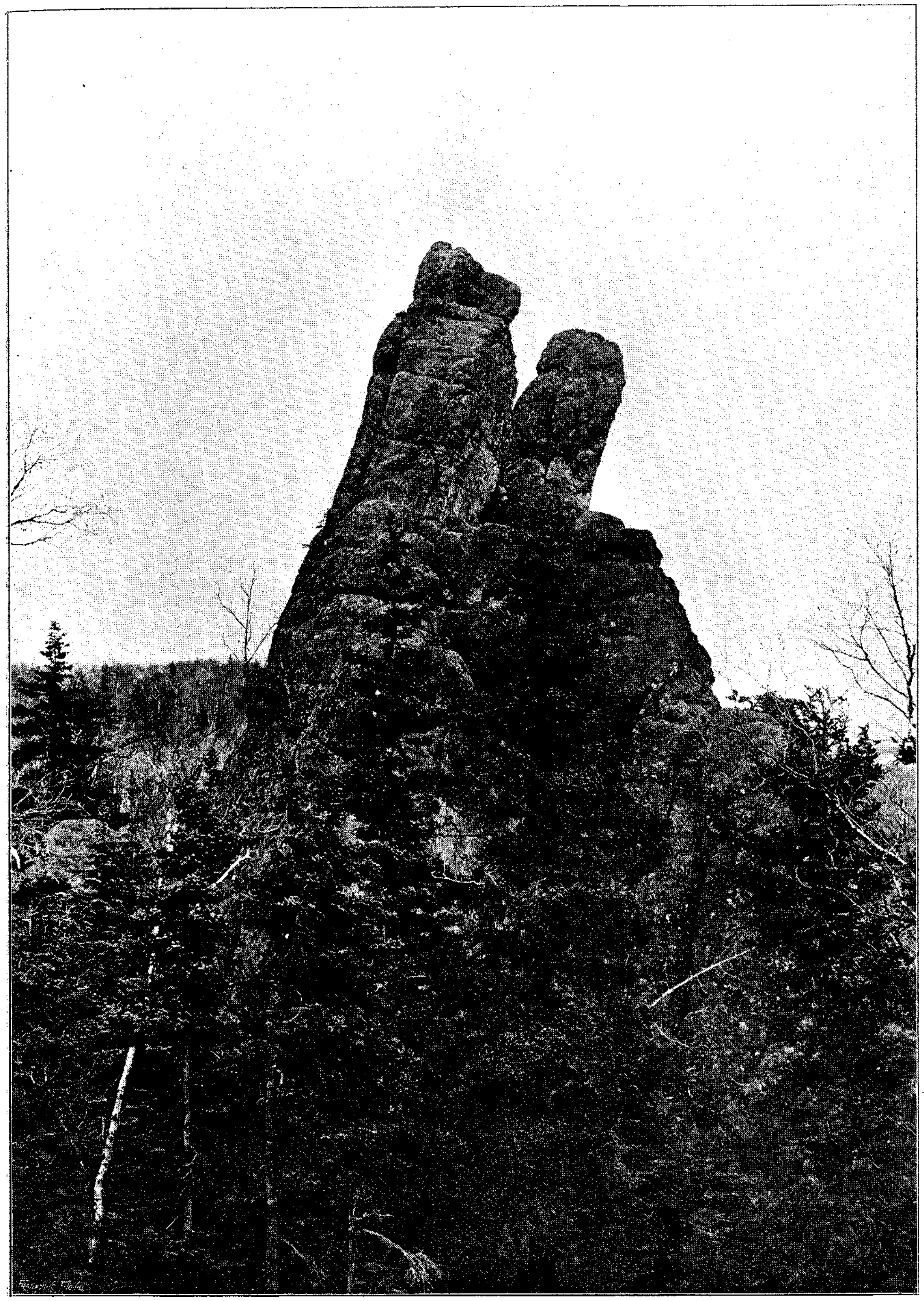
TOPOGRAPHY AND QUATERNARY GEOLOGY.

§ 1. General description.

A glance at the map will show one that the archipelago of Isle Royale has a very strongly marked topography. The main features of it are so well outlined in Ives's description of township 67, range 33, at the northeast end of the island, and the main features of his description are so applicable elsewhere, that it gives me great pleasure to give the unpublished account of the first surveyor of the island, one who did his work honestly and well.

"This township (T. 67, R. 33), is all fractional, even to quarter sections and is formed of the points of the northeast end of Isle Royale, which have been compared by some to the fingers of a man's hand. There is but little resemblance to fingers except in the number of principal points or ridges which form three principal bays, northwest of Rock Harbor and are numbered from that northwest. These points are trap rock ridges, elevated from 20 to 260 feet above Lake Superior with courses nearly southwest by west and northeast by east (N. 56¼° E.), and are sloping somewhat gradually on their southeast sides and have steep northwest escarpments, with many small broken cliffs the faces of which generally dip northwest about 80°" (i. e., like Monument Rock, Pl. VIII). "All of these principal points are points" (made up) "of points with rock ridge islands, continuing from many of them, which are narrow and similar in shape and course to the ridges of the point."

"None" (of these ridges) "except the largest ridge is over about 100 feet high, and that is about from 100 to 260 feet high and has a rounded and unbroken outline, with a steep northwest escarpment all of the way, and is a continuation of the principal ridge which passes through Township 66 North, Ranges 33 and 34 West. Rocks and soil are similar on the ridges through those towns and this. The rocks of all the ridges dip S. E. by S. from about 10° to 30° and 40° with uneven



MONUMENT ROCK.

strata 1 to 3 feet thick. The principal splits run about S. 60° to 70° W. and N. 60° to 70° E., running a little obliquely across the ridges, and dip N. W. about 75° to 85°."

"Parts of the rocks have crossed courses or fractures and the largest ridge has them all the way. Many of the rocks are fractured into small angular blocks and some of them are very fine."

"The mineral veins are mostly in the splits or joints of the rocks, and are from a line to one and two inches thick, composed of quartz and other veinstone, which contains small particles of native copper in many places. The vein of the point between Rock Harbor and the first bay northwest is an exception to the others" (Scovill Point).

"The soil is a few inches to a few feet in depth, and all stony. It is deeper in some of the valleys and is mostly composed of the disintegrated underlying rocks, and rated second rate. There is a strip along the southern slope of the largest ridge, which appears to be good tillable soil of sufficient depth to be but little obstructed by rocks. A few narrow swamps may also be made good tillable alluvial soil by draining."

"*Timber*. All of the points and islands are thickly timbered with a shortish growth of fir, spruce, cedar, white birch, tamarack, aspen, with a thick underbrush, except on the largest ridge, of ground hemlock, spotted maple, hazel, mountain ash, alder, etc. The largest ridge has more white birch than the other parts, with some underbrush. The largest of the timber is about 12 to 15 inches diameter and the best is the spruce. The timber grows close to the water's edge, except on the outer points and islands, where the rocks are bare 20 to 150 links from the water's edge. The bays are mostly deep, vessels of any size may enter all of the large ones, and many of the small ones, and can pass close to the sides of most of the islands and reefs. Ridges were observed to continue from many of the points and islands under water for considerable distances and often near the surface of the water."

"Lake trout are to be found in all of these bays, and a few brook trout and whitefish."

"The variation of the compass needle is fluctuating over the whole township, but the most so from the summit of the largest ridge N. W. The extreme difference noted is 8° 0′ W. and 26° 40′ E."

§ 2. Adjustment of topography to structure.

The foregoing description is very closely applicable to all of the island lying northwest of the course of the Island Mine conglomerate. As we go toward the southwest end around Washington Harbor, there is distinctly more soil, as is seen for example in the records of drill holes Nos. IX and X. At the same time the dip of the rocks is a little flatter, being about 18° at the west or northwest end of the island and about 40° on Amygdaloid Island, at the other extremity. Along the length of the island, moreover, which has with an area of 210 square miles a length of 45 miles for the main island, or 57 miles counting the outliers, there is a slight change in strike, from N. 55° E., at the northeast end, substantially that given by Ives (Irving, N. 53° E.), to about N. 60° E. at the southwest end, which is the course assumed in reducing the drill cores to a cross-section (Irving, N. 65° E.). This slight change in strike and dip may be the cause of the cross fractures of which Ives speaks. These cross fractures are marked by breaks in the ridges, as frequently alluded to in previous pages. For example, in tunnel No. 1, of the Wendigo Company's explorations, in drifting N. an amygdaloid was found 26 ft. sooner on the west wall than on the east, and the vein and fault thus shown was plainly marked by a topographic break which Mr. Stockly has photographed (tunnel No. 1), and also carefully surveyed magnetically. It was supposed that the same break ran through a corresponding gap in the Greenstone. Again, near drill hole No. XII there is a topographic break, indicating a fault of which the evidence has been already given (p. 90).

We see thus that for the main part of the island the topography is very thoroughly adjusted to the rock structure. That structure consists in a series of sheets of ancient lavas, with very subordinate interbedded sediments, the parts more resistant to weathering being the centers of the large sheets, and the parts least resistant being the amygdaloids and sediments at the contacts of the flows. The watersheds of the islands are the central parts of these main flows; the main watershed between the northwest and the southeast part of the island being made by the largest flow that occurs, the great lustre mottled backbone of the island,—the Greenstone (Cf. Pl. XIII). The drainage then follows the valleys underlain by the sandstones, etc., and must depend for escape on cross valleys, unless it can continue to the end of the ridge at the end of the island. As we approach the southwest end of the island, where as we have said there is a greater depth of drift, the strict dependence of the streams on the ridges is not so marked, but still all the main valleys are genuine rock basins. From this we may infer that immediately preceding that invasion of ice which marked the Quaternary era, there was a period, lasting we know not how long, when the series of lava sheets which had been poured forth, solidified, and uptilted in the very dawn of geological history, were eroded and denuded until the topography was adjusted to the capacity of the rocks to resist erosion. We also know of this period that it was a period when the water level, the base level of erosion, was below the present level of Lake Superior, for we find all the peculiar and highly adjusted topography, with its valleys continuing out under the waters of the lake.

§ 3. Ice action.

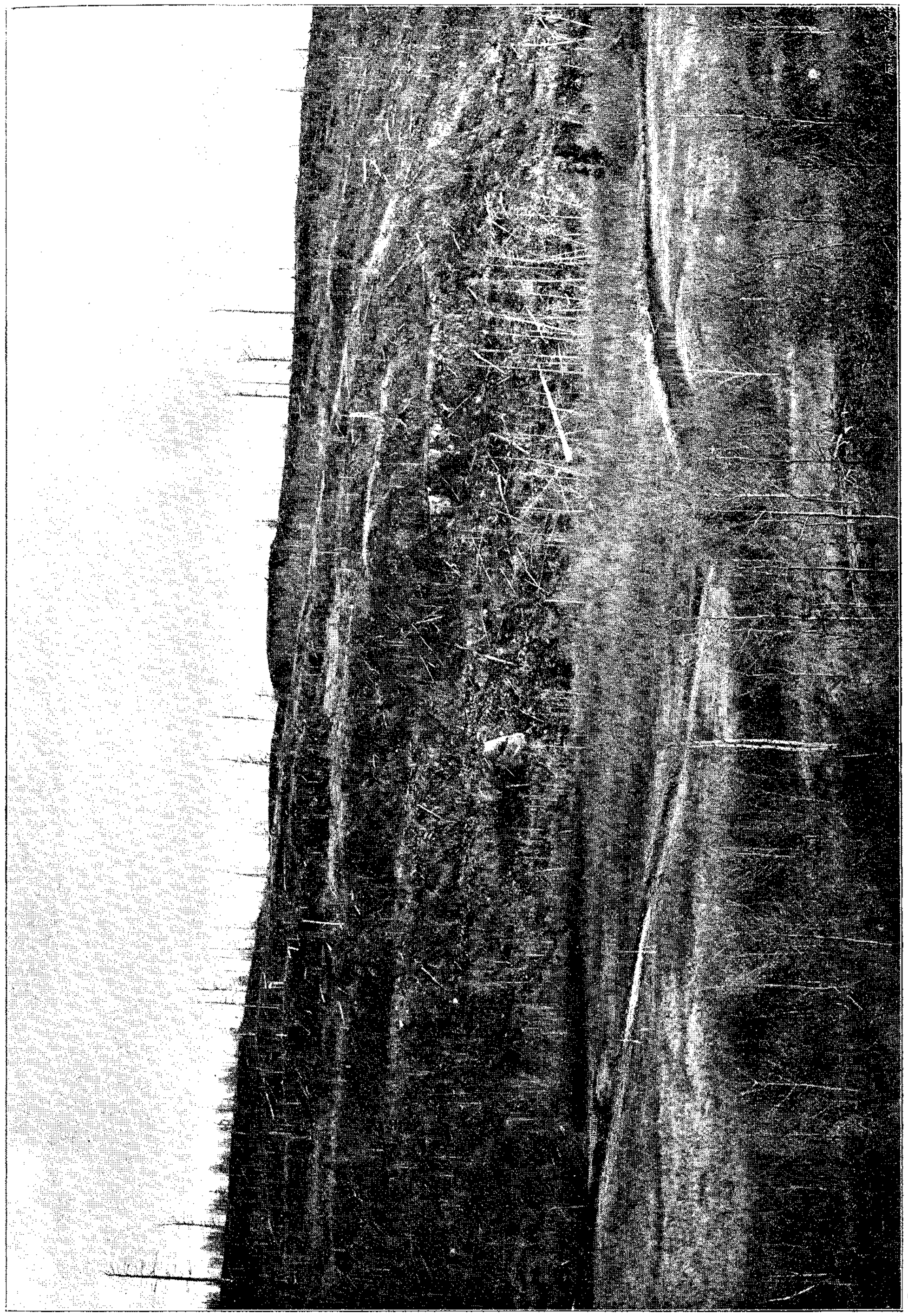
At the beginning of the Quaternary the ice advanced over the island and cleaned off all of the preglacial soil, so far as we know, except so far as the clayey decomposed trap cut in tunnel No. 2 represents it. The evidence of its occupancy is found in the smoothed, polished and rounded surfaces, with grooves and scratches, apparently from the stones imbedded in the ice, which we frequently find. But here we have to put in a word of warning. In an island, surrounded by water which is frozen heavily every year, (as we shall soon see, practically the whole of the island has been exposed to the action of the waters of Lake Superior in the course of their gradual subsidence), the effect of this shore ice may be the same as that of glacier ice, so far as the smaller scratches are concerned. This was already noticed by Desor (F. & W., p. 203). Sometimes such scratches will occur where the cliff is undercut, polishing both the overhanging surface and the present water edge, and showing plainly that they could not have been produced by glacier ice, e. g., in an island of Siskowit lake in Sec. 29, T. 65, R. 35, and in the first mentioned costean (See Chap. VIII) near Ghyllbank. At other times, as in the cases figured by Desor, it is not quite so plain, and the general probabilities of the case must be considered. On the other hand the broader groovings, which often show interruption on a harder spot in the rock, can but be attributed to glaciers.

The ice overrode the whole island. I have not been able to recognize any material as morainal, that is, deposited by the ice directly, and not rehandled by water, although such may occur on the lee sides toward the southwest of the island, buried under rehandled material. The direction of the motion of the ice was evidently from the northeast and very nearly in the direction of the strike of the ridges but a little more from the east, so that the grooves run slanting slowly up the ridges, and one cannot implicitly trust the mutton backs or round ledges of rock rising from the swamps as indicators of the strike. Desor, however, made the strike of the striæ and grooves at Scovill Point and at Chippewa Harbor exactly the same as the bearing of Scovill Point. These observations are not quite in harmony with mine, viz.:

On Sec. 13, T. 66, R. 34, on the ridge of porphyrite south of Cold Run (F. & W., p. 85) and northwest from the Siskawit mine, the glacial grooves were very good and strike a little more east of north than the strike of the beds; their strike was N. 71° E. Close to the line between Sec. 9 and Sec. 10, T. 65, R. 34, glacial striæ strike N. 73° E. My observations seem to agree better with the observations of Desor, that the whole north side of the island is a lee side. Southeast around the head of Rock Harbor the strike is very much more to the north than the direction of glacial movement, but the topography still mainly depends on the nature and strike and dip of the rocks which make a swing to the south around the head of the harbor, with very flat dips. This structure is very evident in the steep slope to the west and gradual slope to the east. When, on the other hand, the beds are swinging back into line around Siskowit Lake the ice action seems to have more effect, and by its scoring to have brought out the conglomerate and sandstone in many places into more prominence. On the whole, however, we have no reason to attribute to the ice anything more than a moderate and superficial action on the topography.

§ 4. Lake action.

When the ice left the island, the latter was submerged beneath the waters of a great lake which lay along the front of the receding glacier. The evidence for this statement must be sought partly off the island. At Mt. Josephine, not far off on the north shore of Lake Superior, Lawson reports terraces up to 607 feet, and very well marked at 509 feet, and over on the south shore there are marked terraces around Hancock, up to 490 feet. Now, since only the highest ridge of Isle Royale attains to the altitude of 500 feet, and this only occasionally, it is evident that the waters which made the terraces mentioned must have covered the island, and at 490-498 feet we have a distinct terrace on the island. We have every other kind of evidence of the submergence of Isle Royale, growing more abundant naturally for the lower levels where the area of the observation is greater. We have numerous raised beaches, with sea cliffs, sea caves in amygdaloids, and skerries from the more massive



DELTA AND TERRACES AT McCARGOE COVE.

rocks. The material, wherever opportunity to study it is given, shows rehandling by water, and boulders of foreign material are scattered over the surface as the flow ice of winter is wont to leave them. Let us mention a few of these features more in detail.

Raised beaches. These are quite numerous at almost every height above the lake surface, from those which are in direct continuity with present beaches, and run up 10, 15 and 25 feet, to those which are much higher and have no direct connection with the present beaches. The former might be attributed to some exceptional storm, if it were not that their pebbles are found covered with lichens, and even occasionally quite an old tree will be found clinging precariously to the cobbles. A good illustration of such a beach may be seen on Sec. 10, T. 65, R. 34.

The higher beaches and terrace lines occur very numerously all over the island. Whole hillsides are often one succession of faint benches as at the head of McCargoe Cove (Pl. IX.). A very noticeable thing is their dependence upon the local topography, the higher ridges being often scored by sea cliffs and terraces at about the height of an adjacent ridge which after it emerged would protect them from the force of the waves. For example, the Minong range where it crosses McCargoe Cove has a distinct sea cliff and bench at an elevation of about 90 feet, just a little above the ranges in front of it (Pl. XIII, cross-section G-H). So the most perfect raised beach I have noticed, as well marked and as bare of vegetation as those but 25 feet above the present lake level, is one that stretches as a barrier beach from one rocky point to another, crossing the little valley of a stream which has cut through it, close to the west quarter post of Sec 13, T. 66, R. 34. This beach is just about high enough (140 ft.) to have felt the full force of the waves unhindered by the ridge that makes Scovill Point, and striking, indeed, is this curving ridge of lichen-covered boulders which looks as though it had been deserted by the waves but a few years. Just at this level we find a number of evidences of a more permanent base level, and rather more action by the waves, for practically the same elevation (135 ft.) is well marked by a bench on the other or north side of Blake Point, and studies around Hancock on Keweenaw Point have shown that there, too, the subsidence from 150 feet to 90 feet above present lake level was comparatively slow.

Another evidence of the higher lake level is in the—

Sea caves. These are excavated in the amygdaloids or softer beds, generally, and may be well seen near the west end of the main island, on Secs. 26 and 35, T. 64, R. 39 (Pl. X). But the earlier explorers have made similar pits.

Skerries. This term is applied to those picturesque towers and jagged remnants of rock that are left when the waves beat and corrode vigorously a massive layer. The most notable instance of them in fossil condition, as we may say, is in the famous Monument Rock or Rocks.* The base of these rocks, (Pl. VIII and cross-section C-D of Pl. XIII) is about at the same level as the beach just above mentioned, and a few yards to the southwest of this we find other precipitous rocks, not so conspicuous, however, which as we go farther in the same direction, develop into a ridge with an exceedingly steep southeast side. When the lake was 140 feet, and more, higher than now the waves beat against the side of this ridge with the full force, not merely of the present Lake Superior, but of a much larger lake, and cut a marked sea cliff, while at the extremity of the point as it then was were the Monument Rocks as huge sentinels, outlying skerries. The top of these rocks is some 70 feet higher than the base, and since their top would have been worn off, if their emergence had been uniformly rapid from top to bottom, we are led to infer a rapid subsidence of the water in the first part of its fall, from about 200 feet down to about 130 feet. Of what happened thereafter we have no record just here, because the shore became that of a landlocked bay.

§ 5. Rapidity of emergence.

If we ask how rapid was this emergence, has it ceased, and what may have been the relative times required for its various phases, we shall find many qualitative indications, even though we are not able to make any numerical estimate

In the first place, the fiord type of coast even in very long and narrow and sheltered bays shows that the present lake level cannot have been maintained long, or these bays would have been filled up. So, too, the numerous streams which enter the lake with a rush, such as the outlet to Siskowit Lake, Sec. 31, T. 65, R. 35, and even more markedly the outlet of Hatchet Lake, on Sec. 12, T. 65, R. 36, close to the old Pittsburg and Isle Royale works, which is a regular cascade, would before this have cut back their courses and deepened their channels to more normal gradients. Moreover, the deltas of the streams are not large. One of

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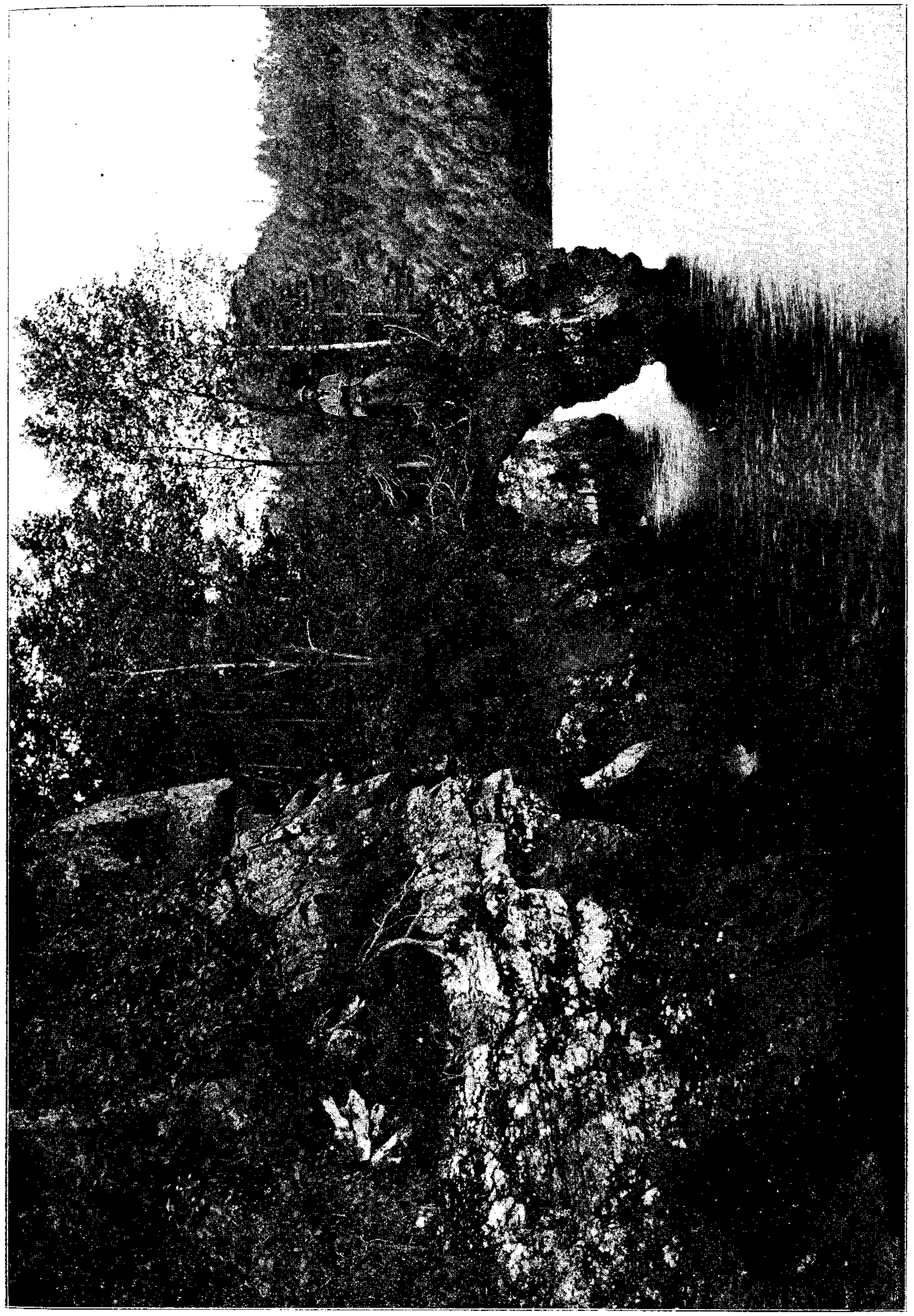
* Also called Castle Rocks and Cloven Towers. Jackson, p. 422.



SEA-CAVE EROSION AT ARCH ROCK.

the largest is at the head of McCargoe Cove, (Pl. IX). In general, however, the absence of extensive deltas from the coast line is apparent, even from a glance at the map, though the map does also show in some of the long and narrow lakes, blunt ends significant of partial filling. We may therefore conclude that the period of the present level is not, geologically speaking, long. For the last forty years or so, however, no material change has taken place in the lake level, for the floors of old adits along the south shore of Rock Harbor, were on the occasion of my visit in September, 1895, under 18 inches of water, showing that the water level was a little higher than when they were put in.* Nor is it surprising that the lake level should now be tolerably constant, for Lake Superior now drains over a rock threshold. (Cf. Crossman's Chart of the levels of the great lakes, 1859-1888, Milwaukee, Wis.)

When we come to consider the next question, that of the relative rate of emergence during different periods of time, the same arguments that tend to prove the recent date of the present level still hold good. Deltas at high levels are not conspicuous. The numerous ponds which are rapidly encroached upon by marsh plants are not yet filled up, in spite of a climate very favorable for such vegetation; frost has done but little to crumble down, and, as I have already remarked, vegetation still less, to cover over, some of these raised beaches. All signs point to comparatively little disintegration since glacial times, and my judgment is that the present shore line is more marked than any at higher levels.

If we ask whether the subsidence of the waters or elevation of the land has been uniform, the following table, No. VI, with the cross-sections, Pl. XIII, will give some idea of the more important benches and the levels at which the receding waters lingered longest.

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*This would not, however, necessarily indicate the other thing, viz.: a rise of water level, as such a change is well within the range of temporary, barometric, monthly and annual fluctuations.

SHORE LINES OF ISLE ROYALE.

[Mason's observations, 5 in. barometer, compared with one of equal size at camp. No corrections for temperatures.]

Location.	Observer.	Altitudes.				Character of features, and remarks. Terrace bench if not otherwise noted.
		0-100.	100-250.	250-460.	460+.	
Washington Island		20-25				
B. M. No. 62, N. of drillhole No. IX	Stockly, level. Lane.			438 ft.		Top of southward facing cliff, sea cliff or fault scarp?
Beaver Island	Lane	10, 30, 60	95-115			Terrace and spit to S. W. cut in one bed, not structural.
Hole No. XV	Lane		92-120			Terrace accordant with structure. Fig. 12.
Island Mine	Winchell Lane.	all around	95 mine	315+		1881-84, Minn., p. 51. Granite boulders; terraces.
West end	Lane	10 20				Sea caves 10 ft. above water line, terrace at pocket beaches.
Todd Harbor	Lane Stockly, level.	30-36 81-90	130-140			
Trail, Todd H. to Siskowit L.	Barom. checked with Stockly's repeated readings. L.	30-36, 95	130-140, 180-200	-312-372 -407-350	485?	Trail has been gone over several times with Barom. N. side of ridge, S. side of ridge less often; at 310 is very well marked.
McCargoe Cove						See illustrations, Plate IX.
Hawk Island	Lane	15				Raised beach.
Amygdaloid Island and Channel	Lane	15 30-40				Beach and sea cliff.
Hill Point	Lane	30 (estimated)				Well marked. Rounded cobbles very well preserved. Plate XIII.
Locke Pt.		15, 30, 35				Terrace.
Blake Pt., North side		30-55	139-140	272		Plate XIII, cross-section C-D: repeated measurements, terrace.
South side						Terrace and skerries.
N. W. of Siskawit mine	Lane	90-100	130 ± 10			Terrace. Barrier beach.
Back of Lea Cove		87				
Conglomerate Bay	Lane	10+40 20				Conglomerate shows well a terrace of varying altitude.
Chippewa Harbor	Lane	25, 35	109 or 140			Beaches, terrace, foot of rise at 123.
Around Lake Richie. Alt. 26 ft.	Mason	36				311 top of cliff. 275? flat bench.
Section 10, T. 65, R. 34		20				Lichen-covered beach. Old birch 20 ft. high down on it.
Siskowit Lake. Alt. 50 ft.	Mason	60	213			Terrace; streams swift, except from Mud Lake, around which the terrace goes.
Greenstone Range			210			Foot of sea cliff.
					462	Sea cliff.
				370		Swamp at foot of cliff.
					467	Terrace.
				383	490-98?	Terrace.
S. Side		85	138, 150 178, 194			
Siskowit Bay		30-40 14-20, 60-65				Terrace N. of bay near Hay Bay.
		95-110				Pt. Houghton, beach line.
Rock Harbor	Mason	30 and 60	203-211	308+		Sea cliff facing N. +terrace.
		96	204 127, 212			Terrace; at 195 it is steep,—on side of bluff; at 204 we are at crest of bluff, becoming less steep 40 ft. below; terrace at 127 ft.; crest at 212 ft.
		6-66 55, 96	135	380 410 456 430 404 271	472 485 510	Terraces largely according to structure? Cliff (271 ft. terrace is doubtful; a number of ridges near this level; bench opposite.)
		25				? at 25 ft. is top of sand spit, on both sides of head of harbor, referable in part to 30 ft. terrace.
S. of Sargent's Lake	Mason			250-280		Terrace.

An era of slow emergence will leave its impress in many shore lines. They will be few in an era of rapid emergence. Moreover in a period of rapid emergence becoming slower, or followed by a period of slow emergence or stationary level, the earlier part of the period is liable to have its marks destroyed by more extended work at lower levels. Let us study the records of the table above, with the object of more carefully considering the relative rate of emergence.

We have only two observations of terraces, etc., above 500 feet, while between 467 feet and 498 feet we find six, then down to 450 feet but one, and down to 400 feet but four more. Hence there must have been a very slow change of the water level when the latter was 485 feet higher than at present. This answers to that terrace noted by Lawson (20th Ann. Report, Minn. Geol. Survey, Part V, 1891) at McKenzie, his *series No. 32,* from 460 feet to 497 feet, and to that at 482 feet, back of Thunder Cape, which Upham (Bull. Geol., Soc. Am. vi., p. 23) correlates with the "Belmore" beach, though I am tempted to correlate it with the Duluth Boulevard beach, 485-490 feet, and the Hancock 490 feet terrace. The next halt for which we have noticed more than one record, is about 380 feet (3 records). Cf. McKenzie terrace at 379 feet and Thunder Cape at 392 feet, i. e., Lawson's Strand No. XV. Below this there is only one observation, 340 feet, (Cf. McKenzie at 347 feet), until we get near 310 feet, when we have four, indicating distinctly a pause after a rapid fall to this point. This is probably comparable with McKenzie, 320-326, or Nos. XXII-XXIII of Lawson's strands—and Upham correlates it as the Thibeault beach. For the next halt three observations agree very closely, giving an average of 273 feet (Lawson's Strands No. XXI). This terrace Upham correlates with his Double Bay beach. Then there is a marked gap (only one doubtful observation), that is, a rapid subsidence until the water level fell to 213 feet. Between this and 194 feet we have six observations. Back of the Atlantic mill and of Hancock we have a similar terrace at 210 feet. It is Lawson's XVII, Upham's first Beaver Bay beach (b). Then there was another rapid fall of water level, for until we get down to 140 feet we have but two rather peculiar terrace records. But between 130 feet and 140 feet the water level seems to have remained constant for quite a while (eight records),—the barrier beach back of the Siskawit mine and the skerries known as Monument Rocks being conspicuous instances of the effects of the water at this level. The back of the Hancock terrace is at this level, and much of the delta of Huron Creek, west of Houghton, may have been built at this level, which is recognizable on the hills back of the Southside location, west of Huron Creek. This is evidently Lawson's marked horizon XII and Upham's "Second Beaver Bay beach." The subsequent subsidence appears to have been somewhat slower, as the records below this point, are more distributed down to 85 feet, but much more abundant between 90 feet and 100 feet. This lower level would then correspond to the front of Hancock and East Houghton (90 ft.), to Lawson's VIII-IX, and the whole interval (140-90 ft.) to Upham's second and third Beaver Bay beaches, and to the broad sloping terrace on which the village of Hancock is built. Then there are no records between 70 feet and 80 feet and few below 90 feet, until we get to 66 feet. Between this and 60 feet there are a larger number of records, and the terrace is very well marked. This seems to be Lawson's well marked VI, and if so it would be the Chester Creek beach of Upham, but Upham makes the 90 feet terrace the Chester Creek beach, in accord with the theory of increasing elevation going north, and, as we shall see, the drainage of the island rather favors that theory. But on the other hand, the period of slow emergence indicated around Portage Lake and Keweenaw Point between 140 feet and 90 feet seems to be too well paralleled on the island at the same levels. Possibly the upper beach lines only have been much deformed, but to tell the truth so far as Isle Royale terraces are concerned, I have seen but little evidence of unequal elevation in comparison with Keweenaw Point. However, my observations were not made with this particularly in mind. Traces of shore lines are scarce below 60 feet, down to 30 feet. Here there is a distinct shore line, in places continuous with the present beach and connected with old sand spits at the head of Rock Harbor (Lawson's IV. Taylor's Nipissing Beach?*). Below this the beach crests are at all levels, but there are many observations at about 15 feet, more than between 30 feet and 20 feet.

On this question, interesting from a theoretical point of view, whether the emergence of the land is due merely to subsidence of the waters, or to an actual elevation of the land, not in all places to an equal amount, it is well known that Lawson (*Loc. cit.*, p. 286) and Warren Upham

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* While this volume was passing through the press Mr. Taylor visited the region of Port Arthur (Am. Geol., August, 1897, XX : 111) and identified the 63 foot beach as his Nipissing, and the levels from 400 to 450 feet (instead of 485 feet, as we make it) as his Algonquin. He agrees with Upham in assuming differential elevation.

(Bull. G. S. Am. VI, p. 27) have come to opposite conclusions. Without presuming to decide the questions on the altitudes of raised beaches given, for I think barometric observations too rough in their nature to decide, I would remark that the hypothesis of differential elevation implies certain effects on the stream drainage, which should be evident on Isle Royale, as it lies in long ridges in the direction of the ice advance and retreat.

§ 6. Drainage affected by unequal elevation.

According to Upham's conception, as the ice retired the land rose, the amount of the rise being greater to the north and northeast but the period of rise later. Hence the tendency of the streams as the land emerged would be to flow to the northeast rather than to the southwest, but as the elevation continued and as the northeast rose more, their gradient would be checked, and there would be a tendency to the formation of ponds and swamps. Whereas streams, formed on a natural declivity such that at the start they flowed southwest, would have their grade accentuated, and would tend to have fewer ponds.

Now let us apply some tests to Isle Royale. The dividing line between ranges 35 and 36 will do sufficiently well to separate the island into two halves, the one to the southwest and the other to the northeast. The former should show the one style of drainage, the latter the other. Now in the southwest half we have longer streams and fewer lakes, and of the seven lakes there all but Lake Feldtmann drain to the northeast, as would be expected if they were due to "ponding back" by northeast elevation. In the northeast half we have thirty lakes and more.

Of the streams, Cold Run, entering Tobin Harbor, I know to be very sluggish, and even where it crosses the east section line of Sec. 14, T. 66, R. 34, it is but little above the lake.* The stream entering Conglomerate Bay is also in a marked valley and starts from ponds, and the stream flowing northeast across the northwest quarter of Sec. 6, T. 66, R. 33, is also ponded as Upham might desire. Many of the ponds, however, drain to the southwest after all, and finally escape through cross valleys. On the whole the drainage is not at all unfavorable to Upham's idea, for this drainage of the waters sidewise, if an opportunity was offered, might be also expected in case the mouths of the valleys opening northeast were raised higher than their heads.

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*This indicates some error on Foster & Whitney's barometric section across the island. Cf. cross-section E-F of plate XIII.

A fuller test could be made by considering the courses of the swamps also, and we can easily see that there is here an attractive field for farther investigation, and detailed study of the drainage. For example, the stream entering at the southwest end of Siskowit Lake, enters sluggishly through a marsh, while that at the northeast end comes in on the run, which agrees with Upham's theory. But on the other hand Grace Creek, flowing southwest, has a *sluggish* flow in a broad valley. So according to the theory, Angleworm Lake might once have drained out into Tobin Harbor. There would be a fine chance to test the theory by searching for traces of such a channel on the divide.

§ 7. Surface materials.

To enter into a detailed description of the rocks whose fragments make up the gravels of the island is foreign to the purpose of this report. The bulk of the materials seems to be referrible to the rocks of the island. But similar rocks occur all around Lake Superior. Hornblende schist and other erratics from the Huronian rocks are however not uncommon, even at considerable elevations. Stockly has seen granite boulders on top of the Greenstone range, near Lake Desor. Near the Island mine are some conspicuous granite boulders. Granite boulders are mentioned by Desor at a height of 200 feet above the lake (F. and W., p. 201).

Back of Ghyllbank is a large boulder of a quartz porphyry, and along the ridge about 116 feet above Lake Superior are boulders of gneiss, hornblende schist, etc. (p. 196). On some of the lower levels fragments of Silurian limestones and cherts have been noticed.

CHAPTER VIII.

STRATIGRAPHY.

§ 1. Explorations near Washington Harbor.

One of the most important things to do is to put on record the developments of the explorations by costeans or trenches of the Isle Royale Land Corporation, as they soon become covered. We begin at the west end of the island, the costeans there being located more exactly on the map, Pl. III.

Beaver Island, foot of costean 30 feet* above lake and (76 steps) 200 feet west from northwest corner of Sec. 32, T. 64, R. 38. Twenty feet up is the first rock exposed, the bottom of which is a small, fine-grained amygdaloid with laumonite (Sp. 14794); below that the trench is already caved in, but there was an amygdaloid in it (Sp. 14793) † of which pieces are numerous.

Higher up, the rock is very fine grained and compact and remains so up to 35 feet greater elevation (Alt. 65 feet). Then we go 80 feet back on a terrace to another bluff which is at bottom minutely mottled (Sp. 14795), and the bed joints dipping 18°, but gets coarser for some distance as we go up. The top of the costean is on the section line between Sec. 31 and Sec. 32, 115 feet above the lake. The course of the costean is N. 30° W.; magnetic variation 26° E. The upper part of this costean seems to develop the big ophite at the bottom of drill hole No. II, 631, and from top of No. IV down to 40 feet.

Section 32. On the shore opposite Beaver Island, to the southeast, we have another costean close under the Greenstone range. Leaving the shore, for 30 steps the surface is flat and covered. Then we have steep cliffs and the exposures are located by their barometric elevation.

At 35 feet, an amygdaloid.

At 55 feet, trap; dip of bed joints 25°.

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* The elevations given in this chapter are estimated, or derived by barometer, and are above Lake Superior.

† Sp. refers to *hand specimens* in the collection of the Geological Survey of Michigan, not to *thin sections.*

From 105 feet to 125 feet, frequent apparent flow junctions, all amygdaloid (Sp. 14798), like numerous similar belts in drill hole No. II.

At 145 feet; up to here mottled, weathering to a coarse meal, and also spheroidally.

At 155 feet, apparently ten one-foot flows (Sp. 14799), then all mottled melaphyre; decomposed detritus at top of costean. This series is very easily matched in drill hole No. II, e. g., at about 57 feet and also lower down.

Ghyllbank. In this neighborhood on Sec. 29 were a number of trenches,—

(1) On trail running northeast from Ghyllbank about 500 steps west and 200 south of the east quarter-post. Beginning at the northwest end and going S. 30° E.,—at 110 feet (40 steps), amygdaloid,—going farther 154 feet, we come to a bluff of mottled melaphyre, ice-scratched and showing stratified talus sloping steeply away; dip of joints about 20°; underlain by fine grained porphyrite. It is planed and rounded, but scratched in more than one direction (Cf. p. 183). The bluff faces toward N. 65° W. and the scratches dip on a line toward N. 25° E., in one case down hill, being scored on a nearly vertical surface.

For 33 feet farther on, the ascent is very steep, the mottling growing coarser, then we have for 22 feet more a gentler slope to summit, the grain getting finer. Altitude of top of trench above bottom, 30 feet by Locke level. The ophite at the top of this costean is in line of strike from, and appears to be the same as that exposed on, Beaver Island.

(2) Fifty feet west of Stockly's station No. 6*, running 200 feet down hill toward N. 30° W. (Pl. III).

(3) Three hundred thirty feet northeasterly (120 steps), a costean at an altitude of about 116 feet, running S. 30° E., on the first marked ridge north of the Greenstone, which falls slightly to the east.

Sp. 14726; on the summit of the ridge is a fine grained trap, amygdaloidal in spots, not lustre mottled, light grey, porphyritic on weathered surface while the fresh surface appears dark.

Sp. 14727; after about 20 feet the outcrop becomes very irregular in the character of the rock, continuing to about 33 feet, after which the ground begins to fall.

Sp. 14728, about 70-80 feet farther on, is from a rounded outcrop of amygdaloid, obscurely scored parallel to this ridge.

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*The table showing the exact location of this section was not accessible to the Survey.

(4) Seventy-seven feet farther, on the northeasterly trail, a costean to the northwest.

Sp. 14729; from the crest of ridge which here has obscure mottling; the outcrop is opened up 20 feet farther to the northeast. There is a veining disclosed in the trench, dipping 80° to northwest, running with the strike of the formation or a little more to the north (Sp. 14730 is part of the prehnitic vein rock, while the country rock is of same type as Sp. 14726). Going northeast, in 55 feet more we meet a boulder of hornblende schist and one of gneiss in the coarsely stratified drift; the outcrop still continues and is a massive fine grained ophite (Sp. 14731), and after 44 feet more there is another pit. The rock in it is red, decomposed, amygdaloidal (Sp. 14732) and riddled with clay and prehnite seams like Sp. 14730.

(5) Another costean, 20 feet farther on; to the northwest it shows massive ophite and 7 feet off from the trail to northwest crosses a vein; the costean also runs 66 feet to southeast, showing amygdaloid at the south end. There is considerable prehnite with copper in this exposure.

It is 858 feet from the last point along the bluff to the Lake Desor trail which is struck about a quarter of a mile (498 steps) from the clearing around Ghyllbank.

These exposures show more copper than any others which I have noticed in this region. There is nothing very characteristic about their rocks. They are not far, apparently, from the horizon of drill hole No. II, 554 (2942), which is also very much charged with prehnite and carries some copper, but I am inclined to take this as due to the fact that both localities happen to be veined.

Besides these costeans, there are three on Sec. 20, T. 64, R 38, near the southeast corner, on the northwest flank of the same ridge as that in which is drill hole No. I, exposing the same mottled melaphyrs, i. e., ophites, and soil of fine gravel with occasional well rounded boulders.

Then at about 1000 steps north of this corner, as per map of Wendigo property (Pl. III.), there are three trenches on the north side of the ridge in which is drill hole No. III.

Then at about 300 steps farther north, as noted on the same map, there are a large number of costeans developing the Minong trap at its southern edge, and there are also a number along its northern edge. These enable us to trace the Minong belt with great accuracy for nearly a mile, and it is practically outlined on the map by the trail to the various costeans which runs along the top of this ridge made by the Minong trap. As thus indicated, the strike is almost precisely one north to two east or N. 63° 25′ E., but since there are faults which seem to throw the outcrop to the southeast as we go northeast, the strike found instrumentally by Stockly, of N. 60° E., cannot be far wrong. The Minong trap is also developed by tunnel No. 5. The dip I measured there is 15°, in close harmony with that derived from the drill records (Chapter III, p. 84). An interesting feature developed, is a curving of joint and flow lines to the southwest, as we look at the trap from the northwest, and to the northwest as we look southwest (Fig. 25), apparently indicating a flow of the trap to the west, which is in harmony with the general law that the traps thin to the southwest. The strike observations in the costeans are disturbed by large magnetic variations. Some nodules of calcite and copper may be observed at the bottom of the trap.

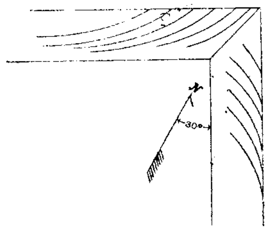


Fig. 25

Illustrates the curvature of joints in the Minong trap.

Of the other explorations of the Wendigo Copper Company as indicated on the map (Pl. III.),

Tunnel No. 1 branches and is very irregular in its course. It is in the gap made by a fault which it cuts, and is in the beds at the top of, and just above, drill hole No. III which is near it. According to Stockly, the amygdaloid is met in the tunnel, on the west side first, and then 30 feet further north on the east side. If these two amygdaloids are one and the same, the fault has changed the character of the throw from that between drill holes No. XVI and No. XV. There are, however, a number of very similar amygdaloids in drill hole No. III, at 275 feet, at 298 feet, etc., at about this horizon. Suppose, for example, that instead of the amygdaloid, drill hole No. I, 298, being thrown back on the east side 30 feet horizontally (i. e. 8 feet perpendicular to the bed), it were thrown forward as indicated for the throw between No. XV and No. XVI, about 50 feet. Then the amygdaloid of drill hole No. I, 362, would appear some 12 feet perpendicular to the dip, below No. I, 298, which may be the amygdaloid we see on the east side, as the discrepancy would be only 4 feet, and the boundaries of amygdaloids are not sharp, and with a 14° dip a slight variation in the dip or level of measurement makes a great difference in horizontal equivalents. Around drill hole No. III the master or bed joints make a dip of 24°, steeper than the true dip, as usual.

Tunnel No. 2 runs first through clayey soil, then into mottled decomposed red melaphyre, massive, non-amygdaloidal (at least with rare amygdules) and zeolitic. It is 60 feet lower than the top of drill hole No. IV and is in the second big ophite which occurs in that hole, i. e., from 40 feet to 108 feet. The decomposition is almost surely preglacial and indicates very little glacial erosion in such sheltered spots. It may be due to a fault, as we have indicated on the cross-section.

Above tunnel No. 2, half way up the hill, a costean and tunnel show amygdaloid above massive trap, as around drill hole No. IV, and at the extreme top of the hill the rock is thin-bedded and amygdaloidal. Drill hole No. IV stands at the top of the hill.

Tunnel No. 3 is driven only a little way, into a very well marked red amygdaloid. It is on the same level as tunnel No. 2, and would apparently strike the same formation. This is one of the indications of the fault drawn upon the geological map.

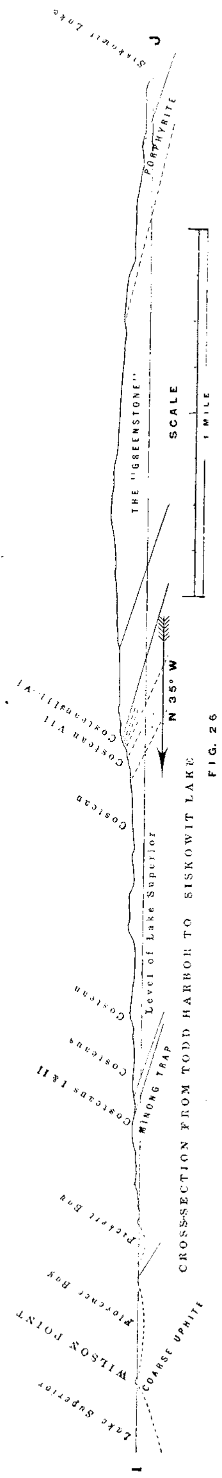
Tunnel No. 4 is within a few feet of tunnel No. 6, and was driven only a few feet.

Tunnel No. 5 is in an amygdaloid of which the Minong trap forms the hanging wall, as already described in the records of drill holes Nos. III and I.

Tunnel No. 6 is only ten feet or so in rock, which is laumonitic, seamed, decomposed and rather more broken than at tunnel No. 2; both of these tunnels run a good way through clayey sand. The ridge back of tunnel No. 6 is said to continue some two miles. Tunnel No. 7 is on the side of the Greenstone range (Sp. 14735).

§ 2. Explorations near Todd Harbor.

The other place where work was done by the Isle Royale Land Corporation was at Todd Harbor on a series of trails radiating from a camp known as Haytown (Pl. XI.). The location of these costeans in relation to the rock series generally is shown on cross-section, I-J, fig. 26. From this section it is apparent that they are largely at the same general horizon as those around Ghyllbank, above the Minong trap and below the Greenstone.



CROSS-SECTION FROM TODD HARBOR TO SISKOWIT LAKE

FIG. 26

Cross-section I-J along trail from Todd Harbor to Siskowit Lake. See Plate XI.

Costean No. **I.** The first costean we describe lies on the trail which runs southwest of Haytown over the Minong range at about 1550 paces west of the east line of Sec. 11, T. 65, R. 36. This costean is about 100 feet above Lake Superior and runs to the S. 15° W. with a spur to the southeast. For 110 feet (40 steps) the rock exposed is a fine grained, compact trap, then 20 steps more to the top of the ridge, then 10 feet more to where the costean forks and for 66 feet more the latter remains in the same kind of rock. On the spur to the southeast after 30 feet the red porphyrite, the same as occurs at the Minong mine, begins on the surface; 44 feet more brings us to a swamp and 143 feet across the swamp to a ridge of mottled melaphyre as in costean No. **II,** hereafter described. Going north from the north end of the costean 120 feet we notice a fine mottling, and in 44 feet more reach the foot of the bluff some 20 feet lower.

Continuing southwest, we notice along the trail a pronounced jointing running N. 30° E. and also the contact of the red porphyrite and the finer grained trap. The red porphyrite often shows flow lines. Over in section 10 we come to,—

Costean No. **II.** This was dug in 1889, and runs southeast across the range. Reckoning from the south end, we have,—

Eighty-four feet, mottled melaphyre.

Forty-four feet more, glacial marks running N. 60° E.

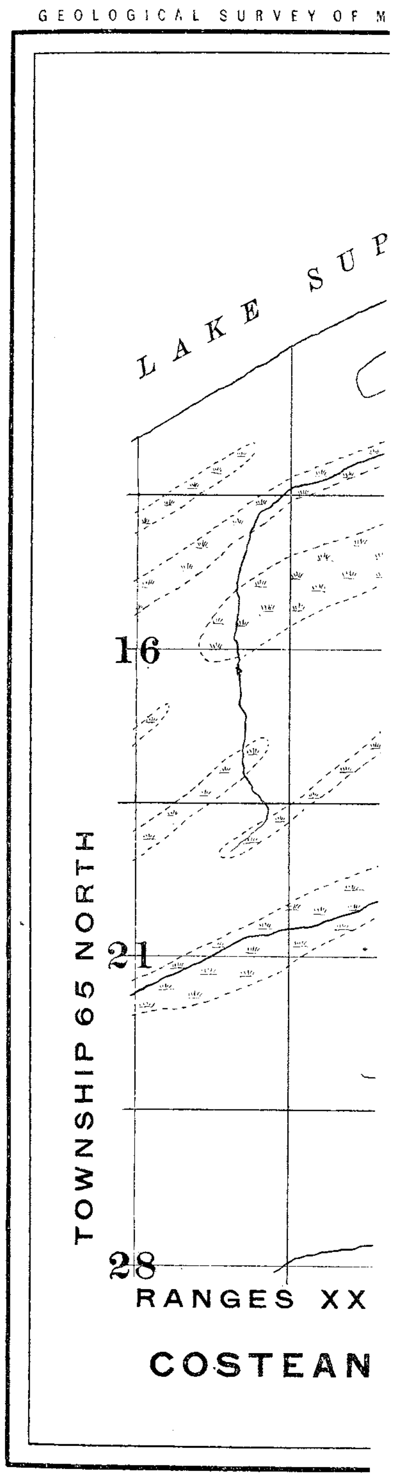
Sixty-six feet more, to top of ridge; altitude 150 feet.

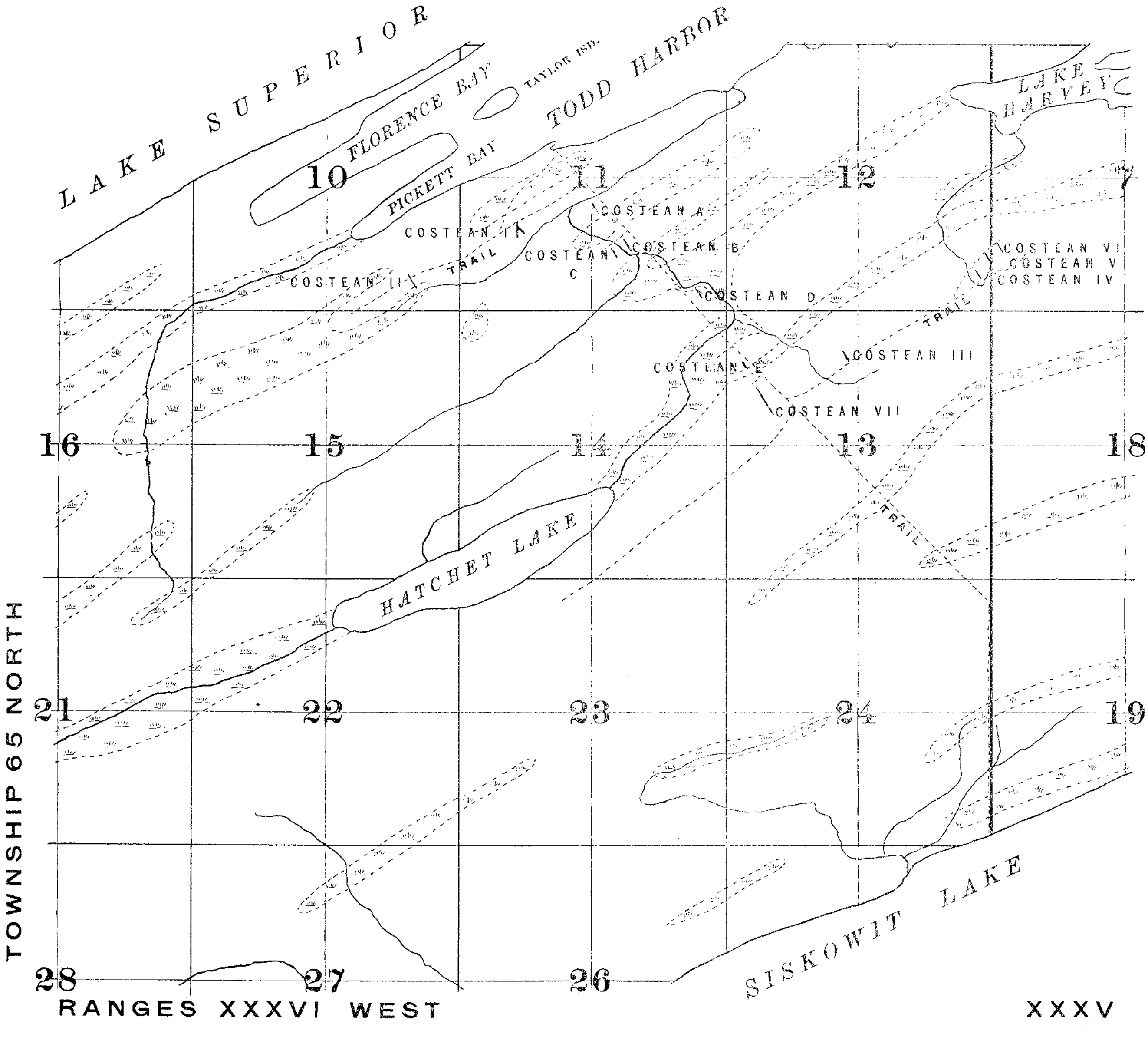
Forty-four feet more, drop of 10 feet in altitude to about 140 feet.

One hundred forty-three feet more, beginning of second rise; glacial scratches, nearly horizontal, strike as before.

Twenty-two feet more, slope of red porphyrite and ophite mixed; dip 20° (?).

One hundred thirty-two feet to trail (Alt. 160 feet),—with a 60 foot to 40 foot bare bluff of a compact hard trap that shows perpendicular jointing, occasional large porphyritic feldspars, agatoid seams and minute mottling; apparent dip to S. 35° E. (magnetic). From this trail it is about 500 feet to a stream flowing northeast (Alt. 100 feet); thence 275 feet to a terrace on the southeast side of the ridge (Alt. 140 ft.); 210 feet more to the top of the ridge which shows a coarse diabasic structure, (Alt. 170 feet); thence 176 feet, down to a terrace at the foot of the ridge; thence 209 feet to the first ledge of rock and first terrace, about 200 feet above water; thence about 275 feet to shore.





COSTEANS, TODD HARBOR, ISLE ROYALE, MICH.

This section, we see, gives us the Minong beds and the ophites immediately over and under them. Some old (? Indian) digging near costean No. **I** is said to have been found.

Costean **A.** On the trail southeast from Haytown, the first trenching is to the southwest of the trail, on the first ridge southeast of the Minong range, represented by Sp. 16037, with characteristic agates and red felsitic rock. Beginning near the center line of Sec. 11, the first 20 feet show spheroidally weathering mottled melaphyre (Sp. 16038), slightly amygdaloidal at top; then on the other side of the 100 feet (85 feet; Stockly) terrace is another rise with a finer grained and more laumonitic and seamed bed (Sp. 16039). The terrace corresponds in altitude to the top of the Minong range.

Costean **B.** Then on the next ridge, S 70° W. of the trail, we have a costean 200 feet long, 114 feet and 50 feet at its northwest and southeast ends, respectively, from the trail, showing the contact of the two flows,—a mottled melaphyre underlain by an amygdaloid. The contact is 20 feet, and the top of the ridge 50 feet, above the northwest end of the costean, and for 100 feet further southeast the mottled melaphyre continues.

Costean **C.** Then a little further southwest, where the stream following a cross fault (?) cuts through the ridge, we have two successive ophites the lower flow being amygdaloidal at the contact and the upper flow being fine grained. The strike appears to be nearly east and west and wavy dip 45° (?).

Costean **D.** The next costean is on the next marked ridge to the southeast near the corner between Sec. 11 and Sec. 13, T. 65, R. 36, about 168 feet above the lake. The ridge is an ophite as usual, and the costean develops a disintegrated seam half way up. It is 187 feet from the trail and shows the bed joints dipping about 14° to the southeast. The next costean we meet is the so called Jumbo costean, No. **VII** but keeping the order of their numbers, we turn aside to,—

Costean No. **III.** This runs up hill to the southeast from a point about 1750 paces N., 1125 paces W., of the southeast corner of Sec. 13, T. 65, R. 36; the course of the costean is N. 36° W.; magnetic variation 50° W. There are 10 to 20 feet of mottled melaphyre north of trail; Alt. about 220 feet at trail (Sp. 16067).

Seventy feet horizontally farther on, the rock becomes slightly amygdaloidal; joint-dips 16° to southeast; strike N. 50° W.

The next 20 feet the same; (Sp. 16066).

The next 100 feet, red and green amygdaloid (Sp. 16065); dip about 14°; much laumonite.

The next 20 feet the trench is filled. This brings us to an amygdaloid at base of cliff; altitude about 230 feet.

Forty feet more to cliff; discontinuous coarse seam like Sp. 16058, about 10 feet up.

At 15 feet up the same texture occurs with chloritic amygdules, not mottled; (Sp. 16064).

Altitude about 250 feet, top of cliff.

The next 40 feet horizontally, heavy amygdaloid; red laumonitic band at the end of this distance; green with white amygdules.

Glacial striæ 5° N. of E. and mutton backs.

The next 50 feet, amygdaloid.

The next 30 feet, the same all the way; (Sp 16063).

The next 30 feet, covered (Sp. 16062).

The next 70 feet, amygdaloid (Sp. 16061).

The next 80 feet, covered.

Costean ends at top of ridge in flat country; altitude probably nearer 240 feet than 310 feet.

Costean No. **IV.** Runs N. N. W.—not more than 60 feet—from 300 paces N., 100 paces W., of the southeast corner of Sec. 12, T. 65, R. 36, at an altitude of 355 feet, beginning with,—

Twenty feet of horizontal ophite, then an

Eight foot perpendicular cliff (at 4 feet down, coarse seam; Sp. 16058), then 70 feet sloping down to about 325 feet; dips of bed joints, 11°, 12°, 17°, 18°, 23°, 9°, 8°; strike of other joints as follows; northeast, dip 82° to northwest; strike, east to west, dip 71°-78° to N.; strike S. 75° E., dip vertical. Twenty feet, steep slope to altitude 290 feet; amygdaloid alternating with fine grained trap in a very complex way (Sp. 16059 and Sp. 16060). Some copper but much laumonite; the remainder of the costean, some

One hundred and fifty feet, is not bottomed in rock.

Costean No. **V.** Runs N. N. W. from a point on the east line of Sec. 12, T. 65, R 36, 369 steps north of the corner. Rock like Sp. 16059 and Sp. 16060, found,—

Ten feet from head of costean (Alt. about 290 feet); the amygdules are irregularly scattered through fine grained trap, and as before there is some copper with abundant laumonite, also calcite, chlorite and quartz. The rock remains unchanged to the bottom of a steep slope.

The next 70 feet horizontal (Alt. 250 feet) is irregularly amygdaloidal and fine grained, not mottled; no distinct flow lines, although there are marked contacts and signs of a flat southerly dip. The section of this costean is practically a continuation of that of No. **IV.**

Costean No. **VI.** This costean is about 100 steps along the trail northeast from costean No. 5, and shows slickensides on a slipping plane running N. 65° E. (magnetic), dipping 46° to the N. W. The slickenside striations make an angle of 45° with the direction of dip (Alt. about 250 feet). They mark the beginning of an amygdaloidal texture. Above them the rock is massive, becoming mottled; below (Alt. 240 ft.) is probably the flow contact line. Taking costeans Nos. **IV, V** and **VI** together, we have a section of some 40 feet of mottled melaphyre underlain by amygdaloids. The top of No. **III** seems to be in the same belt of amygdaloids, but the bottom shows a mottled melaphyre underlying this belt. Not far from costean No. **IV** the stream which is below it falls over this lower mottled melaphyre.

Costean No. **VII,** the Jumbo costean, is located in the S. W. ¼ of N. W. ¼ of Sec. 13, T. 65, R. 36.

Beginning at the top,—

The first 10 feet perpendicular from the top (Alt. 333 feet; Sp. 16070) are in a coarsely mottled melaphyre, weathering to a gravel; then a horizontal terrace bench 20 feet wide; then,—10 feet vertical, more and more coarsely mottled ophite; then 110 feet horizontal and down to altitude 297 feet; along this terrace all mottle dmelaphyre, then—the rock growing finer grained (Sp. 16071)—down a very steep slope (equivalent to 60 feet horizontally) to altitude 272 feet, contact with red amygdaloid. Joints strike N. 55° E. and N. 65° E., dipping 15° to southeast, and amygdaloid bedding also dips 15°-20° to S. 20° E.

Eight feet further down is another contact and we have a series of amygdaloid beds corresponding to costean No. **III** (Sp. 16073), down the cliff to altitude 210 feet when wecome to a heavy bed of ophite, i. e. mottled melaphyre, covered after 15 feet. This point is just about 200 feet above lake level, then for 370 feet the costean does not show rock, but in the drift there is much dark red shaly sandstone; then for,—

The next 60 feet horizontally, falling 4 feet, the bottom is covered, but the costean shows a section of horizontally bedded sand and gravel with water-transported pebbles. (In the ridge N. W. across the swamp at the end of the Jumbo costean there is, in sand and gravel, a small costean (**E**) that did not reach rock, at about the same level—1600 paces N., 1875 paces W., Sec. 13, T. 65, R. 36); then taking up the section below the covered stretch, we find 10 feet of chloritic amygdaloid (Sp. 16051), with a fine grained quartzose greenish seam.

At about 160 feet altitude, terrace;—a fine grained ophite which continues northwest for 80 feet horizontally, through 20 feet of vertical fall; then,—

Twenty feet horizontally; bottom of ophite, thin-jointed (Sp. 16049); underneath it an amygdaloid (Sp. 16048); then,—

Eighty feet horizontally, falling 3 feet; uncovered terrace of mottled melaphyre; then,—110 feet on terrace of mottled melaphyre, finishing with a 20 foot bluff (Sp. 16047). The bottom of a melaphyre is in a swamp, which Stockly's measurements on the adjacent trail made 126 feet above Lake Superior.

The position of these costeans, Nos. **III–VII,** is not far from half way between the correlation lines, (589) feet, the Island Mine conglomerate, drill hole No. X, 193, and (4097) feet, the Minong trap, drill hole No. I, 456, i. e., the costeans would be expected to correspond to a point in the column somewhere near 2400 feet below the top. They would then correspond with the record of the upper part of drill hole No. II, and lower part of No. VI and the costean south of Beaver Island, and it is easy to see that they have a corresponding topographic position, and are petrographically similar, though owing to the lack of any markedly characteristic bed, it is not easy to correlate them bed for bed. If the covered part of costean No. **VII** does really hide a sandstone, as the amount of sandstone in the gravel seems to indicate, it is probably the bed at drill hole No. II, 136–175. (See p. 76.)

We thus finish the description of the exploring work of the Isle Royale Land Corporation. A few suggestions, not meant by way of criticism, but as guides to farther exploration may be pardoned. In the first place it will be noticed that, with the exception of the drill holes, all the exploration is in a comparatively narrow belt below the Greenstone, thence down to the Minong trap. This horizon is that of the Phœnix, Cliff, and Central mines, but they all worked on fissure veins. But few of the fissure veins have yet been proven by the costeans. It is difficult trenching to rock in them as they generally lie in drift-filled gaps. None of the belts shown by the drill cores to contain specks of copper indicated on cross-section K–L, Plate II, have been followed back and opened on their outcrop, as the drilling was the last work done.

There are distinct indications that the copper is more abundant,—

(1) In the porous beds, i. e., near contacts,

(2) In the more decomposed beds, especially those which are prehnitic, and hence,—

(3) Near faults. For example, a conglomerate bears copper in drill hole No. XII, which did not show enough to be observed in drill holes XV and XVI.

Now, as we have remarked in the chapter on topography, the weaker, decomposed beds are generally in the valleys, and the faults are marked by gaps in the ridges. Hence scraping the sides of the ridges is likely to show and has shown little of value. The shore line has also been repeatedly examined. Hence the most hopeful way of exploring in the future would seem to be to sink short drill holes on the southeast sides of the prominent valleys opposite gaps in the ridges, and if the soft bed which produced the valley was impregnated with copper in the neighborhood of the fault which produced the gap, sufficiently to make farther exploration desirable, a shaft could be sunk or trenching done to the northwest.

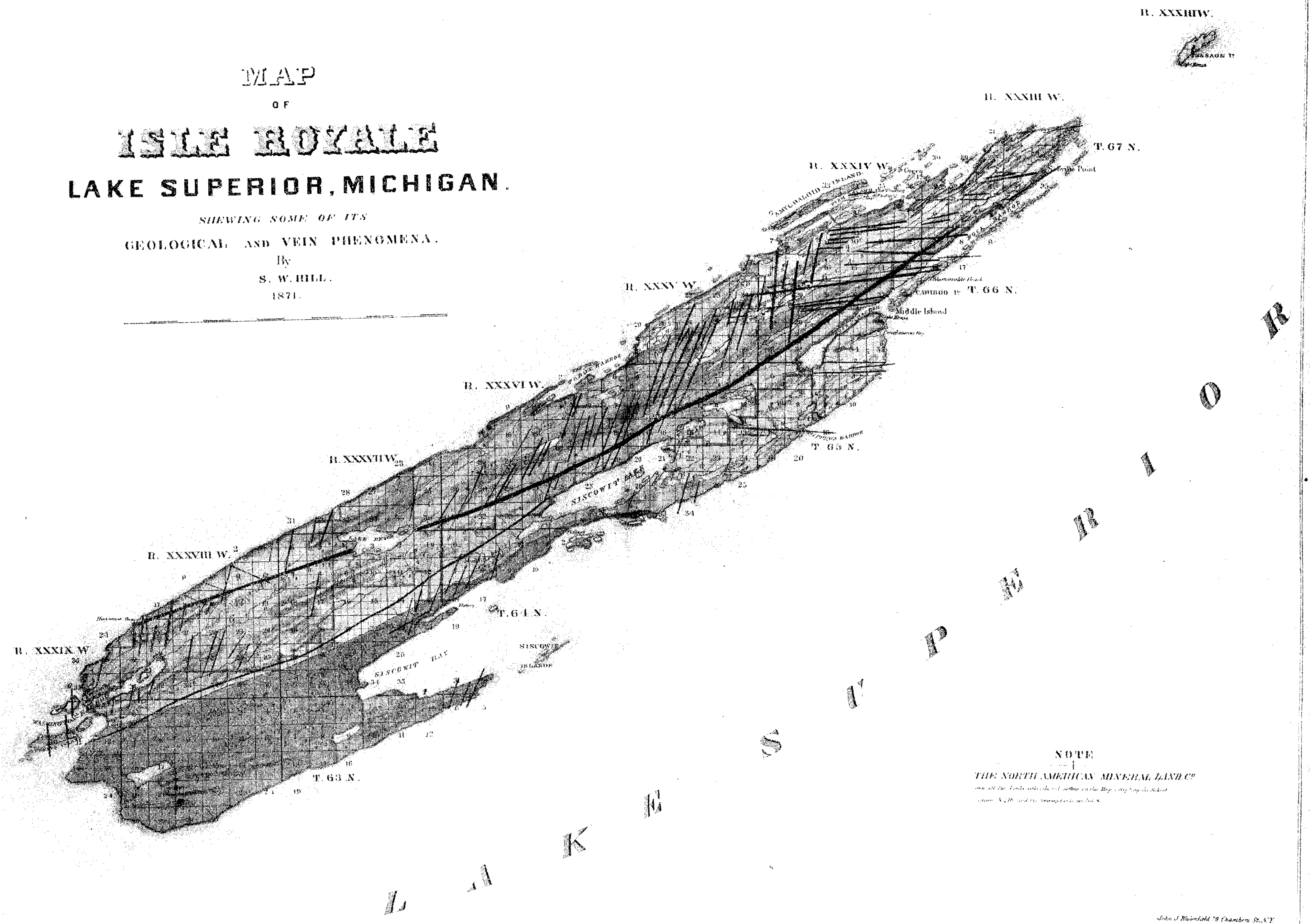
The costean back of Todd Harbor seems to show that the Minong belt is not as rich there as farther northeast, but there has been practically no light shed on the extent and richness of the Island Mine conglomerate, except that it was not rich in the drill cores. Of all the drill hole records, that of the top of No. VII seems to show copper most frequently disseminated in beds of the Ashbed type.

§ 3. Northern rock exposures.

Turning now to the natural exposures, it is not worth while to recount every exposure, the results of which are summarized in the map, but it may be worth while to mention some of the important localities corresponding to the part covered by the drill cores, before proceeding to discuss more in detail the structure of the southeast part of the island.

Beginning again at the west end of the island, which looks as though it may have been mainly determined by one of the north striking faults, the lowest bed that can certainly be recognized is the Huginnin porphyrite at Huginnin Cove, with the large ophites that lie just above and below it and form the northwest front of the island. The west end of the island is made up of a series of points representing the more massive ophitic beds, while the amygdaloids and contacts are more rarely visible. The north side of Washington Island, Double Island and Johns Island are of mottled melaphyre and on the north side of Double Island is a basic conglomerate, while the south side of these islands is like the beds just above the Greenstone. A bed of labradorite porphyrite with large and coarse crystals of plagioclase in a fine grained matrix is a well marked feature here. On the north side of Cumberland Point there is a green feldspathic melaphyre porphyrite, with elongated chloritic flecks, which represents the Ashbed group, corresponding exactly to the massive bed of porphyrite (drill hole No. X, 426) immediately beneath the first scoriaceous conglomerate, i. e., the bed we have correlated with Marvine's No. 45. This bears magnetic S. 87° W. from the west end of Washington Island, or about S. 88° E. in true course. Then comes a jog in the coast where a considerable stream comes in behind a ridge, which may be taken as the termination of the ridge of melaphyre porphyrite. Then continuing out on Cumberland Point, S. 75° E. (magnetic) from the west end of Washington Island, is an outcrop of the ophitic type such as occur above the Island Mine conglomerate. South 81° E. (magnetic) from the same end is another low outcrop of similar rock. Then about three-fourths of a mile southwesterly we get the first outcrop of conglomerate which continues with but few interruptions around the point, and there are no signs of any more trap. In general the dip of the conglomerate is from 9° to 12°, but there are some minor undulations, and one small fold. It is not possible from these isolated outcrops to define the boundaries of the different parts of the series exactly, but it is evident that each of these parts can be recognized, and also that their thicknesses are less than those indicated by the drill holes. Estimates of the thickness by measuring from outcrop to outcrop are not very accurate, for we do not know the mean dip, and there is every sign of considerable cross faulting. One fault comes out on the south side of Washington Island and is well marked, but there are many others indicated by gaps in the topography and to some extent by shifting of the ridges. Hill's map indicates quite a number (Plate XII). We have put on our geological map merely enough of the better indicated faults to give an idea of

MAP
OF
ISLE ROYALE
LAKE SUPERIOR, MICHIGAN.
SHEWING SOME OF ITS
GEOLOGICAL AND VEIN PHENOMENA.
By
S. W. HILL.
1871.



NOTE

THE NORTH AMERICAN MINERAL LAND C^o
own all the Lands within the red outline on this Map, excepting the School Sections N^o 16 and the Swamp Lands marked S.

John J. Bloomfield 79 Chambers St. N.Y.