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THE KEWEENAW SERIES OF MICHIGAN

BY

ALFRED C. LANE

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ERRATA.

Page 25, 11th line from bottom read "slicken-siding" for "slicken-sliding."
Page 27, 7th line from top read "Chamberlin" for "Chamberlain."
Page 35, 6th line from bottom read "glomeroporphyritic" for "glomeroporphyric."
Page 35, 15th line from bottom read "an" for "and."
Page 52, 7th line from bottom read "anamesite" for "anametite."
Page 53, 5th line from top read "has" for "had."
Page 61, middle of page read "enstatite" for "enstalite."
Page 73, 12th line from top read "apatite" for "patite."
Page 73, 13th line from top read "Minnesotare" for "Minnesotiare."
Page 76, 2nd line from top read "Becke" for "Becker."
Page 89, 4th line from top read "G. L. Heath" for "G. H. Heath."
Page 93, near bottom read "gravelly" for "gravel."
Page 98, 18th line from bottom, read "F. E." for "F. W."
Page 104, 2nd line from bottom read "are in" for "is."
Page 105, caption, read "minerals" for "numerals."
Page 117, 11th line from bottom read "Sec." for "Ces."
Page 131, foot-note, read "fits" for "fit."
Page 133, description of figure read "panidiomorphism" for "panidiomorplin."
Page 156, foot-note, read "49-51" for "49-50."
Page 190, 8th line from top, read "Bohemia" for "Bohemian."
Page 203, middle of page, read "Medora foot" for "Medora foote."
Page 210, 16th line from bottom read "porphyritic" for "porphyrite."
Page 257, middle of page read "horizon" for "horizine."
Page 275, 2nd line from top, read "M. 7. 5. S. d. 58-333."
Page 276, middle of page read "Philip S. Smith."
Page 314, 13th line from top read "gray trap."
Page 350, 2nd line from bottom read "conglomerate" for "conglomerated."
Page 371, between 4th and 5th line of §10, insert "belts of the Old Colony is given along the eastern edge of the Calu-."
Page 400, 11th line from top read "mosaic" for "mosiac."
Page 406, 11th line from bottom read "distorted" for "distended."
Page 429, 9th line from bottom read "$\frac{416}{731 - 416}$"
Page 434, 16th line from top dele "=."
Page 452, 12th line from top read "62-324?" for "am. -324? 62?"
Page 457, 10th line from top read "Marvine's" for "Marvin's."
Page 457, 12th line from bottom read "oligoclase" for "oliogclase."
Page 485, 2nd line from bottom read "Honnold" for "Honhold."

VOLUME II.

Page 505, 6th line from bottom read "Dr. L. L. Hubbard."
Page 518, foot-note, read "XXII" for "XXI."
Page 521, 2nd line from bottom read "to sea level."
Page 531, Elm River drill hole 1, read "T. 52 N., R. 36 W." for "T. 32 N., R. 36 W."
Page 541, Location of Hole 8 read "825′ W." for "825′ N."
Page 566, middle of page read "(N. 6° E.)" for "(N. 60° E.)"
Page 566, foot-note read "curves" for "cures."
Page 573, Transfer 10 + from end of line 16 to end of line 19.
Page 582, 2nd line from top read "1-1.5" for "1-0.5."
Page 610, 19th line from bottom read "mine" for "mines."
Page 635, 24th line from bottom read "bed rock surface" for "bed rock margin."
Page 644, 3rd line from bottom read "Bytownite" for "Bytounite."
Page 654, 12th line from bottom read "1.75 × 1.24" for "1.95 × 1.24."
Page 660, 15th line from bottom read "CO_2" for "Cc."
Page 660, 3rd line from bottom read "Conglomerate 18" for "Conglomerate 17."
Page 701, 21st line from bottom read "distinctly" for "dictinctly."
Page 723, 18th line from bottom insert "for" after word "diorite."
Page 683, 10th line from top insert word "base" after word "pumiceous."
Page 756, 8th line from bottom insert "inches of" after "four."
Page 783, 3rd line from bottom read "H. L." for "H. H."
Page 810, 1st line of foot-note, insert semicolon after "result."
Page 818, 3rd line from bottom read "no salt" for "no shaft."
Page 825, 7th line from bottom read "Bee" for "B."
Page 833, 8th line from top read "M. L. Holm" for "J. W. Holm."
Page 844, 5th line from bottom read "Van't Hoff" for "Van Hoff."
Page 847, 3rd line from bottom, dele the apostrophe after "Stokes."
Page 881, 10th line from bottom read "had" for "have."
Page 888, 19th line from top read "valleys" for "valeys."
Page 914, 10th line from bottom read "percussion" for "precussion."
Page 938, 15th line from bottom read "Brauns" for "Braums."
Page 939, 1st line of foot-note read "capital" for "capitol."

LETTER OF TRANSMITTAL.

Lansing, Mich., Nov. 1, 1911.

To the Honorable, the Board of Geological and Biological Survey of the State of Michigan:

Gov. Chase S. Osborn, President.
Hon. D. M. Ferry, Jr., Vice President.
Hon. L. L. Wright, Secretary.

Gentlemen—I have the honor to transmit for publication as a part of the report for 1909 of the Board of Geological and Biological Survey, Publication 6, Geological Series 4, in two volumes, a contribution to the geological survey of the State.

Very respectfully,
R. C. ALLEN,
Director.

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FOREWORD.

May I take the opportunity to express my obligations to Mr. A. H. Menche for help rendered since he left the Survey and to Mr. R. C. Allen, my successor as State Geologist of Michigan, as well as to all those who both on and off the Survey have done so much to help me. I want to thank Mr. Allen in particular for aid in finishing up the illustrations, as well as for his willingness to help me in every way, and especially for permission to announce that while the cross-sections are on a rather small scale, engineers who have need of them on the original scale can make arrangements with the Survey office to obtain blue prints.

It is one of the necessary inconveniences of publishing that by the time a thing is out, it is out of date. I regret that I have not been able to give to the able work of Van Hise and Leith in Monograph 52 of the U. S. G. S. (the report on the geology of the Lake Superior region) the attention which it deserves. The text of this report (part of that for the year 1909, it will be noted) was written before that appeared. I have inserted a few necessary references in the foot-notes, while reading proof, mainly to indicate points where our views diverge. But I have not thought I ought to burden an already bulky report by augmentation. I am glad to say we now practically agree as to the stratigraphy of the Keweenawan and other *facts*, and these will, in due time, speak for themselves.

Very respectfully,
ALFRED C. LANE.

CHAPTER I.

A POPULAR DESCRIPTION.

§ 1. INTRODUCTION.

This first chapter is intended to be a short account of the whole subject put in language that may be understood by people who have taken no course in geology. It is based on an article for the Lake Superior Mining Institute, but I have tried to fit it for an even wider circle of readers,—the miner, the normal school student, and the business man. And I have tried at the same time to convey as much information as possible. In such a chapter the arguments for the various conclusions can not be given and it must be largely a statement of results, for the results may have to be derived from the most refined and technical research.

In my studies of the copper bearing rocks I have received favors from mining men from one end of the range to the other and I take occasion here to express my thanks to C. A. Wright, W. W. Stockly and A. H. Sawyer of the Keweenaw Copper Co., W. J. Penhallegon, who took a very intelligent interest in the matters over which he had charge for the Calumet and Hecla around the Delaware; D. D. Scott at the Phoenx; Dr. L. L. Hubbard, my friend and co-worker in science, and A. Formis who have charge of the Ojibway; Fred Smith and W. F. Hartman at the Mohawk and Wolverine; Capt. James S. Chynoweth; Jas. McNaughton and E. S. Grierson, F. W. Ridley, G. H. Heath, J. B. Cooper, J. Pollard, and many others at the Calumet; R. M. Edwards, Mat. M. Dennis, Charles B. Lawton, R. H. Shields, A. C. Burrage, Norman W. Haire, W. J. Uren, Jas. E. Richards, F. W. Denton, R. R. Seeber, Reg. C. Pryor, Mr. Hotchkiss, of the Adventure, J. M. Wilcox, E. Fenner Douglas, Geo. Hooper, and R. S. Schultz.

§ 2. THE LAKE SUPERIOR BASIN.

The State of Michigan is divided by Lake Michigan into two peninsulas (Fig. 1), which may be likened to the right and left hands of the State. In fact the resemblance is so striking that the district east of Saginaw Bay has long been known as the

Thumb of the Lower Peninsula. But just as the Lower Peninsula lies between Lakes Michigan and Huron with Point Aux Barques projecting as a thumb into Lake Huron, so the Upper Peninsula lies between Lakes Michigan and Superior (Fig. 1). Upon this point occur the famous mines of native copper, which

Fig. 1. Outline map of Michigan showing the "Thumbs;" also the mean annual temperatures. See Chapter VI, § 2.

may perhaps be classed as the richest and the deepest in the world. The rocks in which they occur surround Lake Superior continuously at the west end and patches are found at intervals all around it. They consist mainly of alternate layers of reddish sandstones and pebble beds, that is, conglomerates and layers of once molten lavas known as felsite, trap and amygdaloid. These beds dip toward the lake from all sides and individual beds

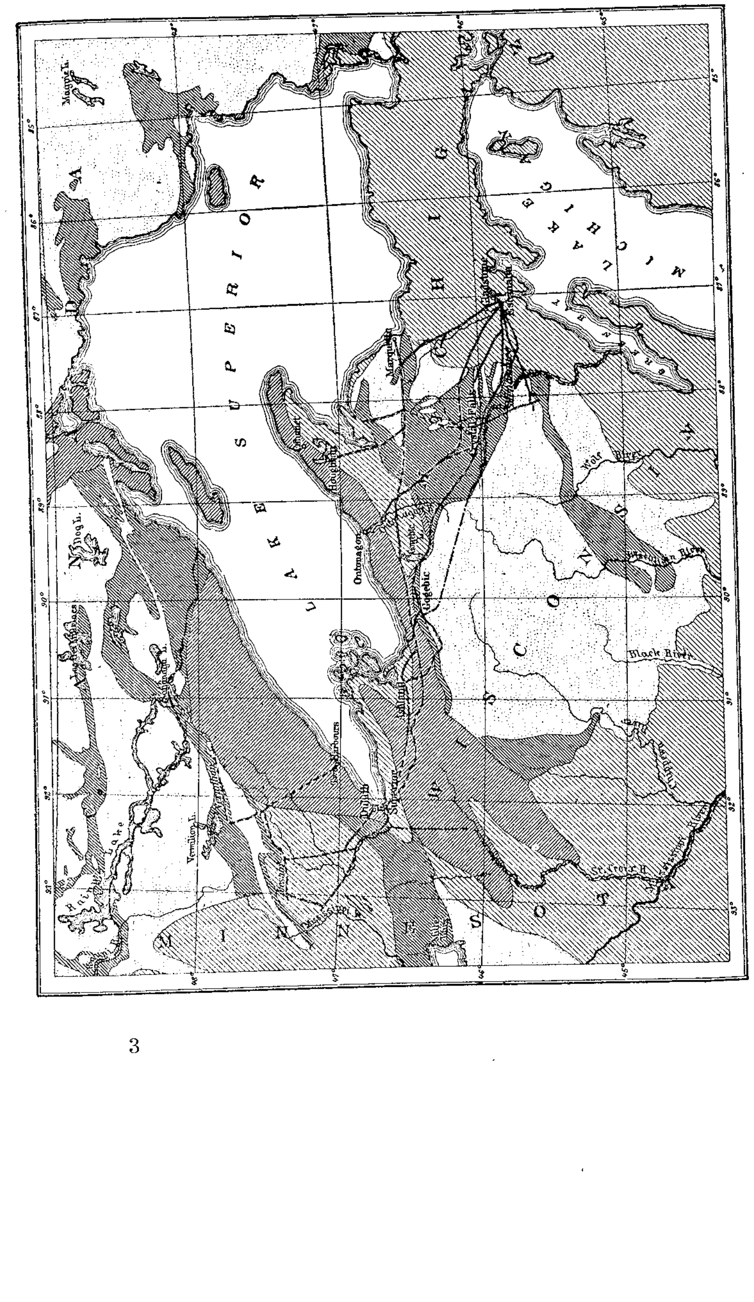

Fig. 2. Lake Superior region. Stippled areas are perhaps Pre-Huronian, those heavily lined down to the left are Huronian, down to the right are Keweenawan; Post Keweenawan is lightly lined down to the left. After Macco, Zeitschrift for praktische Geologie, 1904, p. 379.

can be shown to dip down, pass beneath it, and re-appear on the other side.

Lake Superior is about 412 miles long, and has an area of 31,200 square miles. The greatest depth is 1,008 feet and most of the lake is over 500 feet deep. Its average breadth is about 76 miles and since its depth is from one to two-tenths of a mile, it can be shown that it is a real, though slight, concavity in the round of the earth's surface, for the curvature of the round earth in a distance of 80 miles would mean that the level curve of the water would be about one-tenth of a mile above a straight line drawn from side to side. Thus the downward curve of the bottom of the Lake Superior basin is greater than the natural upward curve of the water surface. But if the bottom of Lake Superior is a downward curve, much more so must be the earth's crust passing beneath it. It is important to remember this, for if a downward bend is formed in the earth's crust it will not be easy to reverse it, any more than it is easy to reverse a crease in a piece of paper. So we are not surprised to find that the Lake Superior region seems to have remained a basin (or synclinal) from away back in geological history.

Accordingly, the beds to the northwest of the Lake dip to the southeast, and those to the south dip northward.

On the north and on the south of this basin-shaped (synclinal) downbend, are upbends, bosses, shields or anticlinals, as they have been called. These upbends have largely been worn away, exposing cores of granite. This granite appears south of Bessemer and Ironwood, and again in the Huron mountains. Intermixed and around these cores of granite come first a series of dark green rocks, in which the mineral hornblende is very conspicuous. These are the Keewatin rocks.

Next come the series of Huronian rocks in which our Michigan iron mines are located (Fig. 4). Like the Keweenawan rocks, the Huronian rocks on the north and south sides of Lake Superior are similar. For instance the Iron Range of Gogebic Lake corresponds to rocks about Port Arthur. Overlapping these there is a fringe of the copper bearing or Keweenawan rocks, which on the south side of Lake Superior are exposed at intervals from Silver mountain, which lies south of the head of Keweenaw Bay, past the south end of Lake Gogebic. On the north side they are found along the north shore of Lake Superior from Duluth to beyond Port Arthur. The succession of rocks is given in more detail in Figure 4, and is described in a later chapter.

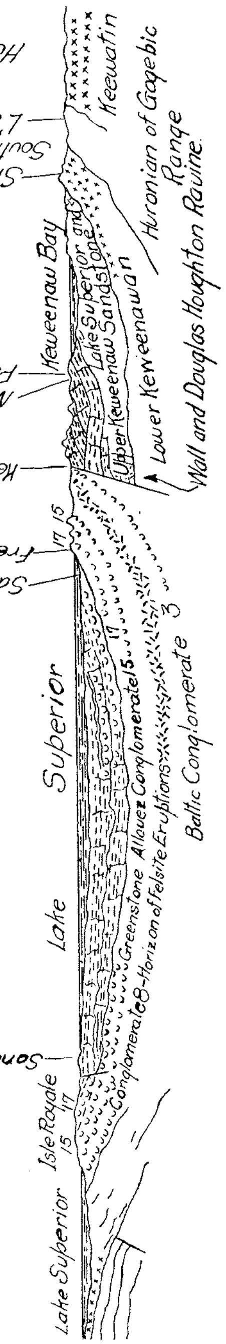

Fig. 3. Cross section through Lake Superior from the Huron Mountains to Port Arthur. After Mines and Minerals.

System	Series Name	Formation Name	Columnar Section	Thickness	Character of Rocks
Ordovician		St. Peter		0 to 75	*Sandstone;* white, waterbearing, in hollows of Calciferous dolomite, but absent often
		Calciferous		255 to 180	Buff and bluish dolomites often sandy, with dolomitic white sandstones.
	Neo-Cambrian Saratogan (Potsdam)	Lake Superior: Munising		200	*Sandstone;* white or light, waterbearing.
		Jacobsville Redstone Hiatus		0 to 1500+ (4000?) not drawn to	*Sandstone:* red and brown and striped with streaks of red clay shale, conglomeritic where it laps upon older formations. scale, the relation of the Freda to the Lake Superior Sandstone being uncertain, probably one formation.
	Upper Keweenawan, perhaps	Freda		(900+)?	*Sandstone:* red, with some felsitic and basic débris, and salt water.
Cambrian or Primordial	Mio-Cambrian	Nonesuch		350 to 600	*Shales:* dark, fissile beds, with dark basic fragments, and products of decomposition of lavas copper-bearing.
	Keweenawan	Copper Harbor: Outer		1000 to 3500	*Conglomerate:* very heavy red, with large rounded bowlders of all lower formations, including jaspilitic iron ores, agate amygdules, gabbro aplites, etc.
		Lake Shore		1800 to 400	*Traps:* basaltic lavas, and at least one—the "Middle"—conglomerate.
		Great		2200 to 340	*Conglomerate:* very heavy, like the outer conglomerate.
		Eagle River		2300 to 1417	*Group* of basic lava flows, with *frequent* beds of sediment, Marvine's (c).
	Lower Keweenawan, perhaps eo-Cambrian	Ashbed		1456 to 2400± (50 sediment)	*Group* of basic lavas of the "ashbed" type with scoriaceous sediment and only 50 feet or so of conglomerate. Locally felsites
		Central Mine		3823 to 25000 r (480 sediment)	*Group:* mainly of lavas of the augitic ophite type, with infrequent sediments. At the top is the "Mesnard epidote" and just beneath the heaviest flow, over 1,000 feet thick at times known as the Greenstone. Under this is the Allouez conglomerate. Marvine's No. 15. No. 13 is the Calumet and Hecla conglomerate or lode. The Kearsarge Lode is shortly above 9.
		Bohemian Range		? to 9500+ (500 sediment)	*Group:* mainly of basic lavas, but with intrusive and effusive felsites and coarse labradorite porphyrites; also intrusive diabase dikes and gabbro and gabbro aplites.
Huronian	Animikean neo-Huronian	Michigamme		1000 to 4000	*Slates:* black and graphitic, and graywacke slates, passing into graywacke arkoses, and quartzites; metamorphosed into staurolite, chiastolite, garnet, and other mica schists and phyllites.
		Bijiki		300 to 800	*Iron formation or schist:* slates with cherty carbonate and soft ore.
		Goodrich		0 to 400+	*Quartzite:* with conglomerate base, and above quartzite or red and green flags, also volcanic material.
	Mio-Huronian	Negaunee		1000±	*Iron formation:* cherty carbonates, altered to jaspilites, etc., with effusives and intrusives altering to hornblende schists and amphibolites.
		Siamo		600±	*Slates:* graywackes and arkoses and volcanics.
		Ajibik		700±	*Quartzite.*
	Eo-Huronian	Wewe		300±	*Slate:* black largely.
		Kona		600±	*Dolomite:* with siliceous cherty and slaty (schistose) bands.
		Mesnard		250±	*Quartzite:* conglomerate and arkose.
Keewatin		(Marinescan)		1000+	Greenstone schists, amphibolites, hornblende schists, sericite schists or crushed felsites, rarely ellipsoidal greenstones and slates and jaspilites, very largely cut by granites, the Laurentian, and numerous other classes of injections.

Fig. 4. Geological Column about Lake Superior. After Journal of Geology, and
Fig. 2. Report for 1908.

§ 3. THE KEWEENAW FAULT.

The center of this basin has been crowded out of place and lifted up. Slow contraction of the earth causing compression of the outer layer of the crust may have produced such a stress as to spring it up (Fig. 5a), or it may have been lifted up on the back of some vast sill of molten rock thrusting its way in beneath (Fig. 5b). Such a great inserted mass (batholite) of heavy rock (gabbro) forms the basal member of the Keweenawan series in Minnesota and in Michigan near the Bessemer poor farm[1] is a similar basal intrusive sheet of gabbro. The latter is not so well exposed as the one in Minnesota. The lines of fracture along which beds have been thus displaced are known as faults (F′F of

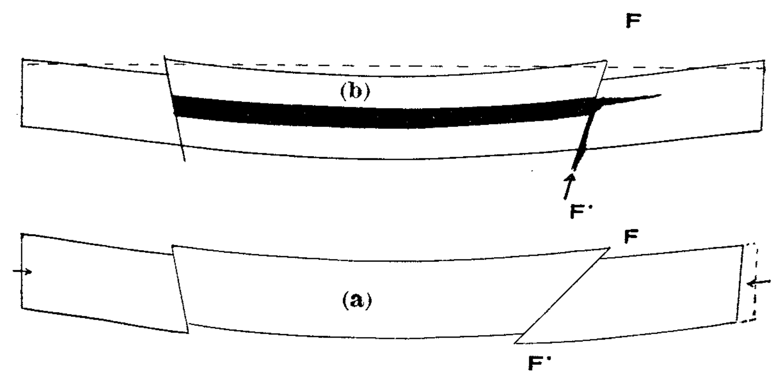

Fig. 5. Figures illustrating two possible explanations of the Keweenaw Fault, the lower (a) formation by compression; the upper (b) formation by the intrusion of a great gabbro sill.

Figure 5). Faults are not really straight although they are generally drawn as straight lines, nor are they always inclined at the same angle at every point. Though at times they are marked at the surface by a single narrow line which may be followed by a narrow seam of red clay, known to miners as fluccan, they are frequently characterized by a broad belt of shattered rock.

The great crack or fault in Michigan runs from Bete Gris Bay on Keweenaw Point southwestward past the north end of Lake Gogebic.

Thus going west from the Huron mountains we pass over flat lying sandstone (the Jacobsville sandstone) around the head of Keweenaw Bay, at Baraga, and near the Mass mill, which belongs above the copper bearing rock. Then we come to a great fault, on the northwest side of which the country is higher and the

[1]Annual report for 1906, p. 488.

rocks are uptilted so as to bring lower rocks, the copper bearing rocks, into view. These beds dip at first steeply, then more gradually northward to the lake. They are matched on the other side by similar beds on Isle Royale, which have steep dips with felsite at the north margin of the island as Keweenaw Point has on its south margin. The backbone of Isle Royale and that of Keweenaw Point is the same lava flow. The former is fringed on the south side by sandstone, while on Keweenaw Point sandstones occur near the various mill sites at Freda.

One reason for thinking that this great fault which bounds the copper range on the south is not merely due to intrusion, but in part to some long, slow action, like the shrinkage of the earth, is that there seems to have been motion along it for ages. Not so very far from it at Limestone mountain (in Sections 23 and 24, T. 51 N., R. 35 W., and again in Section 7 northeast) Paleozoic strata as late as the Niagara are caught and preserved in a fold in the Lake Superior sandstone, which along the line of the fault is disturbed from its normally nearly horizontal position. A picturesque instance of this is the Wall ravine not far north of Lake Linden, which, as well as the more noted Douglass Houghton ravine and falls, is north of and close to the electric line from Calumet to Lake Linden. A mile or two south of the College of Mines a number of ravines also show the fault, and the same region shows indications of faulting before as well as after the deposition of the Lake Superior sandstone, in the overlap of this sandstone upon the upturned copper range. Pebbles of lower beds of the Keweenawan series are also found in the higher conglomerates of the same formation, showing that the uplift began in Keweenawan time, and yet the fault line must have been a center of disturbance ages later.

Such a line of weakness when once formed naturally remains a line of weakness. Hobbs has shown that earthquakes follow the same lines of weakness again and again.

There is another way of looking at the faulting. The Keweenaw and previous formations show great overflows of molten rock from the earth's interior. The granite areas of the Huron mountains show great dikes of these lavas which have been thrust in and congealed. We therefore may easily see that if the lavas came from beneath Lake Superior there would be a tendency for the crust above to slump and perhaps for the sides to come together to fill the void thus left.

There are other main faults like the Keweenawan fault, notably one on the south side of the Porcupine mountain range, and others described by Lawson around Port Arthur.

§ 4. OTHER CRACKING.

With this uplift naturally came a good deal of other fracturing of the rock, splinter faults we might call them, and all this disturbance may have had a good deal to do with setting up and guiding the circulation of the waters that laid down the copper. Some people think that the copper was introduced into the formations at this time, but the writer thinks that it was only collected together into workable deposits.

The amount of uplift differs in various places and in some of them rather suddenly. While around the Calumet mine the beds dip 41 degrees or less, in the vicinity of Hancock and Houghton the dip is nearer 56 degrees, and a few miles farther south in the mines of the Copper Range Co. on the Baltic lode it is about 70 degrees. Numerous data on dip will be found in Chapter V.

There are many fractures running across the formation. The following figure shows a few of those along the Gogebic range, and how the range is by them broken up into blocks.

Further references to these fractures will be found on consulting the index. See, for instance, the fractures on the Wyoming and Manitou properties. Sometimes the beds are only slightly displaced and the fracture is marked merely by a seam in many instances filled with some white mineral like calcite or quartz. The pinkish sawdust-like laumontite, the lead colored copper ore, chalcocite (or glance), native copper, and brass colored copper arsenides like Mohawkite occur in the seams. Along some fractures the displacement is greater but in most instances it is only a short distance. Hardly a mine is without cross-fissures, yet it can not be said that in general the mines are richer next to them in the main Keweenaw range.

Usually, but not always, at a fissure running northward a bed running, or as it is called, striking east or northeast and dipping north under the lake is found to the right as one follows it across the fissure from west to northeast or east, as though the beds had on that side been thrown to the south or downward. This is well marked in the last two fissures of Figure 6. However, in following a bed across what seems on the surface to be such a fracture the bed may never be lost entirely but simply deflected suddenly from its course on entering a belt of much disturbed ground, filled with innumerable minor fractures coated with clay

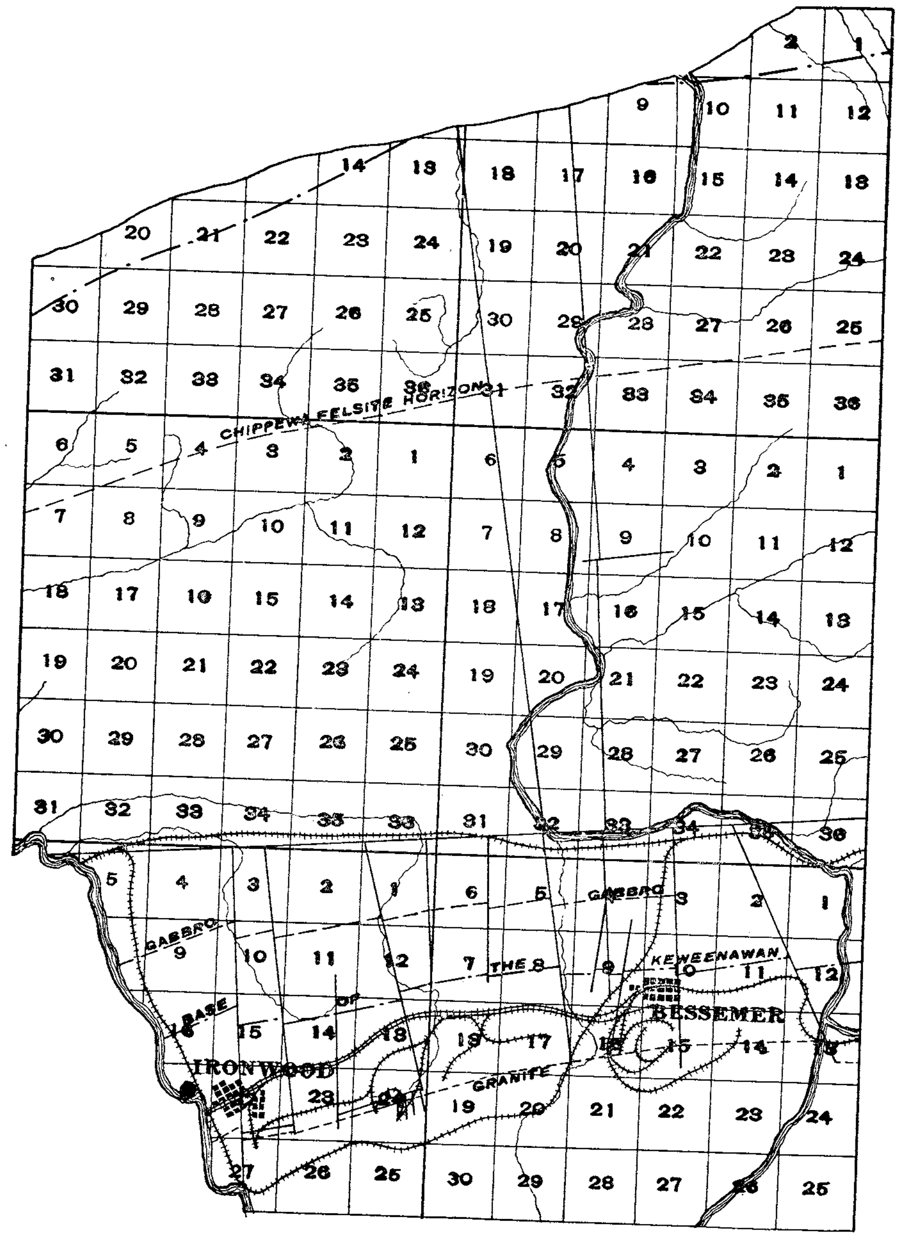

Fig. 6. Cross-fractures north of the Gogebic Range. (From Report for 1906, Fig. 24.)

called clay seams. Such a belt may be called a shear zone or kink in the formation (Fig. 11) as though some gigantic pair of shears had started to cut the formation apart and make a fault, but had stopped in the act.

Some of the beds of the copper bearing (Keweenawan) series are copper bearing for long distances,—so-called bedded lodes. The Kearsarge lode, so-called, is being mined from the La Salle, the south line of T. 56 N., R. 33 W., to the Ojibway, Section 14, T. 57 N., R. 32 W., that is 13 miles, and it is known to bear copper in paying quantities, at least in hand specimens, for twice this distance.

Now when such bedded lodes are crossed by fractures a change in their productiveness occurs. This will be gone into more fully in a chapter on the distribution of copper. Toward the end of Keweenaw Point, where the dips of the beds are relatively flat in the upper part of the formation, the cross-fissures were the first and most extensively mined and the bedded lodes are richer near them. Near Portage Lake the reverse seems quite as often true.

§ 5. SLIDES.

Fractures running across the formation are by no means the only ones which are present. If we bend up a pack of cards we notice a good deal of slipping of one card over the other. Unquestionably there has been much slipping of one bed over another in the uptilting or bending of the Keweenawan beds. Sometimes this is shown by a polishing of the two different beds adjacent to the contact line, "slicken-sliding" it is called. The polish is not perfect and the direction of motion is indicated by scratches. Sometimes one or both of the beds lying next to such a slide are shattered with small fractures or rubbed down to a red clay called flucan.

But probably more often than it is easy to prove these slides do not run at all times exactly with the beds but dip more steeply.[2]

All these fractures parallel to the strike of the beds are liable to be called slides as well as veins. If, however, we assume that when these faults are not parallel to the bedding they dip more steeply, such faults, if they do not produce repetition of the same

[2] A very well known illustration of the kind occurs in the Michigan mine (formerly Minesota with one *n*) in which the "North" vein which dipped 52° to 64° came down on a conglomerate which dipped about 44°, the two intersecting at the 40-fathom to 60-fathom levels, where the greatest masses of copper ever found were located, as described by Lawton in the report of the Commissioner of Mineral Statistics, 1880, p. 76. A mass weighing about 500 tons, 46 feet long, 18½ feet broad, 8½ feet thick, average breadth 12½ feet, average thickness 4 feet, was the largest.

bed, but strike out a part of the series, must be really slides, or as it is called "normal," as shown by the following figure (7).

By studying Figure 7 one can see that shafts or drill holes might miss the conglomerate entirely or seem to find the bed beneath abnormally thin owing to a downward displacement of the bulk of the strata (bed d-e). Now, as a matter of fact, in matching the records in various shafts, drill holes and cross-cuts it much more often seems as though something was gone, than as though some set of beds were repeated. For instance the well-known "slide" under the Greenstone often seems to have wiped out of existence the Allouez conglomerate. The Kearsarge conglomerate appeared at the bottom of the Central mine, but was wiped out in higher

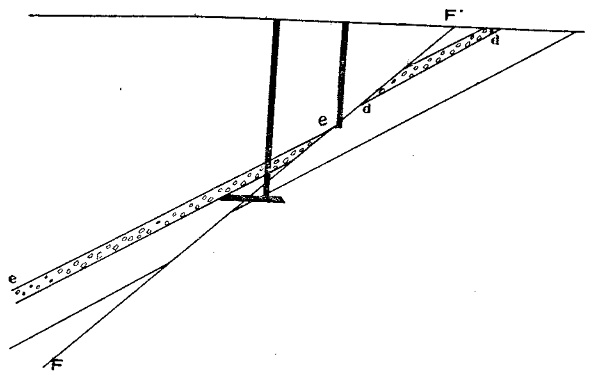

Fig. 7. Illustrating effect of normal slide faulting.

levels.[3] Another slide has in many places reduced the Wolverine sandstone to a mere remnant. It is easy to ascertain when a well-known conglomerate is gone, but not so easy to ascertain that a trap bed is merely reduced in thickness.

§ 6. CHARACTER OF THE BEDS.

The commonest copper bearing rocks are mainly old lava flows, and the usual type is much the same as any ordinary trap or basalt. The amount of silica in the trap rock is about 46 per cent, alumina 15 per cent, iron oxide 13 per cent, lime to 10 per cent, magnesia, say 7 per cent, soda 3 per cent, and not over 1 per cent or 2 per cent each of carbon dioxide, combined water, titanic oxide and potash. Other ingredients are present in only a small fraction of one per cent. The composition as a slag would then be not far from the following:

$$(CaO)\ (MgO)\ (Na_2O\ FeO)\ (FeAl)_2O_3,\ 4(SiO_2).$$

[3]See Lake Superior Mining Institute, 1895, Plate IV.

This would be nearly the composition of the mineral known as augite, but in such a rock there would be only 25 per cent to 30 per cent of augite, a little over half would be a lime soda feldspar and the balance would be magnetite or ilmenite, chrysolite (olivine) and chlorite, zeolites and other minerals usually called secondary. Such a rock, if so coarse that both feldspar and augite can be recognized, would be in Pirsson's and Chamberlain and Salisbury's field classification, a *gabbro*—if less coarse, so that while the constituent feldspar is plainly observable the dark mineral can not be made out (and good geologists have indeed often mistaken augite for hornblende in these rocks), a *dolerite*, while if finer yet it would be, if not porphyritic, a *basalt,* if porphyritic, a *melaphyre.* All these varieties *may* occur in one and the same lava flow, and it is convenient to have some term to apply to a lava flow as a whole regardless of its varying coarseness of grain. We might call these flows *traps,* but time-honored usage in Lake Superior discriminates the main massive part as *trap* from the originally porous upper part as *amygdaloid.* These are semi-popular terms.

The term *gabbro* is kept for the deeper-seated intrusions. Most of those rocks which are generally fairly uniformly coarse in grain are *gabbro.* All the effusives are wholly or partly of the melaphyre type. So we continue to use the term *melaphyre* for the dark colored lavas generally, and call the coarser streaks *doleritic melaphyre,* instead of *dolerite.*

Since many writers confine the term basalt to younger, more vitreous rocks and very many apply it to porphyritic rocks, and since this term has not been much used in connection with these Keweenawan rocks, the term melaphyre being used by Pumpelly, Irving and most writers, we shall not introduce it here, but continue to speak of melaphyre, feldspathic melaphyre, and luster mottled melaphyre, or ophite. The chemical character of these rocks is the subject of a separate chapter and has recently been quite fully discussed by A. Winchell. Variations in composition arise in these rocks from increase in silica or soda and decrease in lime when compared with the prevailing types. In either case the rock is liable to be relatively finer grained considering its thickness. As the soda increases and the lime diminishes we find a strong tendency for the feldspar to have crystallized out earlier and occur clotted together (or glomeroporphyritic) in lighter angular light greenish or reddish forms on the porcelain-like mass of the rock. Such crystals are called porphyritic crystals (phenocrysts). Large porphyritic crystals are characteristic of certain beds, the foot of the Kearsarge lode, for instance, and the Ashbed melaphyres.

As the silica increases there is a strong tendency to flesh, red, and light colors, and the occurrence of phenocrysts of white feldspar, or of quartz either round or nearly square. If the quartz particles are inconspicuous the rock is called felsite, if conspicuous quartz porphyry, or as has been suggested quartzophyre.

These traps are mainly surface lava flows or sheets, like those that fill the Snake River Valley in the west, and cap so many mesas, and line the flasks of volcanoes like Vesuvius, Etna and Kilañea.

The top of each flow is naturally more likely to be open in texture, full of bubbles, and thus more porous and easily crushed. Such tops are known as amygdaloids, and they are sought by the explorer, for in the filling of their pores the copper may be concentrated. A real amygdaloid top to an independent lava flow is likely to be fairly persistent and has numerous round walled cavities often filled with some white mineral. Its top is commonly pretty well marked while its base fades out gradually into the underlying not bubbly compact part of the flow which is distinguished as "trap."

But just as modern lavas or streams of slag are liable to gush over and envelope cooled crusts, or crystallize and leave cavities like those lined with melilite crystals in the pots of slag from the copper cupola furnaces, so was it with these old lavas. Amygdaloidal streaks often run down into the trap, and amygdaloid spots, bombs, or inclusions, characteristic under the Wolverine sandstone, are often found in the solid trap, and coarsely and openly crystallized "doleritic"[4] streaks are also found especially in very thick flows, and between the crystals, calcite, etc., may form giving these streaks also a spotted and amygdaloidal appearance.

The trap under the amygdaloid, the foot wall trap, is liable to be relatively lighter and more feldspathic, feldspar being the lighter mineral. The feldspar is generally oligoclase or labradorite, and appears as rice-like grains if the rock is coarse enough. The darker interstitial matter is mainly augite or its alteration product, chlorite. The olivine is easiest recognized when it is more or less changed to a reddish micaceous mineral. The magnetite is not conspicuous in the hand specimen, but is easily attracted from the powder by a magnet. The hanging wall trap is generally darker and more augitic.

[4]Vol. VI., Part I., Pl. 6, Fig. 3 and p. 167. I think the feldspar crystallizes better in the presence of steam, and that these doleritic streaks are where the lava had more water vapor.

If the rock is very feldspathic and the feldspar is oligoclase there is a strong tendency for the feldspar to crystallize out early, either in sharp crystals or in groups of crystals which, where somewhat decomposed, are quite easily mistaken, especially in the uncertain light of the mine, for the white filled amygdules. Such traps are particularly conspicuous above the "Greenstone" at about the horizon of the Ashbed.

At other times as we have said large crystals of labradorite feldspar are characteristic of a flow. This is true of the big trap whose amygdaloid top is the Kearsarge amygdaloid. When the flows are very feldspathic or siliceous the grain tends to be fine, the fracture conchoidal, the ring clear. When the flows are very augitic the feldspar laths are imbedded in the augite and the olivine and magnetite are crowded between the augite patches. These augite grains increase in size from the base of the flow toward the center. The increase is not absolutely regular and depends on the composition and other circumstances as well, but very commonly the diameter is 2 to 3 ten-thousandths of the distance from the margin.[5] These rocks Pumpelly very graphically called luster mottled melaphyres, since a freshly broken piece held in the light shows lustrous mottlings here and there from the cleavage faces of the augite, which appear as patches interrupted by the enclosed feldspar. The fracture of such rocks is rough and hackly or bubbly, not smooth and conchoidal like porcelain or glass.

On a weather beaten surface the augite centers seem more resistant than the interstices which give the pock-marked appearance that caused the rock to be called in Foster and Whitney's time, Varioloid greenstone.[6] This occurs in *various* beds, but shows up beautifully in the great ridge locally known as the "Greenstone" on Isle Royale (Plate I),[7] at Monument Rock, and elsewhere, and on the crest of the ridge that rises above the Cliff, Phœnix, Central and other old mines of Keweenaw Point. I owe to Mr. W. J. Penhallegon a number of good views. (Plate II.) This rock may finally break down to a coarse gravel, the size of the particles of which is determined by the fact that many of the fragments are single augite crystals or a good part of them.

The same structure comes out, though very faintly, in color patterns, even on rather fresh specimens, in faint shades of purplish

[5]Two to three mm. in 10 meters or yards, or at the rate of 1 inch diameter between 250 and 400 feet from the margin.
[6]House Ex. Doc. No. 69, 31st Congress, 1st Session, 1850, p. 64.
[7]Pl. VII, of Vol. VI, Pt. 1, see also Pl. VIII.

brown and green. With a little more weathering, the same structure may be brought out in shades of yellow and brown, especially on the smooth "joint" planes by which the rock is often riven. On smooth, but not polished, surfaces such as beach pebbles or diamond drill cores, the pattern is brought out better than on polished surfaces. The structure is of course obvious in thin sections. Many of these patterns resemble the mottling of a reptile's (ophidian's) back, as shown by Plate IV, and for this reason many French writers have called this texture ophitic and rocks which exhibit it, ophites, a term which I have adopted for our luster mottled melaphyre.

In intrusives the gases do not escape and the crystallization of the feldspar is promoted and the termination thereof delayed, so that it is much coarser relative to the augite and at the same time less sharply embedded in an augite matrix. In addition to the lavas are sediments which are derived from them. On Keweenaw Point there is almost no material that may not be derived from the series itself, and much of it is, as Marvine has pointed out, extremely local. But the Keweenawan conglomerates contain many pebbles of Pre-Cambrian granites and greenstones, and the Keweenawan north of the Gogebic range also contains pebbles of the iron bearing formations to the south.

The sediments are generally red, maroon or purple and they vary from very coarse conglomerates with huge pebbles many inches in diameter to fine red mudstones. These latter often show beautiful sand ripples and mud cracks, and sometimes have curious markings suggestive of soft worm tracks (See Plate V).

The shales and fine grained rocks are rarely black. The most conspicuous case of this is the Nonesuch shale horizon which will be described later. But a few other cases occur, for instance, a bed in the Rockland district (21, Adventure section, chapter 5, § 25). Such black shales, however, seem not to be bituminous, but to owe their black color to the fact that they are made up so largely of dark particles of the trap-like serpentine. This is shown in an analysis by Dr. Gysander of the Cochrane Chemical Co., made with extra care for us. (See table of analyses, Chapter II, § 16.) It will be seen that there is practically no chance for carbon, but that the black color is due to a composition which may be accounted for by the addition of ground-up trap from which the lime has been abstracted. It is practically a black sand like those along Lake Superior. The presence of palladium, a rare and valuable mineral of the platinum group, such as are found in the Oregon black sands, is very sugges-

tive. The sample was taken from a drill core as far as possible from any known vein or lode though to be sure in the course of drilling up the Nonesuch. A corresponding variety occurs among the conglomerates, those that I am now calling *amygdaloid conglomerates* because they have many amygdaloid pebbles in them. I have also called them *scoriaceous conglomerates,* but the former name reminds one of the fact that they look a good deal like amygdaloid and at the base run into scoriaceous amygdaloid. They have been called *ashbeds.* But the real volcanic ashbeds. like the Mesnard "epidote,"[8] are puzzling fine grained beds. *Clinker beds* would be a better term for these rocks. Moreover, in genuine volcanic bombs and scoria there is a variation in texture from the margin to the center. This is sometimes the case in these conglomerates but not always. We need a term to include all those beds which are characterized by a red shaly cement, matrix or base in which are pebbles of the traps. The red sandy and shaly matter also works into the loose clinkery top of the lava and makes scoriaceous amygdaloid, and it is often impossible to tell where the base of one of these amygdaloid conglomerates is, especially in drill cores. In fact this red shaly or sandy sediment may work far down into the old lava beds or traps, following the cracks that formed as it cooled, and to such little red sediment-like veins I have applied Wadsworth's name of *clasolite.*[9] Clasolites are generally red or gray or epidote yellow-green, and to all intents and purposes the same as the matrix or filling in the amygdaloid conglomerates. Such shales may also be caught up by the lava in its flow.

A conglomerate may change from a conglomerate of red felsite pebbles to an amygdaloid conglomerate in a very short distance. The Calumet and Hecla conglomerate, only a few miles south of the Franklin Junior, as Hubbard showed, and even nearer, is an amygdaloid conglomerate. One feature of all of the conglomerates, especially the smaller and lower beds is worthy of attention. Not only is the material largely derived locally from the formation itself, but it is only slightly rounded. This is notably the case in the Calumet and Hecla conglomerate itself which has accordingly been described as a *breccia,*—a term which it is convenient to reserve rather for angular aggregates made by the breaking up of the beds by disturbances.

This angular character of the pebbles is naturally to be accounted for by the fact that they seem in many cases to have been

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[8]Which do occur, through Irving did not happen to strike one (U. S. Geological Survey Monog. V, p. 32). They are not thick or conspicuous so far as I know.
[9]Which may be briefly defined as clastic vein.

transported only a short distance. For instance, the quartz porphyry pebbles of Calumet seem to have come from a quartz porphyry only three miles away. Such facts would be explained naturally by supposing that the conglomerates are land formations, and in fact red colors are supposed to be often a characteristic of land formations. A deposit of red desert sand, wind blown or washed in by occasional floods, would be altogether natural on the tops of old clinkery lava flows, and it is easy to see how such amygdaloid conglomerates would form.. In many of these amygdaloid conglomerates, there is a sharp break in character between the very fine sandy matrix (which looks much like the dust and sand I collected on mesas out west), and the pebbles or scoria which on the whole can be easiest explained in some such way.

Another fact that would suggest that some of these conglomerates were formed on a land surface rather than as marine deposits is the fact that thin beds are found to be persistent above and below lava beds that vary enormously in thickness. An illustration of this is the two conglomerates (Marvine's 15 and 16), one just below the other, not far above the "Greenstone," which thickens from less than a hundred feet near Portage Lake to probably over a thousand out on Keweenaw Point. The distance between the two conglomerates, 15 and 16, each of which is supposed to be continuous, increases in the same way. The most natural explanation supposes that the two conglomerates were old land surface formations, though this is not the only explanation.

That the felsites should weather into a mass of angular fragments, a cross between a conglomerate and a breccia, is entirely in accordance with their usual habit of weathering.

The writer is therefore now inclined to consider the Keweenawan as more largely a land surface formation than he did in writing his paper on Mine Waters for the Lake Superior Mining Institute in 1908. In this his views have been modified by discussion with Huntington, Barrell and Leith, quite as much as by his own widening experience. This does not by any means imply that many of the conglomerates were not laid down in standing water and others by running water, for they certainly were, but that one must be very cautious in assuming that they were laid down in sea water, though they may have been laid down in lakes.[10]

[10]See Fenner's discussion of the New Jersey Traps, Journ. of Geol. XV, No. 4, (1908) p. 299.

[11]Annual report for 1905.

(1908) p. 299.

§ 7. GENERAL SUCCESSION OF KEWEENAWAN ROCKS.

(1.) *Lowest rocks. Bohemian Range Group.* When work was begun on the Black River cross- section northward from near Bessemer on the Gogebic range, the writer expected that the traps of the South Copper range, which extend from the south end of Lake Gogebic to this place, would prove to be a repetition of some part of the main range coming down from Keweenaw Point and lying north of the Duluth, South Shore and Atlantic R. R..[11] This cannot be made out.

The traps from Bessemer to North Bessemer appear to be older than any beds exposed north. While there are many flows of ordinary character, there are also beds with very conspicuous porphyritic feldspar, something like those below the Kearsarge lode, but more slender. The trap itself is peculiarly blue-black and fine. Quartz and agate amygdules, sometimes of good size, are common. Elongate, so-called pipe, amygdules also occur. Intrusive diabase dikes, near the Bessemer poor farm an intrusive tongue of coarse gabbro, and near the top of the series a genuine feldspar porphyry capped by an angular conglomerate of felsitic breccia combine to give this part of the series a peculiar type. To be sure, high up in the series the Chippewa felsite and associated rocks of the Porcupine mountains have certain points of resemblance to these, but there are a number of dissimilarities such that I can not take them to be the same.

A somewhat similar series of beds also forming the base of the visible series has been carefully described by Dr. Hubbard from the Bare Hills and the mouth of the Montreal river and the south slopes of Mt. Houghton and Mt. Bohemia. The uppermost layer is what Hubbard calls the Mt. Bohemia conglomerate, and up to this horizon occur effusive and intrusive felsites. The Mt. Bohemia gabbro cuts nearly up to this horizon, and may be younger. We may call this the Bohemian Range group. North of Bessemer the thickness seems to be 9,500 feet, but there are probably not over 500 feet of sediment.

The presence of this group between Calumet and Portage Lake and farther south along the range has been an uncertain question. Hubbard made out a strong case for the identity of the Bohemia conglomerate and the so-called St. Louis conglomerate on Section 30, T. 56 N., R. 32 W., and Section 35, T. 57 N., R. 32 W., but that was as far as we have dared carry it with any assurance. The Torch Lake section given later has convinced me that the general

[11]Annual report for 1905.

horizon of the Bohemia conglomerate is that of Marvine's Conglomerate 8, exposed just back of the Arcadian and Isle Royale workings.[12]

Conglomerate 8, the top of this group, we assume, passes a few hundred feet below the Arcadian, Isle Royale and Winona lodes, which appear to be practically identical and may be the same as the first conglomerate south of the bluffs at the Lake, Mass, and Adventure bluffs (*not* the Minnesota *then*). The 2,500 feet of beds between it and the Baltic conglomerate near Portage Lake contain not less than four well-marked red conglomerates, while the traps toward the base are good heavy beds (ophites) 100, and in the case of the Mabb ophite over 200, feet thick, with clinkery amygdaloid tops, very hard to distinguish from amygdaloid conglomerates, especially if at all disturbed. Marvine in Volume I of these reports numbered the conglomerates around Portage Lake. The four conglomerates just mentioned are his 8 to 5. For further details see especially Sections 5, 14 and 16 of Chapter V.

(2.) *Central (Mine) Group.* This group is as well exposed in the Central mine as anywhere else and in the diamond drill section thence south (q. v.). The Clark, Empire, Mandan, Manitou, Central, Phoenix, Cliff, Calumet and Hecla, Torch Lake, La Salle, Franklin Junior, Arcadian, Isle Royale Consolidated, and Winona sections (q. v.) all develop this series. The various exposures in Houghton village from the College of Mines to Hurontown creek beyond the Copper Range station, show the beds. This is a new name I have introduced, naming it after the Central mine, with the thought also in mind that it really covers physically the center and backbone of the Keweenaw Ranges. I placed the lower limit at the top of the Bohemia conglomerate, and the upper limit at the St. Mary's "epidote," a small genuine volcanic ashbed which often looks jaspery and occurs just above the Greenstones.

Thus limited this group is characterized by few and thin conglomerates,[13] but numerous, and at times very thick, lava flows of uniform composition, on the whole not far from that of the standard ophite.

[12]The arguments will be given later. Briefly, the strong group of Conglomerates 8 to 5 are not represented between a narrow felsitic band which almost surely represents the St. Louis conglomerate and Mount Houghton felsite horizon, and the dips of the Torch Lake and Douglass Houghton section are flat enough to swing these conglomerates into line. In that case the Isle Royale Consolidated section would show (721 + 1753) (2473) feet of this group at Houghton down to the Baltic conglomerate and including the Baltic lode, the base of the series not being reached. Unless there is repetition by faulting the workings of the Lake and North Lake and similar developments would also be in this group.

[13]5.65% of 8,500 feet at the Arcadian, 6.65% of 6,247 feet on Isle Royale (400 to 500 feet of sediment).

On Black River the thickness of the group is possbly 25,000 feet, at Portage Lake (90 + 2835 + 3015—27) 5913 feet, out on the Point about 7,000 feet, on Isle Royale (6115—2045) 4070 feet.

Of Marvine's numbered conglomerates, 15 to 9 occur in the Central mine group.

The Allouez or Albany and Boston conglomerate just under the Greenstone is 15, and is not far above the Medora lode.

The Houghton is often a triple amygdaloid conglomerate and is No. 14. The so-called Montreal lode is near it.

The Calumet conglomerate is the lucky 13.

The Kearsarge conglomerate is a heavy conglomerate around Calumet and appears to cover Marvine's 12, 11 and 10, but seems to split back of Houghton.

The Wolverine sandstone is generally, but not always, a deep red sandstone and is No. 9. It is only a short distance below the Kearsarge lode, separated from it by a trap bed showing large porphyritic feldspars, and a long way above the Isle Royale lode. For details of distances between these beds reference must be made to the detailed sections and correlation tables.

The culmination of volcanic activity is in this group. The thickest individual flow is probably the Greenstone which in the Manitou section is 1130 feet thick, but for a continuous succession of flows with no important sediment the three thousand foot interval between Conglomerate 9 and the bottom seems to hold the record.

The general course of this group and its conglomerates is made easier to grasp by Figure 8. This is an outline of Plate VIII.

(3.) *Ashbed Group.* This group was named from the Ashbed mine, and old mine which has not been worked since 1900, whose property covers a strip from the Lake Shore to the center of Section 23, T. 58 N., R. 31 W. The mine itself was so named presumably from an intention to exploit one of the amygdaloid conglomerates known by the miners as the Ashbed (Marvine's No. 17). It includes Conglomerates 16 to 18, and is characterized by lavas which contain more soda than the regular ophites and which are relatively feldspathic and fine grained.

The feldspars in these lavas appear white or green on a green or reddish ground, and are often clotted together (glomeroporphyric). As we go toward the Porcupine mountains a genuine red felsite appears in a thin horizon between Winona and Rockland. I think it extends uninterruptedly to beyond the Black River section, and forms the main mass of the Porcupine mountains. This region seems to have been the center of its dispersal. Intrusive

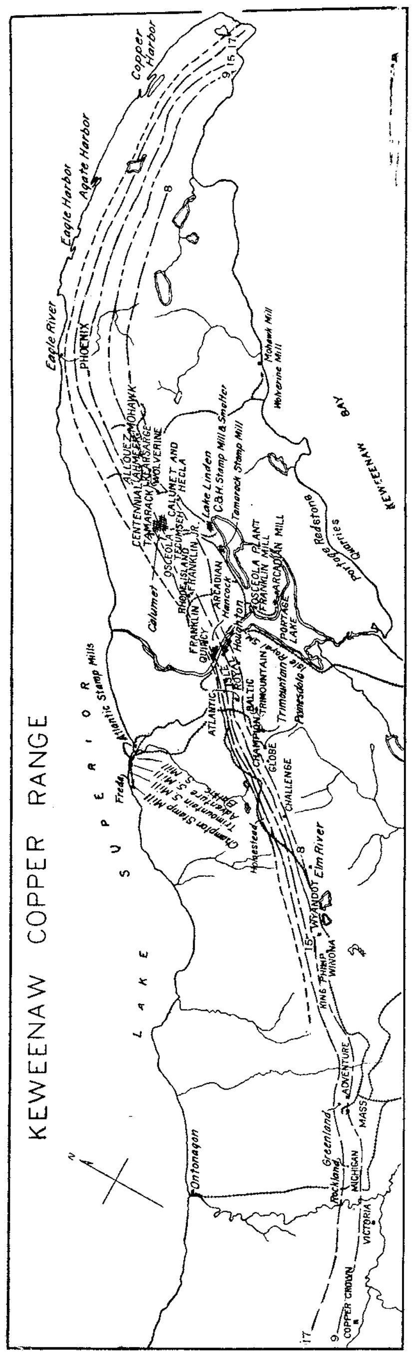

Fig. 8. Outline Map of the Keweenaw Copper Range. After Mines and Minerals, 1906, p. 205.

felsites are found in the Porcupines and between them and Lake Gogebic. The Tamarack shafts are sunk in this group. It is 2400 feet thick there, but on Isle Royale (2045—806) only 1239 feet thick.

I am tempted to regard the Mesnard epidote, which is a volcanic ash, as a correlate to this felsite. At any rate, associated with it are some conspicuous porphyritic beds of darker color, which may represent the other beds of the Ashbed group. If one considers that this horizon can be fairly well followed throughout Michigan, even across Lake Superior to Isle Royale, one is justified in expecting it elsewhere, for instance, in the Temperance River group of Minnesota.

(4.) *Eagle River Group.* This group is characterized by waning volcanic activity. It contains numerous sandstones and conglomerates, and on the whole they are more rounded in this group than in others. The individual lava flows are generally not thick nor coarse grained.

In this 2300 feet Marvine estimates 860 feet of sediment. Around Calumet 1700 feet may be assigned to it and on the Black River north of Bessemer 1417 feet.

Tamarack shaft No. 5 reaches downward to a point a little above the top of the Ashbed group, while shaft No. 2 starts at a point nearly down to the Kearsarge amydaloid giving a section from 3640 feet above the Calumet and Hecla to 1420 feet below (5060 feet), as illustrated by Figure 9. See also the cross-sections in Volume V, Part 1, and elsewhere given in this report. (Figs. 36 and 37.)

The conglomerates which occur around Copper Harbor were treated and mapped together by Douglass Houghton who considered the intervening Lake Shore Traps to be intrusive dikes. When these were found to be continuous interbedded flows the conglomerate above the traps was called the Outer conglomerate, the one below, the Great conglomerate. Hubbard showed that there is at least one conglomerate separated from the Outer by trap above it and from the Great conglomerate by trap below. This he called the Middle conglomerate. But we do not know that these traps which break up the mass of conglomerate and represent the last phase of volcanic activity in the Lake Superior region are everywhere persistent,—in fact north of Calumet they almost disappear and they have not been found in the vicinity of Houghton. So there seems to be a real need for a name for the group as a whole and after consultation with a number of fellow workers "Copper

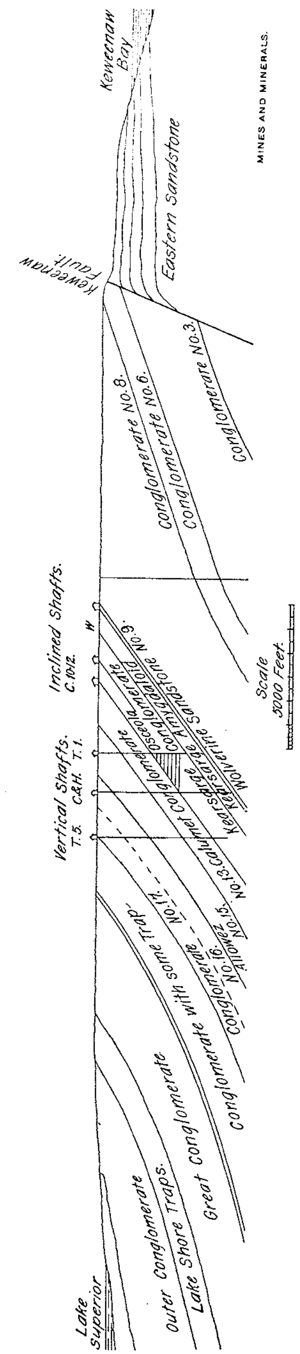

Fig. 9. Outline cross section near Calumet. After diagram prepared for Mines and Minerals, 1906, p. 204.

Harbor conglomerates" seems to be best. When they are separated by the Lake Shore traps into two or three parts one can still apply the adjectives Great, Middle and Outer, and indeed need not always give them the full title. For "Great Copper Harbor conglomerate" or "Middle Copper Harbor conglomerate," one may still say "Great conglomerate" or "Middle conglomerate" when the meaning is clear.

The disadvantage in thus grouping the conglomerates is that Irving made the line between Upper and Lower Keweenaw at the highest and youngest known[14] igneous rocks, the top of the Lake Shore Traps. Thus the Outer Copper Harbor conglomerate is the base of the Upper Keweenawan.

(5.) *The Great Copper Harbor Conglomerate* is a coarse heavy conglomerate at base, with large generally well rounded pebbles of great variety, mainly Keweenawan. Its thickness, not allowing for initial dips, varies from 1800 to 2200 feet at Eagle River and Calumet to possibly 340 feet (?) on Black river, but apparently it is much thicker in the Porcupines.

The top of this group under the Lake Shore trap in the Porcupine mountains is a hardened red mud which is highly charged with epidote and calcite and occasionally with copper. Throughout the formation there are, above the base, alternating streaks of more or less coarse red sandstone and mud rock (red shale) and true conglomerate. Conglomerate is generally the most conspicuous.

(6.) *The Lake Shore traps* are a series of flows, none very thick, the total thickness varying from 1800 feet at the end of Keweenaw Point to 900 feet at Calumet and 400 feet on Black river. They are apparently absent around Portage Lake.[15] They represent the last volcanic outbreak in the Lake Superior region. The Lake Shore traps are melaphyres without any very distinguishing trait. The amygdules are generally rather coarse.

(7.) *In the Outer Copper harbor conglomerate* on Black river may be found pebbles representing all the Lower Keweenawan types including intrusives, amygdules and agates, and also Huronian iron bearing jaspilites and other rocks. A thickness of only 1000 feet is given for the Outer conglomerate on Keweenaw Point. Gordon makes the thickness 5000 feet on Black river, Irving 3000 feet in the Porcupines.

The upper quarter is largely sandstone, the lower quarter largely conglomerate. The Nonesuch lode is *really* in this formation just

[14]The one occurrence, reported by Irving, of a dike cutting the Upper Keweenawan near Lone Rock north of the Porcupines, proves not to be such.
[15]See Chapter V for discussion of relation to Middle conglomerate.

under the Nonesuch shale, being a rather striking conglomerate, the general body a coarse greenish sandstone or fine conglomerate in which are bright brick red pieces of red rock (gabbro aplite). The analysis of the Point Houghton sandstone would probably fairly represent its composition.

The presence in these Copper Harbor Conglomerates of numerous pebbles which, if correctly identified, are of rocks intruded into the Keweenawan at some depth, and of agates, etc., formed in them tends to show that the earlier part of the series must have been considerably eroded, being either uplifted or forming from the very first a land formation exposed to erosion. As erosion continued the knobs of felsite, the harder quartzose red rocks, seem to have been worn down the material becoming finer with more of the dark basic lavas in the sediment.

(8.) *Nonesuch Shales.* The Nonesuch shales are quite uniform and persistent in thickness, appearance and distribution. Their thickness is 350-400 feet on the Montreal, 500 feet at Black river, 600 feet in the Porcupines, and somewhat the same near Rockland. Thence north their occurrence is not so well known, but they appear to pass Portage Lake on the powder company's lands, Section 28, T. 55 N., R. 34 W.

The shales are black, fine grained, micaceous, sometimes greenish, and grade into greenish flags or grits and sandstones. Some of the sandstones have bands of iron ores which completely cover the cleavage faces. The black color is, therefore, due to iron and chlorite and not to organic matter as the analysis proves. It has no more iron than the red sandstones, but the iron is combined with alumina, magnesia and silica, into green minerals like those which occur in the altered conglomerates and amygdaloids. The Nonesuch must have been formed under such conditions that the iron oxides did not readily rust and oxidize. It preserves, beautifully, ripple marks and mud cracks, and seems also to contain traces of crawling animals or sea weed. (Pl. V.)

(9.) *Freda Sandstones.* Above the darker shales and grits of the Nonesuch, red beds appear again,—generally a red, impure sandstone, sometimes conglomeratic and sometimes red shale, in general much like the Outer and Great conglomerate, except that the conglomerate becomes less and less abundant. The higher beds were well exposed near the new stamp mills at Freda and all along the adjacent shore. A drilled well at Freda showed a thickness of not less than 900 feet. They can not be less than 1000 feet thick there though the dip is much flatter than the beds above, more like 10 degrees to 30 degrees from 4000 feet to 12,000. Irving estimated 12,000 feet of thickness in the Montreal section. I strongly suspect a repetition by faulting there, but even if this is so there can be hardly less than 4000 feet.

The relation of these sandstones to the Jacobsville sandstone, and the Apostle Islands sandstones, which all agree to be Cambrian, is a moot point. I believe that the Freda sandstone correlates with the beds of Clinton Point, which Irving grouped with the Cambrian. A full discussion of the grounds for and against the Cambrian age of the Keweenawan must needs be technical, but the writer is inclined to class the Keweenawan as Cambrian, and this much at least of the argument anyone can appreciate, that between the formation of the Freda sandstones and that of the Upper Cambrian sandstones, which are similar to them, nothing is positively known to have happened,—no igneous activity for instance.*

§ 8. SOURCE OF THE COPPER.

Much thought has been spent upon the question of the source and distribution of the copper. After Pumpelly's masterly work on the copper bearing lodes,[16] and the summaries given by Irving and Wadsworth especially, little needed to be added for years. Additional facts have been accumulated, however, and with the growing importance of the western deposits, there has appeared a tendency to apply the same principles that have been used in explaining them to these and other similar deposits of native copper and ascribe the copper to solutions rising through fissures from beneath, charging the formation with its precious content. This view has been especially represented by Smyth and Van Hise. Those connected with the Michigan Survey have never accepted this view but have believed that the copper belonged to the Keweenawan formation itself, and had been segregated therein by wandering waters, which have been generally thought of as working downward.

This whole report is an assemblage of facts bearing on this problem. A few points may be grouped here.

1. The dissemination of copper in small quantities throughout the formation. The average from several thousand feet of drilling at the Clark-Montreal was 0.02 per cent. Hardly a single amygdaloid fails to carry less than .02 per cent copper, and when the copper content reaches .50 per cent it is nearly an ore.

*See also U. S. Geol. Survey Monograph 52, pp. 413-419, and p. 379. In this Monograph doubt is thrown on the Cambrian age of the Apostle Islands sandstones, but my view as to their relation to the Freda is accepted.

[16]Volume I of these reports; Volume III of the Wisconsin reports.

2. The occurrence of native copper in similar formations of red rock associated with salt waters and lavas elsewhere,—notably the New Jersey Triassic, in the Bolivian Puca sandstone, in Nova Scotia, around Oberstein in the Nahe melaphyre region, and in Alaska.

3. The general absence of native copper outside the Keweenawan, in the Lake Superior region, but—

4. Native copper has been found in iron ores (generally thought to be formed by the action of downward working waters) in a few places.[17]

5. The water in the formation is of three kinds:

a. At and near the surface, soft and fresh with sodium in quantities more than sufficient to combine with the chlorine.

b. At some distance (generally 500 to 2,000 feet, before it attracts attention, unless especially sought), the chlorine is higher and the water is charged with common salt. The line between the two classes of waters is often quite sharp.

c. At great depths a strong solution of calcium chloride containing some copper.

6. The middle water (b) often contains more salt than it could possibly have were it a mixture of a and c.

7. The lines between the different kinds of waters are not regular, yet the lowest water probably always comes within two or three thousand feet.

8. The amygdaloids seem, other things being equal, to contain rather stronger (more saline) water than the conglomerates.

9. An unequally heated solution corresponding in composition to mine water (c) will precipitate copper on the same minerals, prehnite, datolite, etc., on which it occurs in the mines, as Fernekes has shown.

10. The traps contain combustible gases, as R. T. Chamberlin has shown.

11. Certain beds are abnormally high in copper for many miles.

12. Copper often replaces chlorite, and in the Calumet and Hecla pebbles chlorite replaces felsite, and the copper the chlorite.

13. Copper may even replace vein quartz.

14. Copper is formed generally after those minerals which are the products of alteration and contain lime, and before those secondary minerals which are the products of alteration and contain soda and potash.

15. Therefore at the time the copper formed the mine water might have lost lime but could not have lost sodium. The rock might have lost both.

[17]Report for 1903, p. 247.

16. The Calumet and Hecla lode averages less rich (very rich in spots) near the surface, attains its greatest richness at a certain depth, say about 2,000 feet, and then gradually decreases in richness.

17. The silver occurs more abundantly in the upper levels.

The conclusion to which these facts have forced me is that the copper was in the Keweenawan formation as a whole, before being introduced into the particular places where we find it, and that the deposits have gathered together[18] by migration of the particles known as ions in the chloride solution, just as in the formation of electrolytic copper in an electrolytic bath the copper goes toward the electro negative pole and the more electro positive or alkaline parts of the solution, and as in Fernekes' experiments, toward the hotter parts of the solution. That the copper should actually be precipitated as a metal, however, depends upon a delicate adjustment of the composition of the solution in which the affinities of iron for oxygen may play an important part. For the copper to be precipitated the solution had to be kept neutral or alkaline and reducing in the part where the precipitation took place. And in the accumulation of copper into workable deposits not merely the electrolytic migration of the copper in the solution but the currents and circulation of the solution of the water in the rock have to be considered. In producing this solution and guiding its circulation, the following factors have to be considered:

(1.) The water originally contained in the lava.

(2.) That which early filled it whether it was buried on land or beneath seas, which may have included condensed volcanic vapors containing copper chloride as in Stromboli, or in the evaporation of desert pools.

(3.) The absorption of water in the hydration of the rocks.

(4.) The absorption of water in the cooling of the formation (water in cooling shrinks more than rock).

(5.) Faults in the formation facilitating the intermingling of solutions of different compositions.

(6.) Erosion of the formation and concentration of the copper contained either in pools on the land surface or in the water which found its way down into the rocks, while the deposition of the Keweenawan as a land formation was going on.

(7.) The ordinary circulation of the water entering at the higher parts and emerging in springs.

[18]Been segregated.

Now, all of these may have had some influence. Most of them *must* have had some. It may well be that the next great discovery of copper will be one of a new type in which some factor so far apparently unimportant becomes the dominant one.

As to the importance of these various factors, however, a few words may be said, though reference must be made to the detailed work. Absorption of water seems to me of first importance in the accumulation of copper, round and round circulation of less. To suppose that the wide spread calcium chloride waters are always volcanic is to suppose that the earth is everywhere sweating,—a sweat salty with calcium chloride. But to this theory there are serious objections. It must remain unsafe then to say to just what extent various sources participated in formation of the mine waters. We may, however, look back to a time when the formation was filled with a water whose main acid was chlorine, but the base was not sodium. This is the practically important thing. Whether oceanic in origin or not these chloride waters are as universal as the oceanic when sufficient depth is attained, and though they vary in strength for the same depth, I have not yet been able to find signs that, other things being equal, there is more chlorine near certain fissures or in certain districts. The reverse of this, that there is sometimes less chlorine near fissures where the circulation has obviously been free, is true. This may be used as an argument against the introduction of the chlorine from without.*

In the accumulation of copper, and after soda may have replaced lime in the mine water, an early occurrence of salt water of the calcium chloride type does not appear especially favorable. In the upper levels, however, where the water is fresh and there has been a good deal of circulation, the copper may be all washed out.

The distribution of the copper in a lode may perhaps be likened to that of the matter on a slime table, bare at the center or top, heavy in spots and streaks in the middle, more uniformly but thinly scattered toward the lower and outward margin.

One thing is noteworthy in a number of cases—a tendency for the copper to accumulate under heavy impervious beds, extending perhaps in thin sheets up into the joints of the same,[19] but even more in stringers into the foot as described by Wadsworth. In such cases the heavy bed has evidently guided the circulation.

*These waters are discussed in the Lake Superior Monograph 52 on p. 544. "In deep underground waters there is essentially the same condition of stagnancy, and therefore we suggest progressive accumulation of soluble chlorine salts." But in spite of the stagnancy Van Hise and Leith see "no adequate reason for regarding these waters as fossil sea waters."

[19]Copper under the Lake Shore traps, under Nonesuch shales, under Greenstone, under Mabb ophite, etc.

§ 9. GASES.

Combustible gas has been found in mine waters, notably at Silver Islet, but also at the Calumet and Hecla. It was natural to attribute it to decaying timbers but that explanation seems no longer necessary since R. T. Chamberlin has found that most igneous rocks yield about 1 or 2 times their volume of combustible gas.[20] Such gas or the hydrocarbons or carbides, nitrides, and silico-chlorides (found by Brun to be normal constituents of lavas) from which they might be derived[21] are powerful reducing agents that might throw out the copper.

Thus Pumpelly's explanation that ferrous salts precipitated the copper though both possible and plausible, is not absolutely necessary. It may be original carbon which produced the calcite which is the mineral most intimately associated with copper. One may readily find crystals of Iceland spar ($CaCO_3$) intergrown with native copper whose virgin luster is thus beautifully preserved. Sometimes the crystal form of calcite (the "dog-tooth"—or other shape) is plated with copper and the growth of calcite continued. Now carbon dioxide is absent from the lower mine waters, though calcite is present in the rocks and a certain amount of carbon-dioxide gas may be abstracted from them. It is easy then to suppose that a slow oxidation of hydrocarbons and carbides originally in the beds has furnished the carbonate, which formed slowly since it is in large crystals, and reduced the copper. We are then not compelled to look to the waters beneath the earth for the source of the copper.

§ 10. ALTERATIONS AND MINERALS PRODUCED THEREBY.

Pile up a series of heavy massive beds (traps) and open porous spongy ones (amygdaloids) like a layer cake, and then tilt the pile and there can be but one result,—a slump and sliding of the upper beds and a crushing of the open porous beds as shown in Figure 10, until by a process of shattering, "brecciation" and filling up and cementation of the porous beds with new minerals, they are made of nearly the same specific gravity as the rest and strong enough to stand the pressure. This is what has happened to the amygdaloids. Even the most casual visitor will be able to see in the

[20]Including a sample from a deep core sent by us; "The Gases in Rocks," published by R. T. Chamberlin, pp. 20-24, 33, 34.

[21] Another possible react.on suggested in Chamberlin is: $6\ FeCl_2 + 3H_2O = 2\ Fe_2Cl + Fe_2O_3 + 3H_2$.

mine dumps and at the stamp mills the soft white cleavable calcite, the white or colorless glassy hard quartz, the yellowish green epidote, and the darker bluer greens of the chlorite (delessite) group, and serpentine. Prehnite, white with a faint greenish tinge, is a common associate of copper. Laumontite, reddish and readily crumbling, is not so favorable a sign of copper. Datolite, almost like porcelain, often with beautiful flesh, and other tinges, is one of the last minerals formed. Datolite is polished to form articles of jewelry as are also chlorastrolite, thomsonite and agate. The concentric banding of the agates, which generally are large amygdules, is cut across in making jewelry, while the chlorastrolite and thomsonite amygdules are polished round.

In general, laumontite, epidote, quartz and prehnite tend to

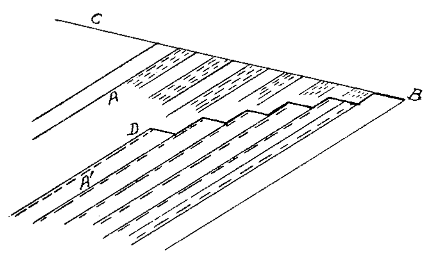

Fig. 10. Illustrates the effect of slump in a series of traps and amygdaloids, the amygdaloids being originally vesicular porous beds as thick as the traps but crushed to a fraction of their original thickness, in which process the line CB takes the position BD and the bed A sinks to A'.

antedate the copper, calcite and analcite are about coeval, while datolite and orthoclase are often later, but there is a good deal of overlapping. Sulphates like barite and selenite are rare and late comers and like the analcite and silver seem rather confined to the upper levels. I am inclined to think too, that the interesting sulphides and arsenides, the lead colored chalcocite, the tin-white chloanthite, the pale reddish nickeliferous Mohawkite, and Keweenawite, are also relatively superficial.

One of the striking factors in the development of stamp mill practice in the past 20 years is the introduction of the diagonal sorting tables of the Wilfley, Overstrom and Deister pattern, and a noticeable and beautiful feature in some of the mills is the production of bands of different colored minerals arranged on these tables according to specific gravity. Next to the copper red there may be a lead colored band of chalcocite present. The yellow-green band of epidote may next appear before we come to the

dull maroon iron rust colors of the red clays and ground up amygdaloid.

The amygdaloids sometimes have the original texture and round bubbles well preserved. Then again they are all brecciated, that is, broken up, the cementing material being calcite and epidote. Sometimes epidote and quartz replace the whole rock almost solidly. Again there is much chlorite. Where great sliding (actual motion) has taken place the rock is reduced to a greasy red clay called flucean which the miners used to wrap in a ball around their candles for candlesticks. It is much more greasy feeling than the red sand or dust that blew into or washed into cracks in the lava and made what we call clasolites.

§ 11. SHEAR ZONES AND SHOOTS.

If we bend a pile of paper and one part of the pile more than the other, we shall find between the parts thus bent a belt where

Fig. 11. Illustrates gaping beds, or pile of cards when unequally bent.

the paper tends to gape apart (Fig. 11.) So in the uneven tilting and slumping of the formation we find changes of dip and strike and at times belts of traps which have been much fissured and shattered, in which secondary action and at times copper formation has gone on, by no means confined to any one amygdaloid, though normally, movement and readjustment would naturally follow the weaker beds, the sandstones and amygdaloids. But if there is a diagonal stress, neither at right angles nor parallel to these beds, the resultant disturbance will follow the weaker beds for some distance, then jump across through a heavier trap bed, shattering it on the way, when the diagonal component of the stress, not satisfied by yielding along the beds, becomes too great. Thus a shear zone will be produced (Fig. 11), which would in many cases have a tendency to gap open and leave places to be filled by breccia and new deposits.

It is certain that some of the stresses to which the Keweenawan rocks have been subjected, have had a diagonal direction. We have noted a tendency of beds to be thrown to the right on the northeast which corresponds to the general eastward curve of the Point. As illustrated, the Quincy mine is not confined to one amygdaloid, and the Baltic lode appears to be in a shear zone,—the Lake perhaps also.

The Calumet and Hecla shoot is shown on Plate IX.

§ 12. SURFACE GEOLOGY AND DISTRIBUTION OF FLOAT COPPER.

After the close of the main up-tilting the copper range uplift may have continued in a lesser way since beds of the age of the Niagara Limestone are disturbed at Limestone mountain. There was later some depression, since about the time the hardwoods first became abundant a sandstone was formed in the Mesabi range[22] and the ocean may possibly have reached Michigan too, though no trace of such sediments have yet been found. Probably before this time the surface was reduced to a comparative level, such as the plateau from the the Quincy to the Calumet, and some time since the Cambrian sandstones mantled the range (possibly when emerging from the Cretaceous sea), rivers seem to have established their course across the range, marking out valleys such as those now occupied by the Ontonagon river, Fire Steel, Flint Steel, and Portage Lake. These valleys may have been cut deeply in the era of elevation preceding the recent ice age, which is marked by the formation of caves such as the Osborn cave at Fiborn and by the deep valleys in the rock surfaces, now filled with drift, whose soles are at times below sea level. At the same time the minor tributaries in their erosion brought out the rock structure, generally leaving the harder traps in ridges. When the ice age came on, the earlier center of collection and distribution seems to have been northwest of Lake Superior. It is called the Keewatin center. Later the ice moved from the east, from a center in Labrador called the Laurentian center, and reaching Lake Superior moved out from it. (Fig. 49.) Around Portage Lake the ice actually moved to 10 degrees north of west. This direction of ice motion is beautifully marked near the Calumet, Arcadian, Quincy, and Isle Royale mines. One can see the stoss and lee sides of the motion, the grooves and trails left by harder knobs. The ice front, which was naturally perpetually oscillating, and the direction of ice motion and transportation, streaming away from the center of distribution and finishing at right angles to the front, also shifted. Hence copper may be found either side of its parent ledge, but that at the surface which is most likely to be found was probably left by the last ice motion. Around Calumet and Portage Lake the ice moved from the direction of Keweenaw Bay, and farmers plowing their fields near Portage canal reap a harvest of copper nuggets which may have come from the Franklin and Quincy.

[22] Leith on the Mesabi Range, U. S. G. S., Monograph 43, p. 189.

From somewhere about the Winona mine on the south, however, the motion was from the other side. Where the motion was from the east and southeast over the eastern sandstones the surface overburden, or drift, is more sandy. The material which was ground off the range itself by the ice is a much stiffer red clay with stones in it. Great quantities of material were washed out of the ice front by water from the melting ice and deposited in sheets known as sand and gravel plains, irregular mixed masses and high hills known as kames, and long narrow hogbacks, known as eskers. Along lines where the ice front lingered some time the deposits are extra heavy and are called moraines.

Keweenaw Point and the Porcupine mountains were relatively early laid bare and made cusps or reentrant angles in the ice front. At one stage of retreat Centennial heights, north of Calumet formed a reentrant (Plate IX). Another hill of sand, Wheal Kate (1508 feet A. T.), towers south of the Mill Mine Junction and the village of South Range, and is easily recognized from the hills either side of Portage Lake. It is part of a heavy moraine which extends entirely around Keweenaw Bay and for miles south the drift is extra thick. Working through this coating which is often of light quicksand, makes explorations and mining difficult, and will retard mining development.

In front of the ice sheet the water was ponded and drained to the Mississippi. On the north side of the Porcupines the highest level of this water was 559 feet above Lake Superior. On the south side of the Porcupines it was higher, at least 34 feet above Lake Gogebic, or 720 above Lake Superior, or 1320 above tide. But around the Ontonagon Valley the beaches and benches at 565 feet above Lake Superior are much more strongly marked. The corresponding level rises as one goes out on the point, being at North Tamarack at least 640 feet above Lake Superior. Thence downward are beaches at numerous different levels formed at successively lower stages of the water. Down to 480 feet above Lake Superior (a strong beach, well-marked, where the electric road crosses it in climbing a hill near the Quincy mine), the beaches are referred to a Lake Duluth. Thence down to a little less than 100 feet above Lake Superior, the level of the strong terrace on which the College of Mines stands, the beaches are said to be of a Lake

Algonquin,[23] which covered all the upper lakes. It was drained at different periods by various outlets, a part of the time by the newly reopened Chicago outlet.

Strong beaches below the Algonquin, 30 to 60 feet above the lake,[24] are referred to a Lake Nipissing which had an outlet down the Ottawa. Possibly the bluffs and terrace on which the Freda stamp mills were placed were formed at this time. The Ottawa outlet has been raised by tilting of the land and there is reason to believe that this is still going on so that the Michigan shore is sinking as well as being cut back by Lake Superior. This is very evident along the lake shore in the Porcupine mountain region.

[23]Leverett, Twelfth report Michigan Academy of Science, 1910, Fig. 7. Fig. 2 shows Lake Duluth..

[24]Leverett, loc. cit. Fig. 8.

CHAPTER II.

NOMENCLATURE AND CHEMICAL RELATIONS OF THE KEWEENAWAN ROCKS.

§ 1. HISTORICAL REVIEW OF NAMES APPLIED TO IGNEOUS ROCKS OF THE KEWEENAW SERIES.

I wish to express especially my obligation to a paper by A. N. Winchell, published by permission of the Director of the U. S. Geological Survey[1] which I understood would represent the usage of the U. S. Geological Survey in their Lake Superior Monograph. Wherever I differ it will generally be found to continue the previous usage of the State Survey, and in this (my final report probably) it seems well not to change without the best reasons. Winchell has in view especially microscopic petrography, and his study of usage goes back therefore only to the microscopic studies of Streng (1877). Since I have in mind more the convenience of mining engineers and geologists in the field, I will go back a little farther, to give more completely the use of the terms.

Douglass Houghton in 1841 used the terms *Trapp* and *range,* and distinguished the *amygdaloid* from the compact *trap* or *greenstone,* which he defined as the compact granular variety made up of feldspar and hornblende, though he expressly stated[2] that under this term, augitic and other rocks were included. As a matter of fact, hornblende is rare in the Keweenawan rocks, and the mineral associated with the feldspar in the greenstone is generally chlorite and augite.

W. A. Burt and B. Hubbard used Houghton's terms, but since in working for the U. S. Linear Survey, under the contract with Douglass Houghton, they had come upon the Mt. Houghton and Porcupine Mountain felsite and quartz porphyries they called them *red trap* and *trap porphyry.* In the Jackson report[3] in which the

[1]Review of Nomenclature of Keweenawan Igneous Rocks, A. N. Winchell, Journal of Geology (Vol. XVI) 1908, No. 8, p. 765. See also U. S. G. S. Monograph 52, pp. 395-407.

[2]"Memoir of Douglass Houghton, first State Geologist of Michigan" by Alvah Bradish, 1889, p. 177.

[3]Report on the Geological and Mineralogical Survey of the Mineral Lands of the U. S. in the State of Michigan. Senate Docs., 1st sess. 31st Congress, 1849-50, No. 5, Pt. III, pp. 371-935.

work of Burt, Hubbard, Jackson, and Foster and Whitney and others is mingled, the main felsitic rock of the Porcupine mountain is called *jasper* and the more coarsely porphyritic rocks southeast around Bergland *quartzose porphyry*. Foster and Whitney continue to refer to the *Trap range*. The greenstone was still considered to contain hornblende. Where columnar jointed and very fine grained it was called *basalt;* when it contained distinctly disseminated feldspar crystals *porphyry* (*porphyrite* as I should call it), and the crystalline and feldspathic varieties (Mt. Bohemia gabbro and gabbro ophite) are called *sienite*. They also mention *compact trap* (ashbed or porphyrite?), *trap breccia* (amygdaloid conglomerate?), *porphyritic trap* (like the Kearsarge foot?) and *epidote trap*. In regard to the use of the term *jasper,* the *compact quartz* or *jasper* is understood to pass into the quartz porphyry.

In Volume II they discuss the terms *trap* and *greenstone*—stating that most of the igneous rocks embraced in the term *greenstone* are labradorite or oligoclase and pyroxene with chlorite and thus the term *diabase* is applied to them by continental geologists. Melaphyre they mention for the first time as "a fine grained compound of labradorite and ilmenite and (probably) pyroxene. Basalt is divided into

{ dolerite, crystalline aggregate of labradorite augite and ilmenite,
{ anamesite, a fine grained mixture of the same.

They recognized the presence of augite, though it was still put after the hornblende in importance and analyzed the Greenstone (note the capital G) from the summit of the cliff at the Cliff mine as given below.

In 1850, Fr. C. L. Koch,[4] one of the founders of Saginaw, an educated German mining engineer, visited the district and recognized (p. 201) the dark mineral as augite, and determined the trap to contain augite and labradorite with some magnetite at times and believe it to be properly called *trap* or, if the magnetite was conspicuous, *dolerite* and the finer forms as *anametite*. No progress was made on Koch for fifteen years. Rivot, professor in the Ecole des Mines, at Paris,[5] used the same terms, *trap, amygdaloid, greenstone,* and was rather inclined to believe the traps to be metamorphic sediments. A. Winchell, 1860-61, did no detailed work on the *Trappose rocks*. Thus the nomenclature of the first generation of geologists and miners still in use, to which I cling so far as

[4]Studien des Gött. Vereins Bergm. Freundé by Fr. C. L. Koch, Vol. VI. Parts 1 and 2 (1852).

[5]"Voyage au Lac Supérieur," by M. L.-E. Rivot, 1885 Annales des Mines Vol. VII, p. 173 et seq.

possible, may be said to be practically that of Douglass Houghton, Bela Hubbard and Foster and Whitney. Koch's work, published in German, was and is yet largely unknown.

The next work in considerable detail on the Keweenawan rocks was that of Thomas MacFarlane (who had just passed away) for the Canadian Survey in 1855.[6] He argued for the term *melaphyre* and also used *trap*. He speaks of the upper part of the melaphyre as being amygdaloid. He made numerous analyses. Some might object that his partial analyses were not accurate and that he overestimated the amount of chlorite. From the modern point of view his analyses are certainly incomplete, but they still have distinct value as showing what parts of the rock were attacked by acids, and have not been replaced. Even supposing that he overestimated the chlorite, the rocks which he calls *melaphyre* are exactly similar to those which around Oberstein and the region of the Nahe river in Germany have been called *melaphyre*.

Moreover, the use of the term melaphyre was continued. H. Credner, the eminent German geologist,[7] applied it to the rocks associated with the Calumet and Hecla conglomerate.

Pumpelly, with whom Credner worked, and Marvine,[8] adopted this term *melaphyre* (melaphyr) while they recognized that the chlorite is produced from hornblende or pyroxene. They distinguished the following varieties of melaphyre—an amygdaloid upper part, a central coarse grained part; fine grained with rubellan (altered olivine); and melaphyre porphyry. Marvine called the Greenstone with the big "G" *diorite,* appreciating its coarseness, but also confusing augite with hornblende? A. A. Julien,[9] described rocks from the iron country, and incidentally some Keweenawan dikes as Black *Dioryte aphanite* (355, 356). These same Keweenawan dikes, C. A. Wichmann[10] called *diabase* recognizing them as labradorite-augite rocks, but refusing to call them *dolerite* as Koch did, since he would limit that term to Tertiary rocks. He recognized the quartz diabase. His was the first application of the microscope to the examination of the rocks. Pumpelly in 1878 and 1880[11] continuing his work under the Wisconsin Survey, followed Rosenbusch's system and described many of the Eagle

[6]"Exploration géologique du Canada, Report des Operations de 1863 à 1866," Appendice relatif aux Roches et Gites Cuprifères du Lac du Portage, Michigan, par Thos. Macfarlane, pp. 153-169. Translated in Vol. I Geological Survey of Michigan, Pt. II, pp. 9-12.

[7]Néues Jahrbuch für Min., 1869, p. 3.

[8]Geology of Michigan Vol. I, Pt. II, Copper Bearing Rocks, pp. 12-13.

[9]Microscopic Examination of Eleven Rocks from Ashland Co., Wis., Geology of Wisconsin Vol. III, pp. 224-238.

[10]Geology of Wisconsin Vol. III, pp. 621-627.

[11]Geology of Wisconsin Vol. III, Pt. II, pp. 27-49. Lithology of the Keweenawan System.

river rocks, and suggested that the term melaphyre should be replaced by the term diabase, classing the rocks as follows:

I. Granular plagioclase-augite rocks: with olivine (chrysolitic) diabase.

II. Porphyritic plagioclase-augite, with more or less unindividualized base: porphyritic diabase or, with olivine, melaphyre.

III. Granular plagioclase-diallage rocks,—gabbro.

He noted that of one great flow that I call *ophite,*— the *Greenstone*—some specimens are diabase, some (as Bed 108) near the base, melaphyre, others as (Beds 95 and 107) of the Eagle river section, gabbro.

The luster mottled rocks he described as *melaphyres,* but did not recognize the altered olivine in the Ashbed type of trap. This is not to be wondered at, for it is rarely fresh and practically *never* in superficial specimens, which were all he had. Pumpelly also made a distinction between *amygdaloid* and *pseudo-amygdaloid,* the latter being a variety of a rock resembling the amygdaloid in its speckled appearance, but the result is one of alteration, not of filling of original bubble cavities.

Irving also contributed to Volume III and found in addition to *melaphyre* and *diabase, quartz* and *granitic porphyry* and *felsitic porphyry,* which he was inclined to suspect were fragmental (brecciated felsites). The *gabbro* of the Wisconsin Survey included a gabbro proper, olivine gabbro, uralitic gabbro and orthoclase bearing gabbro, the diabase, an ordinary prevalent fine grained type with one or two coarse grained varieties, the Ashbed diabase type, a pseudamygdaloidal and true amygdaloidal phase.

Mosler in 1877[12] followed the usage of Pumpelly. In his Monograph V of the U. S. Survey,[13] Irving still following Rosenbusch's usage, makes the following classes (p. 37):

Coarse,—gabbro and diabase, olivine gabbro and olivine diabase, all free from orthoclase; orthoclase gabbro, hornblende gabbro, anorthite.

Fine,—diabase of the ordinary type, olivinitic diabase and melaphyre, Ashbed diabase and diabase porphyrite amygdaloids.

The noteworthy difference shown in the work of the decade 1877-1887 as compared with the work from 1866-1877 is the more frequent application of the term *diabase* instead of *melaphyre.* Rominger, in Volume V of the Michigan reports, written in 1884,

[12]Der Kupper Bergbau am Obern See in Nord Amerika von Chr. Mosler, Berlin, 1877.
[13]"The Copper bearing Rocks of Lake Superior" by Roland Duer Irving, U. S. G. S. Monograph V.

though not published until 1895, drops the term *melaphyre* and speaks of *diabase* and *amygdaloid, quartz porphyry,* and *felsite.* Irving (loc. cit. p. 69) called nothing *melaphyre* unless there was residuary base (glass, calling them olivine gabbro, if coarse; *olivinitic diabase,* if fine.

Many rocks among the Ashbed diabases, that I would call olivinitic he does not so count, taking the altered porphyritic olivine to be altered augite perhaps. Herrick, Tight and Jones[14] followed Irving in referring to *diabases, diabase porphyrites* and *felsitc porphyry.* Wadsworth in 1779[15] classified the basaltic rocks as follows:

	Feldspar		Melaphyre	Tufa
		Basalt		
Basalt	Leucite		Diabase	
		Dolerite	Gabbro	Poroda
	Nephelite		Peridotite	

In 1880 he gave a characteristically thorough review of the literature of the Copper districts. He uses the term *melaphyre* very frequently as a variety of basalt, uses the term *rhyolite* for the more siliceous, *trachyte* for the less siliceous felsites. He uses the term *melaphyre* almost as Macfarlane and Marvine did. Its derivation and application is the same, though he defines it as an altered basalt, and uses it[16] somewhat under protest.

In 1887[17] he examined for the Minnesota Survey among others, many Keweenawan rocks. He mentions the term *ophite* as a variety of his basalts, which take the forms of gabbro, diabase, melaphyre or diorite, according to alteration. Characteristic of Wadsworth is the emphasis he laid upon secondary changes and the account which he took of them in his nomenclature. Many things, for instance micropegmatite, that I should consider primary, he (and Irving followed him), considered secondary. Yet I found as I worked with him for two or three years that we would agree in a great many cases in the application of names though disagree in our conclusions and definitions.

Yet I agree that melaphyre *may* be essentially altered basalt. His last formal work for the Michigan Survey was in 1893[18] where on

[14]Bull. of the Sci. Lab. of Denison University, Vol. II, Part 2 (Granville, 1887) pp. 120-142.
[15]Univ. Comp. Zool. Vol. V, p. 280.
[16]Proc. Boston Soc. N. H. Oct. 19, 1881, p. 259.
[17]Geological and Natural History Survey of Minnesota. Preliminary Description of the Peridotytes, Gabbros, Diabases and Andesytes of Minnesota, Bull. No. 2, M. E. Wadsworth.
[18]Report of the Board of Geological Survey.

page 90 he gives a classfication of rocks and on page 147 uses the term "clasolite" for a deposit of sediment in fissures. In 1897 he gave for the Lake Superior meeting of the American Institute of Mining Engineers a clear and interesting summary of his views on the "Origin and mode of occurrence of the Lake Superior Copper deposits," which was printed in their Transactions. (XXVII, 669.)

Bayley[19] in 1889-97 describes the Minnesota gabbros in some detail and also the Pigeon Point rocks. He found *non-feldspathic* varieties of *gabbro.*

Grant in 1893 and 1894, describes, for the Minnesota Survey, gabbro, diabase, granite and a marginal facies of gabbro. His *augite soda* granite is a *red rock* like Irving's augite syenite and granitells, or Bayley's soda augite granite.[20]

The work of Hubbard, Patton, and Lane began in Michigan in 1889-92. The first publication is in the 1892-3 report, though there the only Keweenawan rocks described under our own names were some diabases intrusive in the iron bearing rocks. We were fellow-students under Rosenbusch and have since worked in close relation. We have tried to use terms as they are used by earlier writers, and we have also tried to apply them so far as possible to the same things. It does not bother the practical man who has only incidental use for a geological report if a rock be called a *melaphyre,* whether stress is laid upon the fact that it is pre-Tertiary or effusive, or is older and contains chlorite and is altered, so long as the hanging wall of his lode is in each case called a *melaphyre.* We therefore continue to use the term *melaphyre* as applied to many of the Keweenaw traps.[21]

I did, however, begin to use one term which is not new, nor as I supposed new in the sense in which I used it, but is new in the district, viz. the term *ophite*[21] as a short equivalent for luster mottled melaphyre, applying it also to rocks which had the same texture as melaphyre, but on too fine a scale to give the luster mottling appearance, and I prepared for Volume VI, a table showing my usage.

To others of the traps, I applied geographic names in the Isle Royale report (p. 170) such as

Tobin porphyrite=Rosenbusch's navites?

Huginnin porphyrite=(a kind of diabase porphyrite).

[19] "Basic Massive Rocks of the Lake Superior Region" by W. S. Bayley, first three parts in Journal of Geology, Vol. I, Nos. 5, 6, and 7, fourth part in Journal of Geology, Vol. II, No. 8, and Vol. III, No. 1.

[20] Numerous papers listed in Bull. U. S. G. S., No. 188.

[21] Bull. Geol. Soc. Am. Vol. 8 (1896), p. 406 Vol. 10 (1899) p. 15. See also U. S. G. S. Monog. 52, p. 398; and Science Vol. XXXII, p. 513.

Minong Porphyrite=(akin to an augite andesite.)

I also prepared a field scheme.

Former Assistant State Geologist F. E. Wright, prepared for the Michigan College of Mines, a synopsis of Rosenbusch's classification of rocks which, though it was accompanied by no text, should nevertheless be considered, because so many of the mining men will have been by its use familiarized with its terms. The same statement also applies to the names used in Kemp's Handbook of Rocks and "Ore Deposits of the United States."

I have remained fairly faithful to the usage in Volume VI, prepared by Hubbard and myself. The only important modification from Rosenbusch's system introduced by me[22] was the attempt to confine the the two chemically synonymous terms, *diabase* and *melaphyre,* respectively to dike and effusive rocks, a proposition which Rosenbusch, though granting its desirability on theoretical grounds, has not accepted[22] for reasons which may be practically sound. A good deal depends on whether it really is practicable to separate the intrusive rocks from the coarser central parts of flows.

In 1903, appeared an important work[23] by a group of the leading American petrographers, which broke away entirely from previous names and made a host of new names, dependent on a complete chemical analysis, though there are methods given by which one may estimate from the chemical analysis the mineral composition of the rock, were it composed of certain standard minerals, and vice versa from the minerals actually present one may infer the probable place in the classification. The lines between the different subdivisions are arbitrarily drawn in the classifications and constituents like H_2O and CO_2 (which are liable to have been added in weathering, but are certainly in some rocks primary and are very significant genetically) are absolutely neglected; other constituents like ferrous and ferric iron, which are equally likely to be modified by weathering, are given much weight and some substances, which are hard for the chemist to determine accurately, are so important in the scheme that samples from the same rock mass apparently differing but little in composition will sometimes find pigeon-holes astonishingly far apart in the classification, without more difference in the analysis than may be due to analytical errors. Occasionally, therefore, there are rocks in the same group in the classification which have little or nothing

[22] Bull. G. S. A., 1893, p. 273, Michigan Geol. Sur., Vol. VI, Pt. 1, p. 220. See Mikroskopische Physiographie, fourth edition, Vol. II, pp. 1160-1161.

[23] "The Quantitative Classification of Igneous Rocks" by Cross, Iddings, Pirrson and Washington. (Hereinafter referred to as the "Big Four") Chicago University Press.

in common other than the bare chemical factors by which they are assigned to that group. All of this simply shows that the classification is not perfect. Few things are. The authors, however, suggest a series of names for field use which are convenient and very much like those which it has been customary to use.

§ 2. WINCHELL'S CORRELATION.

Winchell, with a labor for which I am very grateful (as it corrected some slips in an unpublished table which I had prepared for my own use), has calculated the pigeon-hole and the position under the Quantitative Classification of all the rocks of which we have trustworthy analyses, and has prepared a table of these names, as well as of the older names.[24] It will, then, be well first to go over his table II, slightly modified as herewith given a "Correlation of Nomenclature of Keweenawan igneous rocks," making some comments and comparisons. One thing must be remarked which will account for a good deal of the variety. *The same dike of lava or the same lava flow* may differ very widely in different parts and especially at different distances from the margin, so that it will be absolutely different in texture and quite different in chemical composition in different parts. One great difficulty has been in applying a name to a rock mass and then trying to define the name afterwards. The characteristics of one part will not apply to all parts of the rock. It seems to me, therefore, permissible for the field geologist to apply to a whole lava flow a name which by strict definition will apply only to some large part of it. If we do not do that we shall be driven to using some arbitrary geographic or proper name or number. This indeed we do to some extent and speak of the *"Kearsarge foot,"* Bed 87 of the Eagle river section, Arcadian flow 23, etc. But it seems to me it is a great help to comprehension and memory if we may also speak of the *Chippewa felsite,* the *Mabb ophite,* etc., without meaning thereby that the so-called *Chippewa felsite* may not frequently have more or less conspicuous phenocrysts and so be called more strictly a *feldspar* or *quartz porphyry,* or that the *Mabb ophite* may not be, at the very top, a glassy amygdaloid.

Going over the roll of names cited by Winchell we find that his use of the term *Granite* is agreed on by all. His use of the term *Quartz porphyry* is agreed to by all but A. N. Winchell, who would substitute *rhyolite porphyry.* The term rhyolite has not heretofore been applied to these rocks, though they are chemically

[24]Journal of Geology, Nov.-Dec. 1908, Vol. XVI, No. 8. Monog. 52, p. 400.

and in origin equivalent to the Western rhyolites, and many of them show beautifully the bands marking the flow lines. On this point W. H. Hobbs said in 1900:[25] "The tendency of American petrographers seems to be to abandon entirely terms of the class *quartz porphyry* and to extend terms correlated with *rhyolite* to cover rocks which were previously included in both groups. This tendency seems to me to be an unfortunate one since it results in classing together rocks which are essentially unlike. There may be no important difference between a particular *quartz porphyry* and a particular *rhyolite* but compare a drawer of hand specimens of the former with one of the latter and an argument is unnecessary to show that as a class they are essentially different. The *quartz porphyries* are as a class, devoid of vesicular and fluxion structures— they are in their method of occurrence hypabyssal—and they more generally show the effects of devitrification and weathering, etc." The authors of the Quantitative Classification, whom I shall hereafter refer to, for short, as the "Big Four," would keep the term *quartz porphyry* or *quartzophyre.* I should be tempted to confine the term *rhyolite* to porphyries in which lines of flow were a marked feature. *Felsite* becomes *rhyolite* for Winchell and Grant. Rosenbusch in his latest edition uses *quartzless porphyry* and *felsite* for the ground mass of a porphyry. It seems not inappropriate to continue to speak of porphyries in which the ground mass alone is conspicuous as *felsites,* and such is the usage of the Big Four for "non porphyritic, light colored, rocks."

Obsidian and *apobsidian* are terms applied by Winchell and Wright to certain Minnesota felsites. *Tuff* we all agree upon as a name for volcanic detritus. *Augite syenite* and *granitell* of Irving (the latter distinguished by having quartz), *granite* and *soda augite granite* of Bayley and A. N. Winchell and Grant and N. H. Winchell, are names applied to the *red rock* associated with the big gabbro intrusives. These rocks often occur in pebbles in the conglomerate. They correspond to my *augite syenite* or as I have called them, in accordance with my belief that they stand in the same relation to a gabbro as an ophite to a granite, *gabbro aplite.*[26] The typical thing is the dominance of red and plagioclase feldspar. They are fully described in Wright's paper.[27]

Quartz keratophyre and *granophyre* are terms in Rosenbusch's classification that have been widely applied to these rocks. Bayley found them applicable to some of his Pigeon Point *red rocks,* which

[25]Journal of Geology VIII, No. 1, p. 6.
[26]Report for 1903, p. 236; Vol. VI, Part II, pp. 72-3; Report for 1904, p. 153.
[27]Report for 1908, pp. 361-393.