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A BRIEF REPORT ON A PART OF THE KEWEENAWAN OF WISCONSIN

by

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A Brief Report on a Part of The Keweenawan of Wisconsin

The area with which this report is chiefly concerned is in Burnett County in the valley of the St. Croix River in northwestern Wisconsin and is comprised of Twps. 40N, Ranges 13, 14, 15, 16, 17, 18W; Twps. 39N, Ranges 13-19W inclusive; Twps. 38N, Ranges 13-19W inclusive; Twps. 37N, Ranges 15-20W inclusive; Twps. 36N, Ranges 16-20W inclusive; Twps. 35N, Ranges 17, 18, 19W; and Twps. 34N, Ranges 17-18W. The subject is the structure of the Middle Keweenawan rocks. The study was undertaken in order that the writer might become more familiar with the interpretation of magnetic data.

The Wisconsin Geological and Natural History Survey allowed the writer free access to their records and the writer wishes to express his gratitude for this courtesy. The study could not have been made without it. Mr. H. R. Aldrich of the Wisconsin Geological Survey also gave freely of his time and smoothed many of the difficulties encountered.

There are few exposures of rock in the Burnett County area and the interpretations are, for that reason, chiefly based on other considerations, the most important of which are the magnetic profiles. The basic igneous character of the lava flows of the Middle Keweenawan make magnetic methods particularly applicable

Over most of the area the magnetics are poorly defined and, of themselves, inconclusive. The area, however, is not an isolated structural unit, but a part of the Keweenawan syncline which extends S.W. from Chequamegon Bay, curving to the south as it extends into Minnesota, the synclinal axis probably crossing the St. Croix River somewhere in the vicinity of Wolf Creek. It is evident that the structure of the area under consideration must fit into the general picture as one of the units making up the whole. The Middle Keweenawan has been studied

in other districts where there are more outcrops or the magnetic data was found to be more indicative of the underlying structure. It is proposed here to follow these structures toward the area to be considered. The obscure magnetics may then take on new significance.

The south limb in the neighborhood of the Gogebic Iron Range in Wisconsin has been ably discussed by Aldrich(1) in relation to the major Lake Superior syncline. His summary statement of the sequence of events are:

"3. The formation of this Geosyncline was caused by the downwarping or foundering into the magmatic chamber whence the Middle Keweenawan lava flows had come.

"4. The foundering took place at different rates along the axis of the main fold. It began earlier, or took place more rapidly, or continued longer, off to the northeast of the region under discussion. (Gogebic Iron Range)

"5. As a result of the differential foundering, considerable movement having taken place to the northeast while the horizontal position was maintained to the southwest, warping under torsional stresses became effective.

"6. One principal result of the torsional stresses was the development of two subordinate, oblique, structures on the south limb of the ultimate structures, a syncline striking slightly east of north (15 degrees-30 degrees) and a monocline or anticline immediately to the west and striking 60 degrees-70 degrees west of north. The comparatively complex folding in the Huronian west of Mellen on the Gogebic was due to this early stage of deformation.

"7. Simultaneously with the subordinate folding, the combination of torsional warping stresses and normal compressive stresses incident to the main synclinal development gave rise to strong thrusting up the dip. The Keweenaw Thrust of Michigan was initiated at this time. It's western extension has probably been found in Wisconsin, where it cuts steadily deeper into the series, first bevelling the Lower Keweenawan sediments, then the Huronian. This is accountable for at least a part of the bevelling of the Huronian west of Mellen which was formerly believed to be due entirely to erosion.

"8. Upon subsequent foundering along the main axis in the southwest, the development of the major structure was complicated due to the presence of the two subordinate, oblique structures. These latter inhabited the normal differential movements between the lesser units of structure, i.e., the individual beds or lava flows, and themselves functioned as the units releasing the compressional stresses by differential movement up the limbs of the geosyncline.

"9. As a result of the accumulation of stresses in larger units of structure, failure took place on a correspondingly large scale.

(1) Aldrich, H. R. W. G. S. Bull. 71-1929 "The Geology of the Gogebic Iron Range of Wisconsin."

Whereas, in a normal syncline individual beds may move over one another through differentials of distance inappreciable except in the net result; in the present instance these differentials were integrated and the movement was great. The movement took place as a second series of major thrusts, of which the Lake Owen Thrust is the outstanding example.

"10. During the period of control of deformation by the torsional warping stresses, tensional fractures were developed with a strike approximately normal to the axis of the minor syncline, or parallel to the axis of the anticline. On later adjustments, during the foundering in the region to the southwest, there was movement along these fractures, and the differential tilting took place, in part, by these fault block units....."

It may be seen from the foregoing that the simple major structure became more complex as it grew. The great thrust faults and the cross faults are features to be watched for farther to the south. As one follows the south limb of the geosyncline to the southwest the width of outcrop increases and the dip flattens. It would seem, then, that to the southwest the deforming stresses were not as intense as they were near Mellen. The general trend of the Middle Keweenawan outcrop belt is nearly east-west between Mellen and Drummond. From Drummond it turns southwest. The lines joining the crests in the magnetic profiles also curve around, paralleling the strike. In the vicinity of Totogatic Lake the strike as shown by the magnetics is approximately N30E. As the magnetic crests are followed to the southwest they swing more westerly until in T42N-R11W, N60E is the trend. It is interesting and significant to note that the magnetic lines are not smooth curves but more like a series of long dashes. The breaks where the parallel dashes change direction lie more or less on a straight line. This is suggestive of cross faulting of the type described by Aldrich in the Gogebic(2).

In T41N-R11W the strike is about N75E and the suggestion of cross faults persists. In T41N-R13W the northern boundary of the limb swings

(2) Aldrich, H. R. W. G. S. Bull.71-1929 "The Geology of the Gogebic Iron Range of Wisconsin."

more southerly again. This brings the south limb down to the area under discussion.

To summarize the northeastern extension of the south limb from the Area to the Gogebic we may say that the effect of the Lake Owen thrust on the magnetics becomes less and less noticeable to the southwest until it dies out. The magnetic lines curve rather steeply to the south and "flare out" with the width of outcrop. Then they trend more westerly and converge again as if the dip was steepening. There is another curving to the south as the formation enters the Area. In the whole distance there are suggestions of cross faulting. Disregarding the faulting for the moment, the magnetic data for this portion of the limb is suggestive of a shallow minor syncline trending across the regional structure of the synclinal. This interpretation fits very well with the oblique anticlinal which exists to the northeast as brought out by Aldrich(3). As the traverse lines pass of the Keweenawan to the south the magnetic profiles become smooth except in a few places where anomalous magnetic attractions occur south of the boundary. These anomalous attractions furnish thought for interesting speculation, but more than one of several interpretations is equally applicable at present.

Beginning with the north limb of the geosyncline in Western Bayfield and Douglas counties let us trace the structure to the south and west.

In T48N-R9W the magnetics indicate a strike a little south of east for the traps. Apparently they are nearly flat and are bounded on the north by a strike fault which probably is a thrust. Suggestions of cross faulting appear in the magnetics giving this limb a satisfying, structural, similarity to the south limb.

(3) Op. cit.

In T48N-R10W the topography and magnetics bear out the relation of a fault contact on the north boundary of the traps with cross faulting striking east of north and offsetting the ridges of igneous rock. The magnetic lines are offset also. The offsets trend in a general northeast direction and give the magnetic sheet a step like appearance. The main fault along the boundary is expressed topographically. The strike of the flows is N65E, dip 40SE. There are outcrops of sandstone between diabase indicating a graben or reentrant in the north boundary. This graben trends a little east of north.

In T48N-R12W the boundary fault is exposed on Amnicon and Middle Rivers. The Keweenawan lavas are seen to be thrust over the Lake Shore sediments. Near the thrust fault the sediments are vertical to overturned but their general position is flat lying. The fault seems to be a series of small breaks, giving the main fault a ragged outline. On the Amnicon River it strikes N70 degrees E and dips 38 degrees SE. In section 25 on Middle River the strike is N65W and the dip is about 45 degrees S. Thus the fault line is either curved or we are dealing with more than one set of fractures. Outcrops show that the main fault has been offset in minor amounts. Wells were drilled into sandstone in sections 25 and 35. There must be a southward indentation here in the traps. Gabbro, felsite, and red rock outcrop in the township to the south. They are intrusive into the flows. The magnetic lines in T48N-R12W are convex to the north, paralleling the boundary and checking the reentrant of over a mile in sections 25 and 35. These curving magnetic arcs may indicate a minor syncline.

In T47N-R10W the outcrops in the Poplar River indicate a flattening of dip to the south. The magnetic lines are offset as the strike changes from northeast to nearly east-west. One of the conspicuous breaks strikes N20E and shows an offset of one-fourth to one-half mile.

The syenite in the Poplar River section may have been intruded into such a fault zone.

The dip is flatter in T47N-13W and in the western part of the township the strike is about east-west. The northern contact is marked by an escarpment which can be traced east and west through several townships. It probably marks an overthrust. In sections 17 and 18 cross faulting is suggested by the magnetic lines. The fault strikes N 15-20 W and there is a slight break in the range along this supposed fault.

In T47N-R14W the Black River flows over Manitou Falls, which marks a fault contact between the flows and Lake Superior sandstones. The volcanics strike N 53 degrees E and dip 45 degrees SE. The sandstone dips 60 degrees N at the contact and is horizontal away from it. The sandstone is broken near the contact and the flows are brecciated and slickensided. The slickensides and the upturning of the younger sandstones show that the sediments have moved downward relative to the Middle Keweenawan. The Black River follows a transverse fault. Outcrops show that the rocks on the east side have moved about 250 feet northward relative to those on the west bank. The strike of the traps changes from east west in the east part of the township to N53 degrees E in the west portion. The dip ranges from 30 degrees-54 degrees SE. Magnetic lines parallel the strike very closely. Acidic intrusions are present in the flows.

From here southwest to the state line the evidence is less clear but the data to the east are certainly strongly in favor of a great thrust fault boundary to the Keweenawan eruptives. The throw of this fault in the Middle River section is at least 3,000 feet(4).

(4) Thwaites, F. T., "Lake Superior Sandstones" W. G. S. Bull. 25, 1912

From Solon Springs southwestward the magnetic lines and observed strikes are extremely uniform. The trend is about N 42 degrees E and the dip is flat (about 13 degrees SE).

In Douglas County, between the northern boundary and the uniform magnetics southwest of Solon Springs, is an area of weak and irregular magnetics. Outcrops are rare in this non-magnetic strip and its interpretation is deferred until the Minnesota structure has been outlined. A white friable sandstone is found in the St. Croix valley near Riverside. It is believed to be the Potsdam sandstone of Upper Cambrian age, and is unconformable on the lavas.

In Minnesota, four and one half miles east of Hinckley, is a location near which the boundary of the Middle Keweenawan passes. The rocks are broken and shattered. The actual contact is not visible. On the one side of a dry ravine is diabase and on the other is an abrupt escarpment of broken sandstone. Along the whole contact it is broken into huge blocks lying in different orientations.(5) The boundary passes near Pine City, for a well on the western shore of Cross Lake encountered sandstone and the Middle Keweenawan flows outcrop one and three quarters miles away. At Minneapolis a well reached granite at 2,150 feet. A deep well at Stillwater struck the trap at about sea level or 717 feet from the surface. It is clear that the eruptives extend at least as far as Stillwater after they disappear beneath the Paleozoics. The criteria for a fault boundary on the northwest are not as many as one could desire but it has long been believed that such is the nature of the contact.

In 1927, traverses were run by the Wisconsin Geological Survey in Pine County, Minnesota. Upper Cambrian sandstone is known at Hinckley

(5) Hall, C. W. "Keweenawan Area of Eastern Minnesota" B. G. S. A. Vol. 12, 1901.

and just east of Hinckley in T41N-R20W, Middle Keweenawan lavas dip 45-50 degrees eastward. Subnormal dip needle readings were prominent over these flows. Both positive and negative crests were obtained in T41N-R18W. These latter variations appear to be characteristic of northwestward dipping flows which are known to exist on the lower Kettle River. The area between these two types of variation, i.e., subnormals and positive and negative crests, is practically normal. Normal readings were found east of the northwestward dipping flows, and still farther east variable readings again indicating a dip to the southeast. Flows in the non magnetic area near the N¼8, T42N-R17W were apparently horizontal. Magnetic traverses were not made south of Pine City and little is known of the Keweenawan there.

Judging from road traverses run in Pine County, Minnesota, Hansell(6) concluded that:

"1. Eastward dipping flows near the boundary of the Keweenawan... give negative dip needle variations.
"2. Northwestward dipping flows as exposed on Kettle River give positive dip needle variations.
"3. Between the negative and positive variations mentioned in 1 and 2 is a normal area, probably representing a synclinal basin.
"4. ...East of the readings characteristic of the minor syncline, mentioned in 1, 2, and 3, is another normal area which is possibly underlain by flat or very gently dipping flows.
"5. Apparently the dip of the flows becomes steeper toward the southeast margin of the limb of the syncline and magnetic variations again become larger.
"6. The non magnetic area on the north limb of the Keweenawan syncline in Wisconsin continues into Minnesota. In Minnesota, however, there is a magnetic area within the non magnetic area which is possibly due to northwest dipping flows of a minor syncline on the major limb."

The contact of the flows and the sandstones on the northwest margin of the limb is not definitely placed but seems to extend farther west than mapped in the vicinity of Bruno, judging from the character of the magnetics. In other words the boundary is uneven and may be

(6) Hansell, J. M. Min. Road Traverses. Field Report to W. G. S. 1927

offset by faulting. The dips near Hinckley are steep to the southeast (50 degrees). Near the mouth of the Kettle River the dips are about 20 degrees NW. The axial plane of the minor syncline dips about 75NW while the axial plane of the main syncline dips steeply southeast.

The north limb of the geosyncline gives a picture which fits very well with that given by the south limb. The Douglas County Fault may be a counterpart of the Lake Owen Thrust on the south limb. If such is the case it would be interesting to find the counterpart of the Keweenaw Thrust of Michigan. Possibly the Duluth gabbro lies in such a fault zone. It may be significant that no intrusives of any consequence in the Keweenawan southwest of a line from Drummond to Superior. This line is an axis of considerable change in the trend of the geosyncline, and constriction here may have closed the channelways to invading magmas which came from the Lake Superior Basin.

The minor syncline on the north limb as delineated by the area of weak, erratic, or normal attraction is a considerable feature. It extends southwest from Lakes Nebagamon and Minnesuing, past Belden and Cloverton on the state line, to the lower reaches of Kettle River. When the forces, which inaugurated the great thrusts, acted, this minor syncline was formed as a flexure on the limb of the main structure. Its orientation parallel to the strike fits this theory. Being on the outside of the bend, the stresses were not so concentrated and intense, and adjustment was accomplished, in part, by the formation of this wrinkle. If deformation had continued the fold undoubtedly would have passed into another thrust.

Cross faulting, especially in eastern Douglas County, occurred in the later phases of adjustment just as the cross faults on the south limb did. Southwestward from Solon Springs and Gordon, the cross faulting is either less prominent or absent.

We may attempt, now, to fit the Burnett County Area into the picture.

T40N-R13W

This township is on the south limb of the main syncline. There are no outcrops in the township but geological boundaries can be drawn on the basis of the magnetics. Part of section 6 and the south-eastern portion of the township are normal areas. Near the south township line magnetic variations reappear. The magnetic lines tend to curve toward the south in the western portion of the township.

T39N-R12W

In this township only the western portion shows magnetic variation. The magnetic lines converge toward the center of section 8. This suggests the nose of synclinal fold plunging to the west. The only outcrop in the magnetic area is a red quartzite which has been correlated with the Barron quartzite and is of unknown age. If the quartzite is Huronian the attraction may be due to folded, interbedded, iron formation. It is impossible to make a definite determination until more is known.

T39N-R13W

There are no outcrops in this township to check the conclusions drawn from the magnetics. Well marked, variable and positive magnetic lines, convex to the east, are present in the eastern portion of the township. Outside of this portion the readings are negative and weaker. Near the S.E. 28 sandstone was encountered in a well and quartzite fragments are common in sections, 12, and 13. In his report Hansell(7) says:

" It has been suggested that this formation (Middle Keweenawan) extends into this township, perhaps folded or faulted east, and that the highly variable readings in the northeast corner represent a sharp fold in the formation. This is possible but it is difficult to imagine a thick resistant formation such as the Middle Keweenawan folding into a narrow fold such as is indicated by the magnetics. The fact that the

(7) Hansell, J. M. Township Report for T39N-R13W 1929 W. G. S.

magnetics die out to the west may mean that the fold is plunging in that direction."

Upper Cambrian sandstone is believed to exist to the south and may blanket the west part of the township. It is possible to explain the strong magnetics by supposing a buried, folded iron formation, or an intrusion of igneous rock. Admittedly, at least some of the crests are local but it is not likely that magnetic crests would align themselves as well over an intrusive.

T40N-R14W

Lack of outcrops is again a hindrance in T40N-R14W. The gradual onset of magnetic variations as one traverses south from the normal, northern, part of the township indicate north dipping flows. The magnetic lines strike N45 degrees-50 degrees E in the eastern, and N60E in the central part of the township. The contact of the Middle and Upper Keweenawan is offset in section 30. On the basis of magnetics two transverse faults may be postulated striking east of north. The change of strike comes at these faults.

T39N-R14W

The crests in the western part of the township line up at N75E but in sections 3 and 10 they line up at N65E. East of a line from NE4 to S$\frac{1}{4}$35, which line lies along a depression occupied by Benoit and Rice Lakes, the Yellow River, and a narrow valley in sections 26 and 35, the magnetic lines strike N40 degrees E. Although this line is not an extension of the fault postulated in T40N-R14W, it strikes the township line at nearly the same place and is suggestive. This township occupies a topographic lowland and may be underlain by Upper Cambrian sandstone.

T40N-R15W

The magnetics show that the Middle Keweenawan is present only in

the southern part of the township. The boundary strikes N75E.

T39N-R15W

The magnetic attraction is less well marked in the southern portion of the township than in the northern part. The lines joining the crests are quite uniform in a N75 degree E direction. Cambrian sandstone is known to the north and south of here and as the absence of outcrops, and the well records show, this township is on a lowland or depression in the Middle Keweenawan. This depression may be floored with Cambrian sediments.

T40N-R16W

The magnetic variations in this township are unlike those in other townships. They are long drawn out rises of a few degrees above normal and some are several miles long, with no distinct crests. Such magnetics are not easily interpreted in terms of underlying structure. This township lies in the trough of the synclinal and would be expected to be normal. The readings, however, are not normal and there must be some faulting, folding, or erosional features to account for the magnetic variation. It is likely that the flows are nearly flat lying in the trough, and a bulging up of the floor, which was subsequently scarred by erosion, might account for the phenomena. If such is the case the uncertain magnetic lines probably tend to follow erosional highs rather than the true strike. These highs or lines trend in the general direction of the synclinal axis.

T39N-R16W and T39N-R17W

Just to the south of T40N-R16W in the northern part of T39N-R16W there is an area of normal readings. The remainder of the township produces variable readings. The strike of the magnetic lines is nearly east-west. The dominant readings are positive and experience has shown that this indicates northward dipping flows. In the

western portion of T39N-R16W and in T39N-R17W the crests form northward curving arcs. If these indicate the strike there may be a transverse break near the east lines of sections 27 and 34. It is possible that the beds flatten in the northern part of T39N-R16W and bulge up slightly in T40N-R16W to give the variations found there.

T40N-R17W

This township has no outcrops but there is a magnetic area in the northwest part of the township. The boundary of the magnetic area strikes N45E and agrees well with the strike of the traps on the north limb of the syncline where they are exposed to the northeast. Just what this means in relation to the variation in T40N-R16W is not clear. The north curving magnetic arcs to the south indicate a nosing out of a northeastward pitching syncline. The actual outcrops of the Middle Keweenawan, however, are known for a considerable distance to the southwest. It would seem that there is an anticlinal axis or saddle crossing the trough here.

From here westward to the St. Croix River the country is topographically low and nearly normal magnetically. There are no outcrops of igneous material in here but there are one or two exposures of Upper Cambrian sandstone near the St. Croix River.

T38N-R13W and T38N-R14W

Subnormal readings, except in the northwestern corner, of T38N-R13W indicate that the basic effusives lie to the northwest. The magnetics in T38N-R14W are very weak. If present the lavas must be beneath a thick cover.

T38N-R15W

Outcrops and well records in this and neighboring townships show that the Keweenawan had a rough erosion surface before the Cambrian

was deposited. The dip needle readings in T38N-R15W are not strong and there does not seem to be a similarity of crests on adjacent traverses. The southern boundary is drawn through a change from variable to subnormal readings. Outcrops occur in T37N-R16W. The weakening of the magnetics and lack of outcrops indicate that T38N-R15W lies on one side of the depression or pre Cambrian lowland that extends through Twps 39N-R14 and 15W. Lakes Bass, Pokegama, Warner, and Viola, are the only suggestions of rock control of the present topography.

T38N-R16W

Although the trap surface is not as rough here as it is to the south the well records and outcrops show a rough preglacial surface. The strike on the west side of the Clam River, in T37N-R16W, is N55E and on the east side it is N68E. The dips are 15-20NW. The Clam River probably follows a fault. Relative to T37N-R16W, this township lies on a rock lowland and Upper Cambrian sediments from T37N-R16W may cover all of T38N-R16W. A line from 400 paces east of S¼34 to 500 paces north of N¼6 is a projection of a fault from T37N-R16W. This line parallels the topographic break between the sand plain and the till. East of this break the magnetic lines agree within two degrees of the strike measured east of the Clam River in T37N-R16W. West of this break the magnetic lines strike N62E and parallel similar lines in T38N-R17W. There is a discordance of five to seven degrees between the magnetic lines and the strike measured in T37N-R16E west of the fault. The crests in this township, T38N-R16E, are low and wide.

T38N-R17W

There are no outcrops in this township. The magnetic variations

are weak and irregular.

T38N-R18W and T38N-R19W

These townships are normal magnetically. Some weak crests through sections 5 and 8, in T38N-R19W, have been lined up. This line of crests closely parallels the trend of the non-magnetic area across the St. Croix River in Minnesota. T38N-R18W probably lies nearly on the synclinal axis of the main trough.

T37N-R15W

The only outcrops in this township occur in section 7. Well records show sandstones in the southwest corner and northern half of the township. In the southwestern corner dip needle readings are subnormal. Northward they change abruptly, giving a wide positive crest. A line connecting the normal readings between the positives and subnormals strikes N72E from 250 paces south and 500 paces west of the NW30 to 600 paces east of the SE16. This line is taken as marking the strike and the southern margin of the Middle Keweenawan. This margin is not a projection of that in T37N-R16W. The lack of coincidence is explained by a fault which has moved the outcrops belt to the northwest in this township. The valley of the South Fork of the Clam River in T37N-R16W may follow this fault. Other offsets in the magnetics in this township are similarly interpreted.

T37N-R16W

North of a line from SE34 to near the E¼25 the rock is Middle Keweenawan while to the south it is probably Upper Cambrian. This boundary is based on magnetics. The readings to the south are subnormal. The Keweenawan here has considerable relief and there may be Cambrian sediments in the rock valleys. Strikes were measured in eight places. All but one are N53-55E. The exception occurs east of the Clam River in sections 12 and 13 where the strike is N58-63E.

West of the Clam River the dip is 14-16W while east of the Clam it is 17-20W. The southern margin has a trend of N55E but in T37N-R15W it changes to N77E. A transverse fault is postulated from near the NE25 to about 400 paces east of N¼3. The South Fork of the Clam River follows this line in general. Closely spaced fractures striking N56W appear near the S¼7. A fault projected from T36N-R16W comes within 500 paces of here. There is not a great deal of similarity among the crests on adjacent traverses. It is thought that the influence of rock topography is responsible.

T37N-R17W

The northwestern portion of the township is a preglacial lowland while the area to the south is a rough upland. The subsurface rock topography has a maximum relief of at least 300 feet. The flows have a monoclinal dip of 10-20 degrees west in the western parts of sections 19 and 30. The strike is N63E, the same as in the adjacent part of T37N-R18W. In the main belt of outcrops strikes are N30E to N48E, the average, N39E, being the same as the township to the south. In the eastern portion the magnetic lines trend about N40E. The areal distribution of outcrops trends in the same direction. There may be a fault in this township but if so it can not be so accurately placed as is the case in other places.

T37N-R18W

The preglacial relief on the rock upland in this township is more than 200 feet. Outcrops are found only in the southeastern portion of the township. They strike N60-65E and dip 18NW. Magnetic lines check this strike. There is a line of strong subnormal crests from 200 paces west of S¼8 to the NE1. There is another line of subnormal crests paralleling this one from near the SE28 to near the NE25. The

northern line is away from the outcrops and there is nothing in the well records to indicate a buried ridge. Dickinson(8) suggested a fault parallel to the strike. On the south limb positive crests are usually more easily traced than negative ones.

T37N-R19W and T37N-R20W

The Keweenawan effusives do not outcrop in these townships. A few outcrops of white friable quartz sandstone were discovered. The sandstone is apparently flat lying. In T39N-R19W a similar sandstone overlies Keweenawan which dips westward at about 7 degrees. There is one magnetic line in these townships extending from 400 paces north of E¼3 to 400 paces east of the S¼32, T37N-R20W. It is a pronounced positive crest. The strike of the line is N22E. The appearance of this line of crests in an otherwise nearly normal area may mean an abrupt change of dip, a fault, or an unusually thick flow. In either the first or third alternative the line should approximate the strike of the formation.

T36N-R18W

Trap rock forms an elevation in the west. A line striking N50E from 300 paces south of NE31 with northwest offsets of about one half mile at NE29 and E¼16 and a mile offset in sections 2 and 3, and passing out of the township at NE3 marks the boundary of variable readings. The offsets probably mark transverse faults. The strike of the flows is N50-58E and the dip is 10-18W. There is a lack of similarity of crests on adjacent lines, which may mean that the individual flows are discontinuous. The rough preglacial topography probably is the most important cause of the discontinuity. The abrupt change in the readings at the supposed boundary may indicate a steep face at the unconformity like that at Hurley. The dial compass shows

(8) Dickinson, C. G. Twp. Report for T37N-R18W 1927, W. G. S.

a declination of 2½ degrees east on the sediments and 4-5 degrees east on the flows. It is not known whether this is due to the distortion of the field over the flows or to a westward pull south of the unconformity.

T36N-R17W

There is a rock relief of 150 feet or more in this township. The outcrops are bunchy. At E¼19 strike is N39E; at 500 paces north of center of 8 it is N38E; at the NE4 it is N40E; the dips are 10-15NW. In T36N-R18W the strike is N45-50E. In T37N-R17N the range is from N30-50E and in T34N-R18W the strike is N4-8W. The strike varies in short distances in adjoining townships and is thought to indicate faulting. The magnetics are of little aid in this township. There is, however, a rather vague line of crests which may be traced southwestward from section 1 in a direction parallel to the strike farther west.

T36N-R18W

The relief on the rock surface is 200 feet in 200 paces in one locality. Outcrops appear only in the eastern portion of the township. In the NW of the NE of 1 the strike on an erosion surface is N71E. In section 10 a fracture cleavage zone strikes N20W. A dolerite vein dipping south occurs in this outcrop. Differential movement is suggested by the quartz crystals from a dump near E¼10. The strike in section 12 is N45½E. At 500 paces south of the NE12 joints strike N22E and N87W and dip 70W and 86S respectively. In section 21 there is a shear zone 400 paces south of NE21. In section 24 the strike on an erosion surface is N58E, dip about 18NW. In this township the strike changes from N65-70E to N45E between the northern part of section 1 and the center of section 12. South of section 12 the strikes are near N45E or more nearly N-S. There is a locus of abnormality between

sections 1 and 12. The nature of the abnormality is probably faulting but its kind and position are not easily found. Dickinson(9) was inclined to believe it represented an overthrust from the north.

West of a line from NE3 to SE32 there is little magnetic attraction. If the strikes be projected the flows should occur in the west. One outcrop was found. Either erosion or faulting has reduced the trap surface in the western part of the township. Topographic lows and areas of weak or normal magnetic attraction coincide in this township. One line of magnetic crests was followed N38E; another N45E; another N48E; another N51E.The magnetic lines followed are south of the main outcrops.

T36N-R19W and T36N-R20W

These two townships are practically normal magnetically and there are no outcrops of igneous rock.

T35N-R17W

Probably all of the township except the southeastern part is underlain by trap. The boundary is based on magnetics. The boundary extends from the E¼12 to E¼15, is then offset to the south, and continues with same trend from 200 paces south of center of 22 to 500 paces north of center of 28 and then is offset again to the south into T34N-R17W. There is a depression trending southeast from S½17 to Balsam Lake. It may be a rock depression. The magnetic crests on adjacent traverse lines do not match very well.

T35N-R18W

In this township there is a rough pre-Cambrian topography with a lowland in the northwestern portion. The lowland may have a fairly uniform surface. The strike as measured at the SE8 is N18E. A

(9) Dickinson, C. G., Twp. Report T36N-R18W, 1927 W. G. S.

magnetic line in section 2 gives N20E. West of a line from the NE5 to the NW31 wells fail to strike trap. Hansell(10) suggests the possibility of this being a fault boundary between the lowland and upland.

T35N-R19W

Trap underlies the township as is shown by the weak and variable magnetics, by a superdip traverse on the east township line, and by an isolated outcrop near the south line.

T34N-R18W and T34N-R19W

The strike of the flows near the Interstate Bridge at St. Croix is N4W and the dip 10W. Two shear zones may be seen above the Dalles. Upper Cambrian sediments, separated from the flows by a conglomerate carrying trap rock, lie in the depressions between the trap ridges. The magnetic crests are very wide and not strong. Lines drawn through the crests do not agree with the measured strike.

We may now attempt to integrate the structure of the Middle Keweenawan in the Burnett County area and fit it into the general scheme of the Keweenawan syncline. Some of the most significant features are: the sharp fold in T39N-R13W, the anomalous magnetics in T40N-R16W, the divergence of the magnetic lines in twps. 39 north, ranges 16 and 17 west, and twps. 38 north ranges 16 and 17 west, and the offsets and abrupt changes of direction of the magnetic lines.

As has been mentioned the synclinal sank faster, or continued longer, or began earlier to the northeast. If the same thing happened to the southwest of the Burnett County area then a saddle or structurally high area would result where the least foundering took place. The

(10) Hansell, J. M. Twp. Report, T35N-R18W W. G. S.

evidence is in favor of such a theory. As the magnetic lines are followed westward through T39N-R15W, T39N-R16W, and T39N-R17W, they curve around toward the north limb as if closing around a syncline. In T38N-R16W and T38N-R17W, however, the lines continue to the southwest toward the St. Croix Dalles. The depth of burial in the barrens alcng the St. Croix River is sufficient to mask magnetic phenomena that might confirm the theory of this saddle. This oblique, anticlinal, structure is the most important feature of the Burnett County area for it must have influenced the manner in which later, or continued, deformation took place. When further foundering took place the Burnett County area would be subjected to stresses from both the northeast and the southwest, as well as compression from the sides. The longitudinal stresses acted against each other but were not precisely oppositely oriented. As a result the trough was subjected to complex warping stresses which caused adjustment, in both horizontal and vertical directions, along breaks striking across the structure. The faults shown along the southern margin of the flows and the one in T39N-R16W may represent such breaks. During further movement each of these blocks tended to act as a unit and differential tilting of the blocks was accomplished. Since the longitudinal stresses act south , southwesterly and northeasterly respectively the saddle would be expected to narrow toward the north limb. More abrupt changes in dip would be expected there also. In a resistant formation such as the Middle Keweenawan such conditions would tend to introduce complications. It may be this complication which is manifest in T40N-R16W. This is interpreted as a dome or secondary saddle which has been dissected by erosion and buried. The normal area in the southeastern part of T40N-R17W would then represent a shallow basin of nearly flat flows.

The magnetic lines in T37N-R20W and T36N-R20W probably is parallel to the strike and represents a monoclinal dip to the southeast on the eastern limb of the minor anticlinal structure that must lie between here and the non-magnetic area in Minnesota.

The lowland extending across the south limb in T40N-R14W, T40N-R15W, T39N-R14W, and T39N-R15W, must have been in marked contrast with the highland to the west in early Camorian time. The significance of this lowland is not plain. It may represent a wide erosion valley which cut through the flaring side of the syncline along some plane of weakness or it may mean that the upland is an upthrown fault block.

The sharp fold in T39N-R13W was outlined entirely by the magnetics. The quartizite in section 7, T39N-R12W, may be the Barron Quartzite. The age of the Barron is not definitely known, If it is a Huronian quartzite then the attraction may be due to an interbedded iron formation. If such is the case the unexpected crests in T37N-R14W may be interpreted on the same basis. If, however, the quartzite is stratigraphically above the eruptives then the fold must be in Keweenawan material. The way in which the Keweenawan boundary ties in with the fold makes the latter theory feasible. The fold probably is the result of the effect of the saddle on later deformation. It is difficult to conceive of the Keweenawan lavas being folded in such a manner when elsewhere they are broken rather than closely folded. In T40N-R13W the south limb is narrow but southwest of the fold and in the region of the saddle there is a great widening of the belt of outcrop. This is a natural consequence of the differential settling which left the saddle as a brace across the trough. Some breaking occurred as shown by faults in T40N-R14W and T39N-R14W.

There is yet another significant feature which is not well shown

in the magnetics. The rather vague crests in T34N-R18W and across the northwestern corner of T36N-R19W are at variance with the strike. Similar lines are T37N-R18W do agree with the strike of the formation. Just to the south in T36N-R18W Dickinson(11) indicated that there might be faulting, probably thrusting, between sections 1 and 12. These magnetic lines show close degree of parallelism and it is not unlikely that they represent another system of faults at about right angles to the cross faults. If such is the case and they were initiated at the same time they probably are thrusts and came into being when adjustment was taking place on the cross faults. Whether or not it is of any significance is a matter of conjecture but these lines tend to converge toward the fold in T39N-R13W. Possibly the fold is the result of the same conditions or is their counterpart on the northeast side of the saddle. The existence of these thrusts is a possible explanation and not proven fact by any means.

(11) Dickinson, C. G. Twp. Report on T36N-R18W, 1927 W. G. S.

Summary

1. When the Keweenawan syncline began to sink it foundered to a greater extent to the northeast and to the southwest of the Burnett County Area than it did in the Burnett County area.

2. This differential sinking gave rise to various oblique and cross structures of which the saddle in Burnett County is perhaps the largest.

3. At the same time the combination of compressive stresses forming the main syncline and the warping stresses due to differential sinking, caused thrusting up the dip. The Keweenaw Fault of Michigan is an example.

4. A continuation of, or a later, deformation was impeded by the oblique and cross structures and as a consequence larger portions of the trough functioned as units. The result was integrated movement of considerable magnitude. The Douglas County thrust which continues, in all probability, many miles into Minnesota was begun at this time.

5. Simultaneously, as a direct result of the cross structures which caused larger blocks to act as units, cross faults were developed, allowing movement between these blocks, and differential tilting occurred.

6. The saddle in Burnett County, being subjected to stresses from both the northeastward pitching syncline and the southwestward pitching syncline, developed further structural complexities. The doming in T40N-R16W, the folding in T39N-R13W, and the thrusts in the middle of the trough like that postulated in T36N-R19W, were formed as a result of the combination.

7. The minor syncline in Minnesota may be the direct result of the stresses acting against the bulwark of the Burnett County saddle. It lies at about right angles to the saddle and is symmetrically

located.

8. Deformation must have continued after or not begun until, the Lake Superior sandstones were deposited for they are involved in the faulting.

9. Deformation and long erosion must have occurred before the deposition of the marine Upper Cambrian for it is found unconformably on the trap in the depressions on the limbs and far up the trough.

10. If the contact near Hinckley is a fault contact some movement must have occurred in Minnesota after the deposition of the Upper Cambrian.

11. The later stages of the faulting must have been either quite recent or this syncline recently exhumed from its Paleozoic cover, since ~~for~~ the thrust faults are today topographically prominent.

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SLICKENSIDE

SCRATTERED ROCK

SHATTERED

FRACTURED

DIFFERENTIAL MOVEMENT

FRACTURES AND CLOSE JOINTS

DISTURBED AREA

ST. CROIX RIVER

BURNETT COUNTY AREA

MAGNETIC LINES

POSSIBLE FAULTS

STRIKE AND DIP

SCALE - 2½ INCHES = 8 MILES

Thomas J. Baker

ORIGINAL

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