BEDROCK TOPOGRAPHY AND OVERBURDEN THICKNESS OF NORTHEASTERN ALPENA AND EASTERN PRESQUE ISLE COUNTIES, MICHIGAN

by

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INTRODUCTION

Background

Actual extent and location must be determined for each of our natural resources for better protection, planning, and management of their use. Two reasons for this are the increasing trade competition on the world market and the threat of pollution. Land use maps usually have been developed only around large population centers and tourist areas. From land-use studies better protection and utilization of mineral, agricultural, and water resources can be developed. Resource inventory or land-use studies do not exist for most of the country even though the land is being cleared, filled, and built upon; and sewage and drinking water, building site and farm land confrontations are becoming more frequent.

Maps of bedrock topography and overburden thickness are a necessary part of good land-use studies. "It is unrealistic to conclude that the 'best and wisest' use of a given parcel of land can be determined without due consideration of known or potential resources which may lie beneath the surface." (Allen, et al, 1974). It seems necessary that we produce bedrock topography and overburden thickness maps in land-use studies before potential resources are placed out of reach by man's activities.

The information required is available in most areas. Methods of computer mapping may provide a more economical and rapid means of drawing these maps where facilities are available than a totally manual analysis of the data.

Area of Study

The area mapped includes the eastern one-third of Presque Isle County and northeast one-quarter of Alpena County, Michigan (Fig. 1). Overburden in this area is generally less than 50 feet thick and is composed of glacial till, varved clays, outwash gravels, and river and lake shore deposits. An esker is located at the southeastern of the study area and a kame two miles further east outside the study area.

Bedrock is defined as the lithified limestones, shales, and clay shales, of the Middle and Upper Devonian System (Fig. 2). Bedrock distribution is shown in Figure 3. There is no record of outcrops of lithified deposits younger than Devonian in the study area. Area dip is generally less than one-half degree to the southwest.

Internal drainage and karst topography occur at the surface in the west and east-central portions of the area. Wisconsin glaciation caused fluctuation in lake and land elevations which resulted in karst development in the high-land and low-lake level stages. Subsequent covering by glacial deposits has masked the formations which seem to have been affected the most, such as the top of the Roger's City Limestone, which is porous to vuggy in outcrop.

PROCEDURES

Sources of Data

United States Geological Survey (1974) seven and a half minute topograpic quadrangle maps were used for locating and determining elevations. Contours were in ten-foot intervals with a supplementary five foot interval at the City of Alpena. This interval gives an initial error of elevation estimates of plus or minus five feet.

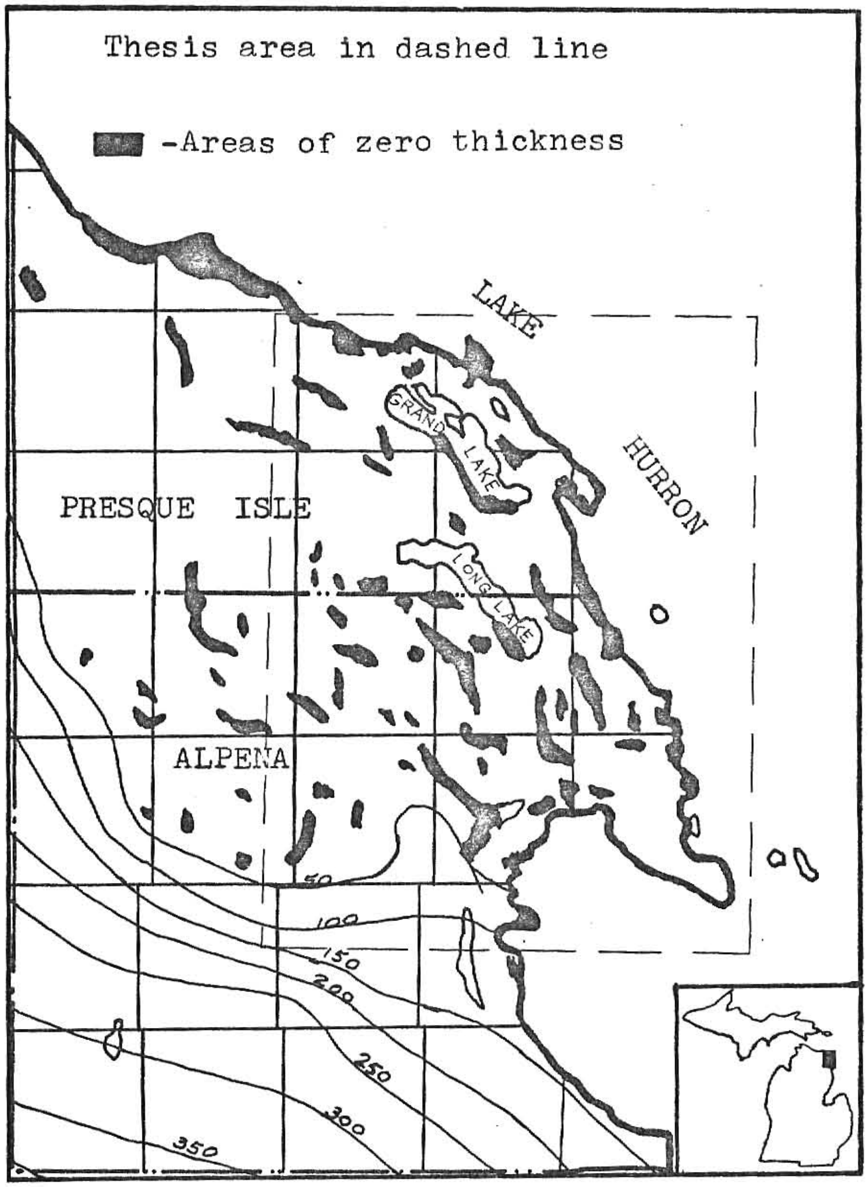
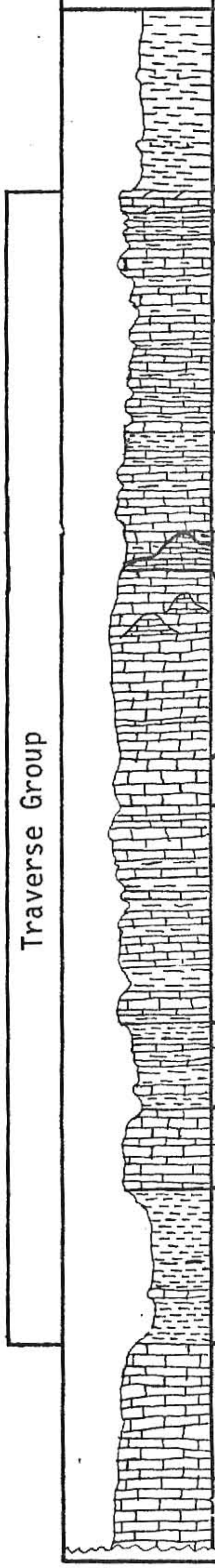


Figure 1 Glacial deposit thickness map, Modified from Michigan Geological Survey (1938).

scale 1 inch=100 feet — Middle and Upper Devonian System



Graphic Section	ft.	Formation	Brief Description
	96	Antrim Shale	Shale, black, carbonaceous with calcareous shale members in the lower part
	10	Squaw Bay Limestone	Limestone, fossiliferous, dolomitic
	16	Thunder Bay Limestone	Limestone, shaly, interbedded with shale
	102	Potter Farm Formation	Limestone, thin bedded with shaly partings
	53	Norway Point Formation	Interbedded limestones and shales with clay in upper 27 feet
	9-21	Four Mile Dam Formation	Limestone, biohermal, with mudstone and shale
	79	Alpena Limestone	Limestone, many bioherms, pure to shaly limestone
	25	Newton Creek Limestone	Limestone, petroliferous
	117	Grenshaw Formation	Limestone, shaly, shale beds and shale partings
	43	Ferron Point Formation	Shale with thin limestone, fossiliferous
	43	Rockport Quarry Limestone	Limestone with a few shale beds near the bottom
	81	Bell Shale	Clay shale and shale, calcareous in part with some thin limestone beds near the bottom
	71	Rogers City Limestone	Limestone, porous with less porous magnesian limestone near the bottom
	145	Dundee Limestone	Limestone, fossiliferous, thick bedded over most of the interval

Figure 2 Stratigraphic section of bedrock, Northeastern Alpena and Eastern Presque Isle Counties, Michigan (after Ehlers and Kesling, 1970, and Fisher, 1969).

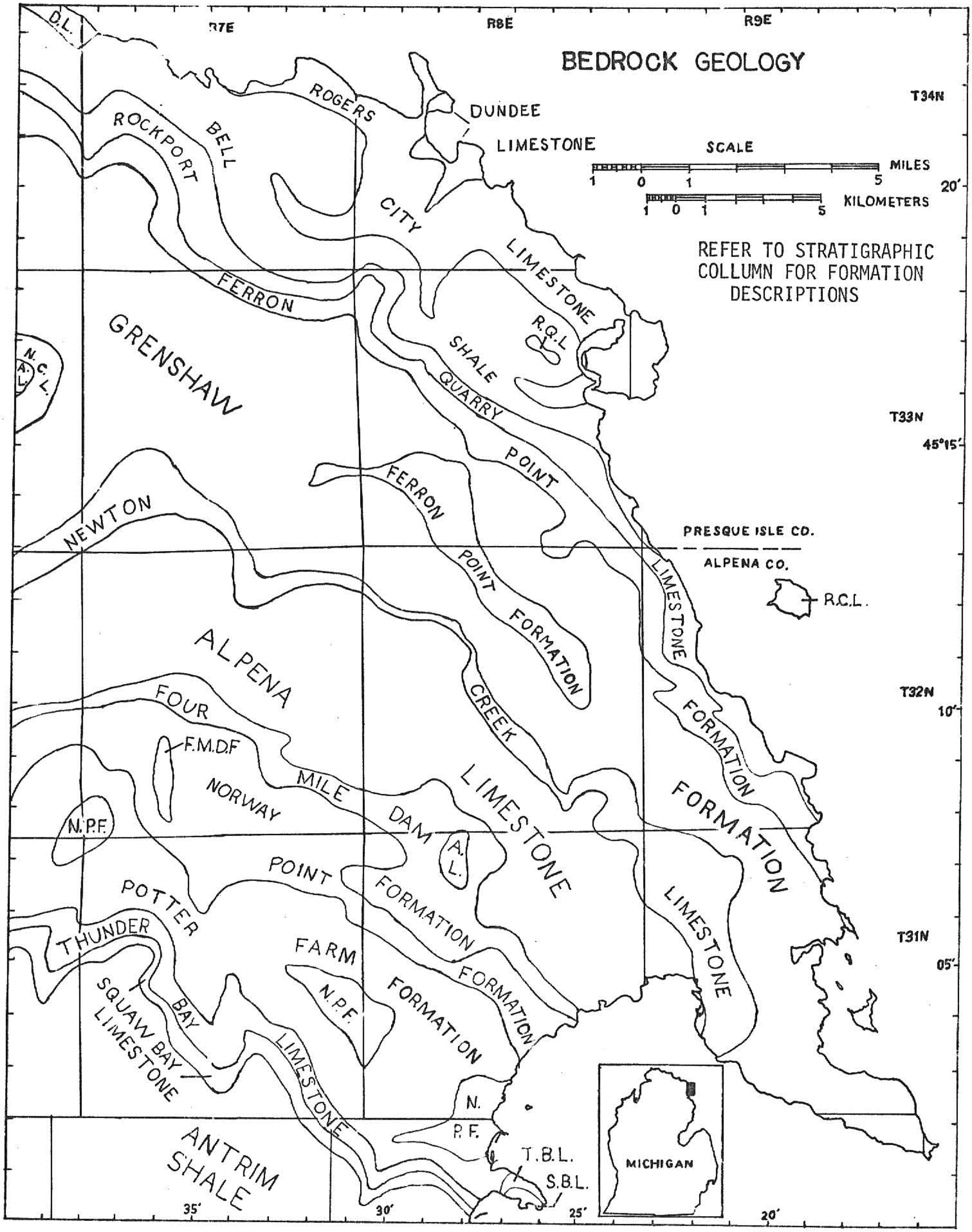


Figure 3 Generalized bedrock topography of northeastern Alpena and eastern Presque Isle Counties, Michigan

Health Department offices of Alpena County and Presque Isle County supplied water well logs. In the initial gathering of data an attempt was made to select only one log for each 40 acre designation that showed the thickest overburden (deepest to rock) or deepest penetration when rock was not encountered (minimum possible to rock). If a difference of greater than 25 feet depth was noted between two logs within that area, both were used. The limiting of data density gives a more even distribution of map points and allows for the selection of program parameters to better estimate surfaces in low control areas and to remain accurate in areas of high control. Parameters selected to accurately estimate areas with high data density will yield estimates of excessively high or low elevations in areas of low data density. Parameters selected for low density data would better predict elevations but would tend to smooth areas of high control. This also gives a lower limit of 1320 feet to data spacing compared to a grid point spacing of 1,000 feet.

Of the 258 logs gathered, two were discarded because they were improperly located; the township-range designation placed them in bodies of water. Other data suspected of improper location designations were not removed so that a valid point of importance would not be discarded. Depth measurements recorded were assumed to be correct.

Water well logs which did not reach bedrock were divided into two groups. Group one containing logs which penetrated deeper than surrounding wells, was used for mapping. I assumed that a basal gravel or sand had been reached and that bedrock would have been reached in two more feet of penetration. This assumption is based upon another assumption that the well penetrated the basal sand or gravel, that water was available, and the drilling rate was dramatically reduced, possibly due to rock, causing the driller to stop drilling at this point. Two feet of depth were added to these logs before being included in the data to improve the interpretation by allowing for possible error in the above reasoning. Group two, which contained logs in which penetration depths were shallower than surrounding data and contained no additional bedrock information, was not used.

A compiled list of outcrops and lithologies of the area (Ehlers and Kesling, 1970) and additional outcrops that were mapped provided data for overburden thicknesses of zero to three feet (outcrops at surface, in ditches and road cuts, and in shallow pits). Quarry bottoms were ignored and therefore quarries do not appear on the bedrock topography map.

Open file information of the Michigan Geological Survey (1914; 1922) provided some test hole data. Personnel from the Presque Isle Corporation, Huron Portland Cement Company, and U.S. Steel Corporation Calcite Plant provided data for several points or gave permission to do seismic traverses on their properties.

Refraction seismograph traverses were completed in areas of lowest data control and where access was available by public or private road. A single phone, binary lights, model MD-1 engineering seismograph was used with an eight pound sledge hammer and steel plate for energy induction. Reverse traverses were run only when unexpected velocities or irregular chart plots were obtained.

Bedrock was nearly horizontal over the distances of the seismic traverses. Where beds dipped significantly beneath the traverse line, the accuracy of fixing the location horizontally cancelled the vertical accuracy gained by a reverse traverse. Therefore, a reverse traverse for each location was not warranted.

To facilitate the computer's mathematical model of the surfaces, four data points are 'imaginary'. These are where a mathematical model would interpret a nearly flat plane of rock projected through a data point into the air. These additional data allow for a more reasonable mathematical model by pulling the projected plane back down. An example is where a single datum point exists on an island.

Data Interpretation Problems

Well Logs--Descriptions used in water-well logs are inaccurate for distinguishing between clay and shale which results in a strata identification problem (Fig. 4). Clay occurring both above and below recognized 'rock' units on the logs, raises questions about actual depth to bedrock. Depths used are based on the logged names of 'limestone' and 'shale' as 'first rock' indicators. The 'clay above these units was assumed to be reworked and not of Devonian Age.

In the logs listing loose rock on solid rock, one foot of depth was added under the assumption that only the upper one foot was moved from bedrock position. Field observations in the area indicated this figure to be from zero to three feet.

Seismic Data--Unexpected low or high velocities from seismic data occurred where the subsurface interface was at a significant angle to the surface. The true velocity is usually found by using a reverse traverse and in all but one case this method resolved the question of the velocity obtained versus the velocity expected (based on geologic map, Ehlers and Kesling, 1970).

EXAMPLES OF WATER WELL DRILLER'S LOGS				
Drillers Description	Zone in Question	Number of feet of Zone Thickness	Cumulative Depth	Interpreted Depth to Bedrock
NW¼NE¼NW¼sec. 10, T. 33 N., R. 8 E.--posted at (58.3,101.4)				
gravel		12	12	
clay		16	28	
blue clay	x	4	32	32
limestone		78	110	
SW¼NW¼NW¼sec. 35, T. 33 N., R. 8 E.--posted at (60.2,79.9)				
clay & boulders		6	6	6
brown limestone		13	19	
blue clay	x	4	23	
stoney clay	x	42	65	
shale		7	72	
brown limestone		20	92	
stoney clay	x	23	115	
NE¼SW¼NE¼sec. 33, T. 34 N., R. 8 E.--posted at (51.2,10.4)				
broken limestone	x	7	7	1
solid brown limestone		46	53	
NE¼NE¼XE¼sec. 32, T. 32 N., R. 8 E.--posted at (18.5,45.6)				
yellow sand		8	8	
blue clay	x	30	38	
gravely clay		4	42	
water, sand	x	12	54	56

Figure 4 Interpretation problem of defining shale, clay, and bedrock from well logs

Figure 5 shows the results of one reverse and one forward traverse each run on both sides of Herron Road, 1/2 mile west of the Paxton Shale Quarry and 1/2 mile north of highway M-32 (SE¼SE¼NE¼, Sec. 24, T.31N., R.6E.). Recorded outcrop positions and reference to the stratigraphic column show that outcrops of the Antrim Shale occur here and extend one mile to the northeast and probably 1/2 to 1 mile to the southwest. The true thickness of the Antrim Shale is a minimum of 96.5 feet as measured at the Paxton Shale Quarry by Ehlers and Kesling (1970). Thirty-six feet from the top of the measured section is a 0.5-foot greenish-gray, calcareous shale and 71 feet from the top is three feet of "'limey material'" (Ehlers and Kesling, 1970). The first calcareous shale occurs in the approximate position of the horizon detected in the traverse. However, the more calcareous composition of the "limey material" would be a minimum or deficient requirement for the velocity obtained from the traverse. Possible explanations are an unusual hardpan, a previously unreported limestone lens, or a change of the calcareous shale lens to a limestone lens.

Treatment of Data

The final data (Appendix A) were entered in digital form on a 370/IBM computer system and processed by the Surface II Graphics System software (Sampson, 1975). (See Appendix B for program listing and explanation). All printer output with surface topography and bedrock topography listings are on file with Dr. Charles P. Walters, Kansas State University Geology Department.

The true surface from which the irregularly spaced data of bedrock elevations were sampled was estimated by a distance weighted dip projection on a 108 x 138 matrix. The estimated surface was then used to

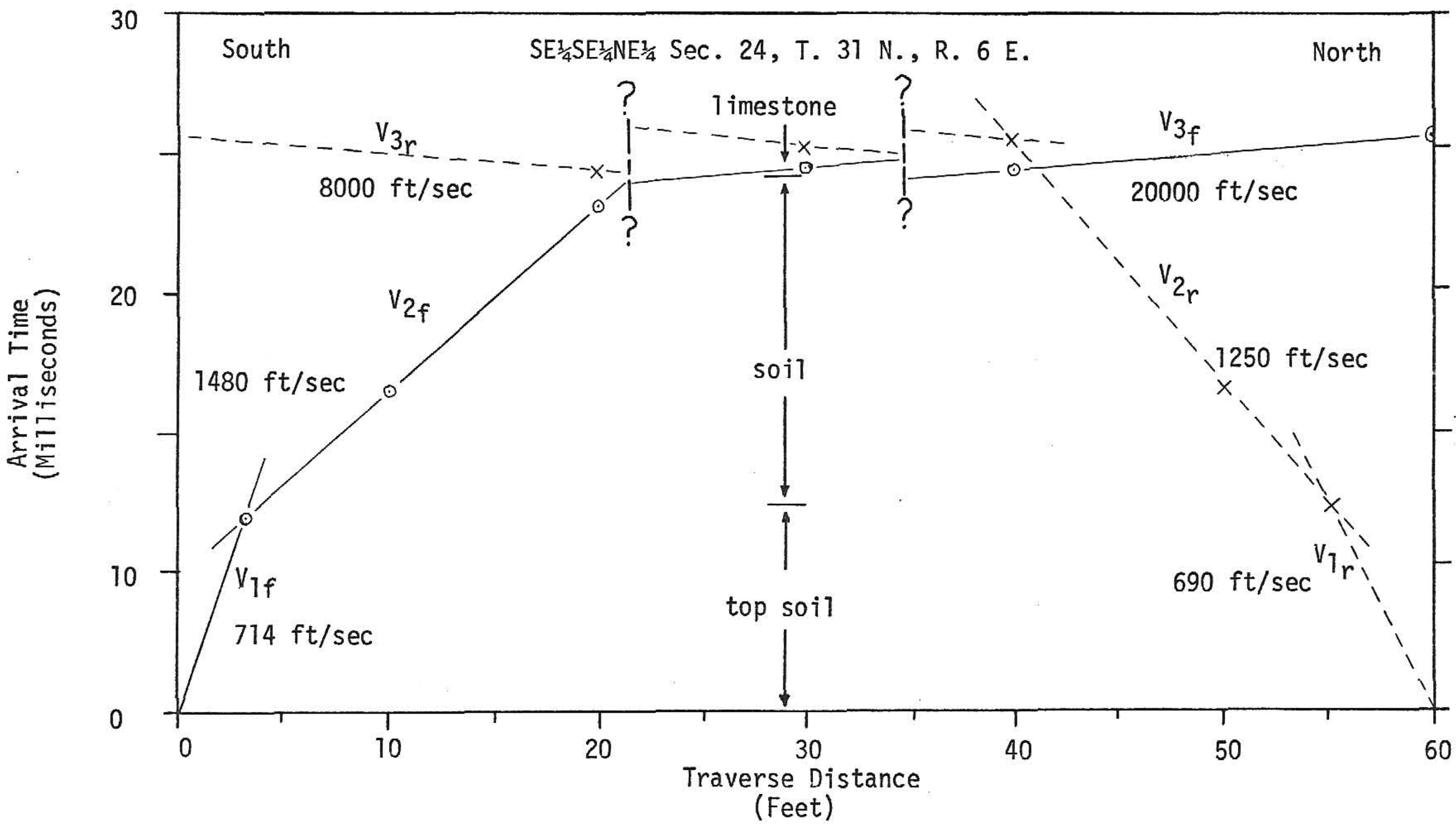


Figure 5 Seismic velocity of a limestone traverse graph at a 'shale' location

back calculate sample values for error analysis of the estimate (Appendix C). The estimated surface was then contoured as a bedrock topography map (Fig. 8). A bedrock topography map was also manually contoured with the additional data of lake and river positions and geology of the area (Fig. 9). The estimated surface was also subtracted from a digital terrain of the present surface yielding a residue contoured as the overburden thickness (Fig. 10). Using a large grid of 108 X 138 in computing the estimated surfaces costs more than using a smaller grid, but greater resolution is obtained in the digital terrain and overburden thickness.

The digital terrain was produced by placing a 1/2 inch grid (1,000 feet on the ground, 5.82 points per mile) on seven and a half minute topographic quadrangles of the area and using the elevation at each grid node. (If hill tops or rivers were within 0.1 inch, 200 feet on the ground, from the grid node they were used as the elevation at that point.) Lake surfaces where encountered were used as surface elevations. Quarry waste piles were included and appear on the overburden thickness map. Quarry bottoms were included in the digital terrain but not in bedrock elevation data. Therefore, quarries do not appear on the maps except for limited expression in the overburden thickness map.

With overburden thickness ranging from zero to 120 feet and low data control of 0.029 data per grid node, more reliable maps were produced by subtracting the less accurate bedrock map from the more accurate surface terrain. Bedrock features expressed in surface topography are smoothed by this method but the many surface terrain 'impressions' are not imposed upon the bedrock map as in the next method.

Subtracting a less accurate overburden thickness map from a more accurate surface terrain imposes topographically positive features of moraines, eskers, and man-made piles on the bedrock topography where there is little data control. Negative features such as stream valleys and sinks will also be reflected in the bedrock topography. These two methods of subtraction are compared in Figure 6. The first method would be more accurate based on the hypothesis that the bedrock topography would have less fluctuation in its relief than the overburden thickness at the scale of observation used. A method of combining these two procedures was not developed in this thesis.

Neither digitizing apparatus nor adequate digitized data were available at the time of this thesis. The totally manual digitization of all data used resulted in several errors of which some could have been prevented by a digitizer. Six errors appear in the final computer maps but are corrected in the data listing and manually drawn map. One point was duplicated, a hole drilled to bedrock (35.1, 115.5, 561). One point was mislocated horizontally; a hole drilled to bedrock should have been at (43.8, 107.9, 550) instead of (43.9, 104.9, 550). And four points were mislocated vertically; an outcrop should have been at (38.8, 71.8, 605) instead of (38.8, 71.8, 705) and holes drilled to bedrock should have been at (41.4, 107.4, 697), (46.9, 75.0, 539), and (50.0, 51.2, 631) instead of (41.4, 107.4, 597), (46.9 75.0 639), and (50.0, 51.2, 731), respectively.

RESULTS AND DISCUSSION

Data Posting

Figure 7 is a posting of data points with the X-Y axis labeled as used in Appendix A. Areas of low control (large distances between data

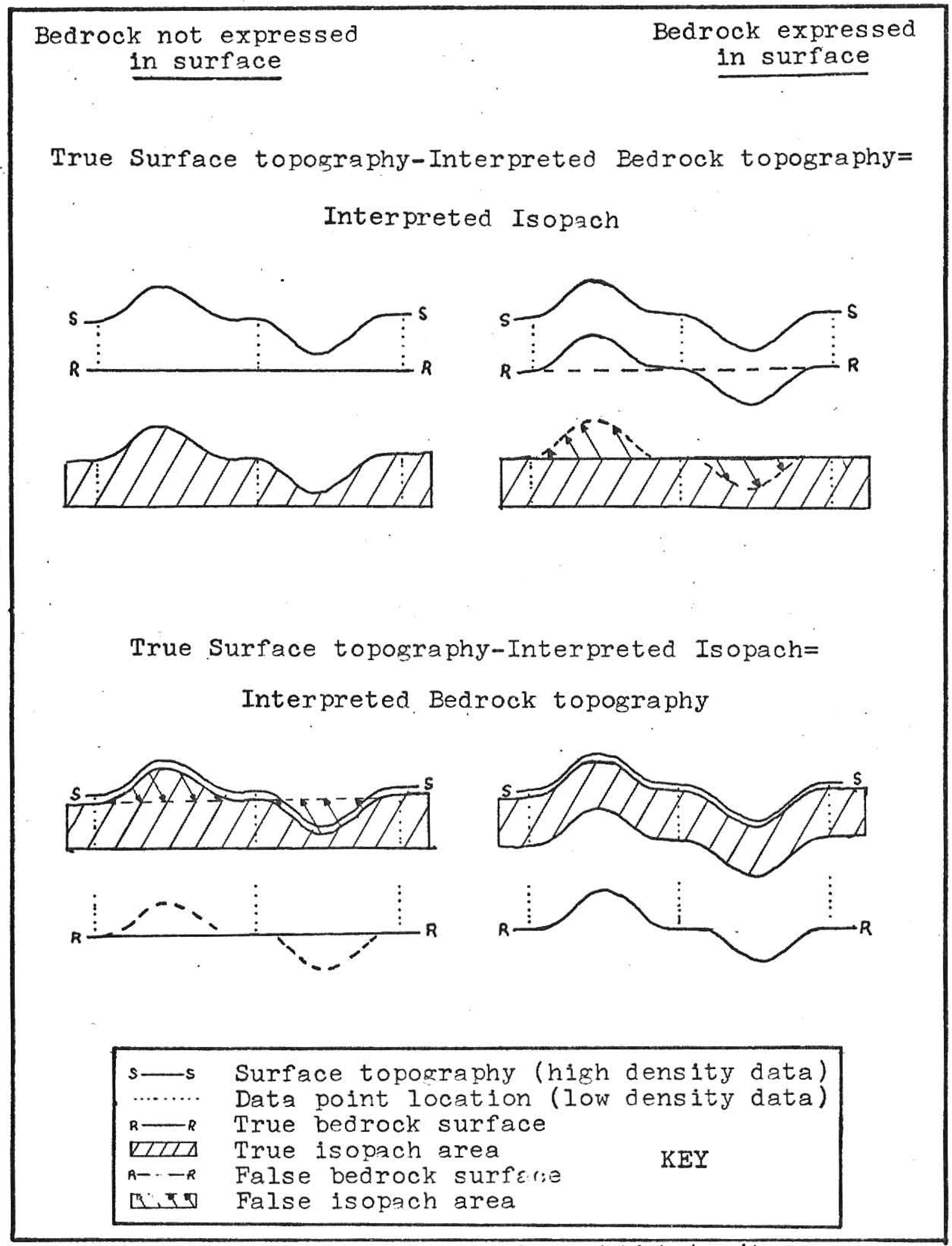


Figure 6 Interpretations of data of low and high density.

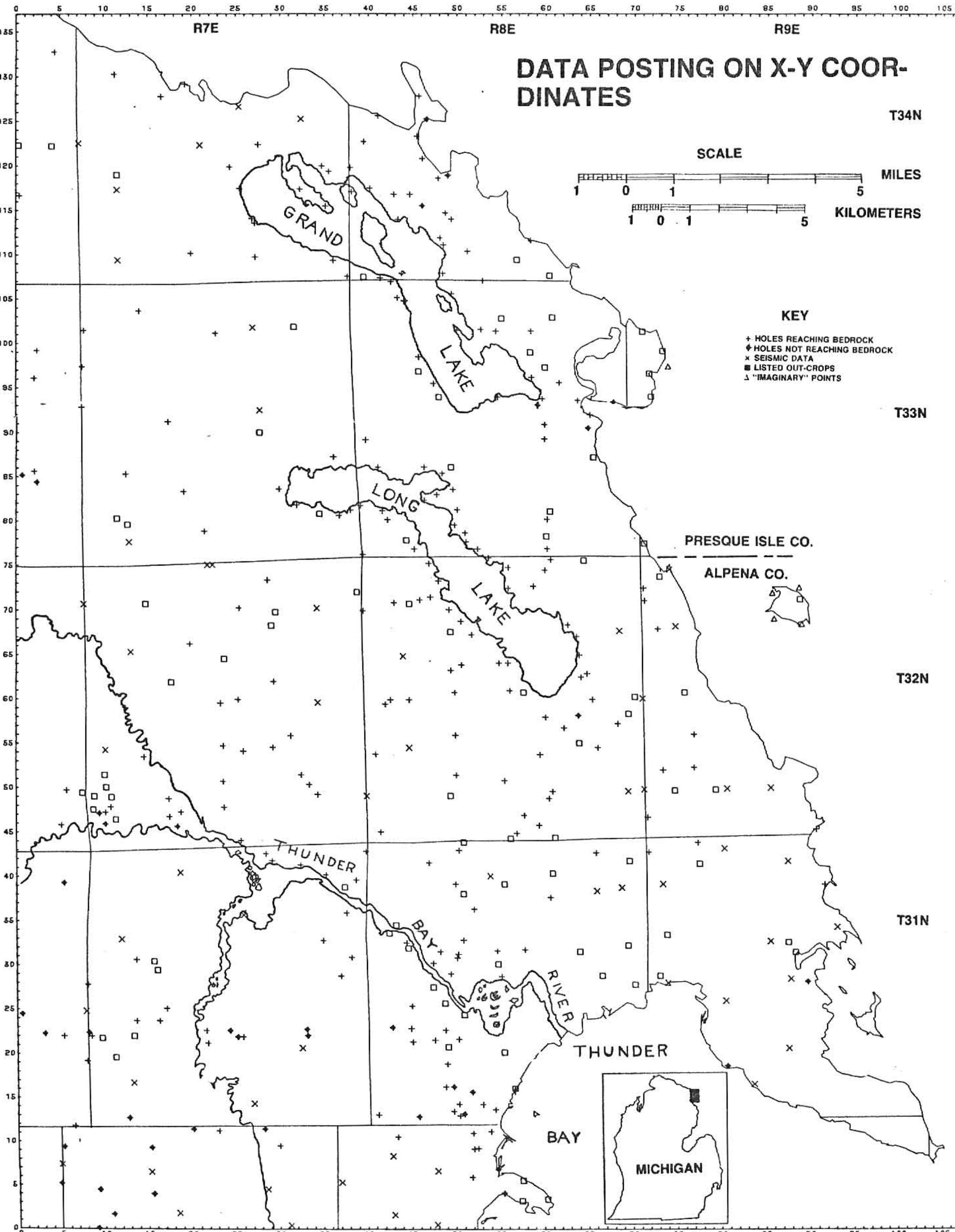


Figure 7 Data Posting

points) appear as areas of low or nearest to uniform relief on the other maps. Low control areas also appear on the overburden thickness map as wide areas inside the five-foot contour.

Bedrock Topography

Figures 8, computer model, and 9, manual model, show bedrock topography based on the data obtained. Total relief expressed is 300 and 340 feet respectively, from the area at 45°21'N, 83°29.5'W to the three hills in the west central area of the map. Ledges occur with the same NW-SE trend as the strike of the rock beds. Thunder Bay in the southeastern part is reflected landward by the landward deflection of contours around it.

Without the addition of lake or river features and bedrock attitude, the computer estimated bedrock surface is smoother than the manual estimate. Parts of the Thunder Bay River channel appear as pockets in the computer model at 45°5'N, 83°29'W and although Long Lake is up to 25 feet deep, the computer model restricts it to only 5 to 10 feet of depth in the center at 45°13'N, 83°29.5'W.

Each interpretation reveals sinkholes at 45°11'N, 83°26'W and 45°15'N, 83°26'W. The northern sink has no expression in the present surface. The southern one is interpreted differently in each version as compound sinks and as a blind valley. It is presently occupied by Long Lake, fill and Devil Lake giving little indication of its existence.

Due to the mathematical dip projection and sample data, two sinks appear in the computer interpretation at 45°2'N, 83°28'W and 45°2'N, 83° 30'W instead of a river valley. The valley has no expression in the present surface.

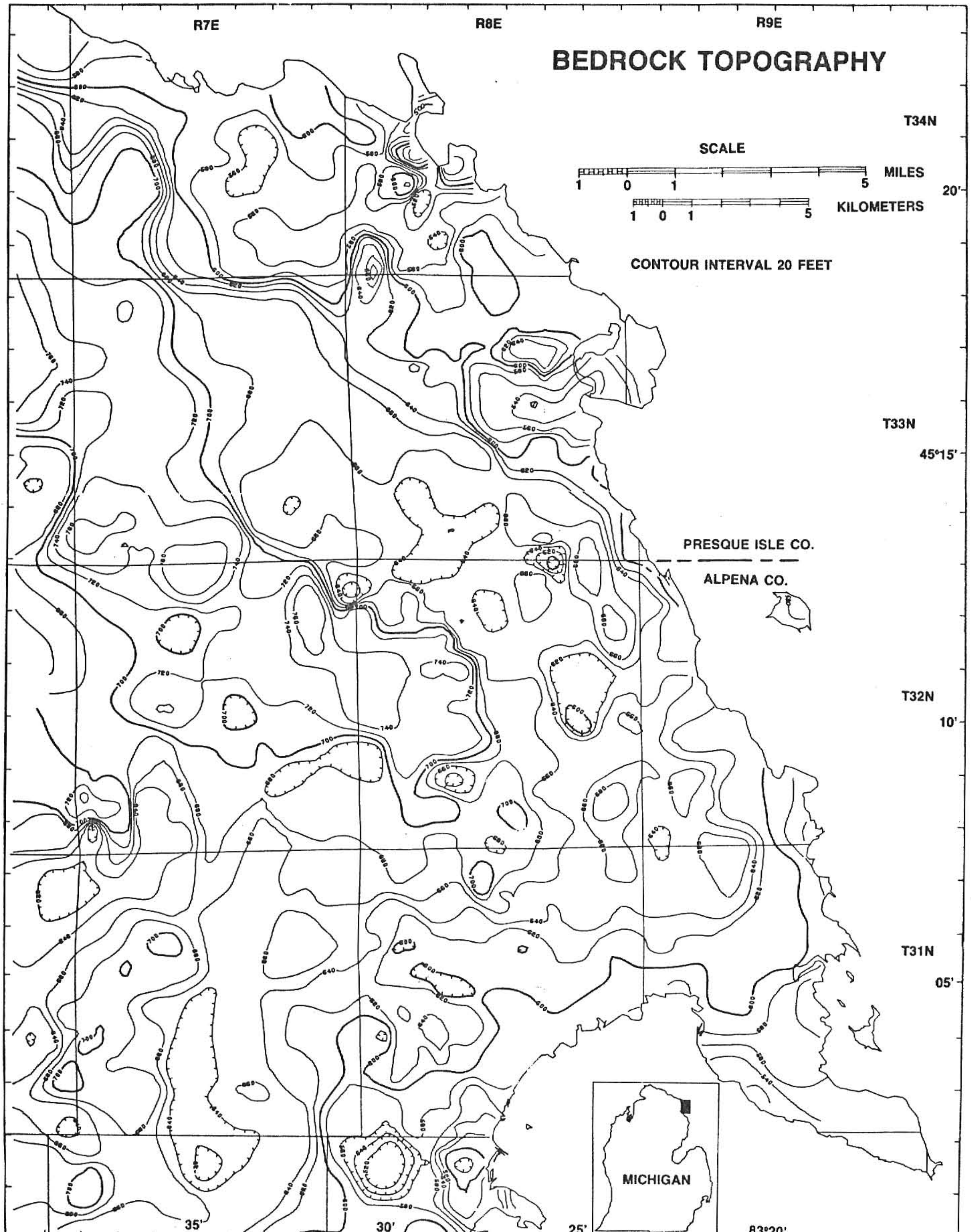


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Figure 8 Bedrock Topography (computer drawn)

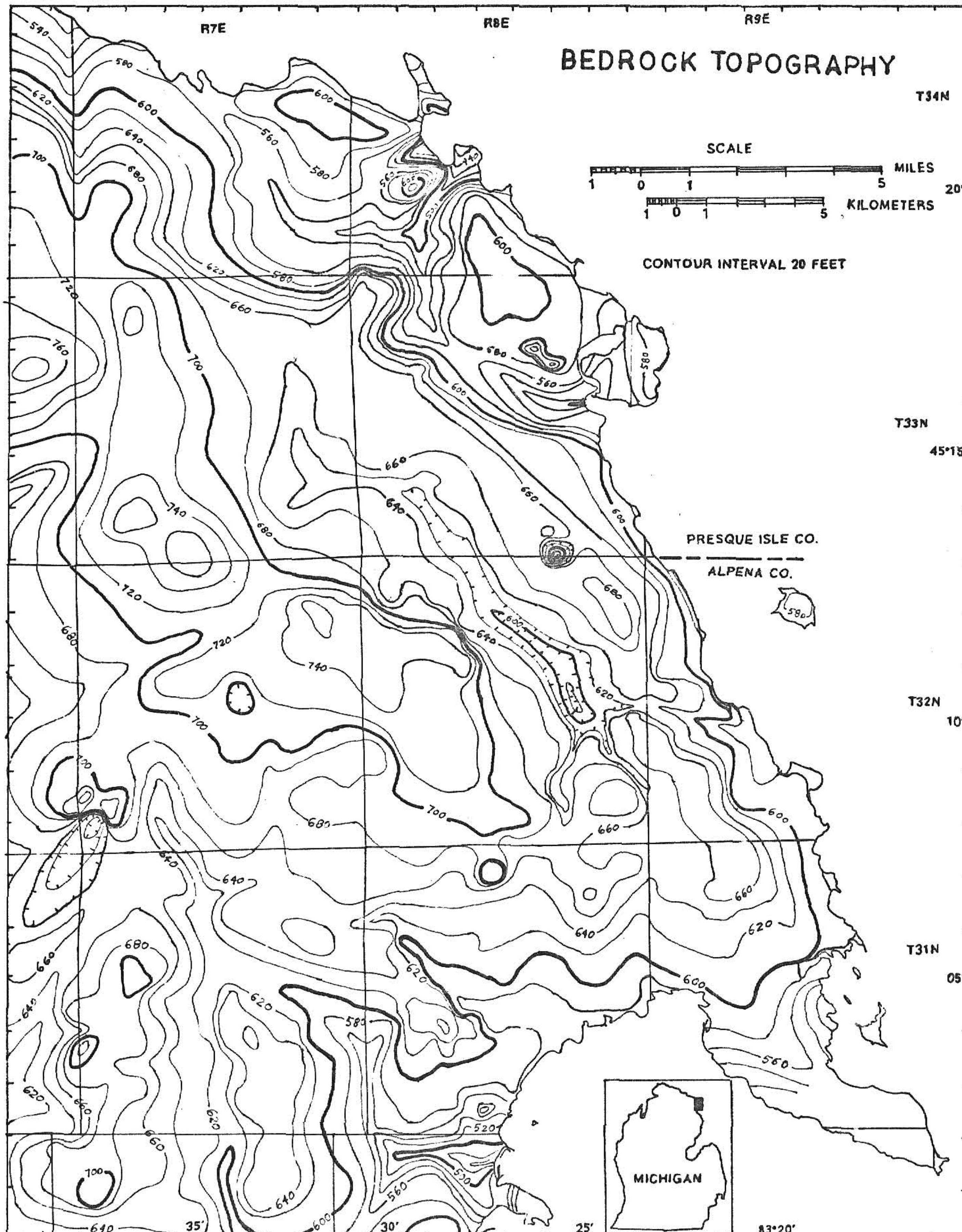

Figure 9 Bedrock Topography (Manually drawn)

At 45°8'N, 83°38'W a branch of the Thunder Bay River flows in an easterly direction over a blind valley trending nearly N-S. A buried swallow hole is tenable in this feature.

Wisconsinan and post-Wisconsinan lake terraces may be indicated by wide areas of regionally low relief separated by steeper slopes. Such levels appearing on the map correlate weakly with Flint's (1957) table of lake levels for the Huron Basin. A 10 foot contour interval might improve the correlation but more data would probably be necessary to bring the correlation from ±15 feet to within ±5 feet.

Overburden Thickness

Figure 10 shows large areas with less than five feet of overburden. These are also areas of relatively low data control. Negative values, due to the estimation of bedrock elevations higher than digital terrain, occupy most of these areas. This is especially true where the ten- and five-foot contours are very close to each other at the edges of the areas.

Another place where additional data are needed is revealed by superimposing the data posting (Fig. 6) on the overburden thickness map (Fig. 8). Absence of data is apparent inside the five-foot contours and in some 'hills' resulting in possible errors in the contours of these areas.

Trends of overburden thicknesses are revealed that can help in the location of extractable rock resources of economic worth, and areas of sand and gravel deposits. The overburden thicknesses map also shows the suitability of different areas for septic systems and sanitary landfills. The location and protection of groundwater aquifers also requires overburden information. Construction problems such as foundation differences or benefits such as gravel deposits could be predicted from the data.

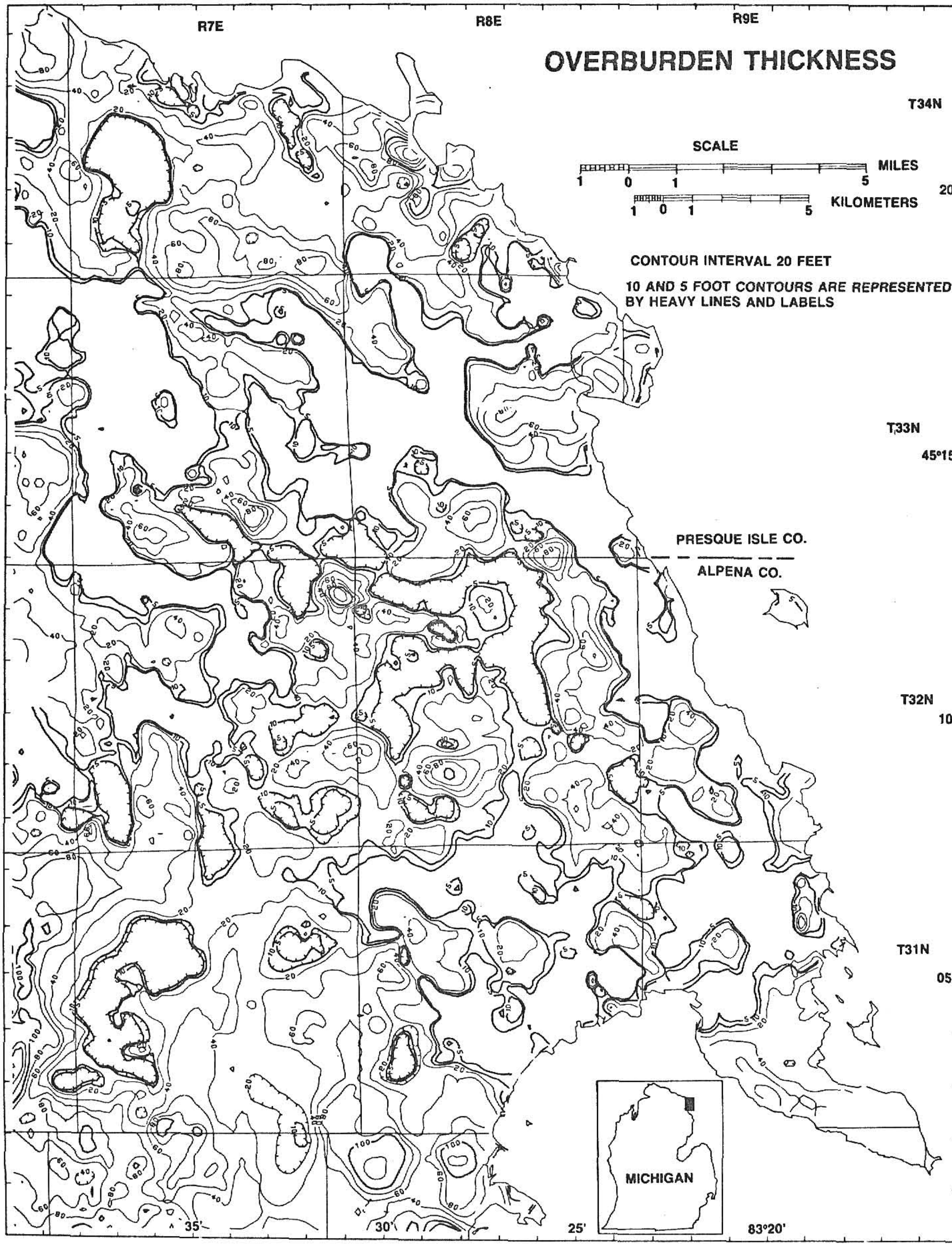

Figure 10 Overburden Thickness

The locations of deposit areas and Wisconsinan erosional features in Figures 8 and 9 provide a basis for studies of regolith deposits and Pleistocene history in the area.

Bedrock Block Diagram

Figure 11 is a perspective block diagram of bedrock topography as viewed from S45°E, 35° above the horizon, and 1900 miles (telescopic view) and with a vertical exageration of 35.2. Here the topographic relief and smoothing in the mathematical model are very apparent. At the south of center on west side and near center of north side 'spikes' are visible. These spikes are caused by the estimating parameters selected and the spacing of data. Two or more points near each other and relatively large vertical separation results in steep angles of the fitted surface. This fitted surface is used to predict values between or next to data points that can be much higher or lower than true values. Therefore, false 'spikes' or 'pits' may occur in the estimated surface.

Conclusions

The use of computer graphics provides speed and versatility in the handling of data. Many man-hours can be saved if difital information and suitable graphics software are available. Once digitized the data are easily retrieved and manipulated. Digitization of data for computer treatment becomes worth the time if it will be used more than once or twice and if the manipulation of data is by systematic procedures. It would be faster to manually manipulate data if digitization and software were not as easily available and if the manual effort not too complex.

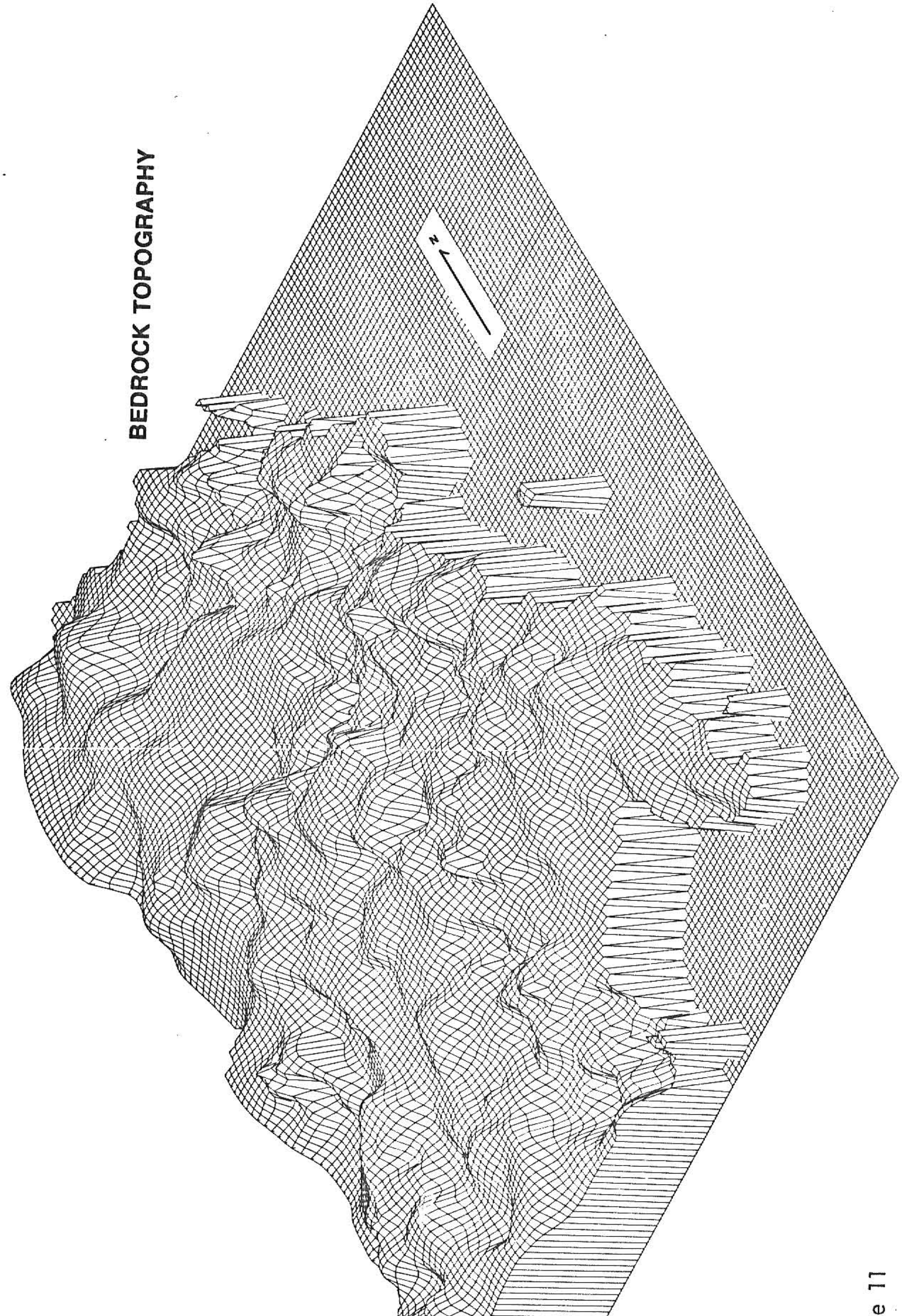

Figure 11

Digital terrain information is available from the National Cartographic Information Center (NCIC), (1975), however, the scale available at the time of this writing was too large for this thesis. Projects over larger areas could utilize the NCIC resources.

The inadequacies of computer software used in the smoothing of valleys, ridges, and other features are significant only if there is a high population of such features or there are very few data where the features are known to exist and human interpretations can yield significantly better results. There are, however, better methods of biasing estimates of surfaces and more accurately representing natural topographies. More accurate estimating methods were available in the graphics software used, but they were not employed because of their higher cost.

The bedrock area investigated was found to be topographically more complex than originally thought and is considered to be a very difficult terrain for computer analysis. The procedure for estimating surface was not capable of utilizing the trends of ridges or drainage valleys.

The original data points and map estimate values at the data points have an average difference of -0.58 feet but a range from -34.7 to 23.9 feet. (Large differences were caused by the weighted average of 4 clustered points at the grid made with one point significantly higher or lower.) This accuracy and the ability to recognize sinks, river channel areas, and ridges show that an office reconnaisance of data with field work, if required, can be accomplished quickly by computer. Particular areas of special interest requiring more detailed studies can be quickly identified from such a reconnaissance.

Karst features seem to be restricted to the central one-third of the area. The only developed river valleys appear in the southern and northern portions. Solution activity was apparently great enough to prevent well-defined surface drainage to the lake. The low elevations at $45^{o}1'N$, $83^{o}28'N$, $45^{o}21'N$, $83^{o}29'$ W could indicate that a sufficient hydrostatic head existed in the area for water to flow underground and dissolve limestone, and possibly erode claystone if the flow was sufficiently great. Karst occurrence does not appear here to be strongly influenced by stratigraphic strike.

It should be pointed out that approximately 75 percent of the area on the overburden thickness map has less than 20 feet of overburden. In light of the number of private water wells for drinking and private septic tanks in rural areas, there is a great danger of water pollution. The pollution potential is increased by the presence of active karst features of unknown extent. Even with water wells up to 120 feet deep, there is still the possibility of contamination from sewage in this karst area.

Further investigations and data development should be focused upon the karst and rock structures. These structures will each exhibit influence from the growth of the other and should not be considered separately. Lake terrace and stream deposit studies will also help unravel the complex history of this area.

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U. S. Geological Survey Topography Map, 1971, Alpena, Michigan:
1:24000 scale, 10-foot contour interval.

Other maps of the above type used are:

Lachine,

Lake Winyah,

Long Lake East,

Long Lake West,

Middle Island,

North Point,

Polaski,

Posen,

Presque Isle,

Thompson's Harbor

APPENDIX A

Data Points

The origin is located at 83°40'00" west longitude and 45°00'00" north latitude. Each unit is 1000 feet in the X-Y directions and 1 foot in the Z direction.

X--East-west coordinates
Y--North-south coordinates
Z1--Bedrock elevations
Z2--Overburden thickness

Drilled Holes to Bedrock

X	Y	Z1	Z2
8.6	22.0	720	3
2.4	99.2	767	2
3.1	93.2	752	6
6.6	11.8	638	90
8.1	19.2	701	15
8.2	27.8	673	16
5.4	22.0	636	90
5.2	45.8	668	25
5.8	49.7	707	15
2.1	85.6	682	67
7.6	97.4	756	15
2.1	96.1	772	10
7.5	92.8	714	20
0.4	116.7	716	3
7.8	101.5	730	0
4.4	132.8	543	73
51.8	5.9	500	90
30.0	9.5	648	25
52.5	9.2	489	102
52.0	9.1	468	126
39.5	76.0	668	1
13.8	30.6	702	0
13.8	23.7	686	2
35.0	32.7	677	0
39.8	42.7	673	8
41.5	44.9	685	4
44.9	22.8	637	0
45.1	21.3	624	5
50.3	21.6	616	3
48.8	22.6	660	0
55.1	28.6	600	4
50.2	31.1	617	9
60.6	37.5	640	2
56.8	44.7	686	2
59.3	45.6	681	3
10.3	47.2	736	3
49.9	39.0	655	5
46.9	41.4	680	4
91.4	39.0	580	4
77.1	43.7	658	9
10.9	47.8	733	7
3[illegible].4	49.1	696	8
23.8	47.7	690	8
26.0	54.0	705	3
23.4	59.4	714	4
29.4	61.8	730	2
42.6	59.7	757	3
42.0	59.2	750	8
43.0	70.6	660	0
39.5	69.7	745	6
25.5	70.1	719	3

X	Y	Z1	Z2
38.1	81.0	651	2
39.2	81.5	655	5
41.2	85.8	665	5
41.7	80.9	652	0
42.3	79.9	655	5
36.8	80.4	661	0
30.0	83.4	653	3
60.4	48.6	680	3
57.6	46.7	707	2
39.8	88.9	665	0
36.2	87.0	655	5
17.4	91.1	735	6
12.6	85.2	736	4
59.4	53.5	674	8
50.0	51.2	731	7
62.1	56.5	652	0
60.0	57.7	659	2
65.7	42.5	654	4
50.6	63.6	748	3
54.8	63.8	655	9
55.8	63.8	652	4
49.2	69.8	660	0
44.7	59.7	732	8
72.6	67.6	622	5
71.1	70.8	659	0
71.0	72.2	652	0
59.9	74.2	668	8
58.6	72.4	672	0
55.8	74.5	659	0
48.0	73.0	655	0
47.1	71.2	654	5
45.9	70.9	687	2
60.2	79.9	664	6
47.8	82.7	646	8
48.4	85.1	646	6
46.4	85.8	651	1
45.7	98.5	590	7
47.4	95.5	609	6
31.3	55.7	715	15
29.3	54.4	697	13
25.4	59.8	696	15
19.9	66.1	696	35
28.7	73.2	706	25
21.6	78.7	747	20
32.0	81.6	637	15
19.2	83.2	720	15
71.5	46.5	646	14
73.2	51.8	660	19
60.8	49.4	635	54
65.9	54.3	650	18
55.4	50.6	691	14

APPENDIX A: Drilled Holes to Bedrock (continued)

X	Y	Z1	Z2
49.9	55.7	737	10
68.1	57.0	647	50
37.6	35.8	650	30
38.2	30.8	644	28
37.0	28.7	626	47
21.7	22.6	628	49
17.2	25.1	646	32
16.4	23.7	673	10
21.9	21.2	620	57
25.9	21.9	658	30
41.2	13.0	567	63
23.1	11.2	624	76
35.3	40.1	665	12
32.4	41.2	664	12
29.2	41.7	651	25
28.5	42.5	655	25
25.7	44.0	673	10
38.7	39.5	668	10
47.6	21.5	616	24
49.0	18.8	589	30
54.4	13.6	538	48
53.0	14.2	541	59
50.4	12.9	559	50
50.3	14.2	580	34
49.7	13.4	566	48
48.8	16.2	584	35
53.9	11.1	514	70
51.9	10.9	505	96
43.4	10.5	513	15
45.0	25.3	641	14
54.6	31.5	613	10
57.7	31.6	601	28
50.8	32.7	615	12
48.2	31.4	613	25
47.4	30.1	594	34
49.4	28.9	584	31
44.4	32.4	584	26
52.0	36.2	630	10
71.6	42.6	645	40
40.9	53.6	662	16
50.3	42.8	671	10
50.1	30.7	602	48
90.4	45.2	555	29
17.5	48.7	632	25
18.9	47.2	650	40
17.6	46.7	627	56
32.5	51.3	663	40
33.4	50.2	691	18
23.7	54.6	700	11
14.7	53.4	678	13
23.7	50.6	691	12
65.3	59.7	618	30
63.8	64.7	607	46
64.0	62.2	607	49
64.7	62.6	620	37
56.0	60.7	672	15
49.8	60.5	721	20
49.4	63.0	739	12
50.5	68.5	635	25
62.5	68.1	643	19
51.7	67.0	643	10
55.8	72.2	644	10
53.6	75.6	648	12
46.9	75.0	639	14
51.0	78.4	639	40
49.8	79.3	617	36
45.3	76.6	642	10

X	Y	Z1	Z2
60.2	76.6	617	73
52.4	76.6	650	10
51.1	77.4	620	40
49.6	83.3	647	11
50.1	81.0	649	22
46.4	82.1	620	32
59.9	89.0	620	10
59.9	90.6	534	84
58.4	96.2	566	46
76.7	55.8	613	17
76.7	52.1	665	25
54.6	94.0	554	42
59.6	93.8	556	42
61.5	95.6	571	35
63.6	93.6	528	60
65.0	91.7	544	45
63.5	66.8	647	12
60.6	75.4	578	105
43.3	105.2	620	0
51.2	110.4	607	1
41.4	107.4	697	3
42.6	107.0	610	0
14.1	103.7	740	1
44.7	116.8	627	6
50.0	101.5	591	9
11.3	130.3	585	26
16.6	127.8	595	13
19.3	129.2	572	11
41.1	125.6	571	20
39.5	122.7	608	40
22.8	101.2	679	10
24.4	119.9	582	25
25.5	117.5	555	46
27.6	122.4	552	48
32.3	117.4	571	37
34.8	120.0	595	30
38.0	119.8	565	55
40.2	117.5	551	56
42.9	116.8	596	41
38.1	117.1	568	32
35.2	115.5	561	40
27.2	113.6	550	51
35.2	115.5	561	40
26.9	114.1	571	30
27.3	109.8	561	83
35.6	119.4	589	52
20.0	110.2	615	55
36.1	109.4	550	51
37.7	107.6	566	62
43.9	104.9	550	46
49.4	105.6	575	25
52.9	107.1	608	10
48.5	111.1	530	69
48.4	107.9	561	42
58.3	111.6	560	20
48.1	111.9	545	55
48.7	114.7	549	71
43.4	114.0	575	40
43.4	114.0	545	58
47.9	118.6	537	60
45.5	123.3	569	16
58.3	101.4	591	20
52.7	101.6	597	34
54.4	101.4	597	32
45.7	127.8	558	42
46.1	120.8	447	156

APPENDIX A: Drilled Holes Not Reaching Bedrock

X	Y	Z1	Z2
5.3	9.4	692	54
4.9	5.2	684	52
9.4	4.5	711	53
9.2	0.1	636	120
5.5	39.3	617	92
8.3	22.4	660	59
3.2	22.3	618	10
0.7	85.2	686	43
9.6	47.1	677	32
2.4	84.4	652	87
0.6	24.5	650	101
15.4	9.3	672	73
15.6	4.0	658	65
11.0	1.7	654	97
54.7	6.8	527	54
55.4	4.1	528	54
42.8	22.9	574	59
33.1	22.7	614	57
24.4	22.6	644	42
12.9	12.7	679	71

X	Y	Z1	Z2
25.3	21.9	646	41
33.2	22.0	607	65
28.3	11.4	638	41
20.2	11.4	633	67
18.5	45.6	628	56
51.8	15.6	553	54
50.9	13.1	528	82
49.7	16.2	583	42
45.8	12.8	583	42
10.3	45.9	589	92
80.5	18.6	535	50
89.5	28.1	540	45
64.8	90.2	550	46
59.1	93.0	514	82
67.6	93.4	541	45
63.7	57.9	581	72
46.6	125.2	489	94
46.1	115.5	500	127
49.0	118.9	443	145

Seismic Data Points

X	Y	Z1	Z2
5.0	7.4	681	55
8.0	24.8	691	11
7.8	70.6	692	15
7.2	122.5	626	36
15.3	6.5	672	68
28.6	4.5	652	38
37.0	5.3	605	51
43.0	1.6	596	40
18.5	1.8	658	75
31.2	0.4	603	77
47.9	6.6	567	54
47.8	0.5	612	16
42.8	8.3	508	12
73.2	39.0	652	3
65.8	38.2	656	4
68.6	38.6	644	6
80.3	25.9	599	7
85.3	32.6	605	5
92.8	34.2	586	6
87.2	41.6	606	9
80.1	43.0	672	7
53.8	39.9	717	8
34.3	70.0	778	7
69.3	49.4	688	2
44.7	54.3	735	3
70.9	59.8	638	5
47.0	64.6	741	5
68.3	67.4	683	4
27.8	92.3	677	5

X	Y	Z1	Z2
26.0	35.6	652	39
13.4	16.7	694	31
27.1	14.3	653	37
32.6	20.6	642	24
18.8	40.4	645	45
12.1	32.9	667	23
73.8	27.9	569	13
10.3	54.2	684	20
83.5	16.5	515	75
87.4	20.6	573	20
87.6	28.4	579	13
39.9	48.9	694	14
13.2	65.2	695	13
22.5	74.9	765	25
21.9	74.9	772	26
13.0	77.5	740	26
71.1	49.6	647	10
34.4	59.4	721	10
73.9	74.3	550	41
74.6	67.9	605	16
80.4	49.7	598	21
85.3	49.8	596	10
27.0	101.8	674	4
25.4	126.6	591	9
32.4	125.2	609	10
11.6	117.3	705	15
21.0	122.3	592	26
11.7	109.4	701	20

APPENDIX A: Outcrops Used

X	Y	Z1	Z2	X	Y	Z1	Z2
9.8	21.8	701	0	23.8	64.4	730	0
7.6	49.4	717	3	38.8	71.8	705	0
9.0	49.0	751	0	29.6	69.6	733	2
8.9	47.5	730	0	29.1	68.1	729	1
4.1	122.2	692	0	12.8	79.5	775	0
0.3	122.3	693	0	14.9	70.6	720	1
60.3	3.4	590	0	34.6	80.6	659	3
57.4	3.2	587	0	27.8	89.8	676	2
57.5	5.5	586	2	11.6	80.2	750	0
11.4	19.6	681	0	74.5	49.5	660	0
13.5	22.0	683	0	49.3	48.9	715	0
15.8	30.4	690	1	63.8	54.8	650	0
16.2	29.4	693	1	70.0	60.0	648	2
42.4	33.5	646	0	69.3	58.1	668	2
37.4	38.7	669	5	57.5	60.5	667	2
49.1	20.7	629	0	49.3	67.3	729	1
56.6	16.0	580	0	64.3	75.3	688	2
55.4	20.1	593	2	72.8	73.5	609	0
63.9	31.4	620	0	44.4	77.6	658	2
66.4	28.7	600	0	44.7	70.5	686	2
69.3	32.1	601	0	71.1	77.2	589	0
73.7	33.3	622	0	60.5	80.8	649	1
72.9	28.7	594	0	60.1	78.0	699	1
70.1	27.7	585	0	49.4	85.8	657	2
50.9	24.3	631	0	65.4	86.9	601	2
48.7	25.6	640	0	58.2	99.0	660	1
47.4	27.4	630	0	73.1	99.1	589	0
54.7	30.0	610	2	71.6	96.6	581	1
44.6	31.8	620	0	59.9	97.3	652	1
50.8	37.9	650	0	79.1	49.6	646	1
43.2	34.4	622	0	88.6	71.0	592	0
55.4	39.0	658	2	75.6	60.5	638	0
56.1	44.1	679	0	71.8	94.0	587	1
60.8	40.2	660	2	45.7	96.9	647	3
61.1	44.2	667	2	48.0	94.0	639	2
69.4	41.6	670	0	55.0	102.8	600	0
10.2	51.4	698	3	60.7	102.9	592	0
10.4	50.0	710	2	70.8	101.3	584	2
50.8	43.7	682	1	56.7	109.4	596	0
88.1	31.4	600	0	60.4	107.6	589	0
87.3	32.5	609	0	39.5	107.5	650	1
77.3	41.3	652	0	31.6	101.9	666	1
11.0	48.9	718	2	11.6	119.0	709	1
11.5	46.4	720	2	11.6	119.0	689	1
17.8	61.8	728	2				

'Imaginary' Data Points

X	Y	Z1	Z2
88.5	72.3	560	18
73.7	97.4	573	7
85.5	71.7	574	6
85.7	68.8	572	8
88.8	68.2	574	6

APPENDIX B

Program Listing and Explanation

A complete listing of Surface II commands and parameters in the order and form they were used, follows.

```
DEVICE          6,'BLACK',,,,
ECHO
IDXY            425,12,5,1,2,3,,5,0,,'(2F6.1,2F5.0,F1.0)'
ROUTLINE        14,18,'(2F6.1)'
EXTREMES        0,107,0,137
PERFORM
TITLE           DATA POSTING ON X-Y COORDINATES
POST            2,0,0.1,0.1,0
SIZCONTOUR      0,6,6
BOX             1,5,1,5,0,0,0,2,0.1
POUTLINE
PERFORM
TITLE           BEDROCK TOPOGRAPHY
GRID            1,1,1,1,0,0,0
NEAR            1,4,11,15
NEAR            2,6,9,17
SAVE            13
PERFORM
ERANALYSIS      1,
PERFORM
BLANK
BOX             4.32,120,6.13,140,0,,,0,
CONTOUR         2,1,0.05,0.03,0
CINTERVAL       0,0,20,0,1,0.08,0,5,5
POUTLINE
PERFORM
TITLE           OVERBURDEN THICKNESS
ISOPACH         16,1
SAVE            15
PERFORM
CONTOUR         2,1,0.05,0.05,0
CINTERVAL       2,0,,,,0.1,0,6
LEVELS          17,14,'(F3.0,I1)'
POUTLINE
PERFORM
TITLE           BEDROCK TOPOGRAPHY  S45E,ELEV. 35, DIST. 10000
RESTORE         13
PERFORM
BLANK
PERFORM
TRANSECT        0,20,,,,1
SIZTRANSECT     30
AZIMUTH         45
ELEVATION       35
DISTANCE        10000
LINES           1,108,138
PERFORM
STOP
```

The program was run in segments as data and program were corrected of typing and programing logic errors.

APPENDIX B (continued)

Format of Explanations

COMMAND: Action invoked by command--first argument (option) used, action invoked; second argument used, action invoked;····n^{th} argument used, action invoked.

Explanations

AZIMUTH: Defines a horizontal viewing angle for a block diagram--45, viewing angle will be 45 degrees counter clockwise from the south.

BLANK: All areas as designated by outline data information will be set to an internal code such that those areas will be ignored in matrix operations.

BOX: Draws a border around a posting or contour map--1, distance between tick marks in the X-direction speci fied in grid units; 5, every fifth mark will b labeled in the X-direction; 1, distance between tick marks in the Y-direction; 5, every fifth mark will be labeled in the Y-direction, 0, no characters will appear to the right of the decimal; 0, reference value for X-axis interval labels; 0, reference value for Y-axis interval labels; 2, label all edges; 0.1, labels will have a height of 0.1 inches.

CINTERVAL: Defines contour levels and anotation--0, contour levels will be specified by parameters 2 and 3 and 4; 0, contours will be calculated from the base level of zero; 20, contour interval is 20 feet; 0, the maximum number of contour levels will not be limited; 1, each contour level will be labeled; 0.08, each contour label will be 0.08 inches high; 0, there will be no characters to the right of the decimal; 5, the minimum distance between succesive contour labels is 5 inches; 5, every fifth level will be plotted as a heavy line.

CONTOUR: Generates instructions for a contour map--2, between each pair of coordinate points there will be two intermediate points generated for drawing contours; 1, all depression areas with closed contours will be hatchured; 0.05, the length of hatchurs will be 0.05 inches; 0.03, contours closer than 0.03 inches will be suppressed (this was not working at the time of this writing); 0, bold lines will be drawn by reverse direction motion of the pen.

DEVICE: Defines which plotting device will be used and its drawing dimensions--6, device number six will be used; 'BLACK', user's name; (blank), default option on size of plotter in X-direction will be used (9999 inches); (blank), default option on size of plotter in Y-direction will be used (29.5 inches); (blank), default option on distance between plots in the X-direction will be used (4 inches); (blank), default option on distance between plots in the Y-direction will be used (4 inches).

DISTANCE: Defines distance between view point and center of a block diagram--10000, viewing distance from the point of observation in grid units of X and Y will be 10,000 units.

ECHO: A listing of all input data will be printed on the printer output.

ELEVATION: Defines the angle of observation elevation--35, viewing angle of the block diagram will be 35 degrees above the base of the diagram.

ERANALYSIS: Statistics of errors at data points will be generated--1, map error at each data point will be printed.

EXTREMES: Maximum and minimum of X and Y ranges are defined for a grid or posting--0, X minimum; 107, X maximum; 0, Y minimum; 137, Y maximum.

GRID: Estimates a grid matrix of a surface from data--1, distance between rows and columns in data units will be given in parameters two and three; 1, distance between columns; 1, distance between rows; 1, grid elements will be estimated by a distance weighted average of projected dips of the surface from surrounding data points; 0, the distance weighting function is:

$$(1-D/1.1xD_{max})^2/(D/1.1xD_{max})^2;$$

0, data will be retained (not released from memory); 0, duplicate data points will be averaged.

IDXY: Reads data information from an external file--425, a maximum of 425 data records will be read; 12, data records are located on file 12; 5, there are five fields on each data record; 1, X variable data is in the first field; 2, Y variable data is in the second field; 3, Z variable data is in the third field; (default), there are no fields containing identification numbers; 5, field five has the data point symbol code; 0, no check will be made for missing Z values; (default), code for missing Z value data (not used); '(2F6.1,2F5.0,F1.0)', data format.

ISOPACH: Initiates the differencing of two matricies--16, the second matrix is on file 16; 1, the grid matrix will be subtracted from the external matrix.

LEVELS: Defines specific levels to be contoured and their anotation (it is used if parameter one of CINTERVAL is a '2')--17, level information records are on file 17; 14, there are 14 levels and records to be read; '(F3.0,I1)', level data format.

LINES: Specifies line density on block diagram--1, the number of lines will be specified in parameters two and three; 108, perpendicular to the X-axis will be 108 lines; 138, perpendicular to the Y-axis will be 138 lines.

NEAR: Grid elements estimated from data are found by a nearest neighbor search as defined by this command--1, nearest neighbor search will be used in phase one of GRID (2, nearest neighbor search will be used in phase two of GRID); 4, the first four data points found will be used; 11, the maximum distance to the nearest data point will be 11 units; 15, the maximum search radius will be 15 units.

PERFORM: All commands listed prior to this command that have not been executed, will be executed before the commands listed after it.

POUTLINE: All outlines read in by ROUTLINE will be drawn on the map.

RESTORE: Reads in a matrix from an external file--13, the matrix will be read from file 13.

ROUTLINE: Reads in X and Y coordinates for map outlines and BLANK reference--14, read data from file 14; 18, the number of outlines to be read is 18; '(2F6.1)', data format.

SAVE: Stores a matrix on an external file--13, save the present grid on file 13.

SIZCONTOUR: Defines map dimensions--0, map size will be specified by parameters two and three in units per inch; 6, length in X-direction; 6, length in Y-direction.

SIZTRANSECT: Defines block diagram dimentions--30, the maximum dimension of the plot will be 30 inches.

STOP: Terminates all execution and closes files.

TITLE: Places a specified character string on printer output and plot labels--DATA POSTING ON X-Y COORDINATES, label is entered.

TRANSECT: Generates a perspective block diagram--0, a base will be drawn; 20, the Z range will be scaled to 20 percent of the maximum X or Y range; (default), lines will be drawn parallel to both the X and Y axes; (default), the scaling of the X and the Y axes will be the same; (default), scaling ratio (not used due to previous parameter); 1, no check for specified size of plot being reasonable.

APPENDIX C

Error Analysis of Estimated Surface

Error analysis of the estimated surface was generated by the Surface II Graphics System (Sampson, 1974) and is based on the difference between the original data value and back-calculated values from the estimated surface.

The correlation coeficient between original and back-calculated data values (Z-original vs. Z-estimate) is 0.99658. The correlation coeficient between original data and the difference between original and back-calculated values (Z-original vs. Z-original minus Z-estimate) is 0.18847. These values show a very high correlation between the original and estimated values, and very low correlation between the original and their difference. This shows the population of estimated values is very close to the population of original values with little detectable difference of estimate accuracy between high or low values.

Number of samples	425.0000
Minimum value	34.7178
Maximum value	23.9731
Mean of samples	0.5885
Standard deviation	4.7400
Variance	22.4676
Skewness	-1.1573
Kurtosis	18.2131
Class interval width	3.0000

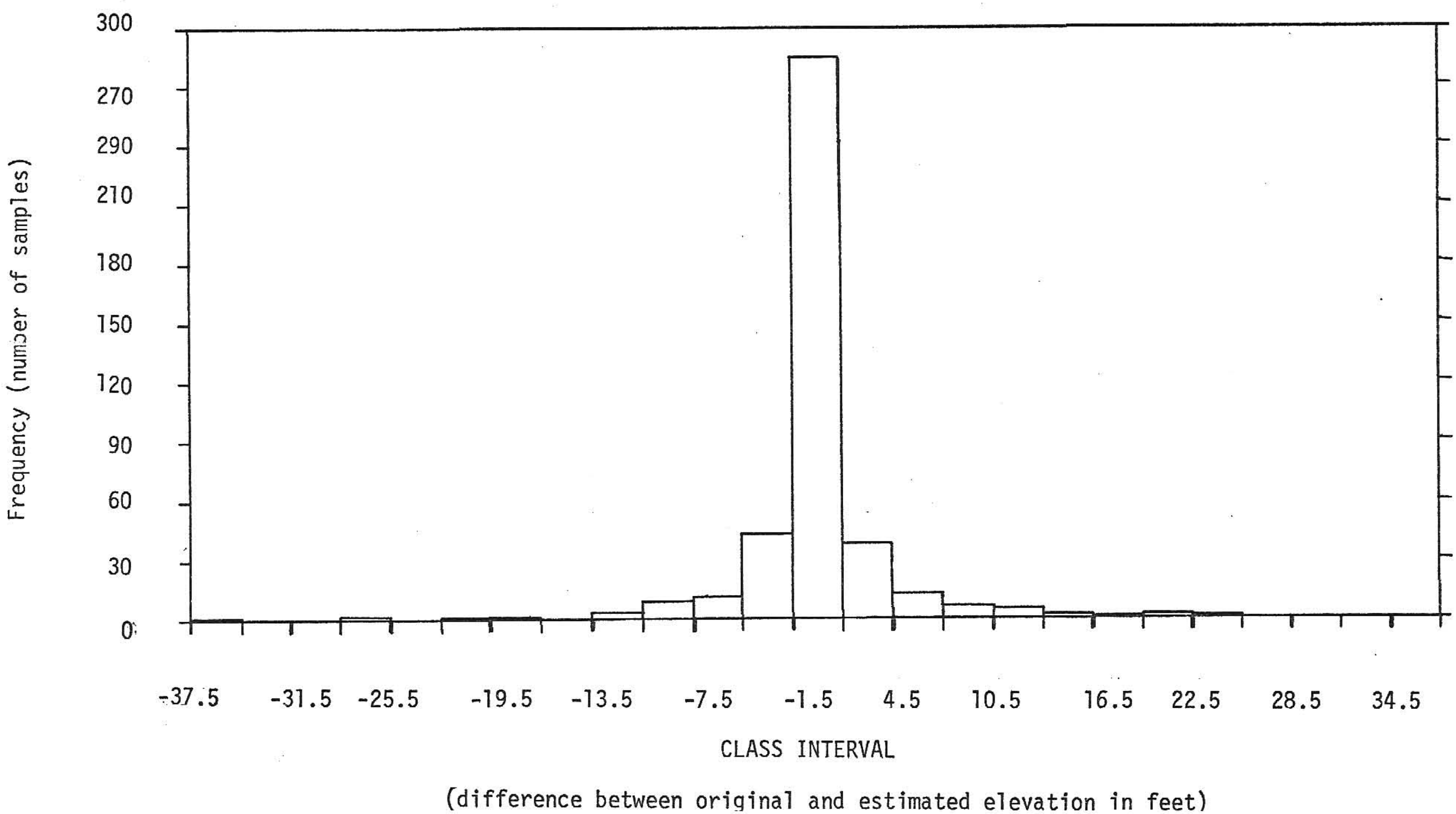
APPENDIX C: Histogram of Error Distribution

***** HISTOGRAM FREQUENCY TABLE *****

CLASS	CLASS LIMITS	STD. CLASS LIMITS	COUNT	PERCENT
-12	-37.5000 TO -34.5000	-7.9114 TO -7.2785	1	0
-11	-34.5000 TO -31.5000	-7.2785 TO -6.6456	0	0
-10	-31.5000 TO -28.5000	-6.6456 TO -6.0127	0	0
-9	-28.5000 TO -25.5000	-6.0127 TO -5.3798	2	0
-8	-25.5000 TO -22.5000	-5.3798 TO -4.7468	0	0
-7	-22.5000 TO -19.5000	-4.7468 TO -4.1139	1	0
-6	-19.5000 TO -16.5000	-4.1139 TO -3.4810	1	0
-5	-16.5000 TO -13.5000	-3.4810 TO -2.8481	0	0
-4	-13.5000 TO -10.5000	-2.8481 TO -2.2152	4	0
-3	-10.5000 TO -7.5000	-2.2152 TO -1.5823	9	2
-2	-7.5000 TO -4.5000	-1.5823 TO -0.9494	11	2
-1	-4.5000 TO -1.5000	-0.9494 TO -0.3165	43	10
0	-1.5000 TO 1.5000	-0.3165 TO 0.3165	284	66
1	1.5000 TO 4.5000	0.3165 TO 0.9494	38	8
2	4.5000 TO 7.5000	0.9494 TO 1.5823	13	3
3	7.5000 TO 10.5000	1.5823 TO 2.2152	7	1
4	10.5000 TO 13.5000	2.2152 TO 2.8481	5	1
5	13.5000 TO 16.5000	2.8481 TO 3.4810	2	0
6	16.5000 TO 19.5000	3.4810 TO 4.1139	1	0
7	19.5000 TO 22.5000	4.1139 TO 4.7468	2	0
8	22.5000 TO 25.5000	4.7468 TO 5.3798	1	0
9	25.5000 TO 28.5000	5.3798 TO 6.0127	0	0
10	28.5000 TO 31.5000	6.0127 TO 6.6456	0	0
11	31.5000 TO 34.5000	6.6456 TO 7.2785	0	0
12	34.5000 TO 37.5000	7.2785 TO 7.9114	0	0

APPENDIX C (Continued):

Histogram of Errors



BEDROCK TOPOGRAPHY AND OVERBURDEN THICKNESS OF
NORTHEASTERN ALPENA AND EASTERN PRESQUE ISLE COUNTIES, MICHIGAN

BY

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ABSTRACT

Maps of bedrock topography and overburden thickness of northeastern Alpena and eastern Presque Isle Counties, Michigan, were drawn by computer. A map of bedrock topography was also manually prepared for comparison. A geologic map was manually drawn from the bedrock topography map and outcrop data. Data were from water well logs, outcrops, refractive seismograph traverses, open-files of the Michigan Geological Survey, and private industry.

The Bedrock Topography map reveals Wisconsinan and post-Wisconsinan sink holes and a river valley. In the northern two-thirds or the area carbonate dissolution apparently prevented river development in the Late and Middle Devonian limestones and shales. In the southern one-third a river cut a valley through the Late Devonian strata.

The Overburden Thickness map shows that 70 percent of the area has less than 20 feet of overburden. The thin cover in rural areas with private septic tanks and shallow water tables poses a ground water pollution problem.