Interim Bedrock Topography Results for Lower Silver River Watershed, Fall 2002

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EXECUTIVE SUMMARY

Studies have been done on the bedrock topography of the northern (lower) portion of the Silver River watershed near L'anse, Michigan as part of a groundwater supply characterization project for Keweenaw Bay Indian Community (KBIC). This work began in the fall of 2001 and continued through the fall of 2002; the combined results are reported here. The geology of the study area mainly consists of glacial till overlying Precambrian metasediments, with diabase dikes intruding all units in a few places. The glacial till is assumed to be the best potential aquifer material. Three different sources of information have been used to find the depth to bedrock: well logs, locating bedrock surface outcrops, and seismic refraction surveys. Most work has been done using seismic refraction, due to the sparse distribution of wells and incomplete mapping of bedrock outcrops. The error in depth estimation from seismic refraction surveys is estimated to be less than one meter in most cases within the study area. Maps of bedrock topography and glacial till thickness indicate that in most places the bedrock is 0-20 feet deep, but there is a bedrock valley of about 80 feet deep in the southwest portion of the study area; this relatively deep valley is thought to be the best location for long-term pumping of groundwater. The diabase dikes may cause a significant problem for groundwater flow modeling, as they often interrupt the materials that groundwater flows through and lie perpendicular the to general flow direction in much of the study area. Use of the magnetic method may yield accurate estimates of location and depth for the dikes, as they have a strong magnetic signature.

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INTRODUCTION

Studies have been and are being done by members of the Aqua Terra Tech Enterprise on the groundwater resources of Keweenaw Bay Indian Community (KBIC). The tribe's land is centered in the L'anse and Baraga region of Michigan's Upper Peninsula. This report focuses on work done on bedrock topography in the northern, or lower, portion of the Silver River watershed (Figure 1) during the fall of 2002. This work builds on that previously done by Kenzie et al (2002).

Figure 1: Study area for this report

Bedrock topography plays a very large role in the way that groundwater travels, as well as having implications for the quantity of water available. Therefore part of the larger groundwater study is to delineate the depth to bedrock in the study area. There are three different ways to determine bedrock depths, in terms of horizontal and vertical locations: locating wells described in published well logs, locating bedrock outcrops (where the surface elevation is equal to the bedrock elevation), and by performing geophysical investigations. The first two methods are preferred to geophysical surveys, since they involve direct measurements of bedrock elevation. However, in very large portions of the study area, there are no wells and bedrock outcrops are either sparsely distributed or difficult to find (usually both). Therefore we rely quite heavily on geophysics, specifically seismic refraction surveys. Seismic refraction allows us, in most cases, to make estimates of the depths to the water table and bedrock surfaces.

This report summarizes the work on bedrock topography that has been done in the study area through the fall of 2002. During this time, a series of student groups performed refraction surveys. Since each of these groups will report on their own specific findings, this report will only deal with certain details of seismic refraction (such as error analysis), as well as the collective interpretation of the results from all groups.

GEOLOGY AND HYDROGEOLOGY

The Silver River watershed region’s geology is very similar to that described for the nearby Sturgeon River watershed, which has been described by Cannon et al (1980). Glacial till of varying thickness covers the entire study area, except where eroded away by the river. The till is made up of sand, silt, clay, and boulders, and is quite heterogeneous both vertically and laterally.

The glacial sediments cover various types of Precambrian bedrock. In the extreme northwest portion of the Silver River watershed (in the Ford Farm Road area), Jacobsville Sandstone is present. Nearly everywhere else, the watershed consists of rocks of the Michigamme Formation, which is made up of quartzite, metagraywacke, and slate.

At least two Keweenawan diabase dikes outcrop in the lower Silver River watershed, in places forming narrow ridges about 2-3 meters higher than the surrounding terrain. The known dikes are located in the southern portion of the study area.

The flow of groundwater in the Silver River watershed is generally south to north, with water moving down gradient to Lake Superior. The only bedrock unit that may be a good aquifer is the Jacobsville Sandstone. The metasediments of the Michigamme Formation and the diabase dikes are thought to have poor permeability, except where fractured. Therefore, the material with the best aquifer potential is the glacial till.

SEISMIC REFRACTION

As stated above, a series of working groups have performed refraction surveys during the past fall. With many different people working on the same project, it is important to keep everyone on the same page in terms of quality control, organization, and specific methods to use in the field. Toward these ends, a seismic refraction survey checklist has been developed by Drenth (2002); this checklist is included in Appendix A.

Geologic interpretation with seismic refraction is based on the fact that different materials have different seismic velocities. Table 1 (Appendix B) shows the results of Warren (1980), who did numerous refraction surveys and compared the results to nearby drill holes in the Keweenaw Peninsula. He found that the glacial till mainly has velocities around 300-400 m/s, saturated till has velocities ranging from 1300 m/s to 1900 m/s, and bedrock velocities are nearly always over 2000 m/s. Since Warren’s work was done on similar materials as those encountered in the Silver River watershed, his results have been used in this study for geologic interpretation (especially his range of saturated velocities).

Tables 2 and 3 in Appendix B display the results of refraction and outcrop location fieldwork done during the fall of 2002. The refraction data have been collected using the procedural scheme outlined in Appendix A and the geologic interpretation has been done using the velocity bounds provided by Warren (1981). Outcrops have been located in the field by GPS measurements where they are noticed close to roads and seismic survey locations.

Appendix C represents an attempt to roughly quantify the maximum amount of error that is present in the depth calculations of Figure 2. The first section assumes that the geologic layers are planar and flat (no dip), and the arrival times are those that result from the deepest refractors encountered in the study area. It is important to recognize that the deeper the second refractor, the less accurate its estimated depth is likely to be; this is because any errors in calculating the characteristics (velocity, arrival time) of the first refractor will be included in the depth calculations for any deeper refractors. Therefore, the maximum error is most likely to occur in the data representing the deepest refractors. This analysis considers the effect of making erroneous estimates of velocities and arrival times, up to errors of 15% for these parameters. This (15%) is thought to represent the largest amount of error in the group’s measurements, and it is found that this corresponds to a maximum depth error of 0.5 meters.

A more insidious problem is known as the hidden layer problem, where the refraction from an interface goes undetected and poor depth estimates result. For example, say that the water table lies above the bedrock surface but we fail to detect it, as may happen if we use too coarse of a geophone spacing (in other words, the thickness between the water table and the bedrock surface is too thin relative to the geophone spacing). The only way to possibly eliminate this problem is to move the geophones closer to each other, so that finer detail may be observed. Figure 2 displays different causes of this problem; either a particular layer is too thin to be resolved by the geophone spacing used, or there is a velocity inversion. We are primarily concerned with the former of these situations, although certain groups have had difficulty with velocity inversions (this is usually represented by a group of “dead” geophones, as the low velocity layer forces seismic energy down instead of out and up to the geophones, despite what the figure depicts).

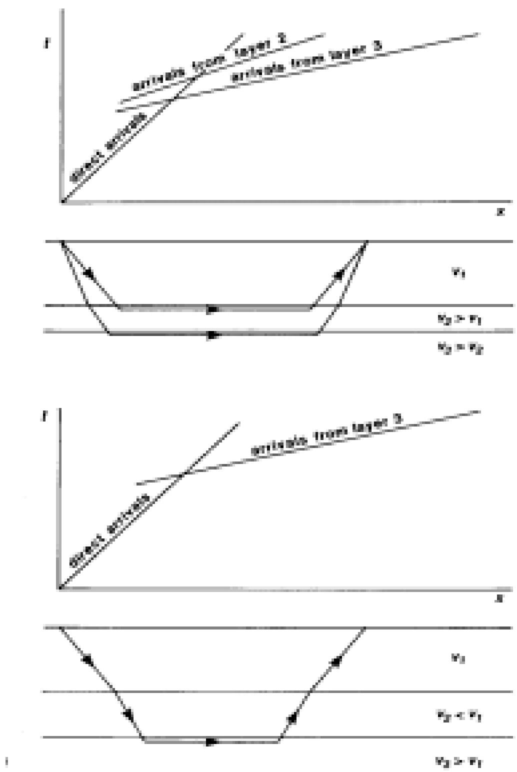

Figure 2: Different causes of the hidden layer problem; top diagram displays a thin layer, bottom diagram displays a velocity inversion (Kearey and Brooks, 1991)

The effect of a thin layer is difficult to quantify in terms of a particular geophone spacing; it is most useful to simply say that the tighter the geophone spacing used, the more likely it is that this problem will be avoided. The ideal geophone spacing for a given survey is the one that allows us to fully represent the geologic situation. There is no hard and fast guideline that can be applied across the board, rather experimentation must be used for each field survey. A quantitative example of the thin layer effect is provided in the second portion of Appendix C. This example is roughly representative of some of the deeper data collected this fall, and it is shown that the calculated depth to the bedrock is 1.8 meters too shallow when the actual depth is 10 meters. Cutting the arrival times used in the example in half would yield values that are roughly similar to those found in the more shallow data observed, and the corresponding depth estimates would be less than 1 meter above the true depth.

BEDROCK TOPOGRAPHY MAPS

Bedrock topography data has been mapped using contouring functions in GMS (Groundwater Modeling System, 1994) in two different ways: mapping the actual elevation of the bedrock surface above sea level as shown in Figure 3, and mapping the thickness of the glacial till (elevation minus bedrock depth) as shown in Figure 4.

Figure 3 shows that the bedrock surface slopes down toward the Silver River and Lake Superior throughout the study area. There seems to be a correlation between the prominent bedrock valley that trends northeast-southwest along the lower portion of the river and the shape of Echo Harbor, possibly representing a zone of relatively deep glacial erosion. Given the amount of data used to create this map, it is probably not

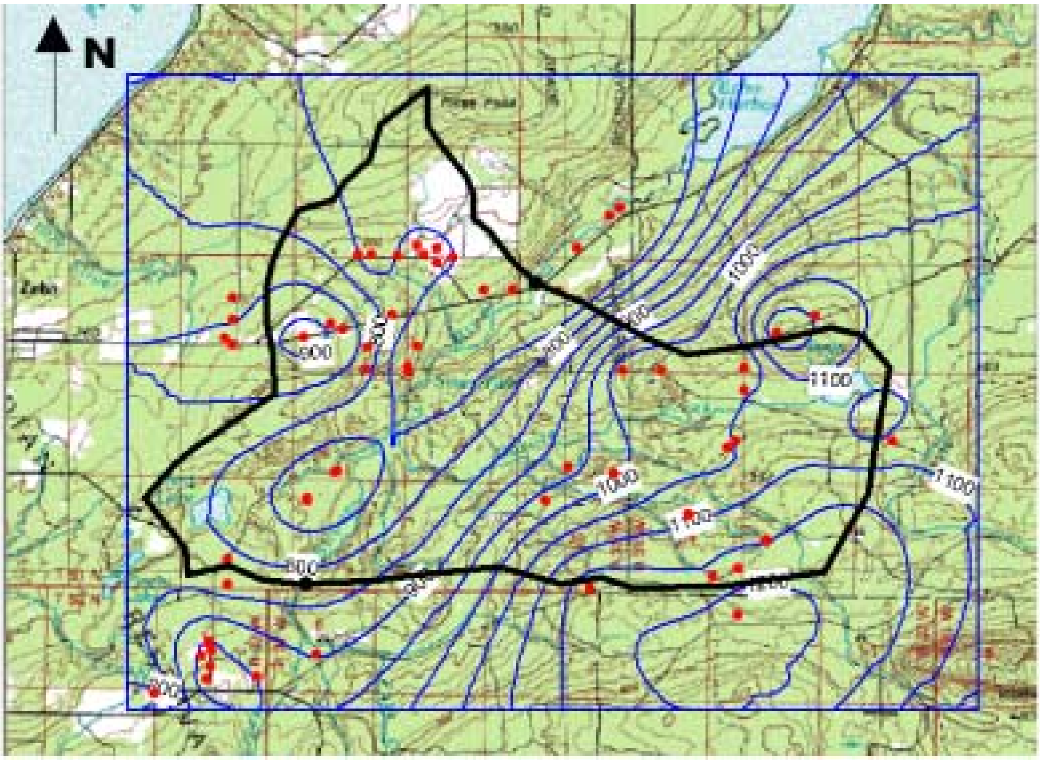

Figure 3: Bedrock elevation above sea level, contour interval 50 feet

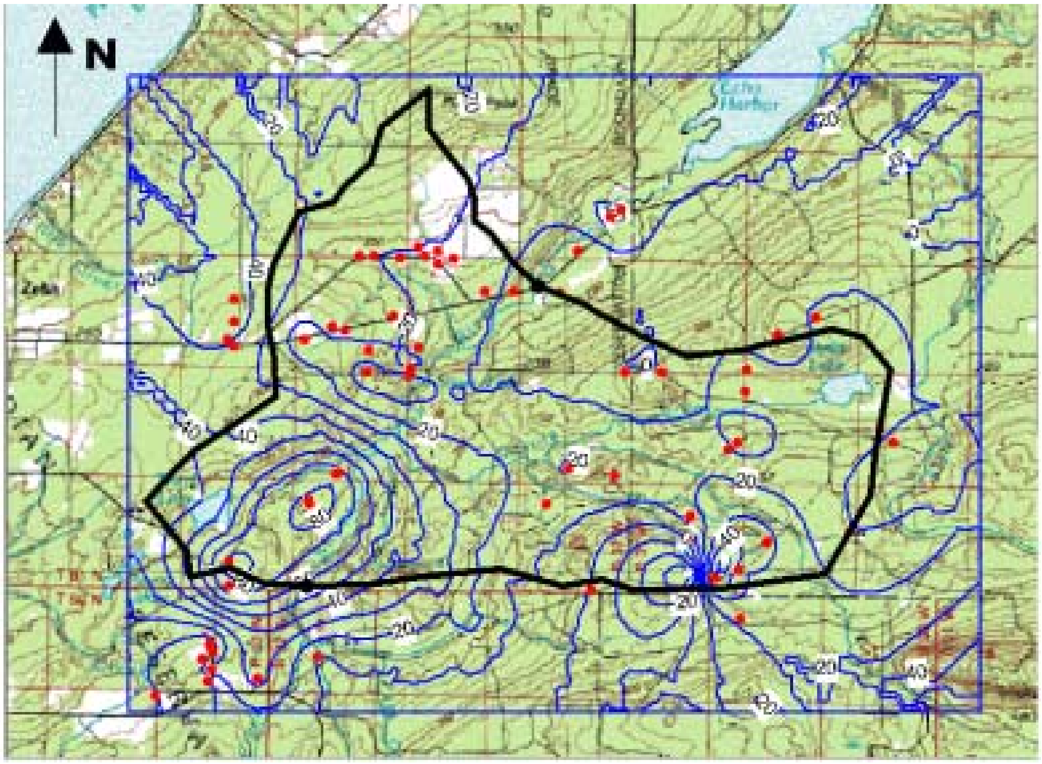

Figure 4: Thickness map of glacial till, contour interval 10 feet

reasonable to contour elevations at increments smaller than 50 meters.

More detailed trends can be seen on the glacial till thickness map, particularly the deep bedrock valley present in the southwest portion of the study area. Most other areas mapped have depths to bedrock in the 0-20 feet range, so the 80 feet of bedrock depth in this valley is quite significant. This is expected to be the best part of the study area for pumping of groundwater, due to the deep and relatively high-permeability till. Another smaller valley, about 40-60 feet in depth, has been mapped in the southeast portion of the study area. This map has been contoured at intervals of 10 feet in order to show the deep valley more clearly, but the map suffers from the small interval, with many contouring artifacts appearing.

RECOMMENDATIONS FOR FUTURE WORK

The quality and quantity of the seismic refraction measurements have been extremely important for the mapping of bedrock (and water table) topography; similar work in the future will continue to require a large amount of refraction data. The emphasis should be placed on efficiency and data quality. One idea is to pursue funding for hiring students to do geophysical fieldwork in the summer, in addition to a highly aggressive fieldwork schedule in the early and middle fall. The summer fieldwork could be very attractive to students who have just finished with Field Geophysics and are looking for a way to make money during the last month of the summer break.

Additional outcrop data (about 40 points) exist for the study area, which hasn’t been included in the results presented in this report. The reason for the exclusion of the points is that they are only represented by horizontal locations, not elevations. Therefore, elevations must be assigned to each point by careful use of a topographic map; this would be a good half semester project for a sophomore student in Aqua Terra Tech.

The diabase dikes potentially cause a very large problem for modeling. Since they strike east-west, and water in the Silver River watershed generally flows from south to north, the dikes may cause large disruptions in groundwater flow where they outcrop or otherwise cause abrupt changes in the thickness of the glacial till. A further complication is that the dikes, which can be assumed to be infinitely long, usually only outcrop along small portions of their lengths, making it impossible to surficially map their extent.

The problem may be solved by geophysics: the dikes have a very strong magnetic signature, which makes it possible to map their lateral extents; Cannon, et al (1980) provide an excellent example of using aeromagnetic data to map the diabase dikes in the nearby Sturgeon River region. Of course, merely mapping the lateral extent of the dikes isn't enough for the purposes of this study, since such qualitative interpretation of aeromagnetic data cannot say if the dikes interrupt materials (such as glacial till) where groundwater flows relatively easily. There are numerous robust methods (including Werner deconvolution, Euler deconvolution, and spectral analysis) for estimating the depths to the tops of the dikes where they don't visibly outcrop, as described by Blakely (1995). Such quantitative analysis of aeromagnetic data (Zietz and Kirby, 1971) *may* yield accurate results, although this is unlikely in most cases. Ground magnetic profiles over the dikes would be more appropriate, using the same methods of depth analysis. Seismic refraction work in the same places would aid a great deal in this sort of interpretation, as the magnetic response of the dikes could be calibrated against their lateral thicknesses. This would make a good semester or multi semester project for someone or a group of students experienced in magnetic and seismic data interpretation.

Given the relative importance of outcrop mapping, more attention should be placed on it. A highly beneficial fall field project would be to turn sophomores and juniors loose in the study area with GPS receivers, and have them literally walk all over the region. As well as locating places where the depth to bedrock is zero, they should record the rock types they encounter, allowing the development of a geologic map (which may end up having important implications for modeling, due to the different hydrologic characteristics of different rock types). An added benefit is that those people would be gaining valuable familiarity with the study area and region, which they will be able to put to good use when they are seniors doing geophysical fieldwork.

CONCLUSIONS

The geology of the lower (northern) portion of the Silver River watershed consists of glacial till overlying metasediments, with diabase dikes intruding all units in some places. The metasediments are assumed to have relatively poor hydraulic properties in terms of movement of groundwater (except where fractured), so the glacial till is thought to be the most important material from the perspective of groundwater supply. It is therefore important to map out the topography of the bedrock, by using well logs, seismic refraction, and locating surface outcrops. The maximum error associated with refraction depth estimates is likely to be one meter or less, assuming that we have adequately resolved all of the geological units for each survey. Mapping the glacial till thickness distribution shows that the bedrock in the study area is covered mostly by 0-20 feet of till, except in the southwest where a bedrock valley about 80 feet deep is present. This valley is thought to have the best potential for groundwater supply. Further work on bedrock topography measurements needs to be efficiently and carefully done; this work could be broadened to include summer workers, as well as sophomore and junior members of Aqua Terra Tech. A potentially large problem for modeling may be the presence of diabase dikes that are assumed to interrupt the continuity of the glacial till in some places. This problem may be resolved by both qualitative and quantitative analysis of magnetic anomaly data, coupled with detailed refraction data collected near the dikes.

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APPENDIX A: SEISMIC REFRACTION SURVEY PROCEDURE (from Drenth, 2002)

Seismic Refraction Survey Checklist

- for questions or assistance with any of these items, see Ben Drenth, Dr. Diehl, Dr. Young, or Dr. Gierke

Before Survey (3-4 days before)

1) reserve seismic equipment on Meetingmaker, or just tell Ben to do it
2) talk with Ben about where to go
3) check to make sure battery for seismograph is adequately charged
4) check to make sure the necessary number of geophones work (i.e. if the 24-channel seismograph is being used, 24 working geophones will be needed)
5) check to make sure inertial switch is working, and make sure you know how to replace/repair it
6) check to make sure GPS batteries are adequately charged
7) make sure you completely understand the operation of the GPS unit
8) make sure adequate memory is available on GPS datalogger
9) place all equipment on cart in Dow 420 (Dr. Gierke's lab, usually unlocked), or in Dow 315 (you will need a key to get in this room)

Equipment Checklist

1) seismograph and charged battery
2) hammer and inertial switch
3) extra inertial switch
4) working geophones (12 or 24, depending on which seismograph is used)
5) cables for geophones, battery, and hammer/inertial switch
6) steel ball or plate
7) shovel (for digging ball out of ground)
8) GPS backpack (with all 4 charged batteries inside)
9) GPS box (with datalogger, antenna, antenna-backpack adapter rod, and antenna-backpack connection cable all inside)
10) two 50 meter tapes
11) two chaining pins
12) plotting (graph) paper
13) field notebook and pencil/pen
14) clipboard
15) straightedge
16) calculator
17) maps
18) vehicle (4WD pickup or sport utility is strongly recommended when on back or 2-track roads)

19) hunter-orange clothing (Native Americans hunt all year long, and you will be partially on an Indian reservation)

During Survey

1) while running survey, make sure all first breaks are clear; if any aren't, keep reshooting/stacking until they are clear, or try adjusting the trace size
2) describe survey layout (array) in field book
3) record date, time, location, and survey layout in seismograph
4) plot forward and reverse profiles before leaving survey area and find layer velocities
5) match up velocities with geologic materials: for unsaturated soils, 200-400 m/s; for water table in soil, 1300-1600 m/s; for competent bedrock, at least 2000-2500 m/s; for fractured bedrock, somewhere between water table and competent bedrock velocities
6) if water table is not seen above bedrock, reduce the array size so that you can be truly sure that the water table is below bedrock level
7) if competent bedrock is not seen, increase the offset of the shot point or the array spacing and redo the survey; repeat until you find competent bedrock
8) take GPS readings for shot points of both forward and reverse profiles; 48 data points for each is the minimum; record file numbers in field book
9) if it rains, try your best to keep equipment dry; most importantly, **do not allow the insides of the GPS backpack to get wet**

After Survey

1) plot up data with spreadsheet and print it out
2) determine velocities and intercept times as accurately as possible
3) make sure you have reciprocity (5% maximum tolerance)
4) you may use Dr. Diehl's "seis" program to compute depths; if it says you lack reciprocity, rework the numbers
5) download GPS data and record in UTM coordinates and elevations in feet, using the NAD (19)27 datum; it is recommended that you type both sets of coordinates and elevations directly into your velocity spreadsheet
6) after you have downloaded all of your GPS data and recorded it someplace very safe (i.e. your H drive), delete your files from the datalogger so that the memory does not get filled up; clogged memory will be cause major problems with any future seismic surveys
7) email the following information to Ben (bjdrenth): UTM coordinates and elevations (in feet) of both forward and reverse shot points, depths to water table below each shot point, depths to bedrock under each shot point
8) clean mud/dirt off of all equipment used and return equipment to proper place

APPENDIX B: SEISMIC REFRACTION DETAILS

Table 1: Refraction velocity histogram from Keweenaw Peninsula (after Warren 1981):

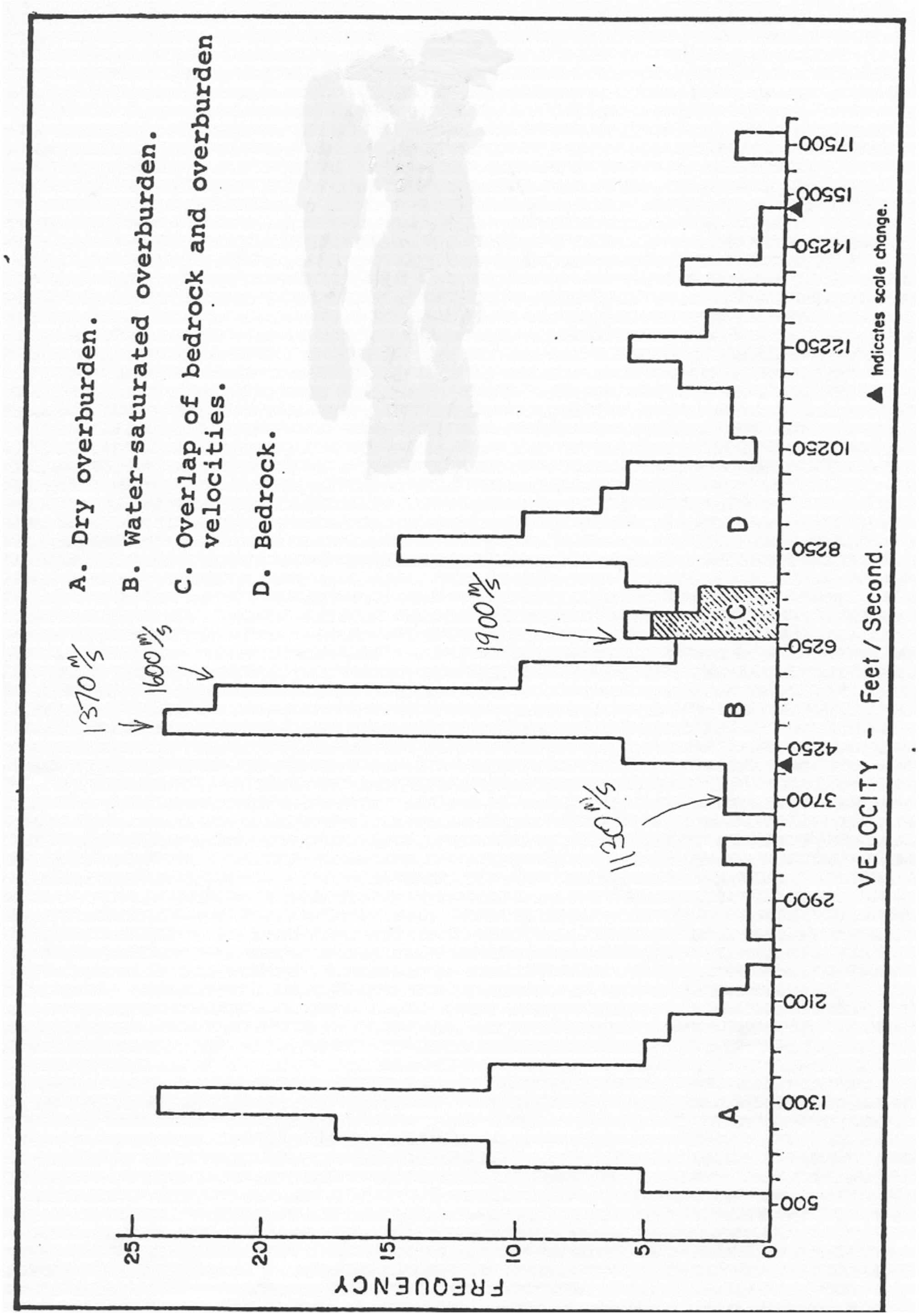

Table 2: 2002 Seismic refraction data

UTM North (ft)	UTM East (ft)	Elevation (ft)	depth to water table (ft)	depth to bedrock (ft)	water table elevation (ft)	bedrock elevation (ft)	Group	GMS Code
16997303	1318347	1107	5	18	1102	1089	Ben, Katie, Matt	gp31
16997225	1318365	1102	5	11	1097	1091	Ben, Katie, Matt	gp32
16999327	1301847	784	38	73	746	711	Darby and Jody	gp33
16999252	1301730	784	37	79	747	705	Darby and Jody	gp34
16997876	1300462	799	23	88	776	711	Darby and Jody	gp35
16998014	1300415	793	23	81	770	712	Darby and Jody	gp36
16993943	1296687	901	45	78	856	823	Darby and Jody	gp37
16994050	1296664	897	43	80	854	817	Darby and Jody	gp38
16995116	1320064	1218	13		1205		Andy and Liz	gp39
16995277	1320092	1208	12		1196		Andy and Liz	gp40
16994477	1318371	1111	18		1093		Andy and Liz	gp41
17006633	1324264	1159	11	12	1148	1147	Leslie, Josh, Yus	gp42
16994666	1295927	892	26		866		Colleen and Linda	gp44
17004193	1321001	1003	6	16	997	987	Leslie, Josh, Yus	gp45
17003128	1320988	1061	4	17	1057	1044	Leslie, Josh, Yus	gp46
16992461	1320685	1254	5	22	1249	1232	Steve and Toni	gp47
16994707	1320642	1207	1	30	1206	1177	Steve and Toni	gp48
16996580	1325899	1192		10		1182	Steve and Toni	gp49
16994337	1319525	1217	5	51	1212	1166	Colleen and Linda	gp50
16994329	1319500	1217	5	62	1212	1155	Colleen and Linda	gp51
16996056	1322015	1178	6	33	1172	1145	Colleen and Linda	gp52
16995989	1321958	1179	6	33	1173	1146	Colleen and Linda	gp53

Table 3: 2002 Bedrock outcrop data

Rock Type	UTM N (ft)	UTM E (ft)	Elevation (ft)	GMS code
diabase	17000728	1320559	1062	gp23
sandstone	17004086	1303186	821	gp24
slate	17003957	1305159	712	gp25
slate	17009798	1313109	645	gp26
graywacke	17005843	1322496	1199	gp27
graywacke	17004064	1317031	1049	gp28
slate	17004038	1315281	1045	gp29
slate	17000729	1327928	1079	gp30
diabase	16993776	1313688	1185	gp43

APPENDIX C: SEISMIC REFRACTION ERROR ANALYSIS

Seismic Refraction: Maximum Error Analysis

- if we assume that we have flat, planar refractors, then the following equations hold:

$$z_1 = \frac{t_{i2}}{2} \frac{V_1 V_2}{\sqrt{V_2^2 - V_1^2}} \quad \text{and} \quad z_2 = z_1 + \frac{1}{2}(t_{i3} - t_{i2}) \frac{V_2 V_3}{\sqrt{V_3^2 - V_2^2}}$$

where z_1 = depth to 1st refractor
z_2 = depth to 2nd refractor
t_{i2} = intercept time of 2nd layer
t_{i3} = intercept time of 3rd layer
V_1 = velocity of 1st layer
V_2 = velocity of 2nd layer
V_3 = velocity of 3rd layer

- consider a situation where we have a first layer velocity of 300 m/s, a 2nd layer velocity of 1500 m/s, and a 3rd layer velocity of 3000 m/s (all typical velocities)
- assume $t_{i2} = 40$ ms and $t_{i3} = 60$ ms (these values are similar to deepest refractions yet seen in study area; the deeper the refractor, the larger the error in estimating depth) →

- let's look at what happens if we have refractions from water table (1500 $\frac{m}{s}$) and bedrock (3000 $\frac{m}{s}$) but we make errors in estimating velocities and intercept times (we will assume that a high velocity estimate corresponds with a low intercept time estimate):

percent error in estimates of all velocity and arrival times	error of calculated depth for 1-2 interface	error for 2-3 interface
5	0.03 m	0.04 m
10	0.07 m	0.2 m
15	0.14 m	0.5 m

- I believe from personal observations of field data that we have a maximum velocity and intercept time estimation error of 10-15%; this means that given the listed assumptions we are calculating the depth of the water table-bedrock surface at ± 0.5 m, at worst (since this is "deep" data, as discussed above)
- of course, there are many other sources of error..., namely hidden layer problems

Hidden Layer Problem Example

- let's assume we have a bedrock refractor (3000 m/s) at a depth of 10 meters, and water table (1500 m/s) at a depth of 8 meters; sediments above water (300 m/s)

- the arrival time of the water table refraction will be:

$$t_{i2} = \frac{2z_1}{\frac{V_1 V_2}{\sqrt{V_2^2 - V_1^2}}} = 52.3\ \text{ms}$$

- the arrival time of the bedrock refraction can be calculated from: $z_2 = \frac{1}{2}(t_{i3} - t_{i2})\frac{V_2 V_3}{\sqrt{V_3^2 - V_2^2}}$,

$t_{i3} = 54.6\ \text{ms}$

- note that t_{i2} and t_{i3} are very similar in magnitude; its reasonable to believe that we could completely miss the water table refraction (due to too coarse of geophone spacing); if this is the case then the depth we calculate to the bedrock would be:

$$z_1 = \frac{54.6\,\text{ms}}{2}\left(\frac{300\frac{m}{s} \cdot 3000\frac{m}{s}}{\sqrt{3000^2 - 300^2}}\right) = 8.2\,\text{m} \Rightarrow \underline{\text{way off!}}$$