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SEISMIC REFRACTION MEASUREMENTS IN BEDROCK OF THE TROUT LAKE REGION OF VILAS COUNTY, NORTHERN WISCONSIN

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ABSTRACT

A seismic refraction survey of bedrock and water table elevations in the Trout Lake region were made as part of a long-term ecological research project on lake ecosystems in Vilas County, Wisconsin. The area lies within the glaciated region of Wisconsin and the glacial material directly overlies Precambrian crystalline bedrock.

Sixty-four seismic refraction spreads were completed in a grid form and covered about 110 km^2. Basically the structure is glacial till over bedrock. Analysis of the data gave a three-layer seismic structure. A top unsaturated layer with a velocity of 0.45 km/s and an average thickness of 5 m overlies a water saturated layer with a velocity value of about 1.7 km/s and an average thickness of 35 to 40 m. This saturated layer directly overlies the crystalline bedrock. Most of the bedrock velocity values obtained range from 4.0 to 6.0 km/s indicating that the bedrock lithology is probably granite with intrusions of gabbro and a sparse distribution of gneiss. Bedrock valleys were located and an east-to-west bedrock dip of less than 1° was detected. A water table map showed a regional east-to-west groundwater flow. Recharge, discharge and flow-through lakes were identified.

INTRODUCTION

Hydrogeological studies for the long-term ecological research project in Vilas County require bedrock topography. We used the seismic refraction method to determine bedrock and water table elevations and, if possible, bedrock lithology. The bedrock velocity and water table contour maps are interpreted in terms of bedrock lithology and groundwater flow directions, respectively. Details are given in Okwueze (1983).

It is well known that geophysical methods can be used to map the structure and the physical properties of earth materials. Various geophysical methods have been used in mapping basement-bedrock topography and water table elevation but the most commonly used and recommended is the seismic refraction survey (Eaton and Watkins, 1970; Fetter, 1980). This is because in most basement areas, bedrock is shallow and the contrast in the elastic properties of the subsurface rocks and the overburden is usually high. One can also use seismic methods to measure the water table when the contrast between the elastic properties of saturated and unsaturated rock is high. The contrast between the seismic velocities of saturated and unsaturated glacial materials is high in this area.

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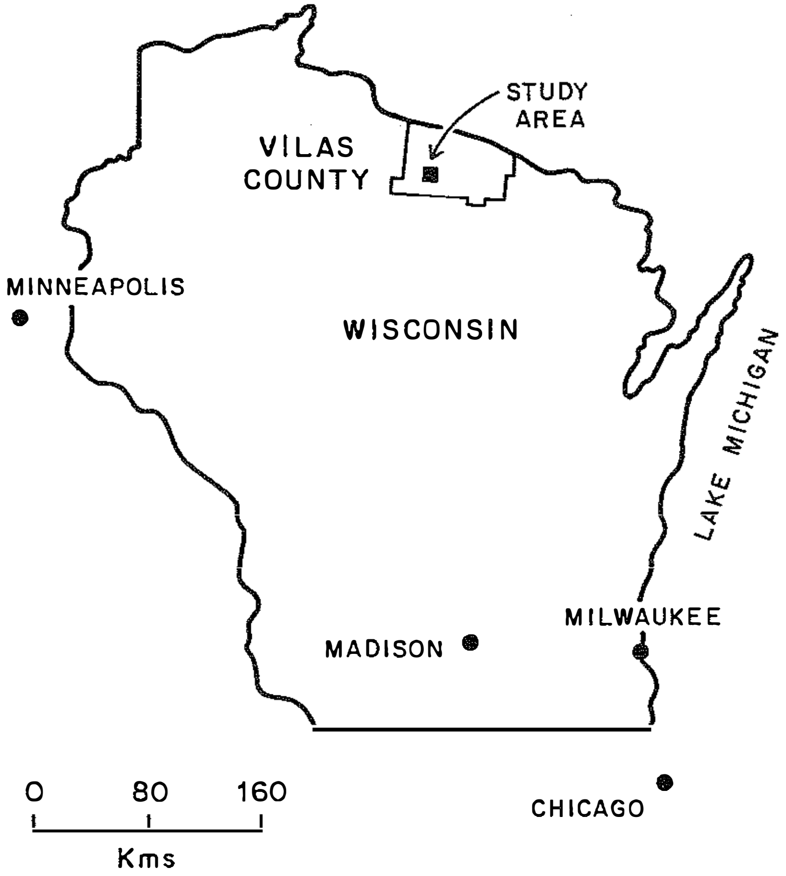

Figure 1. Location map of the study area.

LOCATION AND GEOLOGY

The survey was carried out in Vilas County, Wisconsin. Around 46°N and 89°40'W (Okwueze, 1983). The area is located about 400 km north of Madison (fig. 1), and covers an area of about 110 km^2. The surface elevation is irregular, ranging from a minimum of 493 m to a maximum of 563 m above sea level.

The geology is poorly known because glacial deposits cover the bedrock completely within the study area. The basement rock in northern Wisconsin is broadly classified into two Archean terranes: a granite- greenstone terrane and a gneiss terrane. These lie within the southern edge of the North American Shield in an area called the Wisconsin Dome (Lapedes, 1978). The bedrock within the area of the survey seems to be entirely crystalline (Thwaites, 1929) and composed of lower Proterozoic igneous and metamorphic rock units represented by granite intrusives, diorite, and gneiss (Greenberg and Brown, 1984).

The glaciation processes of the Pleistocene modified the land surface (present bedrock surface) by carving and gouging out soft rock and depositing hills and ridges of sand, gravel, silt, and clay (Attig, 1985).

MEASUREMENT AND INSTRUMENTATION

The seismic equipment consisted of a compact Nimbus ES-1210 F multichannel signal enhancement seismograph from EG&G Geometrics with recording, filtering, stacking, storage, display, and hard copy options. Repeated signals can be stacked to reduce random noise relative to the signal and to increase the signal-to-noise ratio. This is ideal for small energy sources like sledge hammer blows, which were the energy sources in this work. The Nimbus seismograph is powered by a 12 V DC battery. A single 12-geophone string with a total spread of 100 m was used during the survey. The geophones were vertical, 12-Hz types.

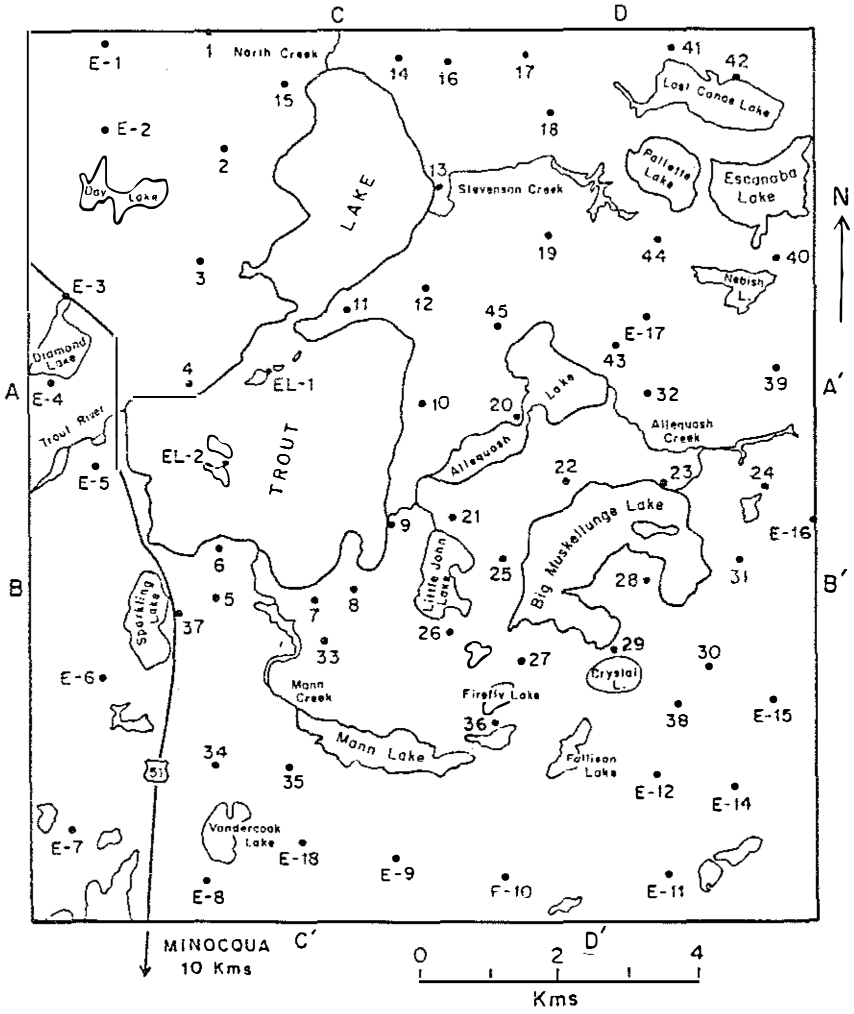

Figure 2. Map of the study area with seismic spread locations.

A total of 64 seismic refraction spreads were completed during the survey (fig. 2). The field situation did not permit a regular grid due to the inaccessibility of some pre-selected stations. The inter-station distance was an average of 1.6 km with a maximum of about 2.5 km and a minimum of 0.5 km. Reversed profiles were used in all cases. The surface elevations of all the station points were obtained by the altimeter leveling method.

DATA PROCESSING AND INTERPRETATION

A typical seismic record and its reversal are shown in figure 3. The times of arrival of seismic wavelets from subsurface refractors for the various source-receiver distances were picked directly from the records. These travel times were plotted against source-receiver distances for both forward and reverse profiles. The compressional wave velocities of various layer, depths to refractors, and dips (where applicable) were obtained from the resulting time-distance (T-X) curves. The time intercept method as developed by Hawkins (1961) was used in the calculation of the seismic parameters. For dipping refractors, the forward and reverse delay-times originating from the same point on the refractor were not equal. The formulae used in obtaining true velocities, depths, and dips in these circumstances were adapted from Mooney (1973). These estimates were used as initial values for seismic refraction modeling.

A computer program by Clay (1981), which uses the generalized reciprocal method (GRM)(Palmer, 1980), was used for the modeling. Each plot of the model curves was compared with field data. By varying and adjusting the parameters of the theoretical models, visual best fits were obtained (fig. 4). Errors were calculated by using the least squares method. Almost all of the stations had negligible dips and errors of seismic velocities were less than 1 percent. The thickness of layer 2 and the top of the bedrock are sensitive to the velocity of the layer. As shown in figure 4, first arrivals from the top of layer 2 extend from about 20 m to 60 m on both profiles. This gives good estimates of layer 2 velocities. A 1 percent velocity error gives a 1 percent depth error. For a 40 m thick layer and 1 percent error, errors of depths to the top of bedrock are ± 0.4 m. Profiles over dipping layers had larger errors and in the worst case the estimated errors of the bedrock depths were ± 4 m.

The data from the 64 stations were interpreted to determine the seismic velocity and thickness of the layers (table 1). The interpretation gave a three-layered structure. A simplified description of the results follows.

A top layer with a velocity of about 450 m/s and an average thickness of 5 m overlies a second layer with an average velocity of about 1700 m/s and an average thickness of 35 m. The change of seismic velocities from layer 1 to layer 2 are consistent with an interpretation that layer 1 and layer 2 are sand and gravel. Water saturation increases the seismic velocity from 450 m/s to 1700 m/s and layer 2 is water saturated gravel. The bottom refractor, whose velocity ranges from 3838 to 7000 m/s, corresponds to velocities generally associated with crystalline rock. The bedrock underlies layer 2 at an average depth of 40 m but varies between a minimum of 28 m to a maximum of 64 m below the surface.

The depth of the bedrock and top of layer 2 varied widely throughout the survey area and maps have been prepared to show this variation distinctly. An

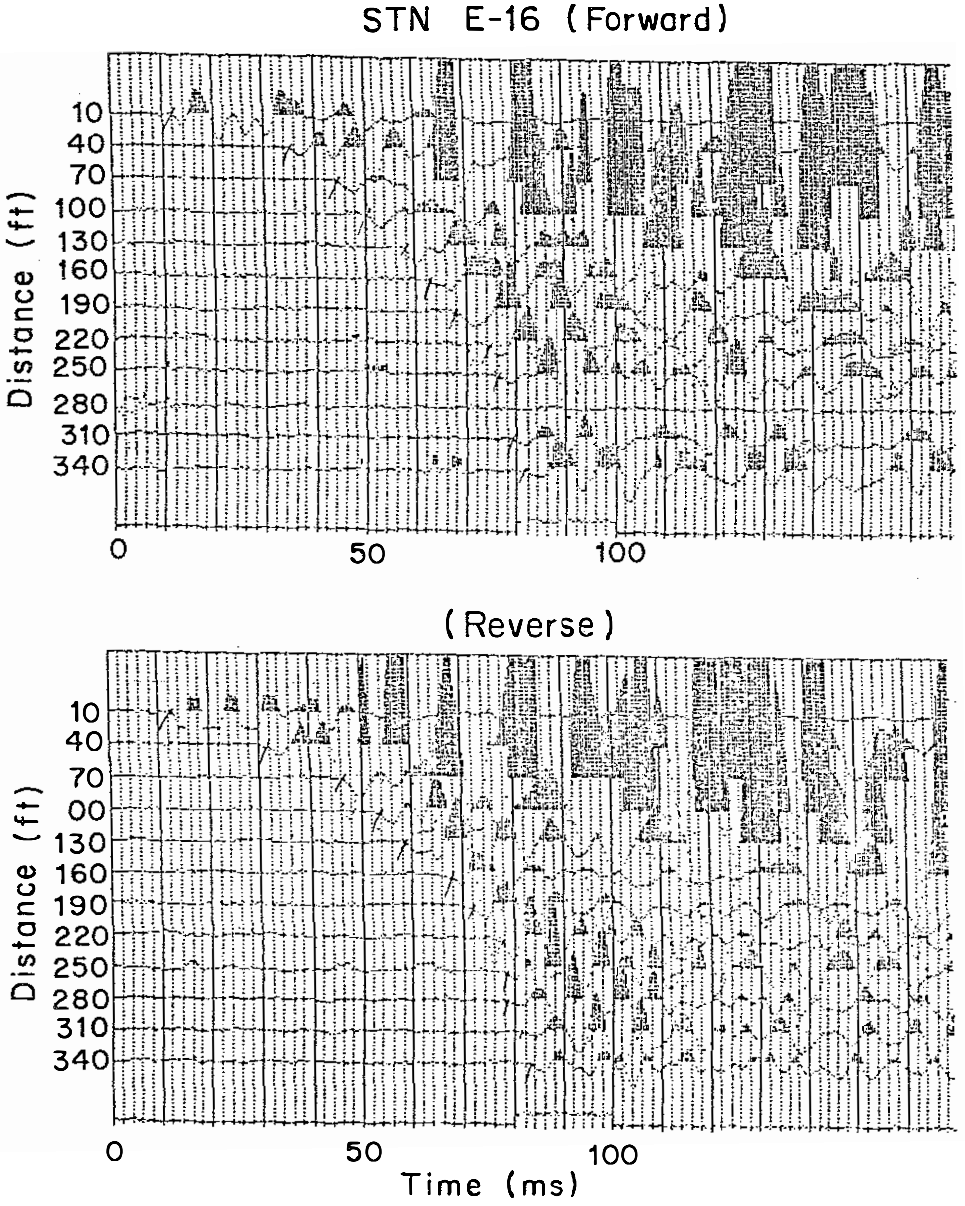

Figure 3. Typical refraction records obtained during the survey for station E-16. The original measurements were in feet along the spread. We retain these distances for simplicity in the figure.

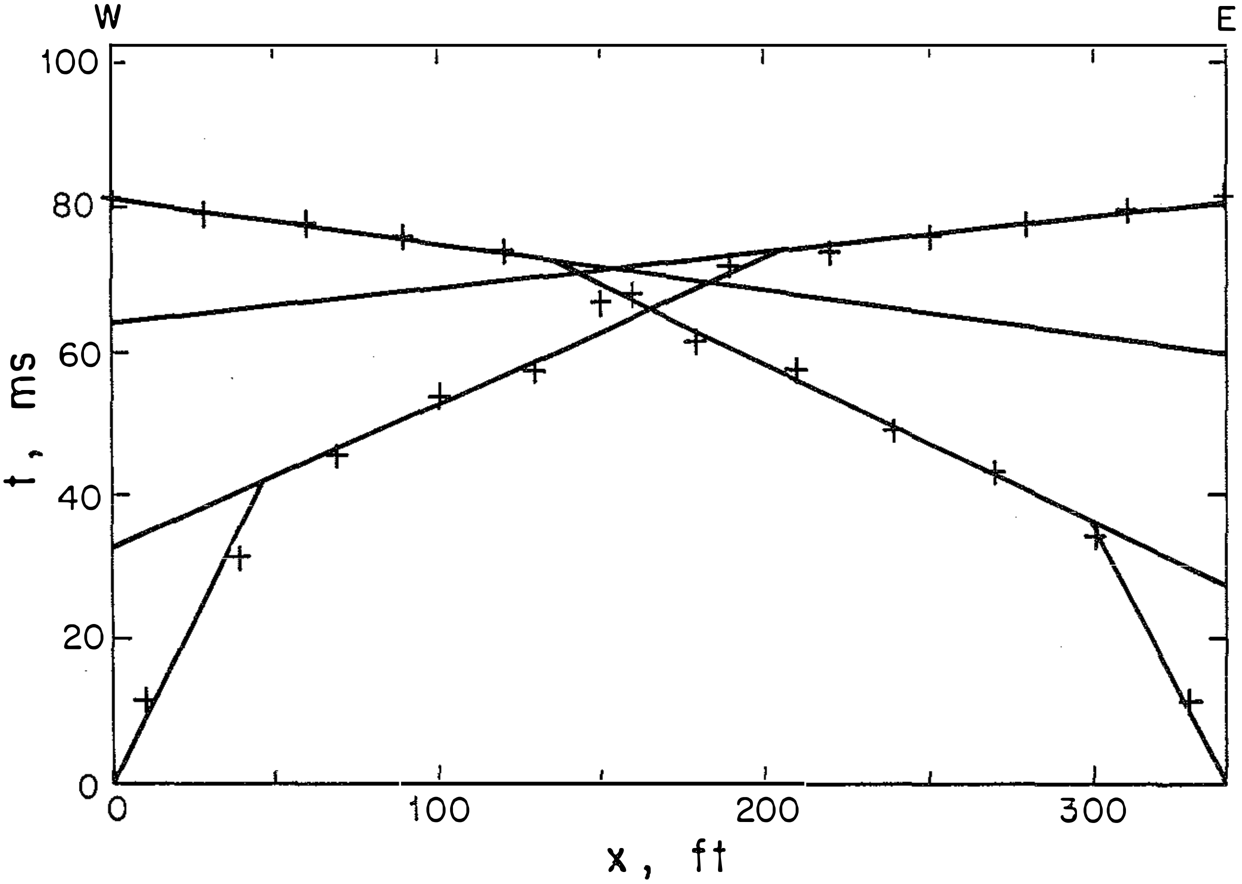

Figure 4. Typical time-distance (T-X) curve from station E-16.

elevation contour map of the top of layer 2 has been presented as a water table map showing the variation of the water table elevations at the various stations and the groundwater flow directions (fig. 5). The map showed a regional east-to-west groundwater flow. Trout Lake was identified as a discharge lake; Escanaba, Lost Canoe and Crystal as recharge lakes; and the rest as flow-through lakes.

Direct measurements of water table elevations were made at 8 of the seismic stations (Galen Kenoyer, verbal communication, 1982; Gary Patterson; verbal communication, 1982). Table 2 shows a comparison of the refraction data and the direct measurements. The seismic measurements were made a year earlier. Even so, the largest difference is a meter.

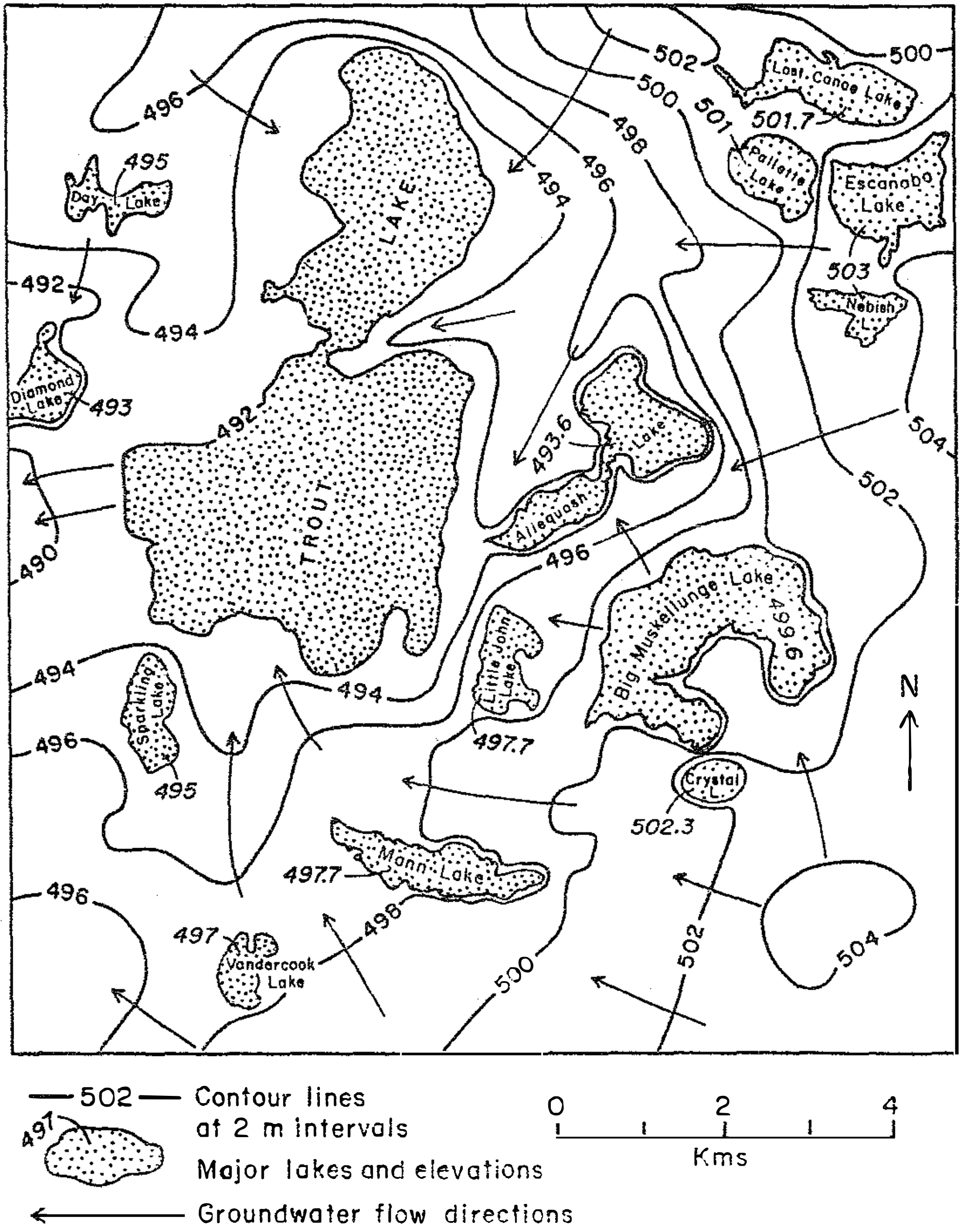

Figure 5. Water table elevation map from refraction data, Trout Lake area, northern Wisconsin, summer of 1982.

Table 1. Summary of results from refraction survey (Summer 1981 and 1982).

Station	Surface Elevation (m)	Water Table Elevation (m)	Bedrock Elevation (m)	Bedrock Velocity (m/s)
1	505	497	463	5425
2	505	494	461	4724
3	516	495	459	5486
4	499	492	440	5822
5	499	493	457	4877
6	497	492	462	4689
7	504	494	453	4724
8	504	493	451	5410
9	494	492	463	4572
10	499	494	455	5080
11	500	494	459	6096
12	500	495	459	5125
13	494	492	452	4570
14	503	497	463	4570
15	498	492	466	4907
16	504	499	473	5212
17	507	502	469	4663
18	506	499	467	4397
19	511	497	475	5791
20	497	494	465	5182
21	504	497	470	5273
22	510	498	473	5334
23	504	500	458	4877
24	504	501	476	4877
25	507	497	465	4572
26	508	499	461	4570
27	505	500	455	4953
28	506	501	462	4816
29	504	501	454	4877
30	509	502	466	5182
31	509	502	479	4877
32	512	500	477	5486
33	501	497	448	4785
34	512	496	448	5624
35	512	497	457	5029
36	505	500	447	6096
37	498	494	447	6020
38	510	503	470	5639
39	515	504	482	4877
40	520	505	475	3992
41	512	501	464	5525
42	509	500	464	4511
43	506	499	475	6218
44	506	499	476	4648
45	506	496	473	5517
E-1	501	495	471	3658

Table 1. Continued.

Station	Surface Elevation (m)	Water Table Elevation (m)	Bedrock Elevation (m)	Bedrock Velocity (m/s)
E-2	504	496	473	3962
E-3	497	490	461	6066
E-4	495	491	460	5182
E-5	494	491	458	4572
E-6	503	497	463	3818
E-7	508	494	460	4572
E-8	508	498	463	4633
E-9	524	-	474	4224
E-10	530	-	474	4267
E-11	512	503	473	5700
E-12	527	504	478	4572
E-14	515	506	479	6096
E-15	518	503	459	4724
E-16	508	503	480	5396
E-17	507	501	471	6197
E-18	513	-	471	4572
EL-1	492	492	457	7000
EL-2	429	492	452	4932

Table 2. Comparison of head values obtained from direct measurement and seismic measurements, summer 1981.

	Water table elevation (m)	
Station	Observed	Geophysical
4	492.6**	492
23	500.8*	500
24	502*	501
25	498.6*	499
27	500.5*	500
29	501.7*	501
30	502*	502
41	501.5**	501

* Galen Kenoyer, measurements - summer 1982
**Gary Patterson, measurements - fall 1982

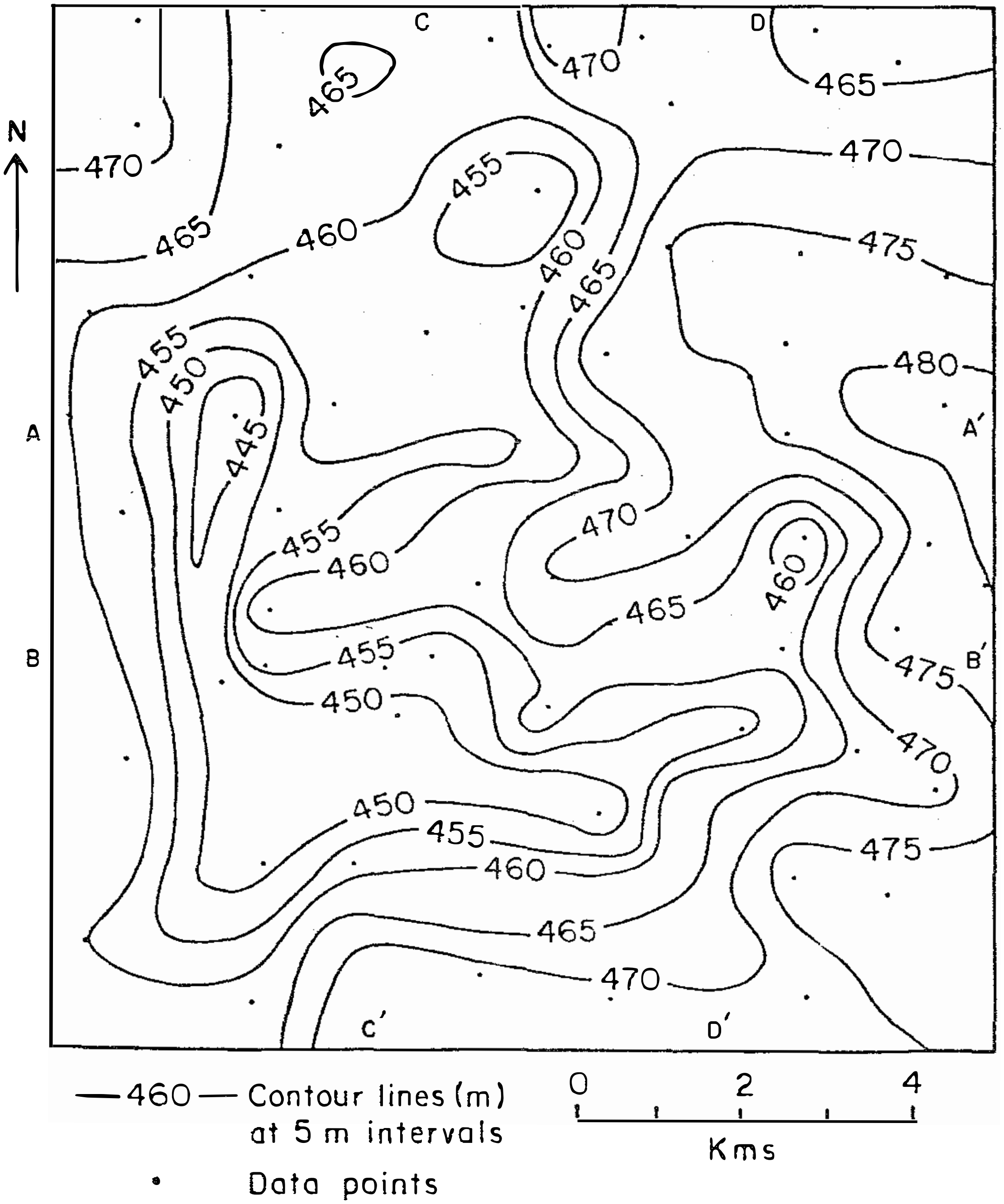

Figure 6. Bedrock elevation map from refraction data, Trout Lake area, northern Wisconsin.

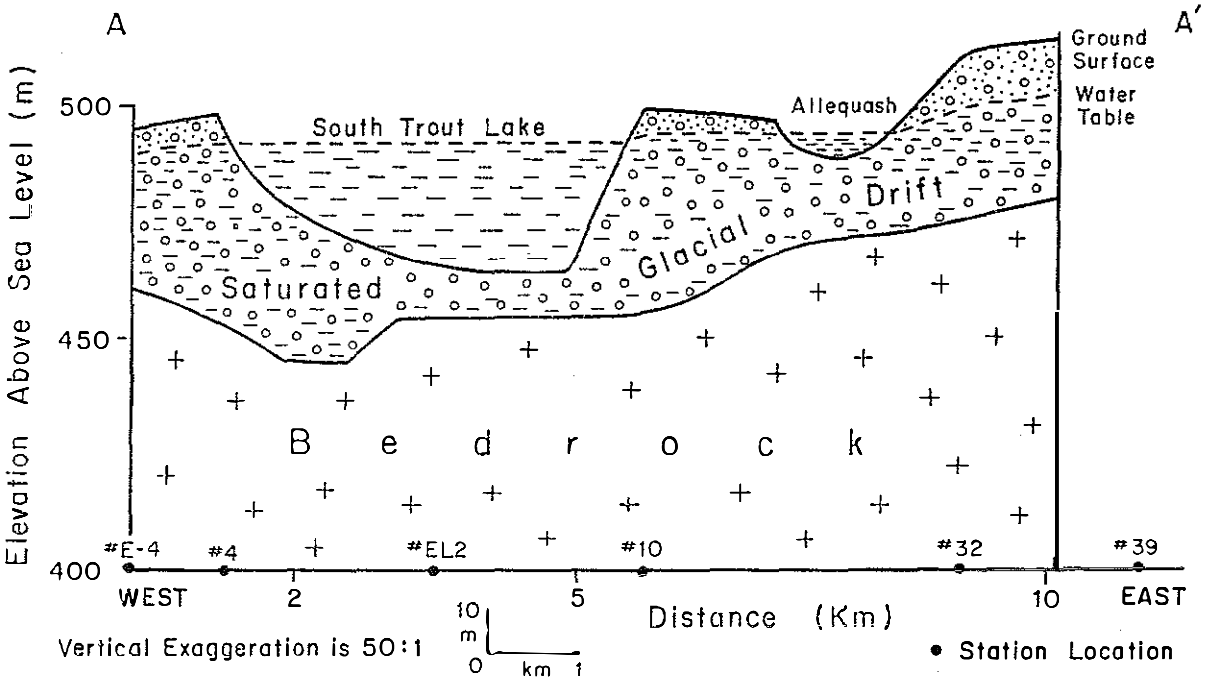

Figure 7. Geologic cross-section along AA' (fig. 2).

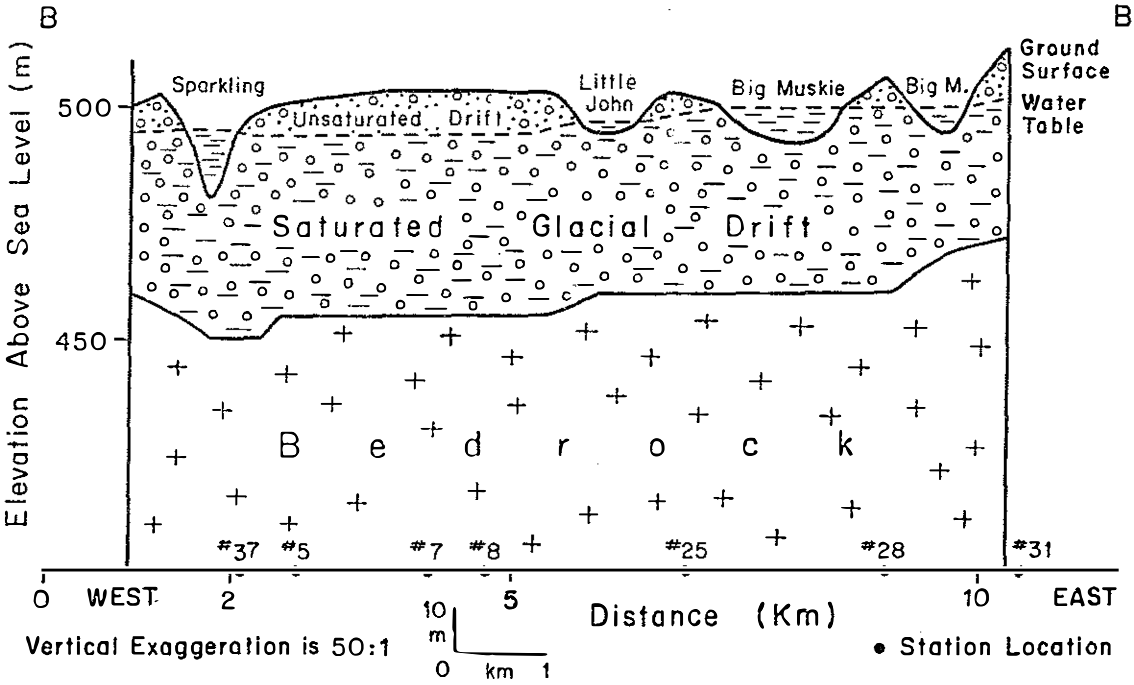

Figure 8. Geologic cross-section along BB' (fig. 2).

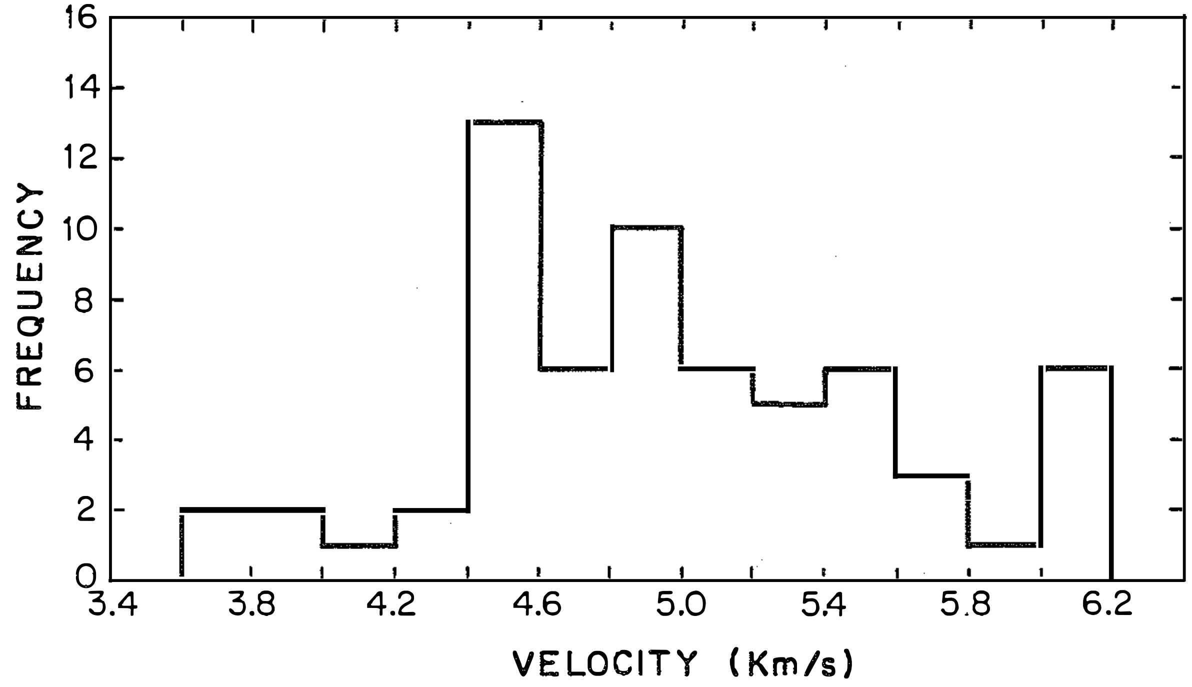

Figure 9. Frequency distribution of bedrock velocities in the study area.

Figure 6 shows the elevation contour map of the bedrock. Bedrock valleys are distinctly present on the map. An east-to-west dip of about 1° was calculated for the study area. Two seismic cross-sections (fig. 7 and 9) prepared from AA' and BB' traverses (fig. 2) show the bedrock surface and the layer 1-layer 2 structure in an east-west direction.

A wide range of bedrock velocities were obtained during the survey. A frequency distribution of the velocities is shown in figure 9. A contour map of bedrock velocities is shown in figure 10. Most of the stations had bedrock (layer 3) velocities in the 5 km/s range. Some stations were 5.5 km/s and greater and some were less than 4.5 km/s. Associations of rock types and seismic velocities are speculative. Using representative velocity values for different rock types (Mooney, 1973), three possible rock types are granite, gabbro, and gneiss. The identifications in figure 10 are based on this association. Whether these particular identifications are correct or not is not important. The data show significant differences in bedrock velocities in the area. These indicate that the rocks have significant differences in the physical properties.

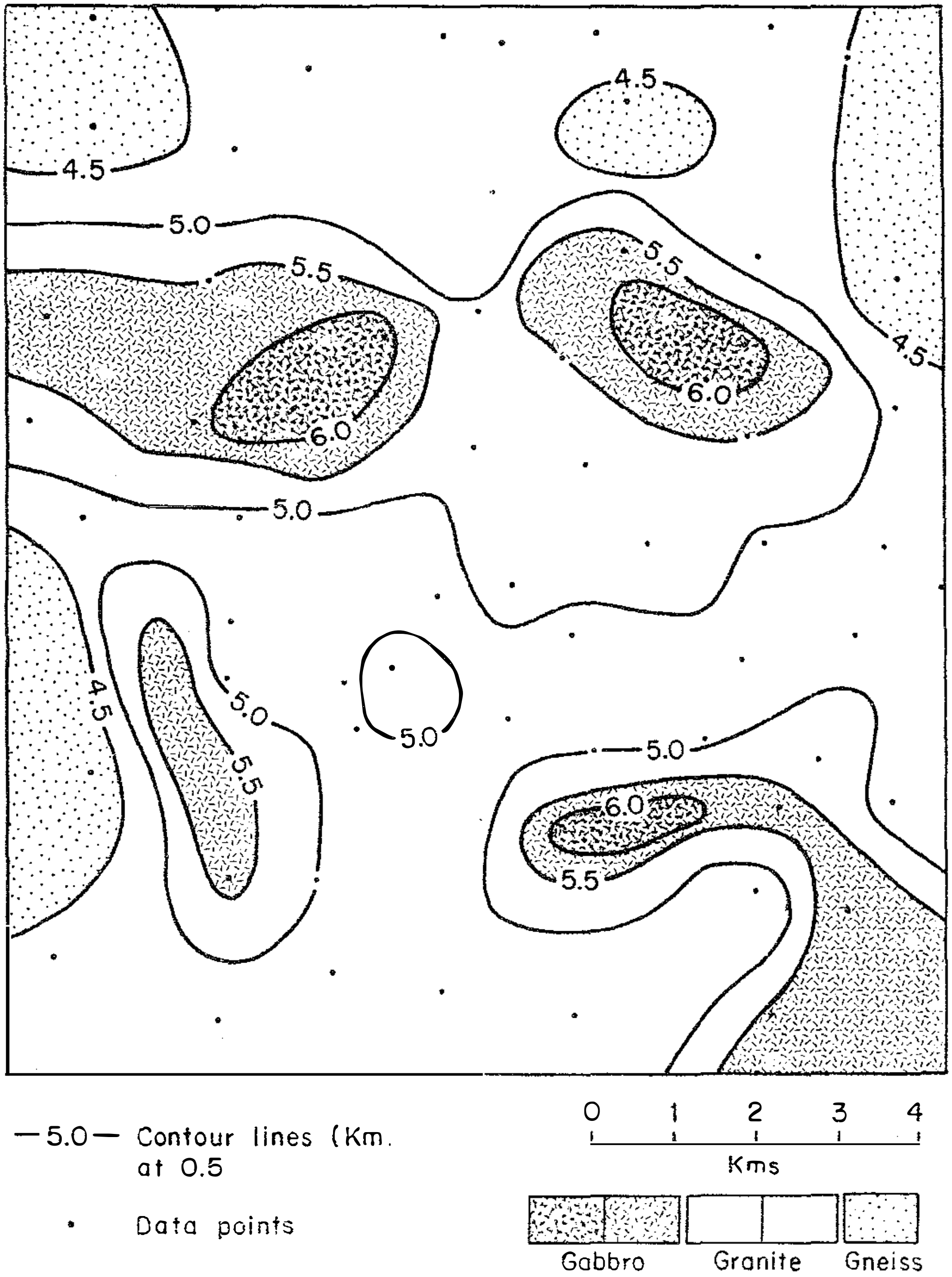

Figure 10. Bedrock velocity contour map of the study area showing probable lithology of the crystalline rock.

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