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THICKNESS OF KNOX GROUP OVERBURDEN ON CENTRAL CHESTNUT RIDGE, OAK RIDGE RESERVATION

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ABSTRACT

The thickness of residual soil overlying the Knox Group along Central Chestnut Ridge was estimated by a conventional seismic refraction survey. The purpose of this survey was to identify sites on the Department of Energy's Oak Ridge Reservation where ample overburden exists above the water table for the shallow land burial of low-level radioactive waste. The results of the survey suggest that the upper slopes of the higher ridges in the area have a minimum of 16 to 26 m (52 to 85 ft) of overburden and that the crests of these ridges may have more than 30 m (100 ft). Therefore, it is unlikely that sound bedrock would be encountered during trench excavation [maximum of 10 m (32 ft)] along Central Chestnut Ridge. Also, the relatively low seismic wave velocities measured in the overburden suggest that the water table is generally deep. On the basis of these preliminary results, Central Chestnut Ridge appears to be suitable for further site characterization for the shallow land burial of low-level radioactive waste.

1. SUMMARY

A seismic refraction survey was conducted by the Tennessee Valley Authority [through an interagency agreement with the Department of Energy (DOE)] from April 7 through April 13, 1983, as part of a low-level waste site characterization study for Central Chestnut Ridge. The purpose of this study was to make a preliminary estimate of the depth to bedrock. Continuation of site characterization at Central Chestnut Ridge would depend on the presence of ample overburden thickness [15 m (50 ft) or more] for shallow land burial of low-level waste.

Survey results indicate that ample overburden is available over most of the site. Minimum overburden thickness ranges between 6 and 10 m (20 and 30 ft) in the Knox Group near its contact with the Chickamauga Formation and between 16 and 26 m (52 and 85 ft) near the crests of the higher ridges in the area. About 6 m (20 ft) of overburden is present in a topographic saddle joining two ridges, whereas the remainder of Central Chestnut Ridge has in excess of 15 m (50 ft) of overburden, and perhaps more than 30 m (100 ft) is present in some areas along the ridge crests. Areas such as the upper Knox near its contact with the Chickamauga, valleys, and topographic saddles probably have insufficient overburden to serve as landfills. All other areas (ridges and their mid-to-upper slopes) have ample overburden.

2. LOCATION

The survey was conducted on Central Chestnut Ridge between Bethel Valley and Bear Creek Valley, about 3 km (2 miles) northeast of the main entrance (east portal) to Oak Ridge National Laboratory on DOE's Oak Ridge Reservation. Nine geophone cable positions were located approximately as shown in Fig. 1.

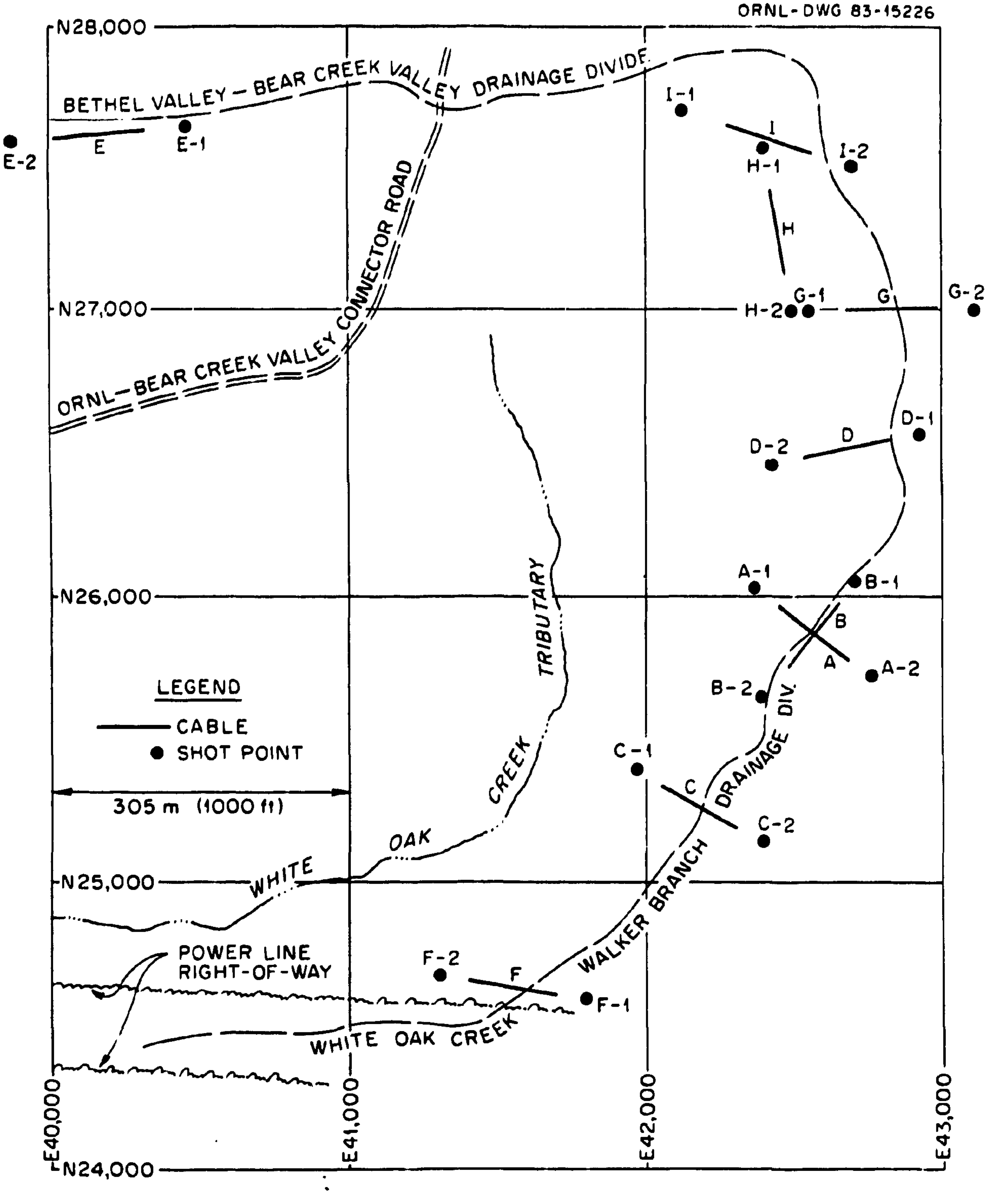

Fig. 1. Location of seismic lines.

3. SEISMIC REFRACTION TESTS

Explosive energy sources are used to generate seismic waves in the overburden and bedrock. Seismic waves are converted to electrical impulses by 12 geophones spaced evenly along a cable that transmits these impulses to a seismic recorder. The recorder (a Geometrics-Nimbus signal enhancement recorder) amplifies the impulses and simultaneously records them on tape and on an oscilloscope screen. The data on the screen can be enhanced by increasing the gain to the threshold of amplifying random noise. Data are played back off the tape to produce permanent paper records (seismograms) as shown in Fig. 2. Each seismogram is interpreted with the aid of the sharper images that appear on the screen. The first timing line on a seismogram records the instant the explosive is detonated and 100- and 500-cycle/s oscillator light signals record timing lines at time intervals of 0.01 and 0.002 s, respectively, throughout the length of the recording.

The purpose of the recording is to determine the time required for seismic energy to reach each geophone located successively farther away from the shot-point. Figure 2 illustrates the contrast between seismograms that were recorded at sites of contrasting overburden thickness on Central Chestnut Ridge. At sites where overburden is thin, refraction energy at the far end of the cable has a higher amplitude, its onset is much sharper, and it arrives much sooner.

The following seismic survey parameters were used at Central Chestnut Ridge. At each cable position, two shot-points were located approximately 7.6 m (25 ft) and either 30.5 or 45.8 m (100 or 150 ft) from the near geophone at each end of the cable (Fig. 3). Twelve geophones were spaced in a straight line at 7.6-m (25-ft) intervals. A single blasting cap, which was buried at a depth of 5 cm (2 in.), provided the energy source for the shorter (7.6-m) shot-hole offset. The purpose of the "cap shot" was to record direct arrival waves at short distances along the line of geophones. Two 0.3-kg charges of explosive were buried about 1.2 m (4 ft) deep in separate holes located about 1 m (3 ft) apart. The two charges were detonated simultaneously to record refracted waves at greater distances along the line of geophones.

Time-distance graphs as shown in Fig. 4 typically demonstrate the presence of three layers of contrasting acoustical properties. The velocity (V_p) of a compressional (acoustical) wave is given by Eq. (1):

$$V_p = \left(\frac{k + 4\mu/3}{\rho} \right)^{1/2} , \tag{1}$$

where k is the bulk modulus of incompressibility, μ is the modulus of rigidity, and ρ is the bulk density (Macelwane and Sohon, 1932). Although density does not vary appreciably as a function of depth, the bulk modulus of incompressibility varies by orders of magnitude between highly compressible topsoil and incompressible rock. Velocities of acoustical waves in the shallow subsurface are overwhelmingly influenced by the elastic moduli (k and μ).

The slopes of the lines in Fig. 4 represent reciprocal acoustical (compressional wave) velocities. The steepest slope (nearest the shot-point) estimates the velocity (V_D) of compressional waves propagated directly through highly compressible topsoil (Fig. 5). The intermediate slope estimates the velocity (V_0) of waves refracted through relatively

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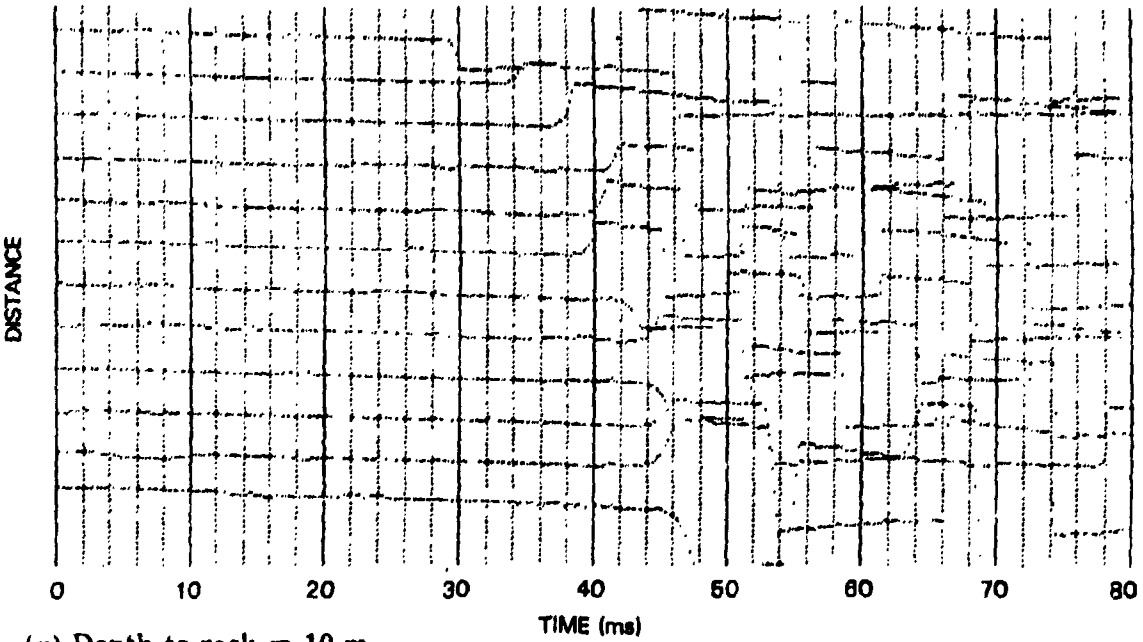
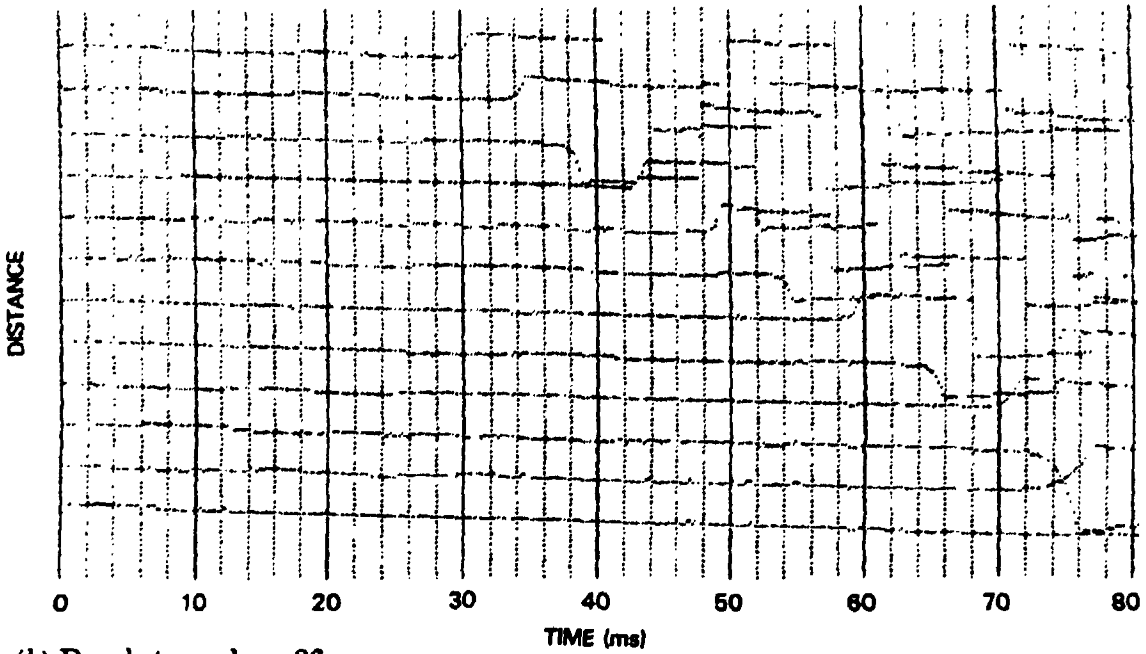


(*a*) Depth to rock = 10 m.



(*b*) Depth to rock = 26 m.

Fig. 2. Sample seismograms from Central Chestnut Ridge.

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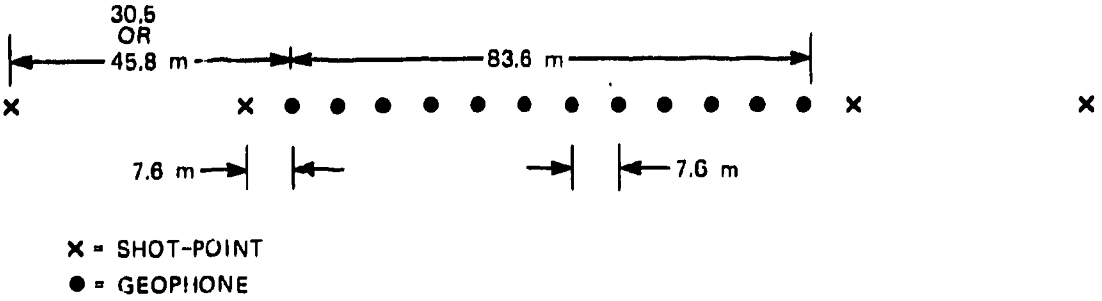

Fig. 3. Shot-point and geophone positions.

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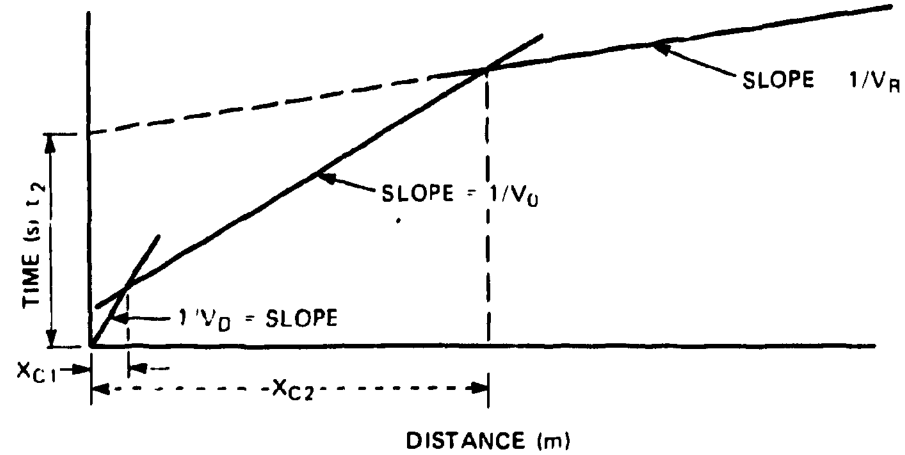

Fig. 4. Time-distance graph.

incompressible overburden at shallow depth. The gentlest slope (at the far end of the cable) estimates the velocity (V_R) of waves refracted at greater depth through highly incompressible rock along the overburden-bedrock interface or possibly along a deeper bedrock-bedrock interface.

The depth to bedrock (D_R) is determined with the use of Eqs. (2) and (3) (Dobrin, 1960):

$$D_D = \frac{X_{c1}}{2}\left[\frac{V_0 - V_D}{V_0 + V_D}\right]^{1/2} , \tag{2}$$

$$D_R = D_D + \frac{1}{2}\left[t_{12} - 2D_D\frac{\left[V_R^2 - V_D^2\right]^{1/2}}{V_R V_D}\right]\frac{V_R V_0}{\left[V_R^2 - V_0^2\right]^{1/2}} . \tag{3}$$

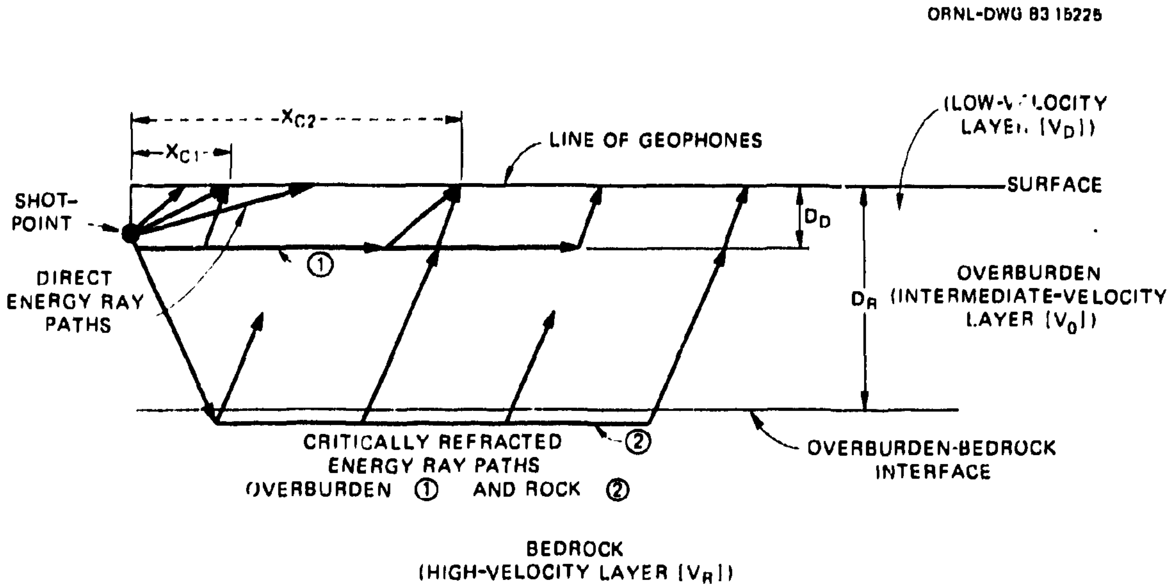

Fig. 5. Compressional wave ray paths through soil and rock (not to scale).

where D_D is the thickness of the low-velocity topsoil, X_{cl} is the critical distance (i.e., the distance from the shot-point where direct-arrival waves through topsoil and waves refracted at shallow depth through the higher velocity overburden arrive simultaneously), and t_{i2} is the intercept-time for the high-speed layer (Fig. 4). Ignoring the depth of the shot introduces an insignificant error.

Overburden and bedrock are readily distinguishable by their contrasting compressional wave velocities. The velocity in highly compressible topsoil is about 0.6 km/s (2000 ft/s), whereas the velocity through relatively incompressible overburden at shallow depth ranges between 1.2 and 1.6 km/s (4000 and 5200 ft/s). Seismic velocities in bedrock along its interface with the overburden range between 2.4 and 3.6 km/s (8,000 and 12,000 ft/s). Below the overburden-bedrock interface, higher speed compressional waves commonly reach 4.9 km/s (16,000 ft/s) and sometimes reach as high as 6.1 km/s (20,000 ft/s).

4. DATA QUALITY

Usable data were recorded at all locations. Good to excellent direct and refracted energy was recorded at all locations except cable position I (Fig. 1) where wind noise forced the operator to reduce the amplifier gains. Although the record quality in the latter case was only marginal (wind noise interfered with refracted arrivals), fairly reliable results were obtained.

5. INTERPRETATION

Measured bedrock velocities on Central Chestnut Ridge range from 3.7 km/s (12,000 ft/s) to 6.1 km/s (20,000 ft/s) with an average of about 4.9 km/s (16,000 ft/s). The variations may be caused by sloping or irregular bedrock surfaces as well as real differences in bedrock velocity.

Thin layers of slightly to moderately weathered rock generally overlie the high-speed unweathered rock. Seismic waves propagate more slowly through these layers at velocities as low as 2.4 km/s (8000 ft/s). Refracted arrivals from weathered rock are generally not identifiable on a seismogram because such layers are too thin and refracted energy from the high-speed layer overtakes refracted energy from shallower depths to become first arrivals at the more-distant geophone locations. Shallow, thin, but undetected layers of intermediate velocity are referred to as blind zones by Soske (1959). Unrecognized blind zones may result in overestimating the depth to bedrock by as much as 20%.

The critical distance (X_{c2}) is more accurately known than is the velocity along the overburden-bedrock interface (Fig. 5). Velocities of 2.4 and 4.9 km/s projected through the critical distance to the time-intercept (t_{i2}), as shown in Fig. 4, are used in Eq. (3) to calculate the minimum and maximum depths to bedrock, respectively, for each shot-point.

Table 1 is a compilation of results. The minimum depth to bedrock ranges between 16 and 26 m (52 and 85 ft) except at cable positions D and F, where bedrock is shallow [less than 10 m (33 ft)]. Cable position D was located in a topographic saddle between ridges, and cable position F was near the Knox-Chicamauga contact, where isolated bedrock surface exposures are locally present. The minimum depths to bedrock are based on speculation that a thin blind zone as defined by Soske (1959) might be present. Maximum depths (based on measured bedrock velocities and assuming that blind zones are absent) along the ridges of the area range between 25 and 38 m (82 and 125 ft). The assumption that blind zones are not present may result in overestimating the depth to bedrock by about 20%. For a given bedrock velocity, calculated overburden depths at opposite ends of a cable generally agreed within 10%. In the two cases where disagreement exceeded 10% (cable positions C and D), the differences are probably real, based on substantially differing critical distances observed when shooting from each end of the cable.

Cable position H was placed in a topographic depression near cable position G to test two hypotheses: (1) that the elevation of the bedrock surface is substantially different from that in adjacent areas and (2) that a groundwater mound exists beneath the depression. Evidence shown in Table 1 does not support the first hypothesis. The differences in overburden thickness can be accounted for entirely by differences in surface elevation between positions G and H. Evidence with respect to the second hypothesis was inconclusive. Velocities on the order of 1.8 km/s (6000 ft/s) through overburden generally suggest saturated subsurface conditions. Measured overburden velocities at opposite ends of the cable (H) were 2.0 km/s (6800 ft/s) and 1.4 km/s (4600 ft/s). No inferences can be drawn from these data with respect to a possible groundwater mound beneath cable position H.

Results of this survey are consistent with those from recent drilling activity on Central Chestnut Ridge.

Table 1. Summary of seismic refraction data

Cable location	Shot location	Depth to bedrock (m)[a]	
		Minimum (V_R = 2.4 km/s)[b]	Maximum (V_R = 4.9 km/s)[b]
A	1	25.1	33.3
	2	22.5	32.2
	Avg depth	23.8	32.8
B	1	21.0	30.1
	2	22.9	32.6
	Avg depth	22.0	31.4
C	1	21.9	31.4
	2	16.6	25.8
	Avg depth	19.2	28.6
D	1	7.9	10.1
	2	10.1	13.9
	Avg depth	9.0	11.9
E	1	25.8	37.9
	2	25.0	36.3
	Avg depth	25.4	37.2
F	1	6.7	10.3
	2	6.2	14.2
	Avg depth	6.5	12.2
G	1	22.7	33.3
	2	23.8	34.1
	Avg depth	23.3	33.7
H	1	18.7	27.6
	2	19.0	28.3
	Avg depth	18.9	28.0
I	1	16.9	27.7
	2	15.7	22.7
	Avg depth	16.3	25.2

[a] To convert meters to feet multiply by 3 28.

[b] To convert kilometers per second to feet per second, multiply by 3280.

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