United States Department of Agriculture | Soil Conservation Service | 160 East 7th Street Chester, PA 19013-6092

Subject: SOI- Ground-Penetrating Radar Field studies conducted in Machinac and Mason Counties, and at the Kellogg Biological Station, Michigan; July 24 to 31, 1991

Date: September 9, 1991

To: Homer R. Hilner
State Conservationist
Soil Conservation Service
East Lansing, Michigan

Purpose:
To conduct ground-penetrating radar (GPR) studies of selected soils in Machinac, Mason, and Kalamazoo Counties. In Machinac and Mason Counties, GPR studies evaluated the occurrence and continuity of ortstein layers in several map units. In Kalamazoo County, the GPR was used to map soils at the Kellogg Biological Station.

Participants:
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Gregory Whitney, Soil Survey Project Leader, SCS, Naubinway, MI
Charles Young, Associate Professor, Michigan Tech. Univ., Houghton, MI
Linda Barrett, Graduate Assistant, MSU, E. Lansing, MI

Activities:
All field studies followed the schedule outlined in Larry Tornes's letter of 3 June 1991. Studies were conducted in Mackinac County on July 22-24; Mason County on 24-25 July; and at the Kellogg Biological Station on 29-30 July.

Equipment:
The ground-penetrating radar unit is the Subsurface Interface Radar (SIR) System-8 manufactured by Geophysical Survey Systems, Inc. [1]. Components of the SIR System-8 used in this study were the model 4800 control unit, ADTEK SR 8004H graphic recorder, ADTEK DT 6000 tape recorder, power distribution unit, transmission cable (30 m), and the model 3110 (120 MHz) and the model 3102 (500 MHz) antennas. The system was powered by a 12-volt vehicular battery.

The 500 Mhz antenna provided the best resolution of subsurface features and was used to study ortstein. The 120 MHz antenna is less rapidly attenuated by earthen materials and was used in areas of moderately-fine textured soils at the Kellogg Biological Station.

Conclusions:
1. Though highly interpretive, the GPR can be used to study the distribution and expression of cemented layers within spodic horizons. Radar interpretations were verified to be correct in 84 percent of the excavated soils sites.

2. The GPR record confirmed the occurrence and discontinuous nature of the cemented materials (ortstein) within the selected sites in Machinac and Mason counties.

3. Soils with well expressed Bsm horizons occur in Mackinac County. However, the cemented materials (ortstein) were not observed to form a continuous or more than 90 percent cemented horizon. Use of the suffix "m" requires a horizon that, though fractured, to be "more than 90 percent cemented" and "root restrictive." The definition of ortstein stipulates that "all or part of the spodic horizon is at least weakly cemented, when moist, into a massive horizon that is present in more than half of each pedon."

In the soil profiles observed during this study, the proportion of cemented materials varied from 0 to 100 percent. Soil were moist. The Bsm horizons were about 40 percent cemented. One half of the observed soil profiles had between 25 and 60 percent cemented materials. Present standards for defining the occurrence of ortstein and the use of "m" appears too restrictive and should be reviewed.

4. Ground-penetrating radar and computer graphic techniques were used to map about 42 hectares at the Kellogg Biological Research Station.

5. Garry Paterson (Soil Scientist, Soil and Irrigation Res. Institute, South Africa) and Charles Young (Associate Professor,

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1. Use of trade names in this report is for identification purposes only and does not constitute endorsement by the authors or their institutions.

Michigan Tech. Univ., Houghton) recieved field training on the operation of the SIR System-8 radar and interpretations of the radar profiles.

All graphic profiles have been return to Dr Delbert Mokma, MSU, for further review and interpretations. It was a pleasure to work with members of your staff and I thank you for this opportunity.

With kind regards.

James A. Doolittle

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ORTSTEIN STUDY

Mackinac County

In Machinac County, soil scientists have observed, documented, and mapped soils having ortstein in areas of poorly drained Kinross (sandy, mixed, frigid Typic Haplaquods), somewhat poorly drained Au Gres (sandy, mixed, frigid Entic Haplaquods), moderately well drained Halfaday (sandy, mixed frigid Typic Haplorthods) and Croswell (sandy, mixed, frigid Entic Haplorthods), well drained Kalkaska (sandy, mixed, frigid Typic Haplorthods), and excessively drained Rubicon (sandy, mixed, frigid Entic Haplorthods). Table 1 is a summary of transect notes collected by the soil survey party prior to the arrival of the GPR.

TABLE 1

PERCENT OF SOILS HAVING ORTSTEIN
(Transects conducted by soil survey party)

	TRANSECTS			
MAP UNIT	**1**	**2**	**3**	**4**
18B - Rubicon	50%			
19B - Kalkaska	80%	100%		
20B - Croswell	90%			
61B - Halfaday	80%			
89A - Kinross-Au Gres	90%	70%	36%	

Field Procedures:
Sites were selected by the soil survey party prior to the arrival of the GPR. Table 2 summarizes the soil map units in which the GPR sites were located. Because of limited time, sites 8 and 10 were not investigated with the GPR. In addition, Site 6 was wet and the soils too attenuating for the 500 MHz antenna to be used. Sites were located in areas which were mapped and documented as having noticeable concentrations of cemented materials.

Most sites were forested. Some survey lines were located along forest access roads. Survey lines were cleared of debris and observation flags were inserted at 5 meter intervals along the survey line.

The 500 Mhz antenna provided the best resolution of subsurface features and was used to study ortstein. However, because of the strong surface pulse and clear time of the 500 MHz antenna, features within the upper 15 to 20 cm of the soil profile were masked by the surface images. The presence of a spodic horizon or an ortstein layer was difficult to discern in areas where these features occurred within the upper 20 to 25 cm of the soil profile.

In future studies, the use of a dielectric spacer or a 900 MHz antenna would provide greater resolution within the upper part of soil profiles. Experimentation with the 900 MHz antenna in areas of soils having ortstein is recommended.

TABLE 2

SUMMARY OF TRANSECT SITES

SITE	SOIL MAP UNIT
1	61B - Halfaday sand, 0 to 6 percent slopes
2	19B - Kalkaska sand, 0 to 6 percent slopes
3	89A - Kinross-Au Gres complex, 0 to 3 percent slopes
4	19B - Kalkaska sand, 0 to 6 percent slopes
5	19B - Kalkaska sand, 0 to 6 percent slopes
6*	89A - Kinross-Au Gres complex, 0 to 3 percent slopes
7	18B - Rubicon sand, 0 to 6 percent slopes
8*	19B - Kalkaska sand, 0 to 6 percent slopes
9	20B - Croswell sand, 0 to 3 percent slopes
10*	19B - Kalkaska sand, 0 to 6 percent slopes
11	19B - Kalkaska sand, 0 to 6 percent slopes

* Not surveyed with the GPR

Similar range and range gain settings were used for each transect. A scanning time of 30 nanoseconds (ns) was used on all transects. Based on calibration trials and ground-truth observations, 30 ns provided profiling depths ranging from about 1 to 2.5 meters. Soils had been moisten to varying degrees by recent rains and had estimated dielectric constants ranging from 4 to about 20. The 500 Mhz antenna was towed by hand along the ground surface at exceptionally slow speeds (@ 15 meters/minute).

Following each radar survey, the graphic profiles were interpreted and ground truth observations were made at several sites. Sites selected for additional probing often displayed unique graphic signatures which were identified and correlated with ground-truth observations. These observations provided verification of and helped to improve radar interpretations. At most of these sites small observation pits were excavated by hand and descriptions of the depth to the Bhs horizon and ortstein, thickness of ortstein layer, and the degree(s) of cementation were obtained.

Radar Interpretations:
Field verification of the radar imagery was difficult and results were highly interpretative.

The radar interpretations did not always agree with the ground truth observations. Several factors were responsible for this lack of agreement. One source of error was the misalignment or slight spatial discrepancy of the auger holes or observation pits with the radar's track or referenced positions.

The radar profiles are based upon a composite of scans averaged over a "footprint" area beneath the antenna. As radar profiles depict averaged conditions existing beneath the antenna, small features or inhomogeneities, unless occurring in concentrations, are often overlooked. The 500 Mhz antenna did not discern small cemented pellets or distinguish reflections from weakly cemented fragments. Generally profiles containing less than 10 to 15 percent cemented pellets or small fragments were interpreted as having no ortstein.

In many soil profiles, the Bsm horizon was observed to have an irregular micro-topography, and to be discontinuous and variable in degree of cementation over exceedingly short distances. These features produce spurious reflections on radar profiles and scattering losses of the radar energy.

Within the study sites, the averaged depth to the spodic horizon was about 25 cm. On most radar profiles (see Figures 1,2, and 5), the spodic horizon formed a nearly continuous interface immediately below the surface reflections. Images of the spodic horizon varied laterally in amplitude. Shifts in signal amplitudes were produced by variations in the chemical and physical properties of the spodic horizon (differences in organic matter content, moisture content, bulk density, or degree of cementation) and the presence of roots, coarse fragments. These factors made the radar interpretations difficult to verify and properties of the Bhs horizon difficult to characterize with the GPR.

On most radar profiles, the upper boundary of the Bsm was seldom observed. In areas traversed with the GPR, the averaged depth to ortstein was about 35 cm. Generally, this horizon was too shallow (25 to 50 cm) and too close to the spodic horizon to be resolved with the 500 MHz antenna. In areas where the ortstein was moderately deep (50 to 100 cm), it was more easily discerned and distinguished on the radar profiles.

Reflections from the Bhs/Bsm interface were often masked by strong reflections from the E/Bhs interface. On radar profiles, the presence of cemented materials was inferred by the appearance of multiple reflections immediately below images of spodic horizon. Multiple reflections are produced by the "ringing" or the reverberations of signals from the cemented materials. In Figures 1, 2, and 3, these reflections have been labelled with a "2" and a "3" (in boxed area).

The multiple reflections, produced by the ortstein layer, varied in signal amplitude and appearance on graphic profiles. Variations in the amplitude of these signals were caused by changes in the degree of cementation (weak to indurated), moisture content, signal interference from the overlying spodic horizon or surrounding tree roots, signal attenuation caused by differences in the dielectric properties of the overlying surface layers, and undesired signal scattering (images reflected away from the radar's receiver) produced by the segmented and irregular upper boundary of the ortstein.

Figure 1 is from an area of Halfaday soils (site 1). The spodic horizon appears as continuous images across the upper part of this profile. In Figure 1, the spodic horizon has been labelled with a "1". The intensity of this image heightens as the reflection coefficient across its upper boundary increases. The reflection coefficient of the E/Bhs interface increases with the organic matter, sesquioxide, and moisture contents, the bulk density, and the amount of cemented materials within the upper part of the Bhs horizon. Images from ortstein and cemented materials (see 2 and 3 in enclosed box) appear discontinuous and irregular in shape, vary in intensity, and occur immediately below the more continuous images of the spodic horizon.

In Figure 1, with the exception of site E, multiple reflections from cemented materials occur at each of the referenced locations (dash vertical line). At the Halfaday site, it was estimated from the radar profiles that cemented materials occurred at 70 percent of the referenced locations.

Figure 2 is from an area of Kalkaska soils (site 11). The spodic horizon appears as continuous images across the upper part of this profile. Images from ortstein and cemented materials (see 2 and 3 in enclosed box) occur beneath the image of the spodic horizon. In Figure 2, ortstein or cemented materials occur at all of the referenced locations (dash vertical line). At this site, it was estimated from the radar profiles that cemented materials occurred in 87 percent of the referenced locations. Compared with Figure 1 (Halfaday site), Figure 2 appears to have a larger and more continuous concentration of ortstein or cemented materials.

In Figure 2, images from two tree roots have been identified and highlighted ("R") in the upper left-hand corner. The underlying strata appear to be strongly contrasting (intensity of the images) and may represent lithologic discontinuities.

Results:
Ortstein was observed in 92 percent of the soil profiles excavated during this study. In the excavated soil profiles, the proportion of cemented materials varied from 0 to 100 percent (see Table 3). The average occurrence (based on a horizontal cross-section of the top of the Bsm horizon) in the profiles examined was 41 percent. The median occurrence was 40 percent. One half of the 81 soil profiles observed in this study had between 25 and 60 percent cemented materials (or between 40 and 75 percent non-cemented materials). Data reflect ortstein concentration below the present standard of half of each pedon required by **Soil Taxonomy.**

Few of the examined soil profiles contained "a subhorizon >2.5 cm that is continuously cemented by some combination of organic matter with iron or aluminium, or both."[2]. Soil profiles were moist and most had a thin (5 to 25 cm), shallow (25 to 50 cm) layer which contained cemented materials. The cemented fragments were generally irregular and elongated in shape with fairly rounded edges (except where broken). The fragments varied in size and degree of cementation. The cemented fragments varied in rupture resistance from weak to extremely strong. In some soil profiles the fragments appeared to have coalesced to formed a "continuous" layer across the bottom of the observation hole. Typically, the upper boundary of the Bsm Horizon is abrupt and irregular with numerous tongues containing materials from the overlying Bhs and/or E horizons. While cemented fragments were ubiquitous in the areas sampled, few soil profiles contained a massive horizon which was continuously cemented.

TABLE 3

DEPTH AND PROPORTION OF ORTSTEIN IN OBSERVATION HOLES ALONG GPR TRANSECTS

		AUGER	DEPTH		PROPORTION	
SITE	**SOIL**	**OBS.**	**AVERAGE**	**RANGE**	**AVERAGE**	**RANGE**
1	Halfaday	7	11"	10-13"	40%	10-80%
2	Kalkaska	13	13"	11-17"	50%	20-80%
3	Au Gres	8	13"	10-20"	36%	10-70%
4	Kalkaska	12	15"	12-19"	34%	0-90%
5	Kalkaska	8	13"	8-36"	34%	0-80%
6	Au Gres	5	16"	11-23"	17%	5-25%
7	Rubicon	5	18"	13-22"	14%	5-20%
9	Croswell	6	17"	10-35"	40%	0-80%
11	Kalkaska	10	14"	11-18"	45%	20-75%

The GPR did record and confirmed the occurrence and the discontinuous nature of the ortstein. During this study, radar interpretations were used to predict the occurrence of ortstein. This was a rather "dicey" task as interpretations were being developed and improved as the study progressed. Sixty-eight interpretations were given in advance of ground truth observations. Of the 68 interpretations, 57 correctly identified the presence or absence of ortstein at referenced locations prior to confirmation with shovels and augers. While interpretations were correct at most sites (84 percent), they erred at some sites (16 percent). In profiles having less than 15 percent ortstein pellets, the radar often failed to detect the presence of cemented features.

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2. Soil Survey Staff. 1990. Keys to Soil Taxonomy. SMSS Technical Monograph No. 19. Virginia Polytechnic Institute and State University, Blacksburg, VA. p. 22.

Table 4 compares transects notes obtained with the GPR and from the excavated pits. Differences in the proportion of ortstein can be explained, in part, by (1) variations in sample size (radar data represents all the sites along each transect, auger data were from selected sites along each transect), (2) the radar inability to detect small concentrations (<15 percent) or fragments, (3) and sampling biases. Many of the excavated pits were selected to better understand subtle variations in the imagery. As a consequence, this selection may have been biased towards profiles lacking or containing low concentrations of cemented materials.

TABLE 4

PERCENT OF PROFILES HAVING ORTSTEIN AS DETERMINED WITH THE GPR AND SOIL AUGER

		GPR		AUGER	
SITE	SOIL	OBS.	Ortstein	OBS.	Ortstein
1	Halfaday	13	70%	7	100%
2	Kalkaska	25	84%	12	100%
3	Au Gres	20	75%	8	100%
4	Kalkaska	22	46%	12	83%
5	Kalkaska	20	65%	8	75%
7	Rubicon	22	77%	5	100%
9	Croswell	9	78%	6	100%
11	Kalkaska	30	87%	10	100%

In areas of occurrence within the United States, ortstein is reluctantly mapped by soil scientists. In Machinac County, extensive areas containing well expressed Bsm horizons have been mapped. Cementation is discontinuous resulting in the formation of pellets, nodules, and fragments rather than a massive, continuous, cemented horizon. Cementation (when moist) within the Bsm horizon varied from weak to indurated. Based on my observations, few areas contain Bsm horizons as well expressed as those observed in Machinac and Mason county. However, the ortstein in these areas appears to be more discontinuous than presently allowed in **Soil Taxonomy.** Present standards for and descriptions of ortstein in **Soil Taxonomy** should be reviewed and changed.

ORTSTEIN STUDY

MASON COUNTY - Dune

A grid was established to observe the distribution of ortstein across a portion of a dune. The area selected for this study was on a north-facing slope of a dune which was crossed by a roadway. The dune was in an area observed during and early field study (see my report to H. Hilner of 15 September 1989).

The dimensions of the grid were 30 by 25 meters. The grid interval was 5 meters. Relative elevations were obtained with a transit and stadia rod at each of the 35 grid intersects. The lowest point within the grid was selected as the 0.0 meter datum. Relief was 3.4 meters.

Figure 3 is a three-dimensional surface net diagram of the study site. This diagram was prepared using the SURFER software package. All measurements are in meters. The vertical scale has been exaggerated by a factor of three.

In the 1989 trip report, the dominant soils were reported as being Wallace (sandy, mixed, frigid, ortstein Typic Haplorthods) and Groton (sandy-skeletal, mixed mesic Typic Eutrochrepts). The ortstein at this site was well expressed. Soils on the summit of the dune are excessively drained while those on the footslope are somewhat poorly drained and poorly drained.

At the time of the present study, in the lower-lying areas, the depth to the water table was observed to ranged from 1.2 to 0.3 meters. Soils were moist. Ortstein was observed on summit and backslope positions, but was absence on footslope positions.

Figure 4 is a terrain corrected radar profile of transect X=0. The profile has been processed through the RADAN software package. Along this transect line, slopes were too severe and the horizontal distance (30 meters) too short for the top surface normalization (terrain correction) program to capture the entire record. The steep slopes over relatively short lateral distances resulted in the radar profile being slightly truncated on both the summit and the footslope positions.

In Figure 4, the two continuous lines in the upper part of the soil profile (A) represent the soil surface. Immediately below this interface are several segmented images (B) from features which occurred within the upper 50 cm of the soil profile. Features responsible for these images include: the E/Bhs interface, several tree roots (immediately upslope from observation site 5 and 15), a wetting front, and layers of colluvium or overthicken surface materials (near observation site 20).

In Figure 4, a line has been drawn which approximates the upper boundary of the ortstein layer (C). This layer appears discontinuous and variable in expression over short distances. In

Figure 4, cementation appears to weakens and to become indistinct below observation site 20. Below this referenced location, the ortstein can not be traced on the radar profile.

The RADAN software allowed the editing of colors and color transforms. Colors and color transforms were used to improve the clarity of the images and interpretability of the radar profiles. Using RADAN, the amplitudes of the reflected signals can be depicted as specific colors by varying the proportion of each primary colors (red, green, and blue). The color transform defines the range of amplitudes which will correspond to a specific color. Customizing the color transform allows the establishment of various amplitude threshold values at which the color changes.

The water table is not evident in Figure 4. The adequacy of water tables as radar reflectors depends on the contrast in dielectric properties between unsaturated and saturated soil materials. In sandy soils, the capillary fringe is abrupt and, therefore, generally produces a high amplitude image. However, the narrower wavelength of the 500 MHz antenna distinguishes a large number of small, heterogeneous pockets of soil moisture within and near the capillary fringe. These pockets intercepted and scattered the energy from the 500 MHz antenna producing highly irregular and discontinuous images of the water table. With the 500 MHz antenna, the image of the water table is often difficult to detect. The water table would be apparent on radar profiles collected with the 120 MHz antenna. The 120 MHz antenna has a wider wavelength which averages the large number of small, heterogeneous pockets of soil moisture into a smooth interface.

MASON COUNTY - Saugatuck Site

A radar transect was conducted near the area of Saugatuck (sandy, mixed, mesic, ortstein Aeric Haplaquods) soils studied during the 1988 field trip. Compared with the 1988 observations, the moisture content of the soils was higher, the ortstein layer more discontinuous and containing more noncemented or weakly cemented materials.

Figure 5 is the radar profile from the transect. The spodic horizon appears as continuous images across the upper part of this profile. However, near "A", the spodic horizon appears to be interrupted. This break in the spodic horizon may have been caused by the presence of slightly wetter surface layers to the right of A. Wetter soil conditions would slow the velocity of signal propagation, alter the depth scale, and produce an apparent change in the depth of the imagery.

In Figure 5, ortstein or cemented materials (see 2 and 3 in enclosed box) occur at each of the referenced locations (dash vertical line). The ortstein layer is moderately deep (@ 60 cm) beneath observation sites 0 and 5, and shallow (25 to 30 cm) beneath observation sites 10, 15, and 20. Multiple layers of cemented materials (layers 2 and 3) occur below sites 10 to 20. The ortstein layer appears to be discontinuous and, judging from

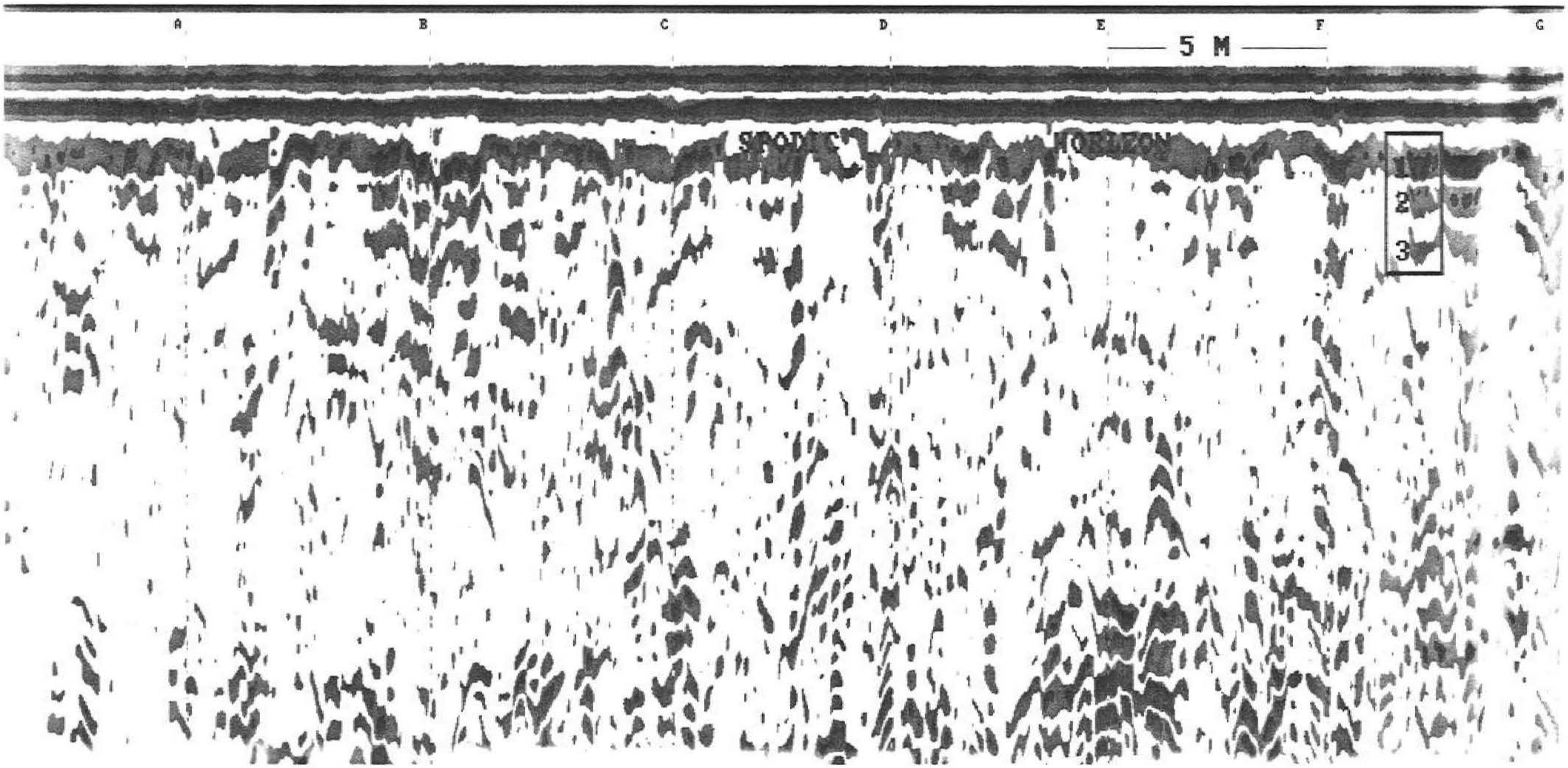

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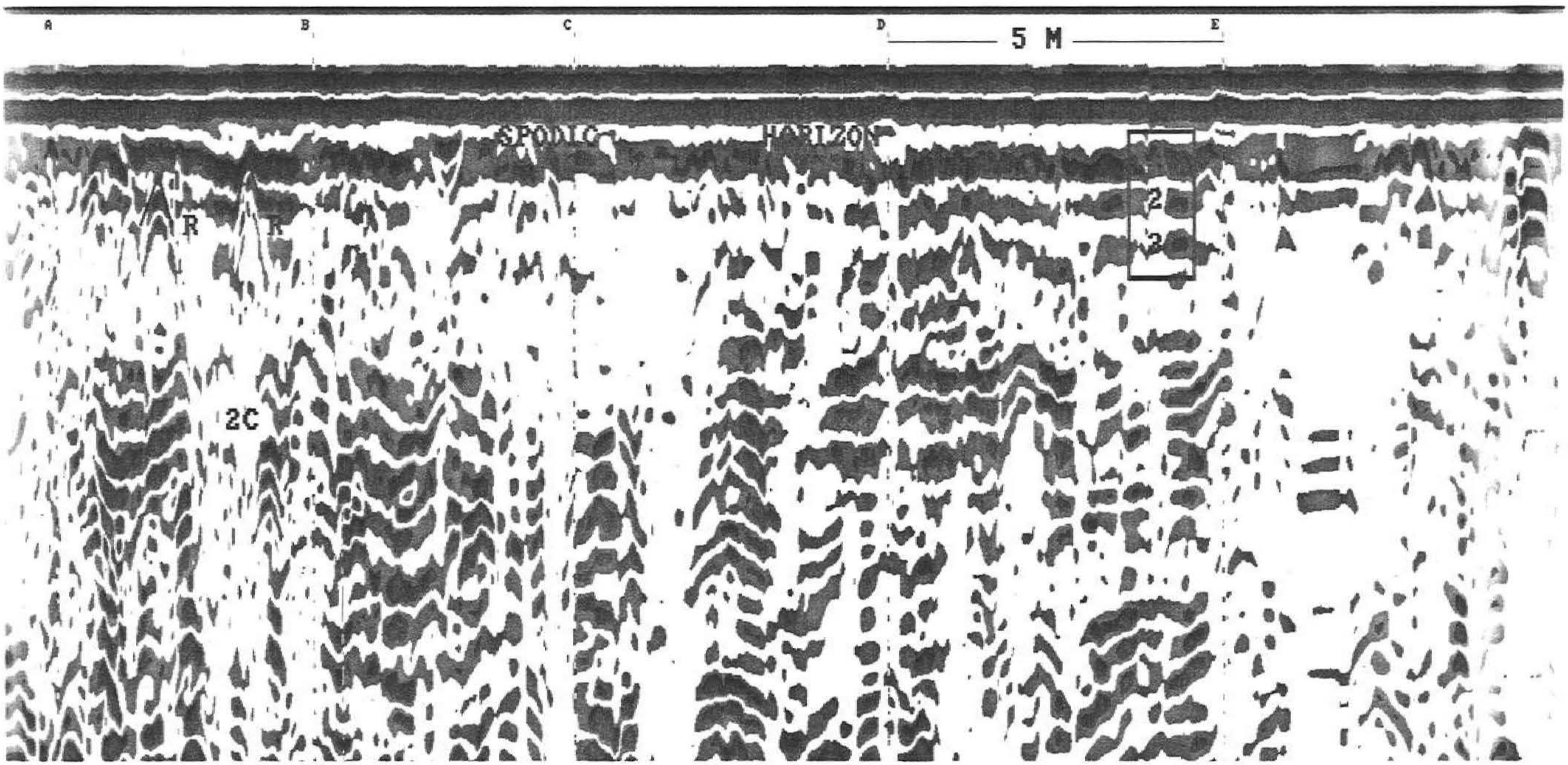
FIGURE 2



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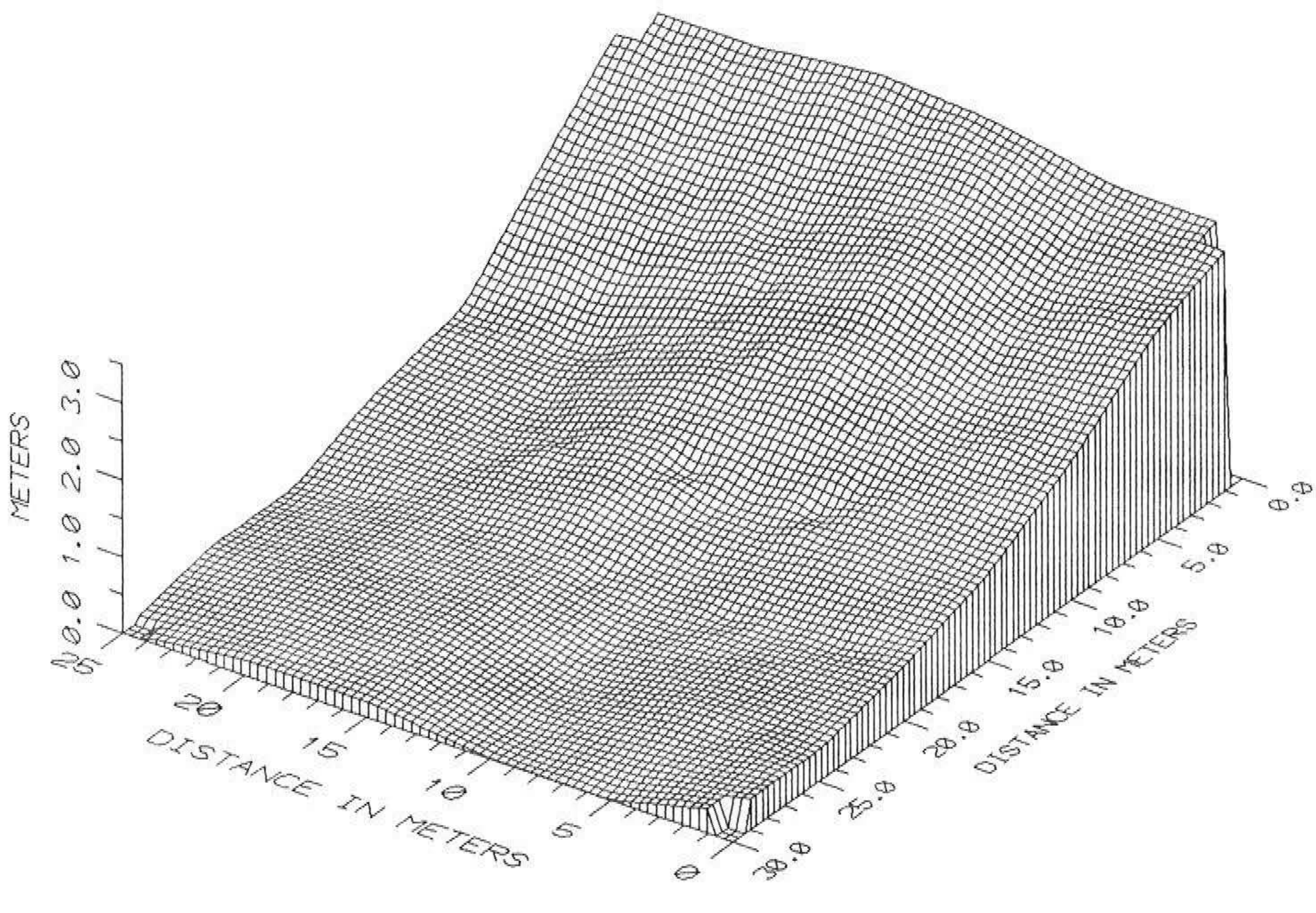
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FIGURE 4

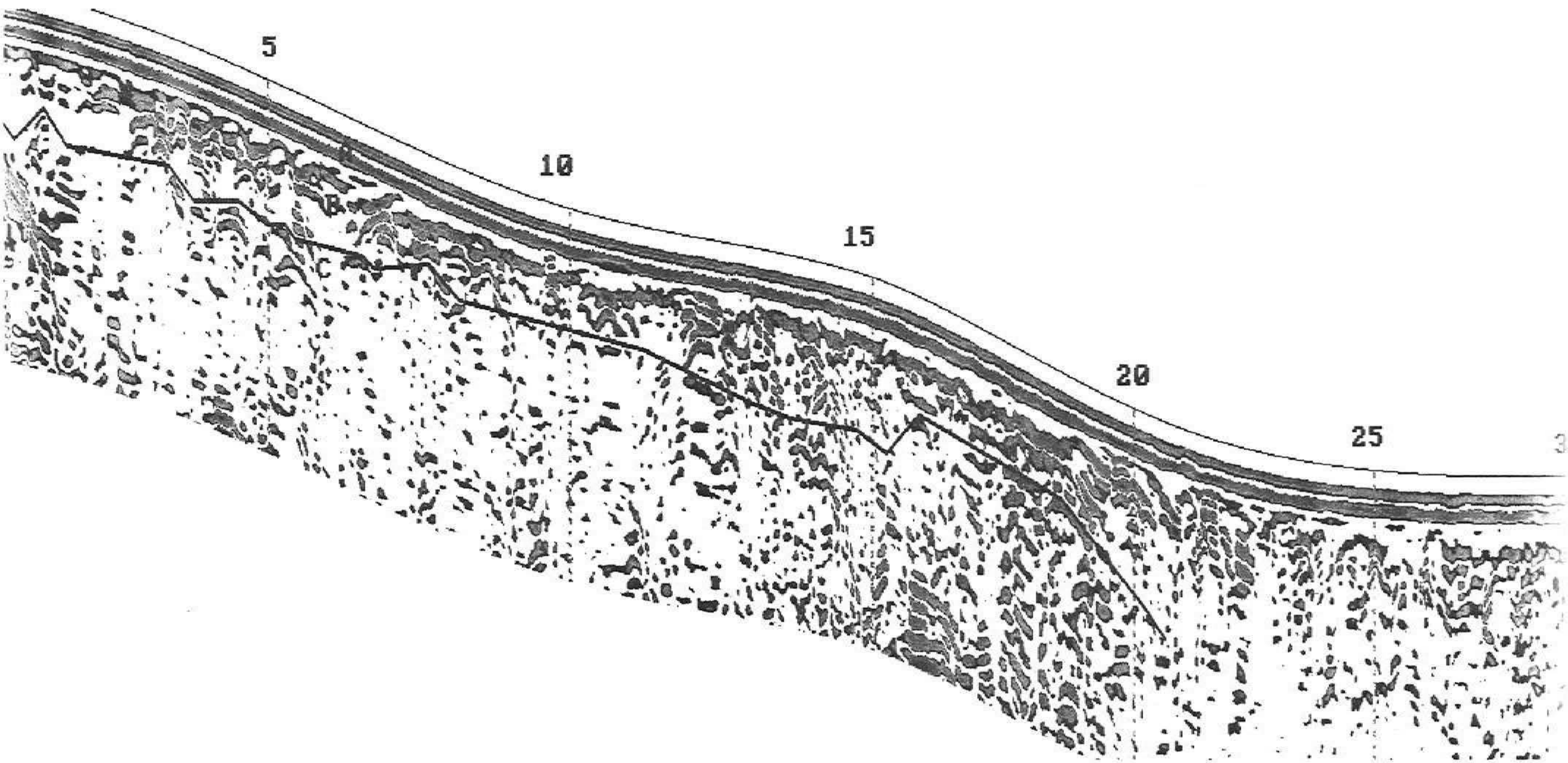


FIGURE 5

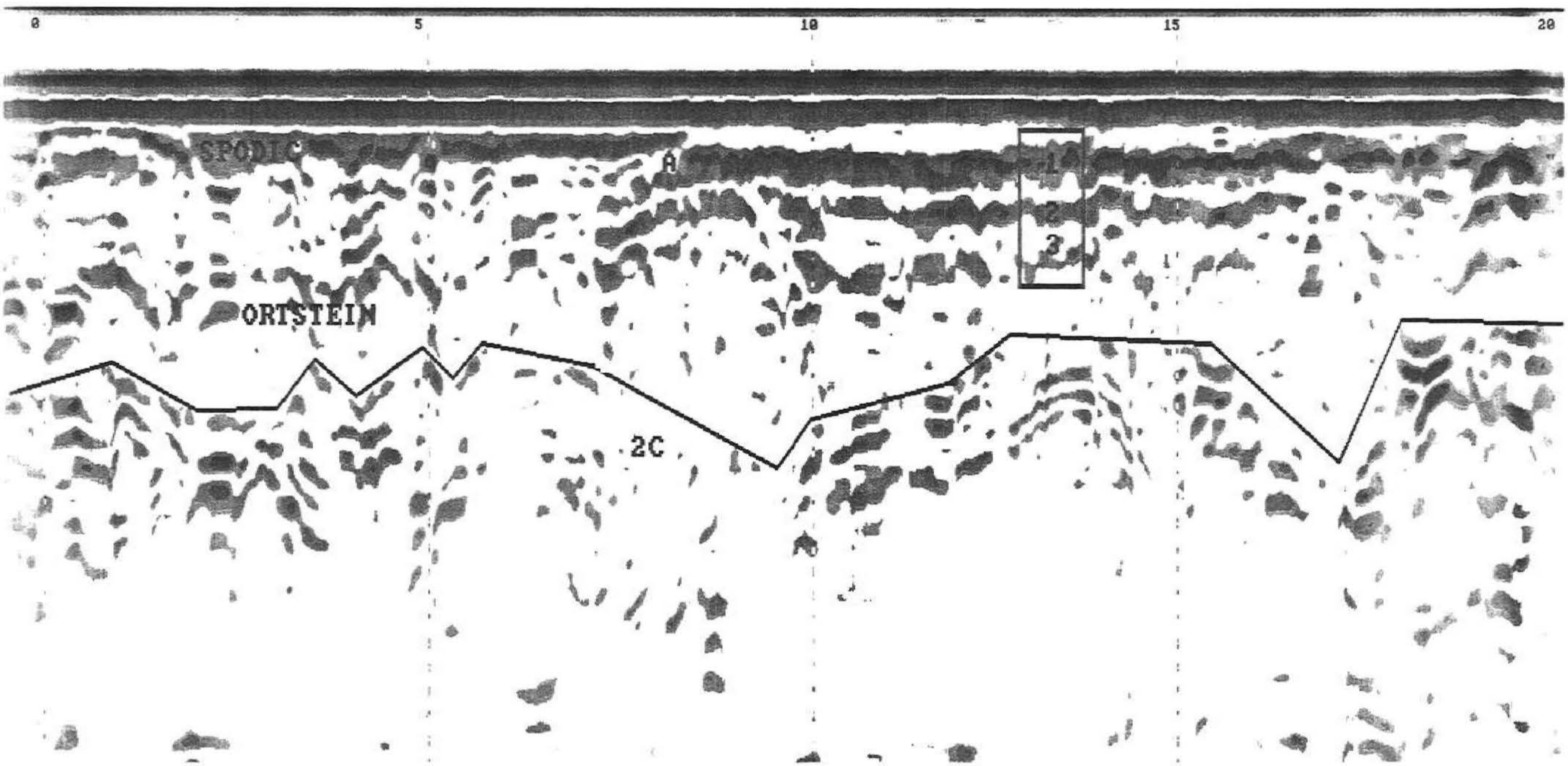
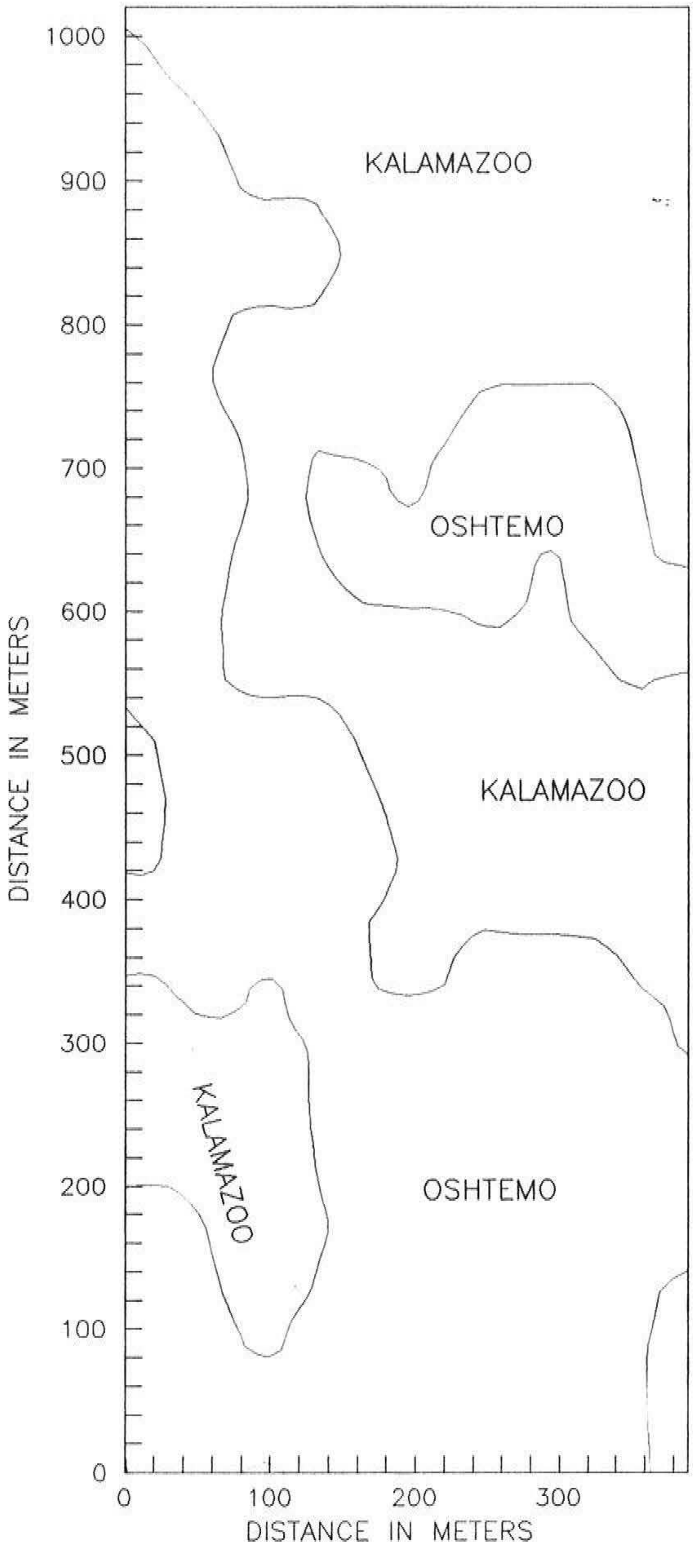


FIGURE 7.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