UNITED STATES DEPARTMENT OF AGRICULTURE **NSSC**
SOIL CONSERVATION SERVICE **CHESTER, PA 19013**

SUBJECT: SOI - Ground-Penetrating Radar and Electromagnetic Induction field studies; 13-16 May 1991

DATE: 3 June 1991

To: C. Budd Fountain
State Conservationist
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Purpose: To test the effectiveness of ground-penetrating radar (GPR) and electromagnetic induction (EM) techniques for updating soil surveys in MLRA 77.

Participants:
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Activities:
Ground-penetrating radar (GPR) and electromagnetic induction (EM) field studies were conducted in Cimarron County on 13 May, in Texas and Beaver Counties on 14 May, in Woods County on 15 May, and in Oklahoma County on 16 May.

Equipment:
The GPR unit used in this study was 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) antenna. The system was powered by a 12-volt vehicular battery. All GPR profiles accompanying this report were processed through the RADAN software program.

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

The electromagnetic induction meters used in this study were the EM31 and the EM38 manufactured by GEONICS Limited. [1] Measurements of conductivity are expressed as milliSiemens per meter (ms/m).

Results:

Results from this study indicate that the GPR can be used as a quality control tool for soil survey updates in Oklahoma. The GPR can be used in MLRA 77 to rapidly complete a large number of soil transects and to document map unit composition. While results will be depth restricted and highly interpretative, the GPR can be used to chart the occurrence and depth to: argillic horizons, calcic and petrocalcic horizons, and bedrock (within depths of 4 feet), and to separate taxonomic soil units.

In Oklahoma, the use of GPR techniques will be most effective in areas of coarse or moderately-coarse textured soils and in areas underlain at relatively shallow depths by bedrock. However, in many areas of the state, the GPR can be used with limited depth of penetration as a quality control tool for soil survey operations, for site investigations, and for applied research.

Ground-penetrating radar must be supported with ground-truth observations. As the depth of penetration in most moderately-fine and finer textured soils will be less than the full soil profile (6 feet), the GPR should be used in areas where there is no expected, dissimilar or contrasting soil materials in the lower part of the soil.

As much of Oklahoma is covered with relatively conductive earthen materials, the expanded use and diverse applications of electromagnetic induction (EM) techniques is recommended. While the best radar results are attained in electrically resistive mediums (dry, upland sandy sites), EM techniques are suited to the more electrically conductive sites which are prevalent in Oklahoma. The state office has an EM38 soil conductivity meter with an effective profiling depth of either 0 to 0.75 or 0 to 1.5 meters. In several states, SCS is using EM techniques to map soil salinity and to monitor ground water contamination emanating from animal waste holding ponds. In addition, EM techniques have been used to map bedrock surfaces, thickness of peat, clay, or sand and gravel deposits, measure soil water content, and for groundwater investigations. Like GPR techniques, the use of EM must be supported by ground-truth observations.

I deeply appreciated this opportunity to work in your state and with members of your fine staff. I commended your soil scientists for the development of a most ambitious schedule and the successful execution of it.

With kind regards.

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The upper boundary of the bedrock has been highlighted in Figure 2. Mansker soils (Calciorthidic Paleustolls) lack images of an argillic horizon and bedrock interfaces. The radar profile of the Mansker soil is similar to the profile of Kerrick (Petrocalcic Calciustolls) soil. Both soils contain disseminated lime through. Radar profiles of these soils lack strongly expressed images from contrasting soil horizons and contain diffuse subparallel bands in the upper part.

Texas County
In Texas County, radar and EM surveys were conducted in areas of map unit DaB, Dalhart fine sandy loam, 1 to 3 percent slopes; map unit DsB, Dalhart loamy fine sand, 0 to 3 percent slopes; map unit Rc, Richfield clay loam, 0-1 percent slopes; map unit UcA, Ulysses clay loam, 0 to 1 percent slopes; and map unit VoB, Vona loamy fine sand 0 to 3 percent slopes. The classification of the Richfield, Ulysses and Vona soils are: fine, montmorillonitic, mesic Aridic Argiustolls; fine-silty, mixed, mesic Aridic Haplustolls; and coarse-loamy, mixed, mesic, Ustollic Haplargids, respectively.

Despite the range in soil textural families, depth of radar penetration was limited in all of these soils by the argillic horizon. In Oklahoma, the 120 MHz antenna will be restricted by argillic horizons having textures as fine as or finer than coarse-loamy with a mineralogy which is predominated by montmorillonitic clays.

Wood County
In Wood County, radar surveys were conducted in an area of Pratt (sandy, mixed, thermic Psammentic Haplustalfs), Shellabarger (fine-loamy, mixed, thermic, Udic Argiustolls) and Tivoli (mixed, thermic, Typic Ustipsamments) soils. Pratt soils occur on low dunes, Tivoli soils are on high dunes, and the Shellabarger soils are in playas. In areas of Pratt and Tivoli soils penetrating depths ranging from 10 to 20 feet were consistently achieved in barren areas. In vegetated areas, the relatively high water and ion content of the shrubs severely attenuated the radar signal and limited profiling to depths of less than 5 to 10 feet. In areas of Shellabarger soils profiling was restricted by the moderately-high clay content of the argillic horizon.

Figure 3 is a representative profile from an area of Pratt and Shellabarger soils. This figure has not been terrain corrected and, regardless of relief, the soil surface appears to be horizontal on the radar profile. The deeper radar penetration in the low dune area is a consequence of the radar traversing an elevated mound of coarser-textured materials. Strata within the dune are nearly horizontal, their curved patterns reflect the slope of the soil surface across the dune. In areas of Shellabarger soils, the shallow depths to a moderately-fine textured argillic horizon confined the radar's penetration.

Oklahoma County
In Oklahoma County, radar and EM surveys were conducted in areas of Darsil (thermic, shallow & coated Ustic Quartzipsamments), Harrah

(fine-loamy, siliceous, thermic Ultic Paleustalfs), Huska (fine, mixed, thermic Mollic Natrustalfs), Newalla (fine-loamy over clayey, siliceous, thermic Udic Haplustalfs), and Stephenville (fine-loamy, siliceous, thermic Ultic Haplustalfs) soils. In areas of Darsil, Harrah, Newalla, and Stephenville soils, the radar's depth of penetration and EM values (see Table 4) were related to soil texture, depth to bedrock, and bedrock lithology (sandstone or shale).

Figure 4 is a representative radar profile from a gently sloping area of Stephenville, Darsil, and Harrah soils. Radar penetration is greater in the area of Harrah soils than in the area of Stephenville soils. In Figure 4, the depth of penetration of the GPR was related to the presence of a strata of shale within the Stephenville profile, its absence within the Harrah profile, and the predominance of sandstone within the Harrah profile. Compared with sandstone, shale is more attenuating and depth restricting to the radar. In Figure 4, the inclination of the bedding planes beneath the Stephenville soil has been indicated by dark lines.

The Huska soil is fine textured and is sodium affected. The high salt and clay content of this soils severely restricted the depth of radar penetration and made the use of GPR techniques futile. The EM measurement collected at the Huska site reflect the high sodium content of this soil (see Table 5). These values reflect variations in soil type, salt concentrations, and landscape position across the study site.

During the coarse of this field investigation soil scientist were encouraged to use and received training on the use of the EM38 and the EM31 meters. It is hoped that many of these soil scientist will continue to use the EM38 meter which is in the Oklahoma State Office.

The following is a list of the measurements obtained with the EM38 soil conductivity meter. Presently the greatest utility of the EM38 meter is the measurement and mapping of soil salinity. However, as the following list will confirm, values obtained with the EM38 meter are unique to soil taxonomic units and can be used to detect variability in the physical and chemical properties of soil.

The EM38 meter measures the apparent conductivity within the root zone. Measurements are expressed in milliSiemens per meter (mS/m). Profiling depth is determined by the frequency, intercoil spacing and coil orientation. The frequency of the EM38 is 13.2 kHz; the intercoil spacing is 1.0 meter. The depth of measurement ranges from about 0 to 0.75 meter in the horizontal dipole mode (EMH) and from about 0 to 1.5 meters in the vertical dipole mode (EMV).

Discussion:

Cimarron County

In Cimarron County, radar and EM surveys were conducted in areas of map units: Md, Mansker-Dalhart loam, 1-3 percent slopes; Pa, Portales clay loam, 0-1 percent slopes; Pb, Portales clay loam, 1-2 percent slopes; and PC, Potter-Mansker loams, 1-3 percent slopes. The classification of these soils are: Dalhart, fine-loamy, mixed, mesic Aridic Haplustalfs; Mansker, fine-loamy, carbonatic, thermic Calciorthidic Paleustolls; Portales, fine-loamy, mixed, thermic Aridic Calciustolls; and Potter, loamy, carbonatic, thermic, shallow Ustollic Calciorthids.

In areas of Dalhart, Portales, and Mansker the radar's depth of penetration was limited by either the high clay content of the argillic horizon or high carbonate content of the calcic (Bk) horizon. In these soils, the profiling depth of the 120 MHz antenna ranged from 1.5 to 2 feet. The rapid attenuation of the radar signal in these soils was attributed to their relatively high base, clay (fine-loamy textural family with a large proportion of smectitic clays), and carbonate content (carbonatic family).

Although the radar's depth of penetration was restricted, interpretations of the radar profiles consistently provided correct taxonomic identification and separation of the Dalhart, Kerrick (fine-loamy, mixed, mesic Petrocalcic Calciustolls), Mansker, Portales, and Potter soils within soil delineations. Dalhart soils have argillic horizons which were clearly expressed on radar profiles (Figure 1). Soils with calcic horizon (Kerrick, Mansker, Portales, and Potter series) lacked argillic horizons but displayed diffuse imagery in the upper part of the radar profiles (Figure 1). In these soils, the dissemination of carbonates in the upper part of the soil profile has reduced the electromagnetic gradient between the surface layers and the subsoil or underlying materials. The taxonomic separation of carbonatic from noncarbonatic soils, soils with argillic horizons from those lacking argillic horizons, or soils with calcic horizons from those with petrocalcic horizons can be accomplished with existing GPR techniques. However, separation and identification of closely similar soils and some map unit inclusions may be difficult to accomplish with GPR techniques alone. In addition, present GPR techniques are too depth restrictive to identify features in the substratum. The use of GPR techniques to expedite and increase the volume of data collection must be supported by sufficient ground-truth, soil observations.

It was possible to separate on the radar profiles areas of Potter from Mansker soils and to charted the depth to bedrock (Figure 2). In areas of Mansker soils, the moderately-fine textured soil materials limited the depth of radar penetration (120 MHz antenna) to about 4 feet. However in areas of Potter and similar soils having shallow (0 to 20 inches) to moderately deep (20 to 40 inches) soil conditions, the radar profiled the underlying bedrock to depths as great as 8 feet. In Figure 2, the Potter soils is identified by the lack of an argillic horizon and the presence and depth to bedrock.

TABLE 1
EM38 Conductivity Meter Measurements in an area of Ulysses clay loam, 0 to 1 % slopes (SE1/4 of Section 14, T. 5 N., R. 11 E.)

Observation	EMV	EMH
	(mS/m)	
1	19	21
2	24	23
3	23	22
4	25	22
5	23	24
6	29	28
7	30	27
8	30	27
9	26	23
10	26	26
11	26	28
12	32	31
13	22	22
14	42	34
15	74	64
16	64	50
17	59	41
18	32	26
19	24	28
20	31	30
21	42	32
22	39	30
23	38	38

TABLE 2
EM38 Conductivity Meter Measurements in an area of Richfield clay loam (NE1/4 of Section 35, T. 6 N., R. 12 E.)

Observation	EMV	EMH
	(mS/m)	
1	17	13
2	21	17
3	18	16
4	23	20
5	16	12
6	16	11
7	12	12
8	15	17
9	9	7
10	20	12
11	16	10
12	17	9
13	19	12
14	19	12
15	19	11
16	19	10
17	16	9
18	18	10
19	13	8

TABLE 3

EM38 Conductivity Meter Measurements in an area of Richfield clay loam (SE1/4 of Section 26, T. 6 N., R. 12 E.)

Observation	EMV (mS/m)	EMH
1	15	10
2	14	15
3	12	12
4	10	9
5	5	3
6	9	5
7	6	2
8	3	3
9	5	5
10	4	4
11	6	6
12	9	4
13	7	7
14	11	7
15	11	10
16	11	8
17	11	6
18	17	9
19	17	8
20	19	11

TABLE 4

EM38 Conductivity Meter Measurements in an area of Stephenville-Darsil-Newalla Complex 3 to 8 % slopes (Boys Ranch, Oklahoma County)

Observation	EMV (mS/m)	EMH	
1	28	28	Newalla
2	20	10	
3	12	9	
4	2	.01	
5	5	.01	
6	.01	.01	Stephenville
7	8	.01	Darsil
8	12	1	
9	13	.01	
10	2	.01	
11	8	.01	
12	5	.01	
13	7	.01	Harrah

TABLE 5

EM38 Conductivity Meter Measurements in an area of Renthin-Huska complex, 1 to 5 % slopes (Oklahoma County)

Observation	EMV (mS/m)	EMH (mS/m)
1	100	74
2	76	52
3	60	60
4	100	80
5	40	32
6	60	56
7	78	64
8	46	38
9	42	32
10	78	59
11	67	52
12	70	12

FIGURE 1

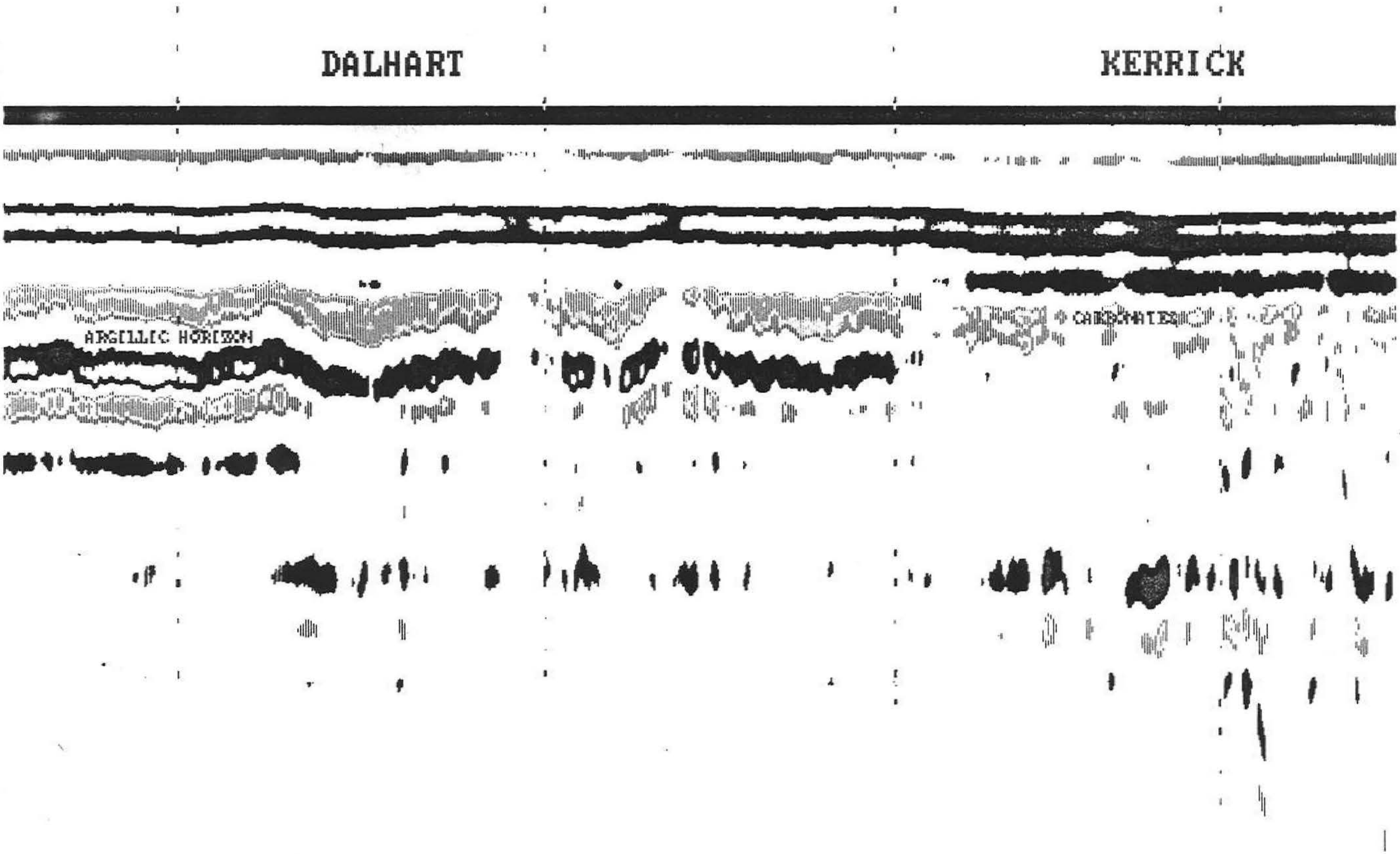

FIGURE 2

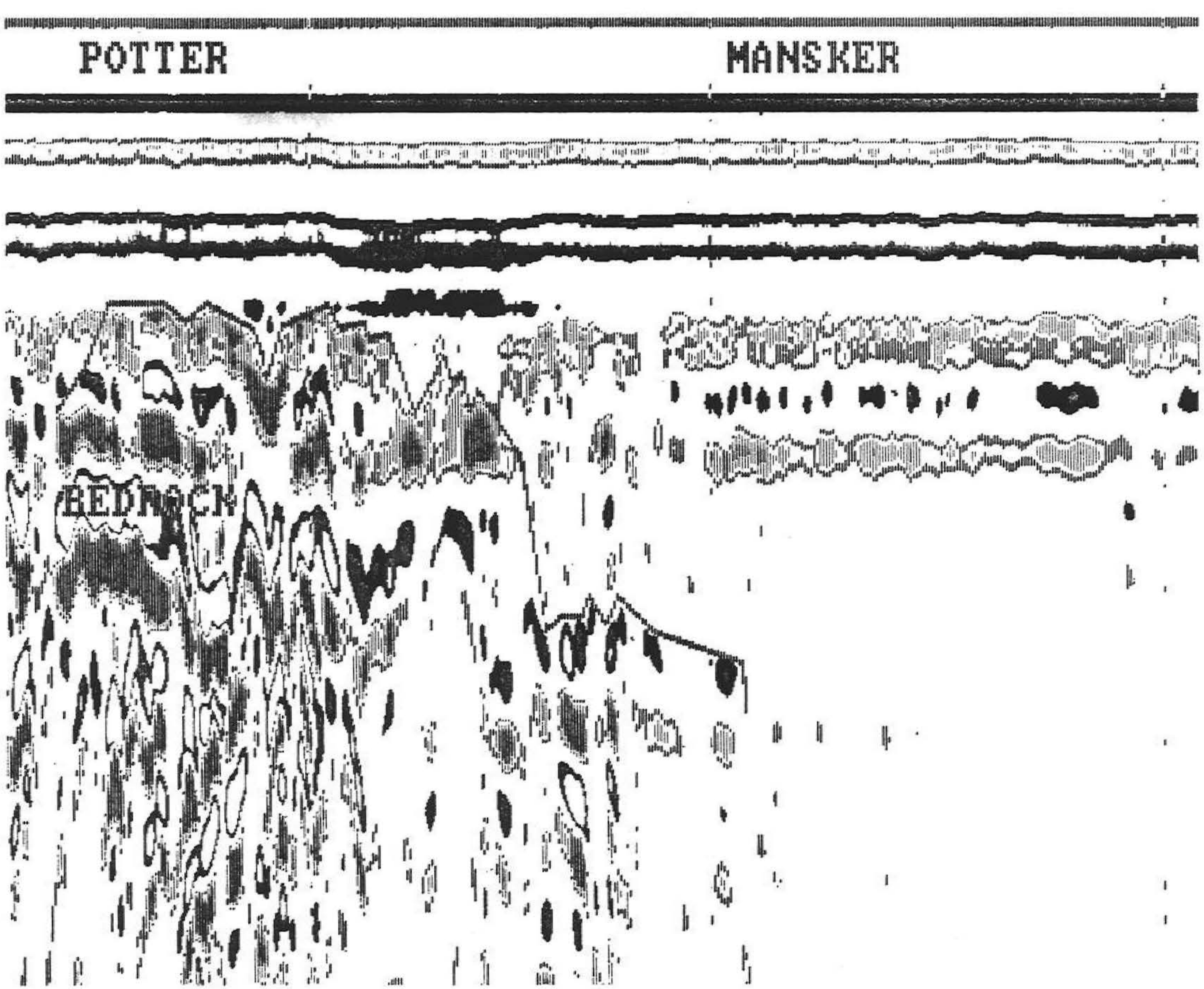

FIGURE 3

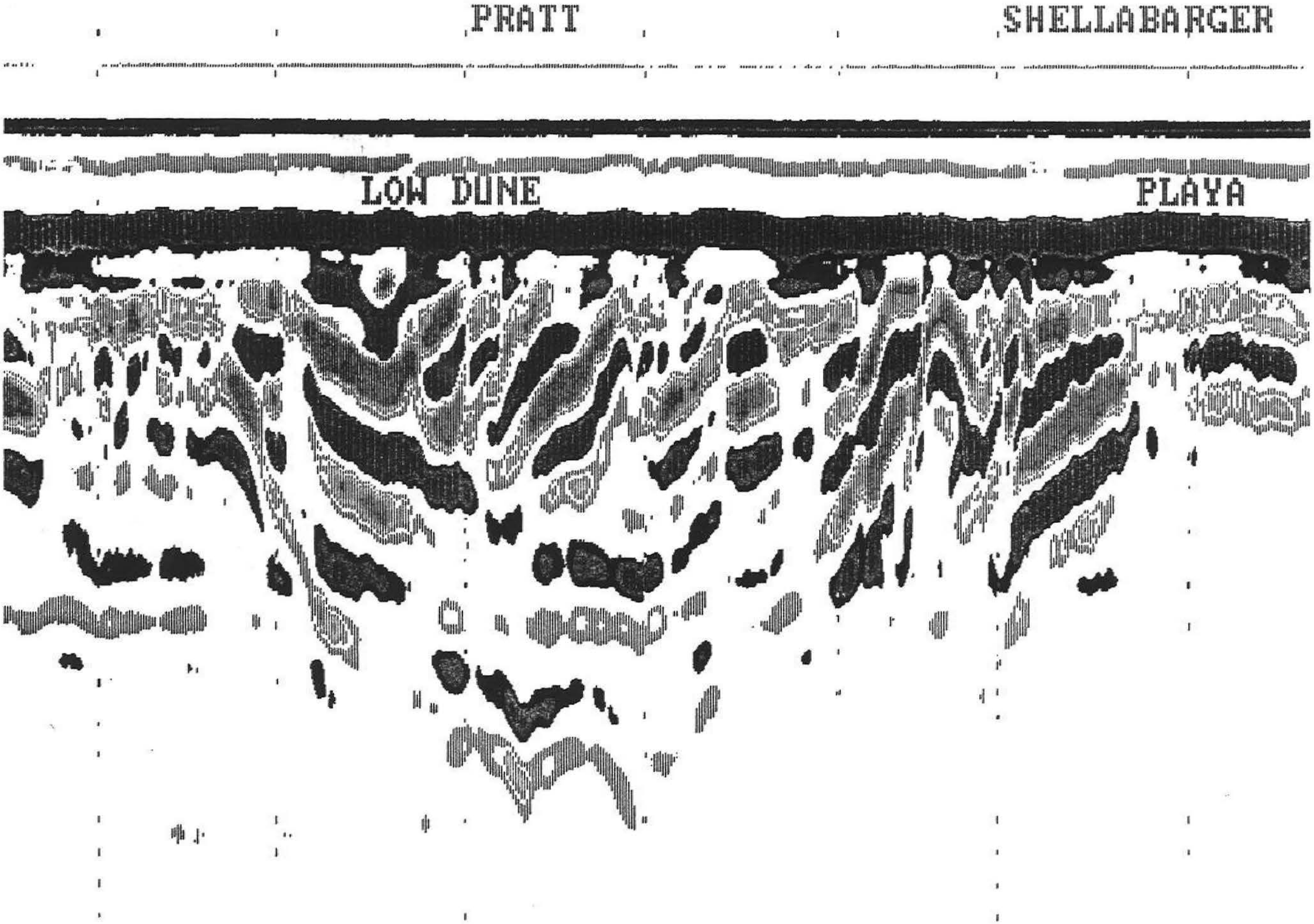

FIGURE 4