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Natural Resources Conservation Service **610-490-6042**

Subject: Investigation of traffic pans with ground-penetrating radar (GPR); Kinsella Farm, McLean County, Illinois; 12 July 1995. **Date:** 31 July 1995

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Purpose:
To evaluate the effectiveness of using GPR techniques to assess traffic pan development in an area of Miami loam, 2 to 5 percent slopes, central Illinois.

Principal Participants:
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Katie Doolittle, Earth Team Volunteer, NRCS, Chester, PA
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Dan Towery, Natural Resource Specialist, Conservation Technology Information Center, W. Lafayette, IN

Activities:
On 12 July, the feasibility of using ground-penetrating radar techniques to evaluate traffic pan development in a cultivated area of Miami soils was evaluated. On the morning of 13 July, I met with Dan Towery (CTIC) and discussed the previous days activities and reviewed the taped files of the radar profiles.

INTRODUCTION
Ground-penetrating radar is an impulse radar system designed for shallow, subsurface investigations. This radar system transmits short pulses of electromagnetic energy into the ground from an antenna. Each pulse consists of a spectrum of frequencies distributed around the center frequency of the transmitting antenna. Whenever a pulse contacts an interface separating layers of differing electromagnetic properties, a portion of the energy is reflected back to the receiving antenna. The receiving unit amplifies and samples the reflected energy and converts it into a similarly shaped waveform in a lower frequency range. The processed reflected waveforms are displayed on a VGA video screen, printed on a thermal recorder, or are stored on an internal disk drive for future playback and/or post-processing.

Soil scientist have used GPR to estimate depths to argillic (Asmussen et al., 1986; Truman et al. 1988; Collins and Doolittle, 1987; Hubbard et al., 1990) and traffic pans (Raper et al., 1990). In the study conducted by Raper and others (1990), GPR was used to predict the depths to traffic pan. These researchers compared the depths to traffic pans predicted from radar profiles with those defined by penetrometer measurements. While depths predicted from GPR interpretations closely matched those anticipated by penetrometer, different scaling factors were required for different soil types. Unfortunately, these researcher had no means to evaluate differences in traffic pan development from the GPR profiles.

Graphic or thermal recorders use variable gray scales to display radar data. These recorders produce images by recording strong reflections as black and lesser intensity reflections in shades of gray. Differences in the degree of compaction or density of traffic pans have been associated with variations in the gray scale and identified on radar profiles. However, prior to the availability of processing software, it was difficult to assign numerical values to the gray scale and associate differences in traffic pan development with penetrometer measurements. Only qualitative interpretations were possible.

Presently, radar data can be post-processed through software packages such as RADAN. This software can allocate distinct color values and ranges to the amplitude values displayed on the gray scale of the radar profiles. Numerical values can be assigned to each distinct color value and correlated with observed penetrometer measurements. Figure 1 shows the color scale and transform that was used in this study. Reflections (both positive and negative) with the highest amplitude are the most distal to the origin (Fig. 1, left) and are black and white (Fig. 1, right). Reflections with the lowest amplitudes occur near the origin and are gray or dark gray.

MATERIALS AND METHODS

Equipment

The radar unit used in this study was the Subsurface Interface Radar (SIR) System-2, manufactured by Geophysical Survey Systems, Inc. (GSSI).* The use and operation of GPR have been discussed by Morey (1974), Doolittle (1987), and Daniels and others (1988). The SIR System-2 consists of a digital control unit (DC-2) with keypad, VGA video screen, and connector panel. Radar profiles were plotted on a model GS-608P thermal plotter/printer. The system was powered by a 12-volt DC battery. The model 3105 (300 mHz) and 3102 (500 mHz) antennas were used in this investigation.

The radar profile included in this report was processed through RADAN software. Processing was limited to customizing color transform and color tables, and annotations.

Field Methods

The study site was located in MLRA 108; Illinois and Iowa Deep Loess and Drift. Transect lines were established in four different field. Fields were in oats or corn. The selected fields were located in an area of Miami loam, 2 to 5 percent slopes. Miami is a member of the fine-loamy,

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* Trade names are used to provide specific information. Their mention does not constitute endorsement by USDA-NRCS.

mixed, mesic Typic Hapludalfs family. Transects were short, but variable in length. Survey flags were inserted in the ground at intervals of 2 or 5 feet.

INTERPRETATIONS:

A. The radar profile -

Reflected radar waveforms were plotted on thermal sensitive paper in a raster-scan, thermal plotter/printer. Through a thermo-chemical reaction, radar images are developed as the thermal sensitive paper is moved under a fixed thermal printhead. The intensity of these images are dependent upon the amplitude of the reflected signals.

Figure 2 is an example of a radar profile obtained with a model 3110 (120 mHz) antenna. The horizontal scale represents units of distance traveled along an antenna traverse. This scale is dependent upon the speed of antenna advance along a traverse line and the rate of paper advance through the thermal plotter. The vertical scale is a time or depth scale which is based on the velocity of signal propagation.

The four basic components of a radar profile have been identified in Figure 2. These components are the start of scan pulse (A), inherent antenna noise (B), surface image (C), and subsurface interface images (D). Each of these components, with the exception of the start of scan pulse, is generally displayed as a group of dark bands. The number of bands can be limited by high rates of signal attenuation or superimposed signals. These bands limit the ability of GPR to discriminate closely spaced interfaces. The dark bands occur at both positive and negative signal amplitudes. The narrow white band(s) separating the darker bands represent the neutral or zero crossing between positive and negative signal amplitudes.

The start of scan image (see A in Figure 2) results from direct feed-through of transmitted pulses into the receiver section of the antenna. Though a source of unwanted clutter, the start of scan pulse is often used as a time reference line.

Reflections unique to each of the system's antennas are the first series of multiple bands on radar profiles. Generally the width of these bands increases with decreasing antenna frequency or signal filtration. These reflection (see B in Figure 2) are a source of unwanted noise on radar profiles.

The surface image (see C in Figure 2) represents the ground surface. Below the image of the surface reflection are images from subsurface interfaces (see D in Figure 2). Interfaces can be categorized as being either plane or point reflectors. Most soil horizons and geologic strata appear as a series of continuous, parallel bands similar to those appearing in Figure 2. Features that produce these reflections are referred to as "plane reflectors." Small objects such as rocks, roots, or buried cultural features can produce a hyperbolic pattern similar to the feature appearing (weakly expressed) to the right of E in Figure 2. Features that produce these reflections are referred to as "point reflectors."

B. Calibration -

The GPR is a time scaled system. This system measures the time that it takes electromagnetic energy to travel from the antenna to an interface (e.g. soil horizon, stratigraphic layer, bedrock surface) and back. In order to convert the travel time into a depth scale, either the velocity of pulse propagation or the depth to a reflector must be known. The relationship among depth (d), two-way, pulse travel time (t), and velocity of propagation (v) are described in the following equation (Morey, 1974):

$$v = 2d/t$$

The velocity of propagation is principally affected by the dielectric constant (e) of the profiled material(s) according to the equation:

$$e = (c/v)^2$$

where c is the velocity of propagation in a vacuum (0.3 m/s). The amount and physical state (temperature dependent) of water has the greatest effect on the dielectric constant of a material.

Calibration trials were conducted to determine the dielectric constant and velocity of propagation of electromagnetic energy through the surface soil layers, establish a crude depth scale, and optimize control and recording settings. During calibration trials, multiple traverses were conducted with the 500 and 300 mHz antennas. A scanning time of 30 nanoseconds (ns) and a scanning rate of 32 scans/sec were used in these trials and in all subsequent field work. Considerations of desired versus achievable depths of observation and the resolution of subsurface features influenced the selection of antennas and scanning times. In areas of Miami soil, depths of observation were limited to the upper part of the argillic (Bt) horizon. Though exceedingly restricted, both the 300 and 500 mHz antennas provided adequate depths of observation for traffic pan investigations. However, because of its superior near-surface resolution, the 500 mHz antenna was used exclusively in this study.

An empty coffee can with a 15 cm diameter and a flat, metal weight with a similar diameter were buried in the soil. The upper surface of the coffee can was buried at a depth of 20 cm (see Figure 3A). In Figure 3A, the coffee can is represented by a hyperbolic pattern with a strong (black) amplitude. The location of the buried can has been highlighted by a dark line. The upper surface of the metal weight was buried at the contact of the surface layers and the argillic (Bt) horizon and at a depth of 30.5 cm (see Figure 3B). In Figure 3B, the hyperbolic pattern representing the metal weight is weakly expressed. This image appears as a slight inflection in the presumed argillic horizon (brown-colored, continuous band). To verify this interpretation, a radar profile was obtained with the metal weight removed from the soil (see Figure 3C). In Figure 3C, a break appears in the argillic horizon at the location of the filled, excavated hole. As the hole was filled with soil materials from both A and Bt horizons, the clear boundary separating these two horizon was absence. This produced the illusion of a gap in the Bt horizon.

Based on known depths (20 and 30.5 cm) to buried reflectors, the velocity of propagation through the surface soil layers and a depth scale for radar profiles were estimated. Based on the round-trip travel time to this reflector, the velocity of propagation was estimated to be 0.092

m/ns. The dielectric constant was estimated to be 10.6. These estimated values are appropriate for the surface layers of the Miami soil.

DISCUSSION:

Figure 4 contains representative radar profiles from site. Each profile has been processed through RADAN software. The color scale and transforms used were the same as those appearing in Figure 1. In Figure 4, the horizontal scale represents units of distance traveled along a traverse line. The segmented, vertical lines appearing in the upper profile are flagged observation points and occur at 2 m intervals. The vertical scale is a time or depth scale, which is based on the estimated velocity of signal propagation (0.092 m/ns) from the calibration site. In this figure, the range of observation has been reduced from the scanned 1.38 m to 90 cm. Range reduction was performed during post-processing and was used to enlarge the images within the upper part of the profile. The actual depth of observation was restricted to the upper part of the argillic horizon. The acquired images are confined to the surface layers and the upper part of the argillic horizon.

The amount of energy reflected back to an antenna from a subsurface interface is a function of the dielectric gradient existing between the adjoining materials. The greater or more abrupt the difference in dielectric properties, the greater the amount of energy reflected back to the antenna, and the more intense will be the amplitude of the image recorded on the radar profile. In each of the profiles appearing in Figure 4, the soil surface appears as a continuous, high amplitude (black), plane reflector. The argillic horizon appears as a continuous, slightly lower amplitude (brown) reflector extending across each profile. This horizon appears variable in expression as it has included zones of slightly higher amplitude green, light green, and dusky brown colors (see Figure 1).

Between the soil surface and the argillic horizon is another reflector. This reflector is continuous and is multicolored in the upper profile and dominantly black in the lower profile. In the upper profile, this reflector includes areas of pink, blue, green, orange, and yellow. These colors indicate a plane reflector with variable and intermediate electromagnetic gradients. In the lower profile, this reflector is predominantly black and pink. These colors indicate high amplitude reflections and a feature having strong or highly contrasting electromagnetic gradients (see Figure 1). The identity of this reflector was not confirmed. This plane reflectors represent a near-surface features or horizons. As these profiles were obtained in adjoining areas of Miami soil, differences in these "near-surface plane reflectors" are believed to be a manifestation of variations in tillage practices or the rooting patterns of the cultivated crops.

In Figure 4, the upper profile was collected in an area of small grains; the lower profile was collected in an adjoining area of corn. Distinct and recognizable differences occur in the general graphic appearances of the near-surface plane reflector between these two units of management. It appears possible that GPR techniques can be used to chart differences in some soils properties which are attributed to variations in management practices.

Figure 5 is the upper 90 cm of a radar profile obtained in another area of Miami soils. This site was in corn. The general appearance of this

profile is similar to the lower profile in Figure 4. As both of these profiles were collected in cultivated (corn) areas of Miami soil, the affects of management are evident, repeatable, and identifiable (contrast with graphic signature of small grain appearing in Figure 4, upper).

In Figure 5, the location of tire tracks were annotated by a double-click pattern. In the lower part of the radar profile, beneath most of the double-clicked marks, higher amplitude signals (yellow or brown; see Figure 1) occur. The locations of these higher amplitude signals beneath the paths of tires suggests that GPR is probably detecting differences in soil density or compaction related to management.

RESULTS:

1. This brief study suggests that ground-penetrating radar can be used to detect and to help characterize some near-surface soil properties and perhaps traffic pan development in some mid-western soils.

2. Further studies are encouraged and required. These studies will require multiple studies using GPR techniques and the taping and processing of radar profiles through RADAN software. As I consider this to be a significant and worthwhile application of GPR, I would be most pleased to assist in this project. However, my available time is limited and would be best spent conducting GPR field work and processing radar profiles. Additional resources will be required to obtain field measurements (penetrometer, soil texture, soil moisture). The cooperation of the Soil Quality Institute and land-grant universities is recommended and considered vital to this project. Major professor(s) and graduate student(s) should be assigned to help complete this research task.

3. It is suggested that research include:

A. Determine the relationship between traffic pan depth and expression (as defined by penetrometer) with the GPR image in an area of uniform soil and management. Establish whether GPR techniques can be used to chart variations in traffic pan development.

B. If the relationship between penetrometer and GPR images is found to be robust, the study should be expanded to encompass a larger area with more variable soils and landscape components. The expanded study should provide information on the affects of varying moisture and clay contents on reflected radar images and the prediction of traffic pan development.

C. Assess the strength of these relationships in areas of varying management practices.

D. If the aforementioned research activities are successful, graphic and numerical methods should be explored to plot and express GPR data across variable soil patterns and units of varying management practices.

It was my pleasure to have the opportunity to conduct this field research. I hope that the co-operative spirit which pervaded this study can be continued.

With kind regards

James A. Doolittle

James A. Doolittle
Research Soil Scientist

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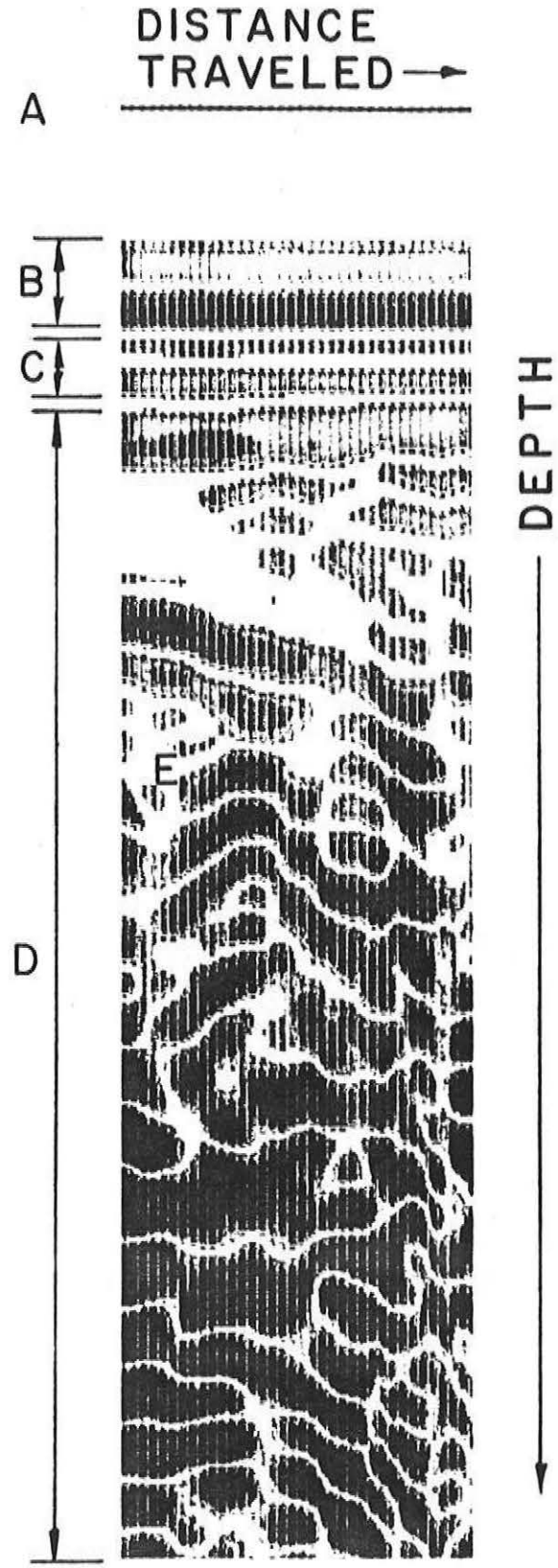

RADAR PROFILE

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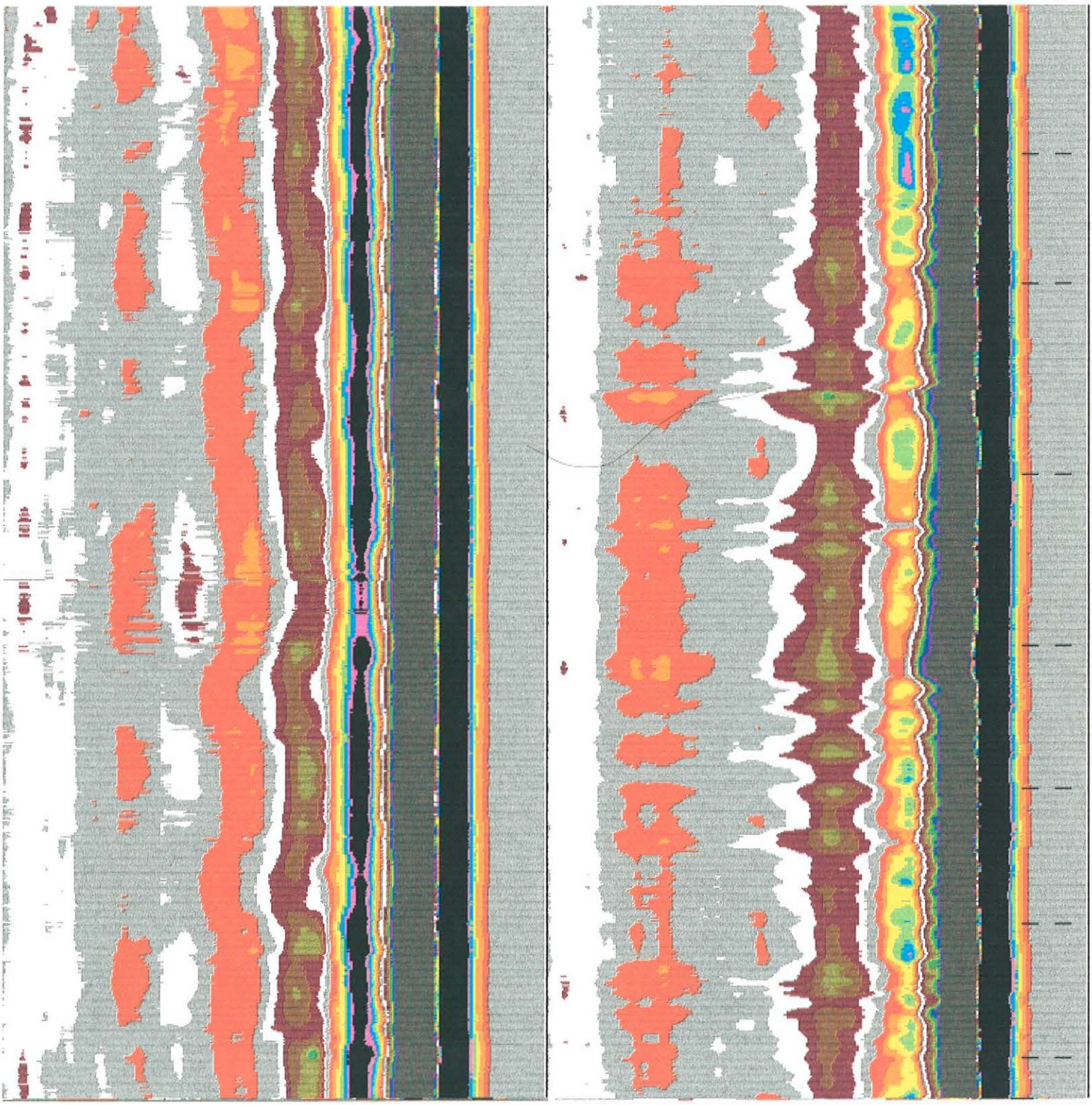
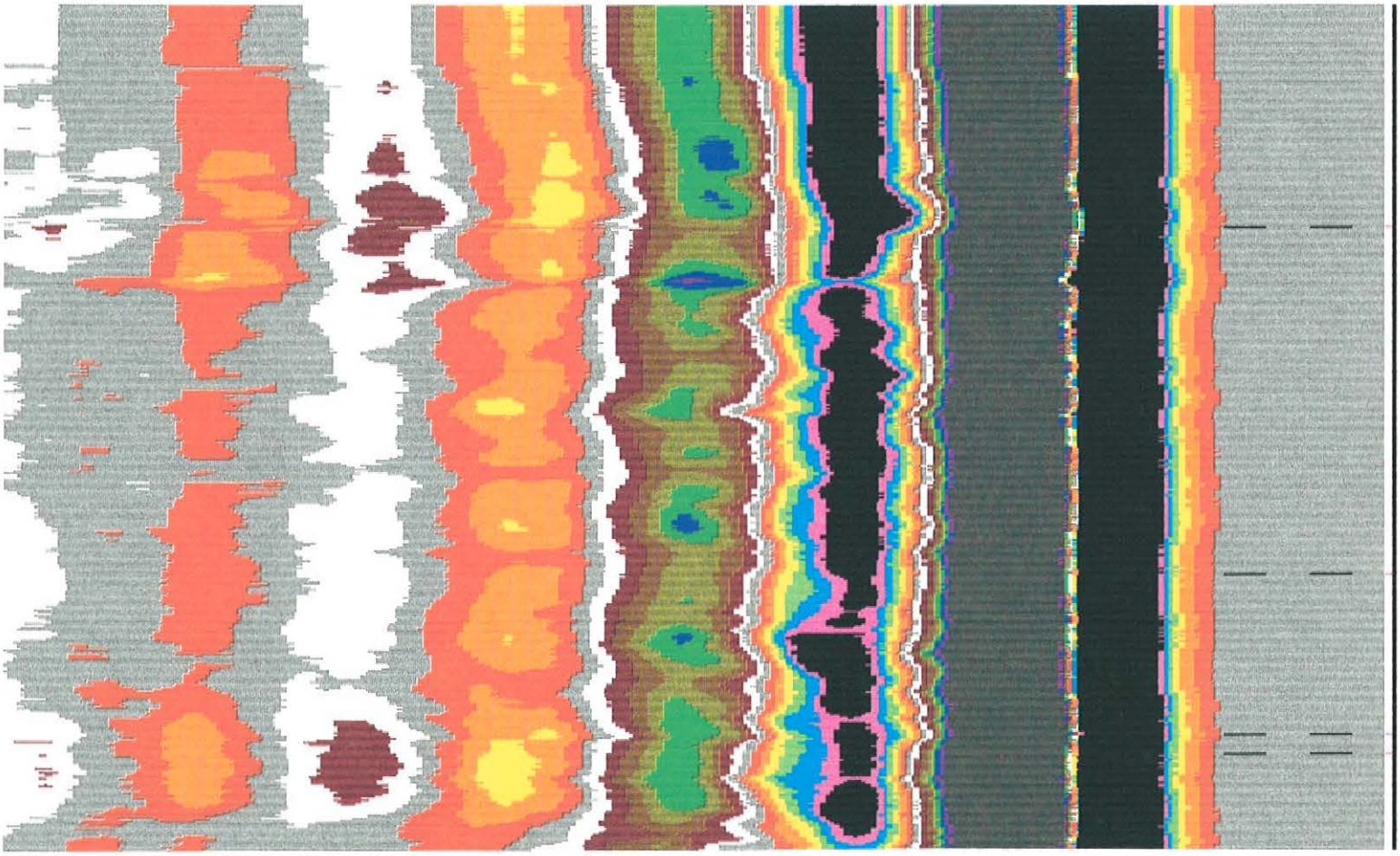
Vert. IIR high pass N=1 F=2.4



FILE11A Created Jul 12,1981 15:08 Modified Jul 28,1995 12:28
512 samples/scan 32 scans/sec position: 0 nS range: 30 nS
Vert. IIR low pass N=1 F=30
Vert. IIR high pass N=1 F=2.4