DOE/ER/14251--1

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TECHNICAL PROGRESS REPORT

DEPARTMENT OF ENERGY GRANT

TO THE PENNSYLVANIA STATE UNIVERSITY

PROJECT TITLE: CRETACEOUS SHALLOW DRILLING, U.S. WESTERN INTERIOR: CORE RESEARCH

PROJECT NUMBER: DE FG02-92ER14251

Submitted By:
Michael A. Arthur, Principal Investigator
Department of Geosciences
Pennsylvania State University
503 Deike Bldg.
University Park, PA 16802

DOE Program Manager: Dr. William Luth

Date Submitted: February 17, 1993

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EXECUTIVE SUMMARY

Project Title: Cretaceous Shallow Drilling, U.S. Western Interior: Core Research

Objective: Construct a subsurface transect of Cretaceous strata that were deposited in the Western Interior Seaway, ranging from organic-rich, marine hydrocarbon source rocks in Kansas and eastern Colorado to nearshore, coal-bearing units in western Colorado and Utah.

This project is a multidisciplinary study of Cretaceous carbonate and clastic rocks in cores from four holes or groups of holes along a transect across the old Cretaceous seaway that extended from the Gulf Coast to the Arctic during maximum transgressions. In particular, we proposed to focus our study on the Graneros Shale, Greenhorn Limestone, Carlile Shale, Niobrara Formation, and lower Pierre Shale in cores from four holes or groups of holes from western Kansas, southeastern Colorado, southwestern Colorado, and eastern Utah.. This series of cores would provide unweathered samples and continuous smooth exposures required for geochemical studies, mineralogical investigations, and biostratigraphic studies. The rocks range from pelagic carbonates that contain organic-carbon-rich marine source rocks at the eastern end of the transect to nearshore coal-bearing units at the western end. The Cretaceous part of a recent AMOCO core (AMOCO #1 Bounds) from western Kansas was released to the USGS in January, 1992, and is presently in the USGS Core Research Center (CRC) in Denver. Most of the objectives for the eastern (most pelagic marine) end of the transect can be met with this existing core; no new drilling is planned for this end of the transect.

Three holes that form the western end of the transect were drilled and continuously cored in June, 1991 in the Kaiparowits basin near Escalante, Utah using a USGS drill rig funded by USGS energy programs. Two cores, each with total depths of 300m, collected the coal-bearing sequences of the upper Turonian to lower Campanian Straight Cliffs Formation. A third core about 280m long contains all of the marine Tropic Shale that is the age equivalent (Cenomanian/Turonian) of the Greenhorn Limestone and Graneros Shale in eastern Colorado and western Kansas.

In June, 1992, a 700-foot hole, funded by DOE, was drilled and continuously cored near Portland, Colorado on the Brush Hollow Anticline east of the Florence oil field, the oldest oil field in the U.S. This sequence, deposited in relatively deep water on the west side of the Western Interior Seaway, includes cycles of terrigenous-clastic and pelagic-marine sediments to contrast with the pelagic carbonate-dominated cycles of Kansas and the clastic-dominated cycles of western Colorado and Utah. A second, 800-foot hole, also funded by DOE, was drilled in July, 1992 about 10 miles southwest of the Portland hole in Pierre Shale that is the reservoir for hydrocarbons in the Florence field. Because the Pierre Shale in the Florence basin is highly fractured, coring was attempted on only 250 feet of the drilled 800-foot section with 96% recovery.

A core workshop was held in August at the USGS in Denver during which the research team discussed objectives and interactions, identified sampling

requirements and examined available cores. Arthur and Dean constructed a Sample Protocol (see attached) to guide sampling for the research team and any other investigators. Description, photography and other documentation of all cores by Arthur, Dean, Sageman and Kauffman was accomplished in a 3 week effort before and after this workshop. About 30% of the total samples requested has been distributed; the remainder will be distributed by March 1, 1993. Geochemical analysis and biostratigraphic- paleoecologic determinations are well underway by the WIS research team for all but the Portland #1 core, which is being cut, sectioned and archived at this time. Year 2 of the project will complete the main phase of data acquisition and analysis.

We have planned a Core Workshop and special Poster Session on the results of this project for the 1994 American Association of Petroleum Geologists Annual Meeting to be held in Denver. A synthesis volume will be assembled by the project investigators for publication in early 1994; the volume will consist of 2 parts with the first part providing the documentation of materials (core descriptions, photographs, logs, etc.) and the second including individual interpretive papers by project investigators.

Project Performance Period: June, 1991 to January, 1993

Principal Investigators: **Michael A. Arthur**, Department of Geosciences, 503A Deike Bldg, Penn State University, University Park, PA 16802; phone: (814)863-6054; FAX: (814)863-7823; EMAIL: OMNET, M.Arthur or Internet arthur@geosc.psu.edu; **Walter E. Dean**, U.S. Geological Survey, MS 939 Federal Center, Denver, CO 80225; phone: (303)236-5760; FAX: (303)236-0459; E-Mail: OMNET, W.Dean

DOE Program Manager: Dr. William Luth

TECHNICAL REPORT
U.S. CONTINENTAL DRILLING PROGRAM
CRETACEOUS SHALLOW DRILLING PROJECT: CORE RESEARCH

OBJECTIVES AND BACKGROUND

• This project is a continuing multidisciplinary study of middle to Upper Cretaceous marine carbonate and clastic rocks in the Utah-Colorado-Kansas corridor of the old Cretaceous seaway that extended from the Gulf Coast to the Arctic during maximum Cretaceous transgressions. It is collaborative between the U.S. Geological Survey (W.E. Dean, P.I.) and University researchers led by The Pennsylvania State University (M.A. Arthur, P.I.) and funded by DOE and the USGS, in part. Research focusses on the Greenhorn, Niobrara and lower Pierre Shale units and their equivalents, combining biostratigraphic/paleoecologic studies, inorganic, organic and stable isotopic geochemical studies, mineralogical investigations and high-resolution geophysical logging. This research requires unweathered samples and continuous smooth "exposures" in the form of cores from at least 4 relatively shallow reference holes (i.e. <1000m) in a transect from east to west across the basin.

•The major initial effort was recovery in Year 1 of the project of continuous cores from each site in the transect. This drilling provided samples and logs of strata ranging from pelagic sequences that contain organic-carbon-rich marine source rocks to nearshore coal-bearing units. This transect also will provide information on the extent of thermal maturation and migration of hydrocarbons in organic-carbon-rich strata along a burial gradient. The drilling used a U.S.G.S. drilling rig and crew with core preparation at the U.S.G.S. Core Research Center. Velocity, neutron density, resistivity, and magnetic logs were run in the U.S.G.S. wells. The slow logging speeds provided sufficient resolution that required to resolve sequence boundaries and small-scale cyclicity (on the order of 10s of cm). Nearly continuous core is available from the easternmost site, drilled by Amoco in eastern Kansas (Amoco Rebecca Bounds #1, Greely County, Ks.), where the middle to Upper Cretaceous strata are largely pelagic and have not experienced deep burial. The westernmost holes were drilled by the USGS in June, 1991, on the Kaiparowitz Plateau in Utah to sample mid-Turonian to lower Campanian nearshore and terrigenous coal-bearing strata (near Escalante Utah, 2 holes recovering nonmarine-marginal marine strata on plateau, 1 hole through the Cenomanian-Turonian Tropic Shale at foot of plateau). The main hole in the transect (U.S.G.S. Portland #1 and Wetmore #1) was drilled to the east, in the Arkansas River Valley near Canon City, Colorado (Florence oilfield) to obtain cores of offshore, deeper-water (and more deeply buried) pelagic-hemipelagic strata.

OBJECTIVES OF WESTERN INTERIOR SEAWAY SHALLOW DRILLING TRANSECT

• *Sea Level Change and Sequence Stratigraphy*

The drilling provides sampling of strata deposited during two major transgressive-regressive cycles of the Western Interior seaway that reflect global changes in sea level. The origin of these sea-level changes is puzzling because much of the Cretaceous is thought to have been ice-free and characterized warm, latitudinally equable climates and,

therefore, ice-volume changes could not have induced much variation in sea level. On the other hand, the Cretaceous was a time of unusually active sea-floor spreading and plate-margin and mid-plate volcanism so that tectonically induced changes in sea level should be expected, possibly corresponding to thrust loading on the western edge of the basin.

- Key issues are:

1. The precise timing and rates of sea-level change, and their influence on lithology, sedimentation rate, and sediment geochemistry;
2. The amount, type, and degree of preservation of organic matter, and their relationships to sea-level variations whether tectonic or eustatic.
3. Rates of subsidence, apparent sea-level change, and facies migration will be closely examined in light of purported global tectonic-eustatic events. Ties with seismic reflection profiles, well logs, high-resolution stratigraphy, and high-quality samples will enhance this effort.

- *Organic Matter Deposition and Burial*

The cored sequences encompass several episodes of enhanced burial of organic carbon that have importance both within the Western Interior Seaway and globally. These periods of widespread oxygen deficiency in oceanic deep-water masses (so-called "Oceanic Anoxic Events"), marked by widespread organic-carbon-rich sequences, loosely called "black-shales", include several hydrocarbon source-rock sequences as well as economically important coal sequences.

- Of particular interest is:

1. The onshore-offshore facies patterns and relationships of organic-matter accumulation, changes in organic-matter type and degree of preservation, and relationships to transgressive episodes;
2. Variations in faunal and floral components and sedimentary structures will be used to evaluate the extent and intensity of oxygen deficiency during black-shale episodes and correspondance in timing to global events;
3. Effects of organic-matter enrichment on the geochemical characteristics of the sediments also will be examined particularly as they relate to the cycling of Fe, Mn, S, N, P, and trace elements; and
4. The transect of cores will provide fresh, unweathered samples for the study of the effects of thermal metamorphism and other geochemical characteristics with increasing burial depth.

- *Cyclostratigraphy*

The Western Interior Cretaceous sequences are renowned for their expression of small-scale cyclicity, with periods of tens of thousands of years that commonly are attributed to Milankovitch orbital variations. However, the linkages of these presumed orbital variations to sedimentary processes in a supposed ice-free world are poorly understood in contrast to ice-volume-dominated Quaternary cycles with similar periodicities. The continuously cored sequences and high quality geophysical logs in a cross-basin transect provides a tremendous opportunity to examine the sedimentary expression of orbital cyclicity in a geographically restricted part of the Cretaceous ocean that apparently was finely tuned to these orbital variations.

•Of particular importance are:
1. The sequences of the Western Interior seaway have the greatest diversity of faunal and floral assemblages of any Cretaceous sequence in the world, and the detailed biostratigraphies provided by these assemblages, together with abundant volcanic ash layers, will provide a unique high-resolution time sequence to calibrate the cyclicity;
2. These "absolute" age data will allow calculation of important variables such as rates and timing of sediment supply, organic productivity, and changes in water-mass characteristics that contribute to the sedimentary expression of Milankovitch orbital cycles.

• *Paleogeography, Paleoclimatology, and Sediment Fluxes*
The globally warm, equable, ice-free Cretaceous climate is generally viewed as having been about as far removed from our present glacially dominated climate as that of any other geological period. The origins of this warm climate are poorly understood, but are presumed to be related to a major expression of a "greenhouse" phenomenon, such as might result from increased volcanic outgassing of carbon dioxide. However, even the warm, equable climate paradigm is being challenged, at least for some parts of the Cretaceous, as new data are obtained. The Western Interior Cretaceous sequences of the U.S. are an important part of the global expression of high eustatic sea levels, tectonism, warm climate, and oxygen depletion because of the relative geographic isolation of the seaway and, therefore, its strong susceptibility to paleoclimatic and paleoceanographic change.

•As such, these sequences deserve a detailed study in order to:
1. Elucidate trends in geochemical properties and organic-carbon accumulation rates and their potential global impact;
2. Provide validation of climate models (e.g. GCMs);
3. Provide explanations for the significance of bioevents and substantial changes in global biotic diversity during the Cretaceous;
4. Document rates and timing of biotic extinction and evolution in detail; and
5. Investigate the possibility that such shallow Cretaceous seas were the sources of oxygen-depleted oceanic deep-water masses and anoxia.

Most of these objectives are being pursued by the Cretaceous Shallow Drilling working group comprising USGS and University scientists coordinated by M. A. Arthur and W. E. Dean.

ACCOMPLISHMENTS

Drilling and Core Acquisition

This is an ongoing project that actually began in FY 1991 somewhat prior to DOE funding. As stated above, the primary objective of the project is to construct a subsurface transect of organic-rich Cretaceous strata across the Western Interior Seaway (WIS) based on continuously cored material. We initially concluded that cores from four relatively shallow (<1000m) reference holes from western Kansas to eastern Utah would be required at a minimum. in order to construct this transect. The first two holes (western Kansas and southeastern Colorado) would be the most economical because of the proximity to Denver and shallow depth. The first hole would be drilled in eastern Kansas, where the middle to Upper Cretaceous strata are largely pelagic and have not experienced deep burial. The second hole in the transect would be drilled to the west, in the southern Denver Basin near Florence or Cañon City, Colorado to obtain cores of more deeply buried offshore pelagic-hemipelagic strata. The first two cores should contain well preserved marine organic matter in the Niobrara and Greenhorn Formations deposited during maximum transgression of the WIS. A third hole, or, more likely, a series of overlapping holes, would be drilled in the northern San Juan Basin in southwestern Colorado to sample mid-Turonian to lower Campanian nearshore coal-bearing strata of the Mesa Verde Group and Mancos Shale. A fourth hole, or a series of overlapping holes, would be drilled on the Kaiparowits Basin in Utah to sample upper Turonian to lower Campanian nearshore and terrigenous coal-bearing strata of the Straight Cliffs Formation, and the underlying marine Tropic Shale.

During FY 1991 three holes were cored in the Kaiparowits Basin of south central Utah by a drilling rig and crew from the USGS Branch of Coal Geology. All three holes were about 900 feet deep, and continuously cored with 98%+ recovery. Two holes (USGS-CT1-91 and USGS-SMP1-91) were drilled on top of the Kaiparowits Plateau and collected the coal-bearing sequences of the Upper Cretaceous Straight Cliffs Formation. A third hole (USGS #1 Escalante) was drilled at the base of the Kaiparowits Plateau near the town of Escalante, Utah and collected all of the marine Tropic Shale and the top of the Dakota Sandstone. These three holes were funded by the USGS Coal, Onshore Oil and Gas, and Evolution of Sedimentary Basins Programs, and the cores are presently in the USGS Core Research Center in Denver. They constitute the western end of the transect.

Two cores of the Mesa Verde Group from the Southern Ute Indian Reservation (SUIT #1 and #2) in the northern San Juan Basin were collected as part of a BIA-funded project. These cores are presently on hand in the USGS-Core Research Center in Denver, and are available to the project. The lower part of the desired section, the Mancos Shale, has been sampled in detail by Mark Leckie (University of Massachusetts) and colleagues in a series of trenches near Mesa Verde National Park. Although it would be desirable to have core coverage of the Mancos, we feel that the combination of the Mesa Verde cores and Leckie's trenched section for the time being give us the desired coverage in southwestern Colorado.

In January, 1992, the Cretaceous part (about 1000 feet) of the AMOCO #1 Rebecca K. Bounds core from Greeley Co., Kansas was released by AMOCO and shipped to the USGS Core Research Center in Denver. The section from the middle of the Upper Cretaceous Niobrara Formation to the top of the Upper Jurassic Morrison Formation was continuously cored with better than 90% recovery (see Figure 4). This hole constitutes the eastern end of the transect. All that remained was a key core from ther southern Denver Basin in southeastern Colorado.

During June, 1992, a 700-foot hole (USGS #1 Portland), funded by DOE, was drilled and continuously cored in Cretaceous strata east of the Florence oil field near Cañon City, Colorado on the property of the Ideal Cement Company (Holnam, Inc.), Portland, Colorado. The drilling was done by a rig and crew from the USGS Branch of Coal Geology with core recovery of essentially 100%. The section recovered includes the lower half of the Niobrara Formation, the Carlile Shale, the Greenhorn Formation, the Graneros Shale, and the top of the Dakota Sandstone (see Figure 1). Of particular note was the excellent recovery of very distinct limestone-marlstone cycles of the Greenhorn and Niobrara. Both of these pelagic carbonate units contain abundant marine organic matter that may be sources of petroleum in the Florence field as well as in the Denver basin. Logging was very successful and provides digital data for processing and cyclostratigraphy (Figures 2 and 3). A second, 800-foot hole, also funded by DOE, was drilled in July, 1992 about 10 miles southwest of the Portland hole in Pierre Shale that is the reservoir for hydrocarbons in the Florence field. Because the Pierre Shale in the Florence basin is highly fractured, coring was attempted on only 250 feet of the drilled 800-foot section with 96% recovery. Most of the material recovered was homogeneous dark gray claystone with closely spaced high-angle fractures, but parts of the section contain multiphase layers or concretions of limestone, siderite, and (or) phosphate.

Coordination of the Scientific Effort

Considerable time has been spent in assembling and "educating" the scientific working group for this Project. All participants met for 4 days at the USGS Core Research Center in August, 1992 in order to discuss objectives and to come to agreement on individual efforts, sampling requirements and strategies, and synthesis of results. Table II provides the schedule and topics of this August "Workshop." The workshop successfully met its goals, which included having the group understand the techniques and significance of each aspect of the Project. Participants were asked to contribute a short oral presentation (and posters where appropriate) to the group. In addition, much time was spent examining and discussing core material.

Dean and Arthur also prepared a Sampling Protocol for the Project (appended to this report) which will be published as a USGS Open-File Report. This is an important document because it describes the procedure for outside investigators to have access to samples from these cores.

Sampling and Scientific Results to Date

Description and sampling of cores has ensued, and analyses are underway by the different participants. Detailed descriptions are available for the Rebecca Bounds #1 core in digital (computer file) form; Arthur, Sageman and Dean described these over a two week period in July and August, 1992. Figures 5 and 6 are examples of the detail and the scheme used. Kauffman and Leithold have nearly completed their description of the Escalante #1 core in the same detail. Again, these will be put into digital form. White, Sageman and Dean will describe the Portland #1 core during a period in mid-March, after it is cut and photgraphed. We hope to publish an Initial Reports volume (preparation and submission by August, 1993) featuring these detailed descriptions and other available biostratigraphic data.

Preliminary results are available for sampling of the Bounds (BO1) and Escalante #1 (ES1) cores for the fascinating Cenomanian/Turonian (Hartland-Bridge Creek) interval (Figures 7 and 8). Note that this interval constitutes one of the best hydrocarbon source potentials in the basin. Figure 9 illustrates the approach we are using in working out the relationship of lithology, biofacies and sea level variations (sequences) for the Cenomanian-Turonian interval in the cores (work of Sageman, Kauffman, Arthur and others), which is being tied to outcrop data. In addition, we have preliminary results for the lower part of the Niobrara Fm in the BO1 core (Fig. 10). Cutting and preparation of cores of the Portland #1 well is nearly completed at the USGS Core Research Center, and description and sampling will soon follow. Sampling so far has followed the outline below, and analyses are progressing (mainly to be accomplished in Year 2 of funding).

General Sampling

Arthur and Dean will sample ES1, BO1 and PO1 @ 1 ft. (ca. 30 cm) intervals
- Dean generates TOC, Carbonate, Pyrolysis on ES1 (see Fig. 8)
- Arthur/White will generate TOC/Carbonate/pyrolysis profiles
  - from this, samples will be selected for Inorganic geochemistry
  - samples selected in certain intervals for stable isotopes
  - selected samples for detailed organic geochem. (Freeman)
  - samples to Bralower, Leckie and Sliter for paleontology

Fort Hays Ls to lower Smoky Hill transition (see Fig. 10)

BO1; boxes 4,5,6,7,8 (and later in Portland #1 when cut and photgraphed)
sample at 10 cm intervals for TOC/Carbonate
sample 2 cycles at 2-4 cm intervals
- (587-588 ft. w/carbonate cycle but laminated; 599-602' laminated to bioturbated cycles)
- coordinate with C. Savrda on ichnofacies
- Bralower gets chip vertical from every sample for nannofossils
- Leckie will analyze foram samples @ 20 cm intervals
  - select samples to give contrasts

Objectives: TST-HST transition; following oxygenation and clastic input signal changes with sea level cycle.

Mid. Hartland through Bridge Creek Ls. (see Figs. 7,8, 9)

BO1, PO1, ES1

Limestones LS2-8 for detailed samples @ 2-4 cm sampling

Bralower; Leckie do micropaleontology at that sampling interval

Arthur/Dean: TOC, Carbonate, Pyrolysis and geochemistry.

Freeman/Pancost/Arthur biomarkers and stable isotopes

Savrda does ichno- and biofacies w/Sageman

Objectives: Sequence stratigraphy and biotic/geochemical signals

High resolution sampling of several milankovitch cycles

In the next year we will be completing these analyses, which will involve about 1000 samples total. We will host a meeting of the Project Working Group in August, 1993 at Penn State in conjunction with the SEPM Meeting on "The Stratigraphic Record of Global Change." A number of the investigators will be reporting preliminary results of the Cretaceous Shallow Drilling Project at that meeting.

Funding ($k)

Funding Source	FY1991 Science Overhead	FY1991 Drilling Science	FY1992 Overhead Drilling	FY1992 Science Overhead	FY1993 (est.) Drilling
USGS	$80	$26	$200	$66	$200 $66
total	$106		$266		$266
DOE			$91 $66	$72	$99 $40
total			$229		$139

Previous and Current Contracts

DOE to USGS for drilling and logging	$100k	3/92 to 3/93
DOE to Penn State for academic science	$269k	3/92 to 3/94

Project Output:

Abstracts

Dean, W.E., and Arthur, M.A., 1992, Continental Scientific Drilling Transect of the Western Interior Seaway: Society of Economic Paleontologists and Mineralogists, Abstracts for 1992 Theme Meeting, Ft.. Collins, Colorado, p. 22.

Sageman, B.B., Arthur, M.A., and Dean, W.E., 1992, Use of carbon and trace element data to recognize trends in sedimentation rate: application to sequence stratigraphy of the Greenhorn cyclothem: Society of Economic Paleontologists and Mineralogists, Abstracts for 1992 Theme Meeting, Ft.. Collins, Colorado, p. 59.

Sageman, B.B., Elder, W.P., Harries, P.J., and Kauffman, E.G., 1992, The application of bioevent data to Cretaceous chronostratigraphy of the Western Interior, U.S.: examples from the Greenhorn cyclothem: Society of Economic Paleontologists and Mineralogists, Abstracts for 1992 Theme Meeting, Ft.. Collins, Colorado, p. 59.

Kauffman, E.G., 1992, The evolution of Cretaceous biostratigraphy in the Western Interior Basin of North America: Society of Economic Paleontologists and Mineralogists, Abstracts for 1992 Theme Meeting, Ft.. Collins, Colorado, p. 37.

Kauffman, E.G., 1992 Obradovich, J., and Cobban, W.A., 1992, An integrated high-resolution chronology for the Cretaceous Western Interior Basin of North America: Society of Economic Paleontologists and Mineralogists, Abstracts for 1992 Theme Meeting, Ft.. Collins, Colorado, p. 37.

Leithold, E.L.,1992, Prodelta sedimentation in a dynamic foreland basin: record of sea-level change in the proximal Greenhorn Sea: Society of Economic Paleontologists and Mineralogists, Abstracts for 1992 Theme Meeting, Ft.. Collins, Colorado, p. 40.

Dean, W.E., and Arthur, M.A., 1992, Cretaceous resources, events, and rhythms: Continental Scientific Drilling transect of the Western Interior Seaway (abs.): *in* Carter, L.M., ed. USGS Research on Energy Resources--1992 Program and Abstracts, V.E. McKelvey Forum on Mineral and Energy Resources: U.S. Geological Survey Circular 1074, p. 17.

Hettinger, R.D., and McCabe, P.J., 1992, Testing new coal models-=the 1991 Kaiparowits Plateau driling project (abs.): *in* Carter, L.M., ed. USGS Research on Energy Resources--1992 Program and Abstracts, V.E. McKelvey Forum on Mineral and Energy Resources: U.S. Geological Survey Circular 1074, p. 34.

Open-File Reports

Dean, W.E., and Arthur, M.A., 1992, Sample handling and curation protocol for the Western Interior Seaway Scientific Drilling Project: U.S. Geological Survey Open-File Report 92- , 6 p.

TABLE I.

U. S. CONTINENTAL SCIENTIFIC DRILLING PROGRAM
U.S. GEOLOGICAL SURVEY
CRETACEOUS WESTERN INTERIOR SEAWAY DRILLING PROJECT (preliminary -1992)

o DRILLING AND LOGISTICS:

Location: Lat. 37°45'N, Long. 111°36'W
Locale: Near Escalante, Utah
Drilling: three holes, 3" diameter
Depth: 900 to 1000 ft (274 to 305 m) each
Completion Date: June 26, 1991
Cost: $80,000 (USGS)
Core Recovered: 98%+
Core Repository: USGS Core Research Center, Denver
Fluid Sampling: None
Drilling Management: USGS
Special Concerns: None
Hole Identification: USGS #1 Escalante, CT1-91, and SMP1-91
Status: samples are being collected for geochemical, sedimentologic, and biostratigraphic studies

Location: Lat. 38°23'N, Long. 105°01'W
Locale: Portland (near Florence and Canon City), Colorado
Drilling: one hole, 3" diameter
Depth: 700 ft (213 m)
Completion Date: June 28, 1992
Cost: $50,000 (DOE)
Core Recovered: 99%+
Core Repository: USGS Core Research Center, Denver
Fluid Sampling: None
Drilling Management: USGS
Special Concerns: None
Hole Identification: USGS #1 Portland
Status: Hole was cased to 700' with 11/8" steel pipe for heat-flow measurements; samples are being collected for geochemical, sedimentologic, and biostratigraphic studies

Location: Lat. 38°14'N, Long. 105°06'W
Locale: Wetmore (near Florence and Canon City), Colorado
Drilling: one hole, 3" diameter
Depth: 799 ft (244 m)
Completion Date: July 17, 1992
Cost: $50,000 (DOE)
Core Recovered: Of the 799 feet drilled, coring was attempted on 254.04 feet with recovery of 243.44 ft (96%).
Core Repository: USGS Core Research Center, Denver
Fluid Sampling: None
Drilling Management: USGS
Special Concerns: Problems associated with drilling in fractured shale
Hole Identification: USGS #1 Wetmore
Status: samples are being collected for geochemical, sedimentologic, and biostratigraphic studies

o SCIENTIFIC OBJECTIVE:

Construct a subsurface transect of Cretaceous strata that were deposited in Western Interior Seaway, going from organic-rich, marine hydrocarbon source rocks in Kansas and eastern Colorado to nearshore coal-bearing units in western Colorado and Utah.

o PRINCIPAL INVESTIGATORS:

Walter E. Dean, USGS, Denver; Michael A. Arthur, Penn State Univ.

o INSTITUTIONAL INVOLVEMENT:

Government Agencies: USGS; DOE

Universities: Penn State; Northwestern; North Carolina State; Univs. of Massachusetts, North Carolina, Colorado, & Rhode Island

o FINDINGS (preliminary):

1. Cyclic production and preservation of both oil-prone and gas-prone organic matter, in response to global sea-level change, were distinctive features of strata deposited throughout the Western Interior Seaway.
2. The Pierre Shale, the reservoir for hydrocarbons in the Florence Field, consists mostly of organic-poor (mostly less than 1% organic carbon) claystone with closely spaced high-angle fractures. These features make the Pierre Shale an excellent reservoir rock, but the source rocks for hydrocarbons in the Florence Field must be organic-rich strata such as those recovered in the Portland core.

TABLE II.

WISK WORKSHOP SCHEDULE
AUGUST 12-14, 1992
DENVER USGS CRC

WEDNESDAY: **OVERVIEW OF CRETACEOUS W.I.S.**

8:30 AM Greetings and Overview Dean and Arthur
9:00 AM Stratigraphy and Setting of W. Interior Seaway Kauffman
10:00 AM Coffee Break
10:20 AM Kauffman presentation (cont'd)
11:30 AM Discussion/question period
12:00 Lunch
1:15 PM-5:00 PM Individual Presentations (about 20 min. each)
(Designed to outline potential for different techniques)
Leckie: Nearshore Mancos Paleoenvironments
Savrda: Trace Fossil Indicators of Benthic Environment Niobrara and Bridge Creek
Leithold: Sedimentology/Sequence Stratigraphy, Tropic and Tununk Fm.
Arthur/Sageman/Dean: Inorganic Geochemical Indicators of Redox and Clastic Sedimentation Variations
Elder: Milankovitch-scale cycles, Sea Level and Cross-basin correlation Ceno./Turon.
Obradovitch: An Update on Cretaceous Radiometric Timescale
Bralower: Cenomanian-Turonian Calcareous Nannofossils
and others as interested.

THURSDAY: **AVAILABILITY OF MATERIALS AND COLLABORATIVE EFFORT**

8:30 AM Overall Objectives of the Project Arthur/Dean
9:00 AM Summary of Coring and Core Materials Availabie Dean
9:30 AM Sampling and Sample Policy Campbell and Dean
10:00 AM Coffee Break
10:20 AM Orientation to Core Materials
12:00 Lunch
1:15.PM Break into Working Groups to Discuss Partitioning of Work and Collaboration

FRIDAY: **CORE EXAMINATION AND PRELIMINARY SAMPLE SELECTION**

End day with brief discussion/question session

USGS #1 Portland S20, T19S, R 68W, 38o22.6'N, 105o01.3'W, elev. 5200' (1585 m)

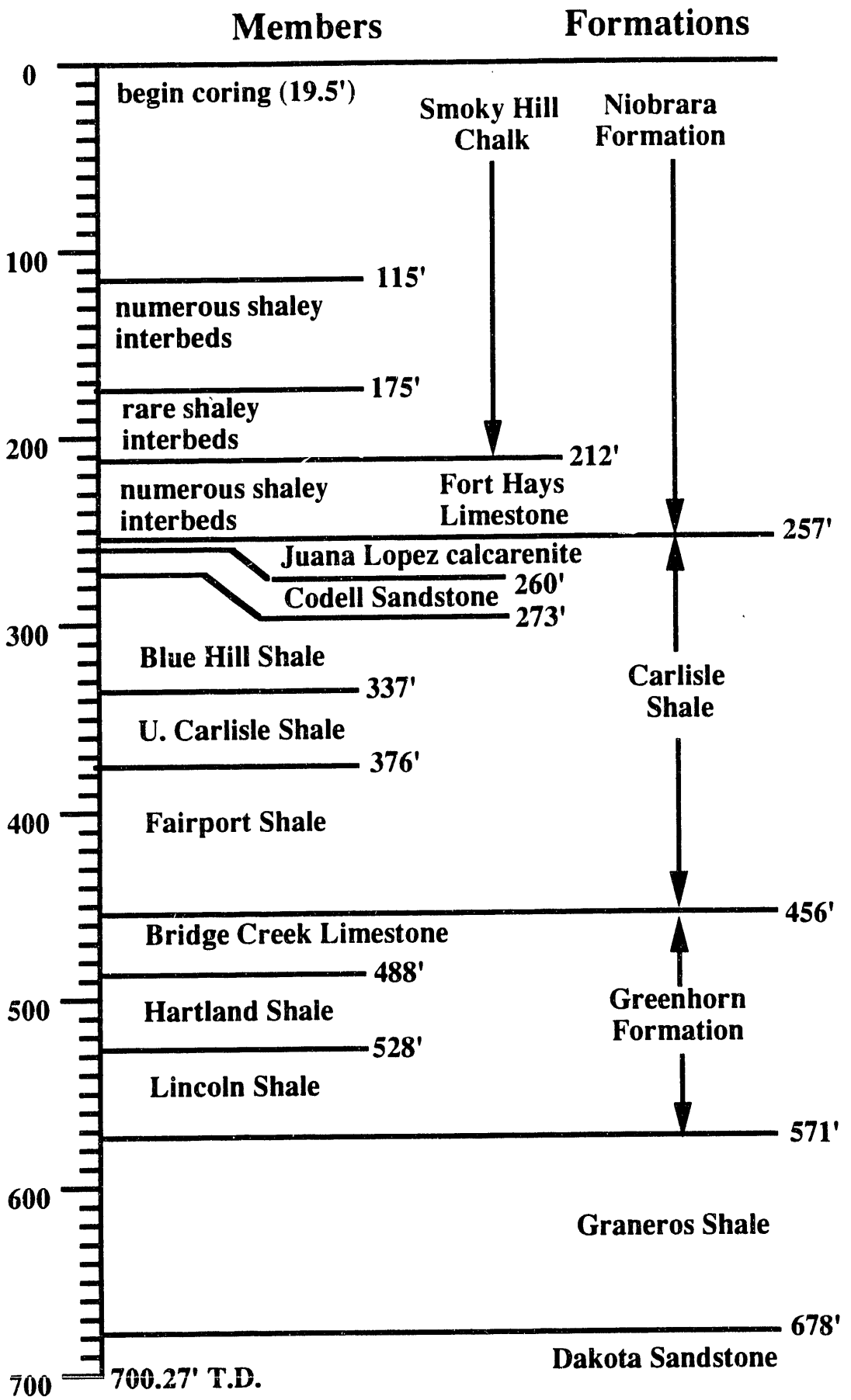
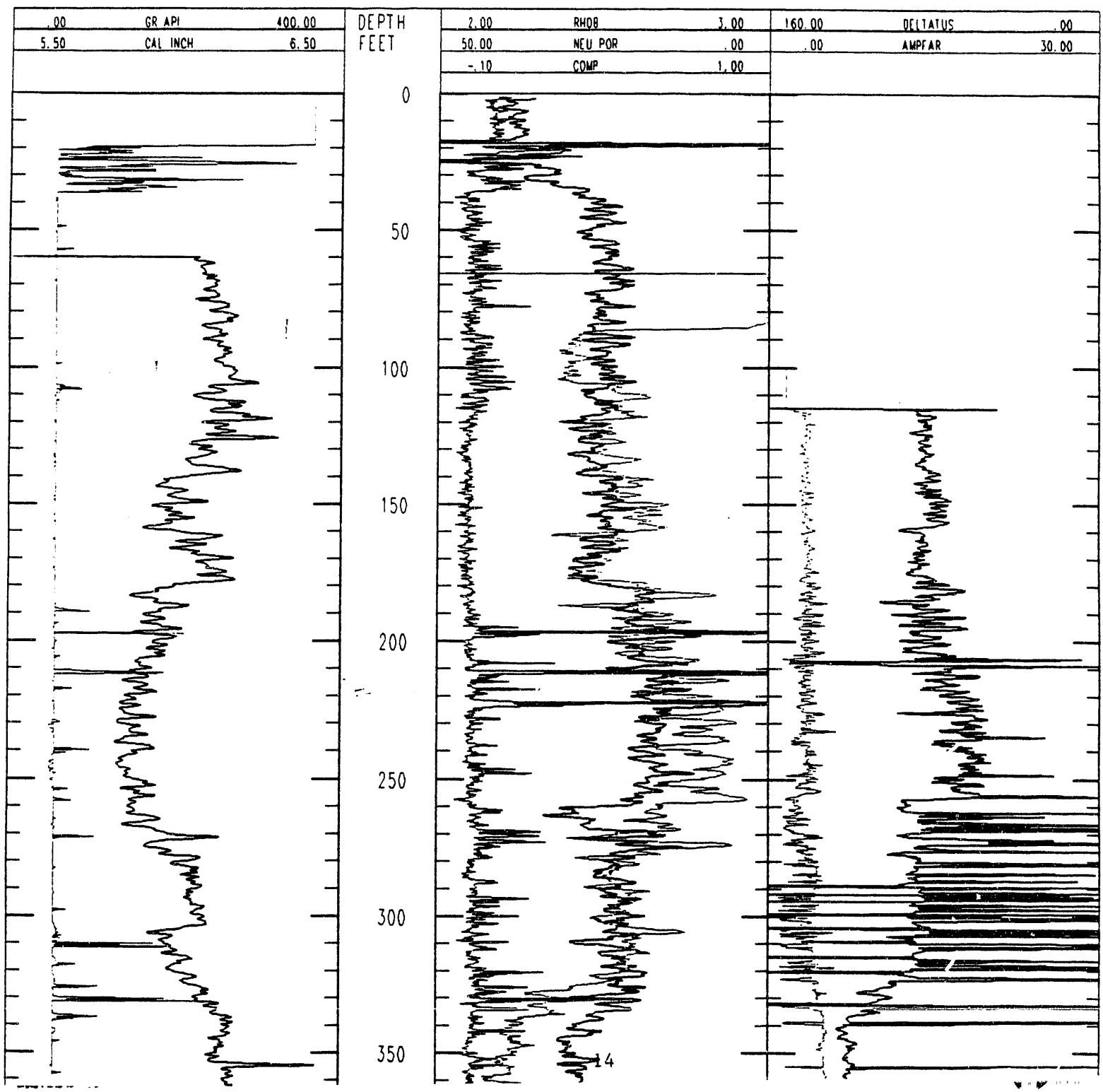


Figure 1

plotted 10 July 92

Well Name: 1-PORTLAND

Figure 2a



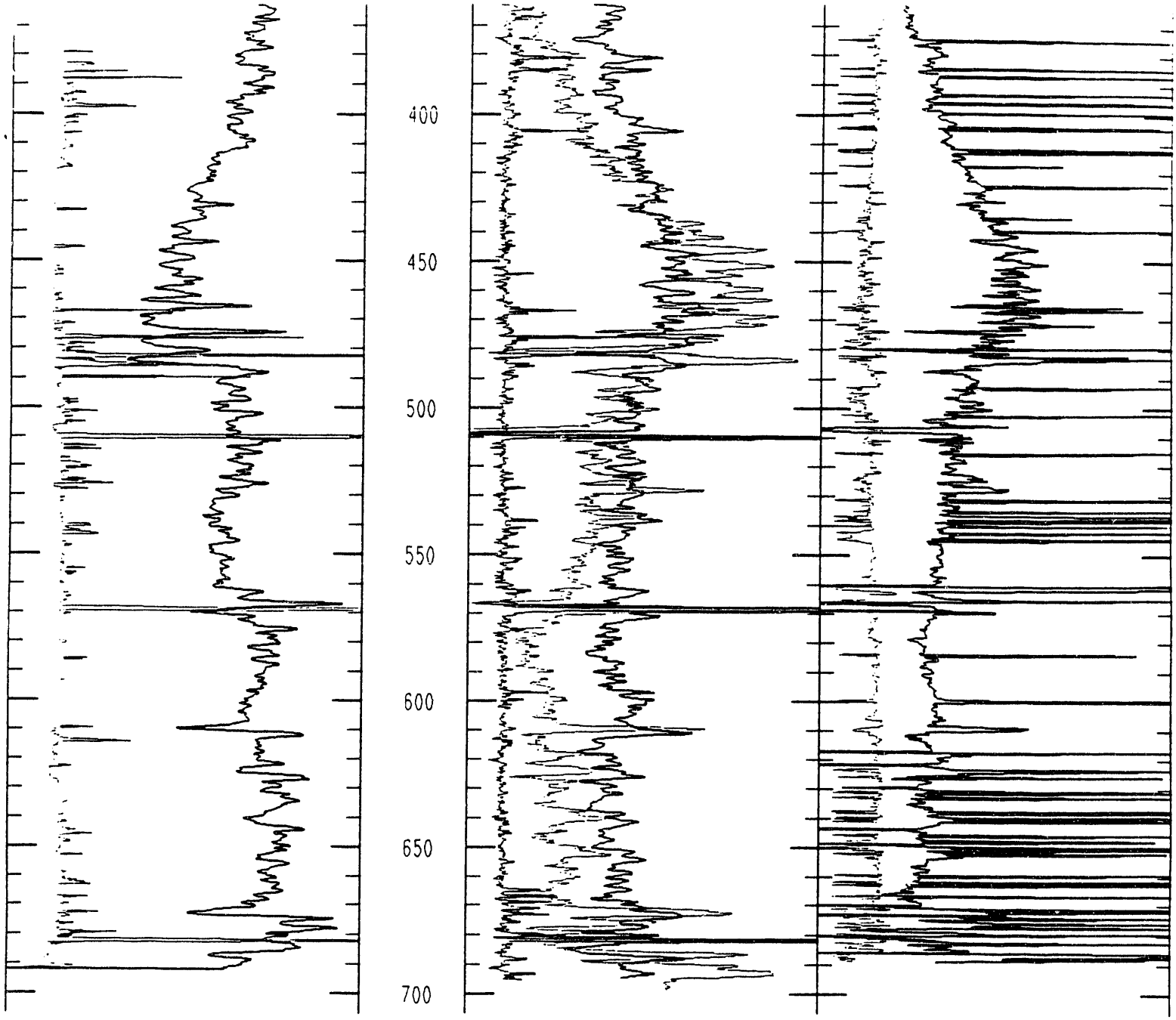
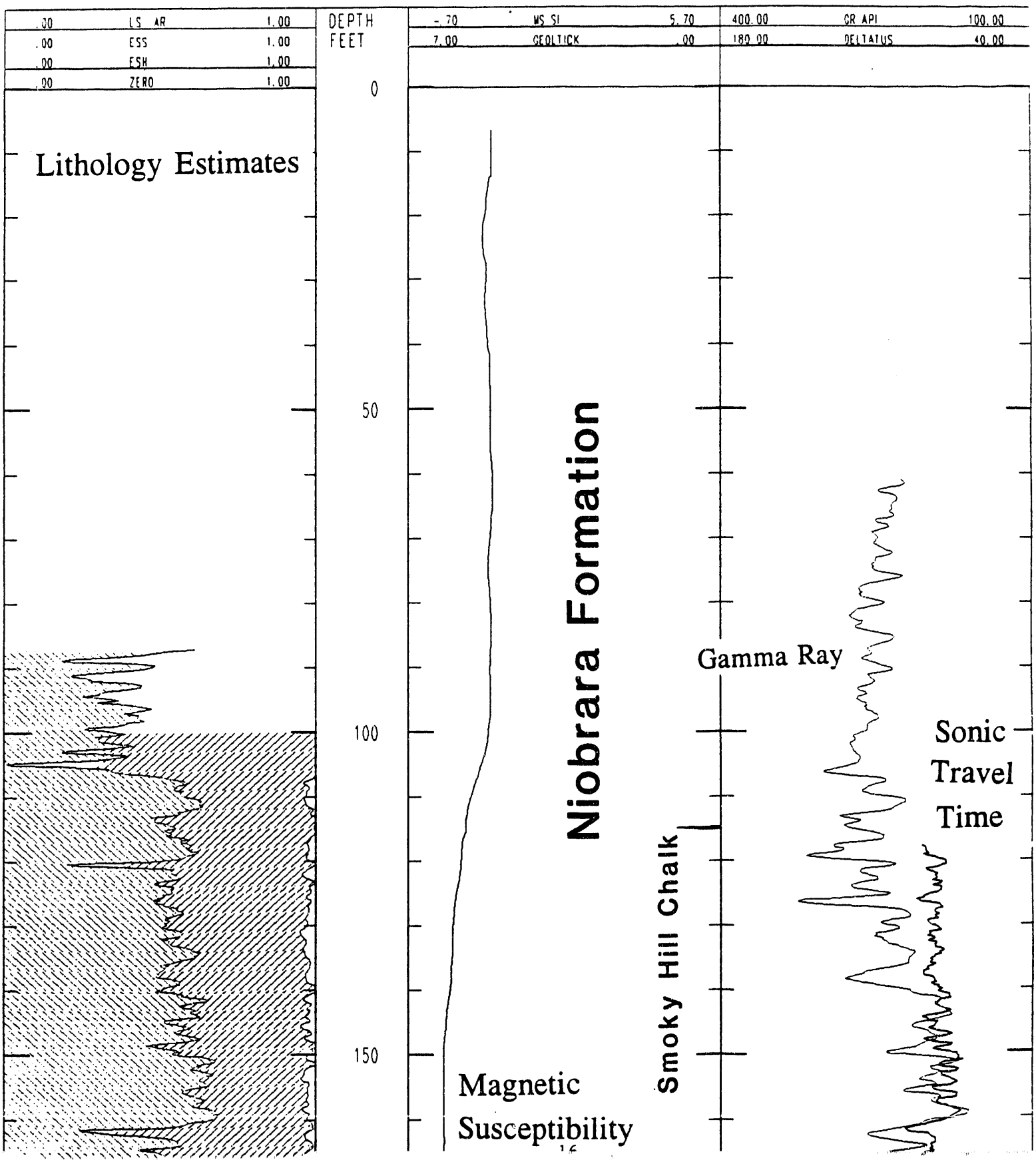


Figure 2b

Well Name: 1-PORTLAND

Figure 3a



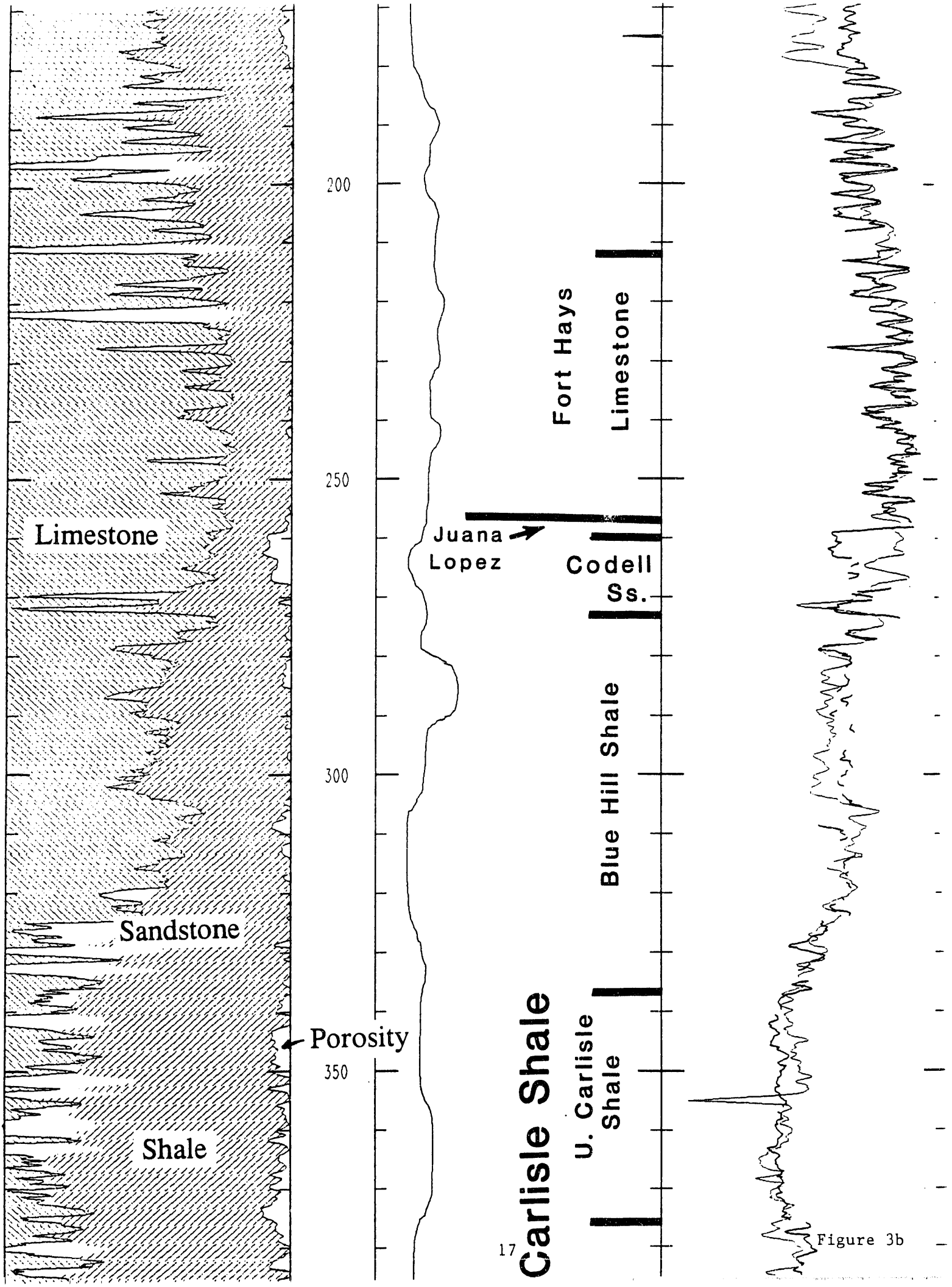

Limestone
Sandstone
Porosity
Shale
200
250
300
350
Juana Lopez
Fort Hays Limestone
Codell Ss.
Blue Hill Shale
Carlisle Shale
U. Carlisle Shale

Figure 3b

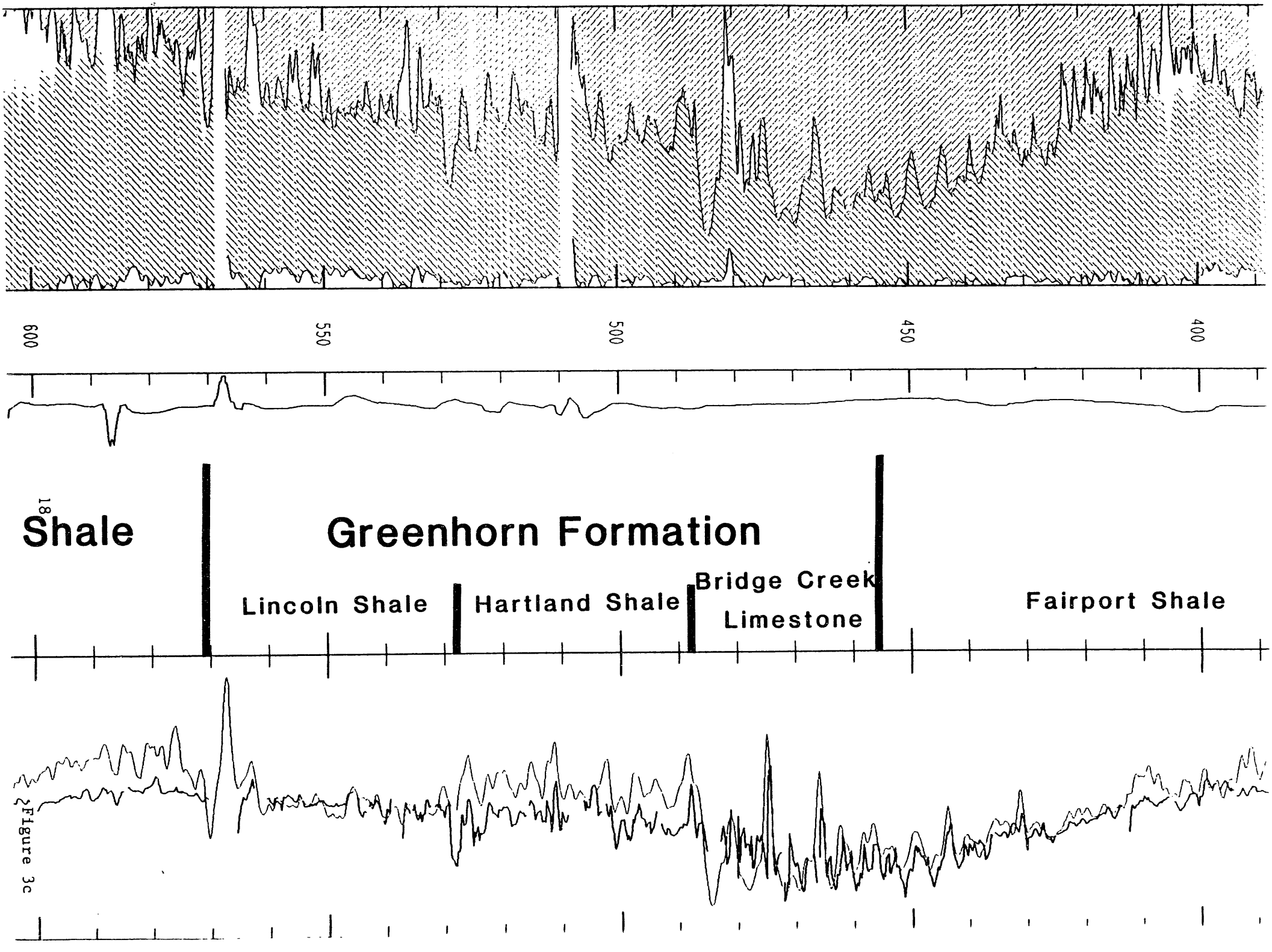

600
550
500
450
400
Shale
Greenhorn Formation
Lincoln Shale
Hartland Shale
Bridge Creek
Limestone
Fairport Shale

Figure 3c

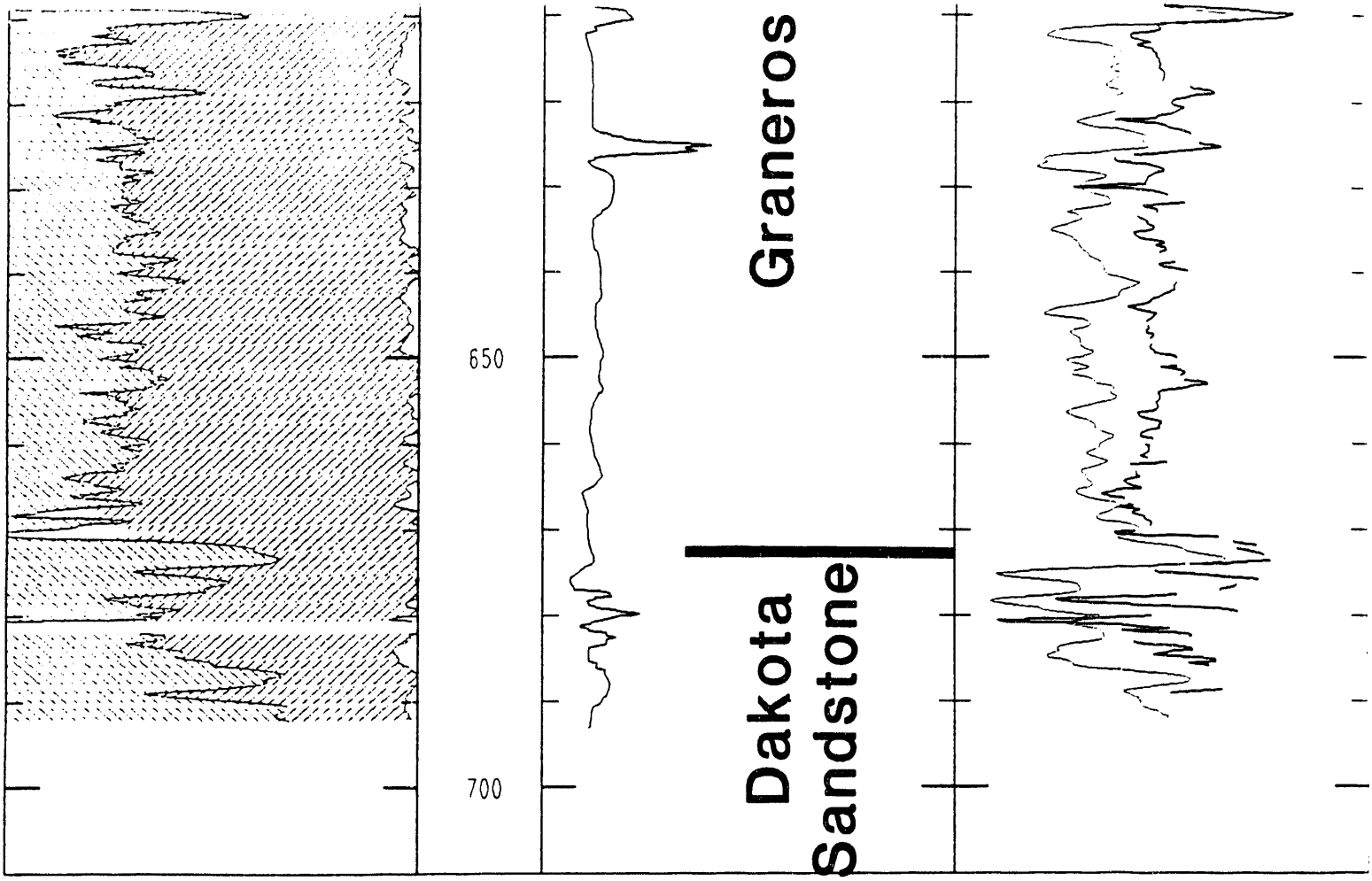
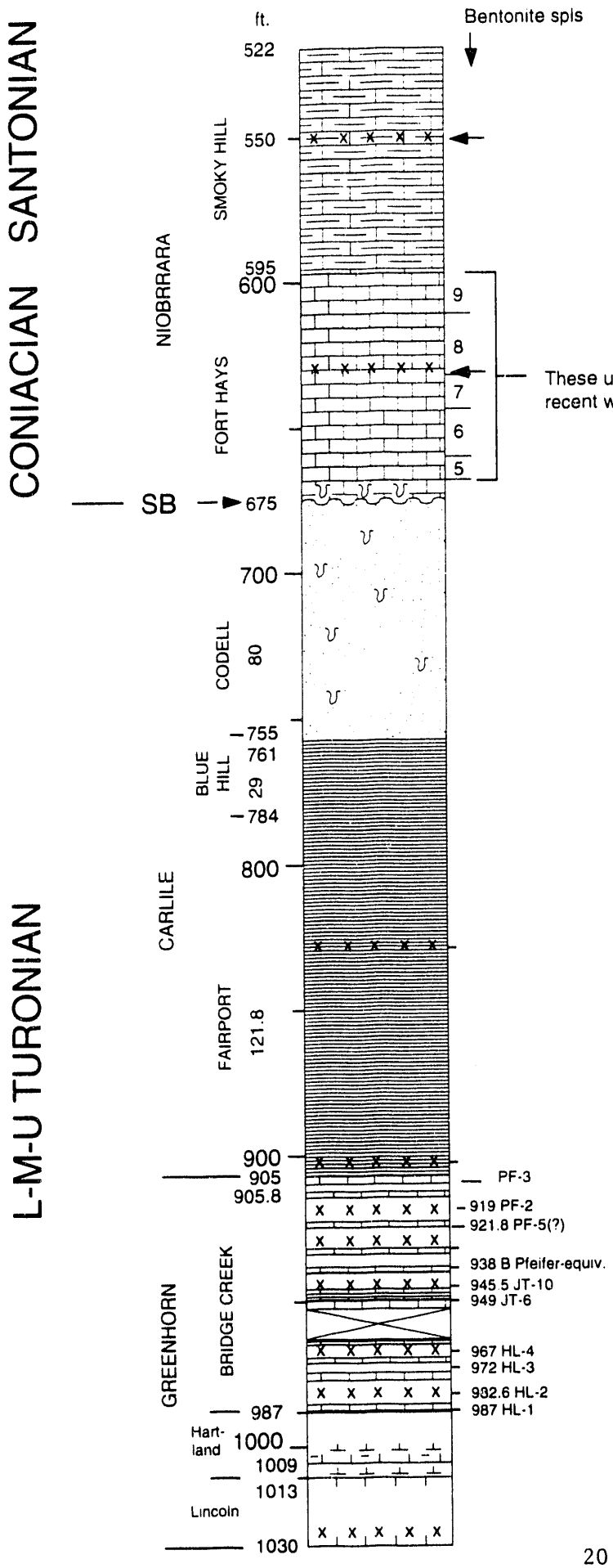


Figure 3d

LOG OF BOUNDS CORE, KANSAS

LOC 15129



These unit #'s correspond with LaFerriere and Hattin's units in their recent well log correlations in AAPG Bull. 1989, v.73, #5, p. 630.

Figure 4a

Rebecca K. Bounds #1

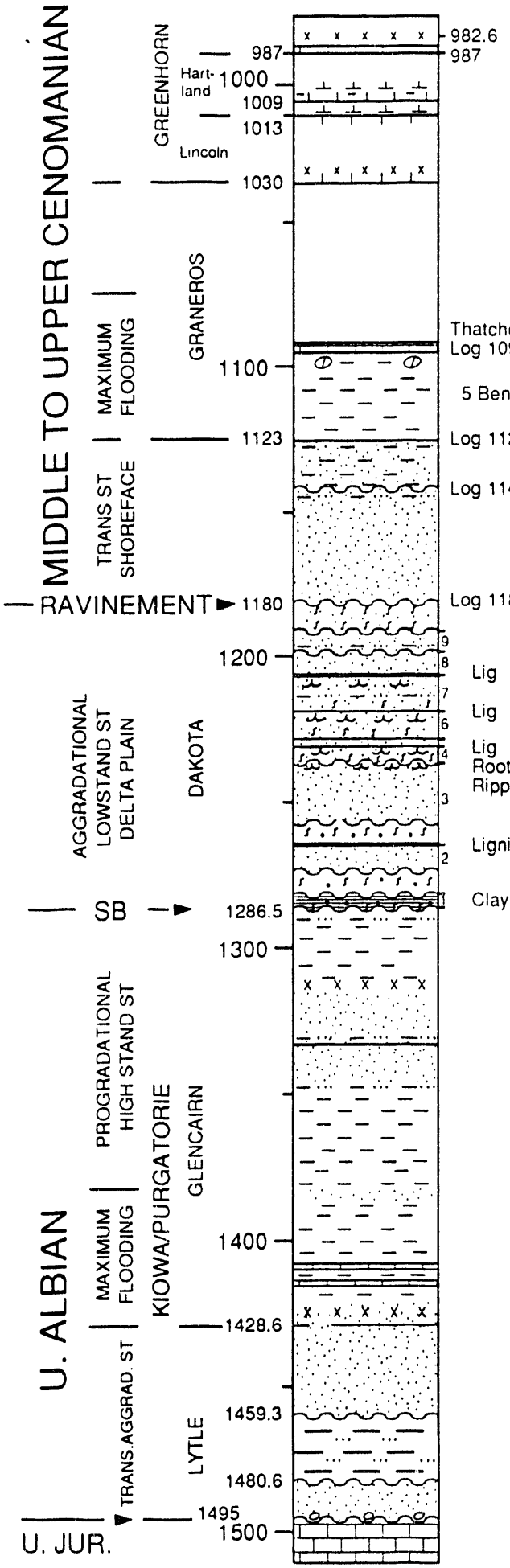
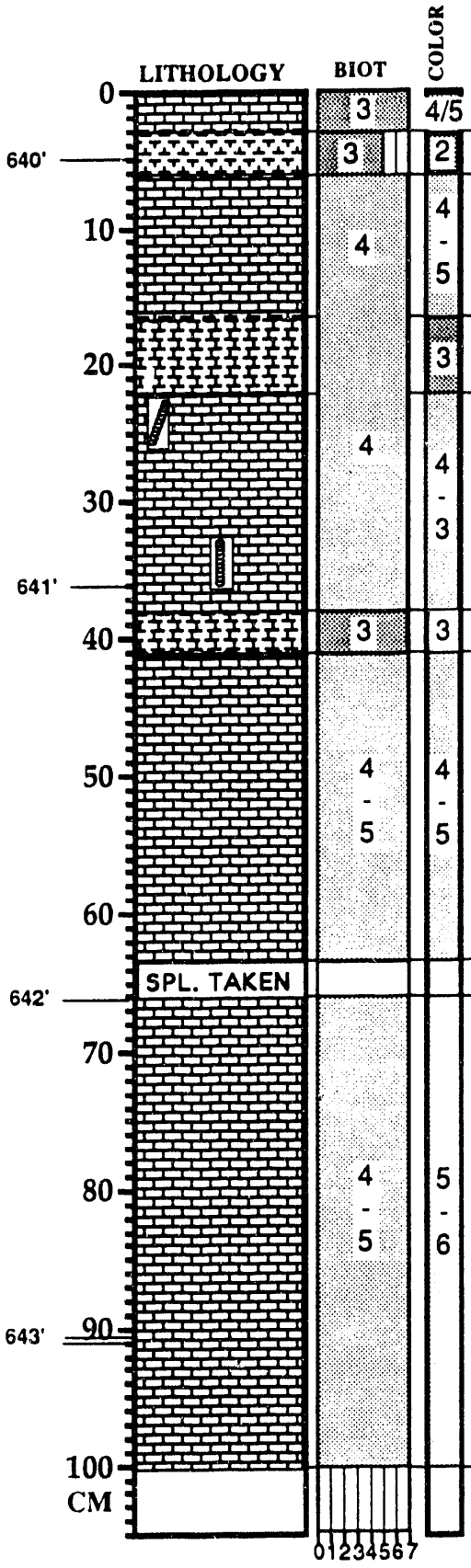


Figure 4b

CORE: AMOCO Rebecca K
Bounds #1

BOX # 12a
BOX FOOTAGE 639-649'



3308 cm

Unit 167 - 3 cm; LIMESTONE; very bioturb. (7) w/ Chond. & Plano. burrows (3); yel. gry. to v. lt. gry. (4/5); common sln. seams; l. cont. grad. over 1 cm

3311 cm

3314 cm

Unit 168 - 3 cm; MARLSTONE; sli. bioturb. (5) w/ lg.Plano. burrows (3); ol. gry. (2); abund. lno. frags.; sln. seams at base; l. cont. grad. over 1 cm

Unit 169 - 10 cm; LIMESTONE; v. bioturb. (7) w/ lg. Plano., Teich., & Zooph. burrows (4); yel. gry. to lt. gry. (4/5); few lno. frags.; l. cont. grad. over 1 cm

3324 cm

3330 cm

Unit 170 - 6 cm; MARLY LIMESTONE; mod. bioturb. (6) w/ lg.Plano. & Teich. burrows (4); lt. ol. gry. (3); many sln. seams; l. cont. grad. over 4 cm

Unit 171 - 16 cm; LIMESTONE; similar to Unit 169; yel. gry. to lt. ol. gry. (4/3); l. cont. grad. over 2 cm; sln. seams at base

3346 cm

3349 cm

Unit 172 - 3 cm; MARLY LIMESTONE; v. bioturb. (7) w/ lg.Plano. & Teich. burrows (3); lt. ol. gry. (3); many sln. seams; l. cont. grad. over 1 cm

Unit 173 - 22.5 cm; LIMESTONE; v. bioturb. (7) w/ lg. Plano., Teich., & Thall. burrows (4/5); yel. gry. to lt. gry. (4/5)

3371.5 cm

3374 cm

Unit 174 - 2.5 cm; BENTONITE? (sample taken)

Unit 175 - 22.5 cm; LIMESTONE similar to Unit 173 but lighter, v. lt. gry. to white (5/6); common lno. frags.

3408 cm

MAA/WED/BBS - 6/92

Figure 5

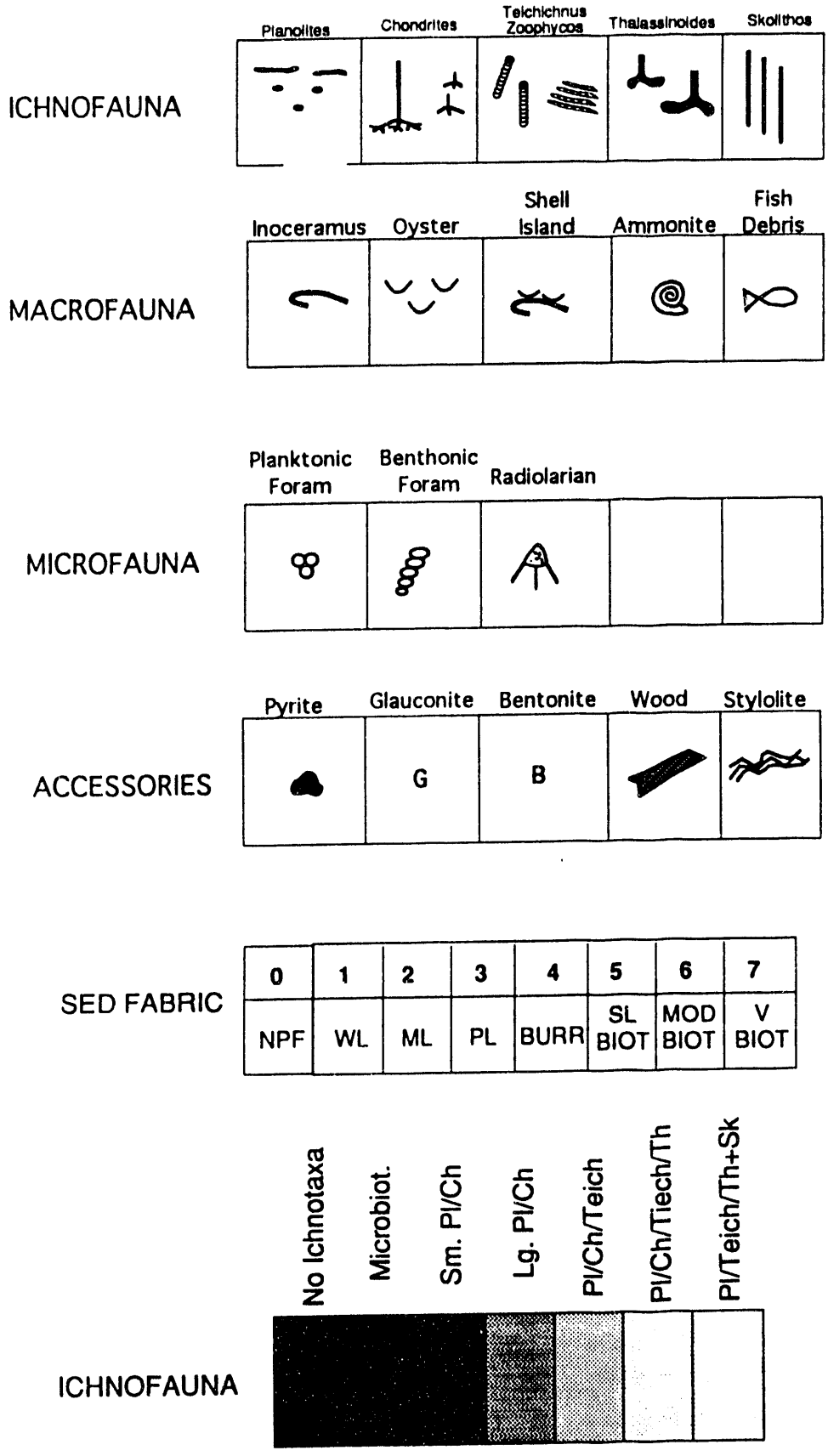
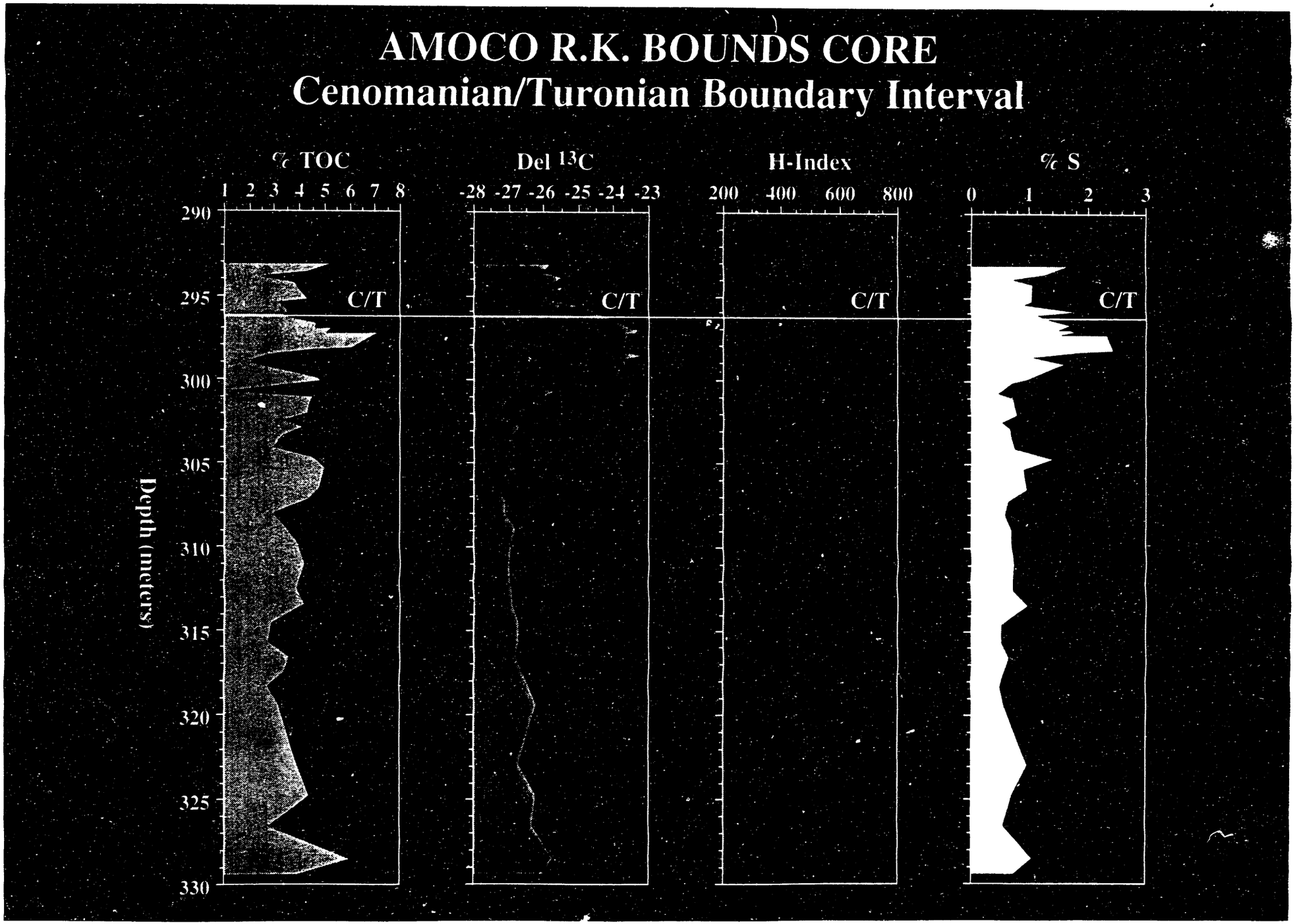

ICHNOFAUNA
Planolites
Chondrites
Teichichnus Zoophycos
Thalassinoides
Skolithos
MACROFAUNA
Inoceramus
Oyster
Shell Island
Ammonite
Fish Debris
MICROFAUNA
Planktonic Foram
Benthonic Foram
Radiolarian
ACCESSORIES
Pyrite
Glauconite
G
Bentonite
B
Wood
Stylolite
SED FABRIC
0
NPF
1
WL
2
ML
3
PL
4
BURR
5
SL BIOT
6
MOD BIOT
7
V BIOT
ICHNOFAUNA
No Ichnotaxa
Microbiot.
Sm. Pl/Ch
Lg. Pl/Ch
Pl/Ch/Teich
Pl/Ch/Tiech/Th
Pl/Teich/Th+Sk

Figure 6

Figure 7


AMOCO R.K. BOUNDS CORE
Cenomanian/Turonian Boundary Interval
% TOC
1 2 3 4 5 6 7 8
Del 13C
-28 -27 -26 -25 -24 -23
H-Index
200 400 600 800
% S
0 1 2 3
290
295
300
305
310
315
320
325
330
Depth (meters)
C/T
C/T
C/T
C/T

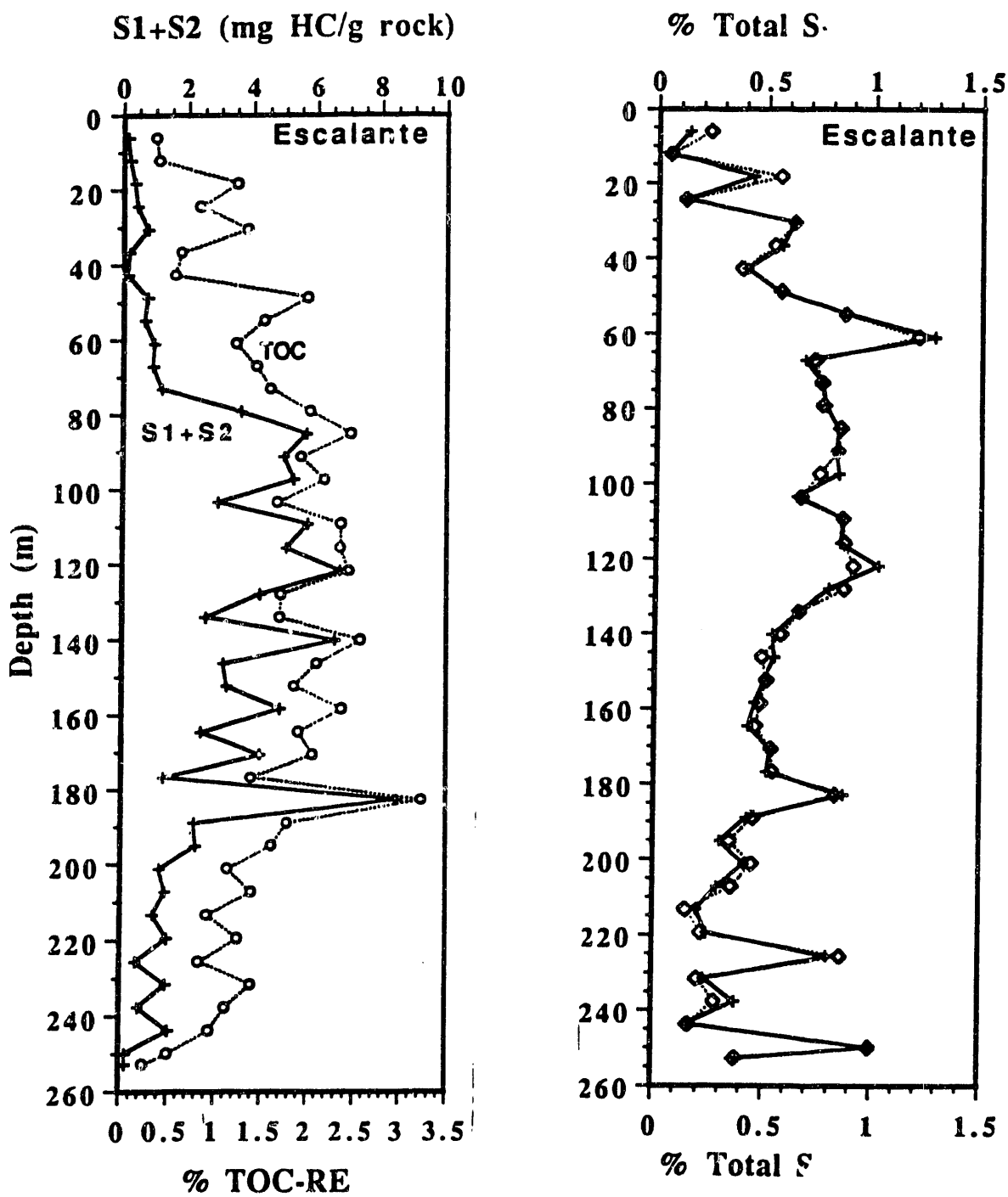
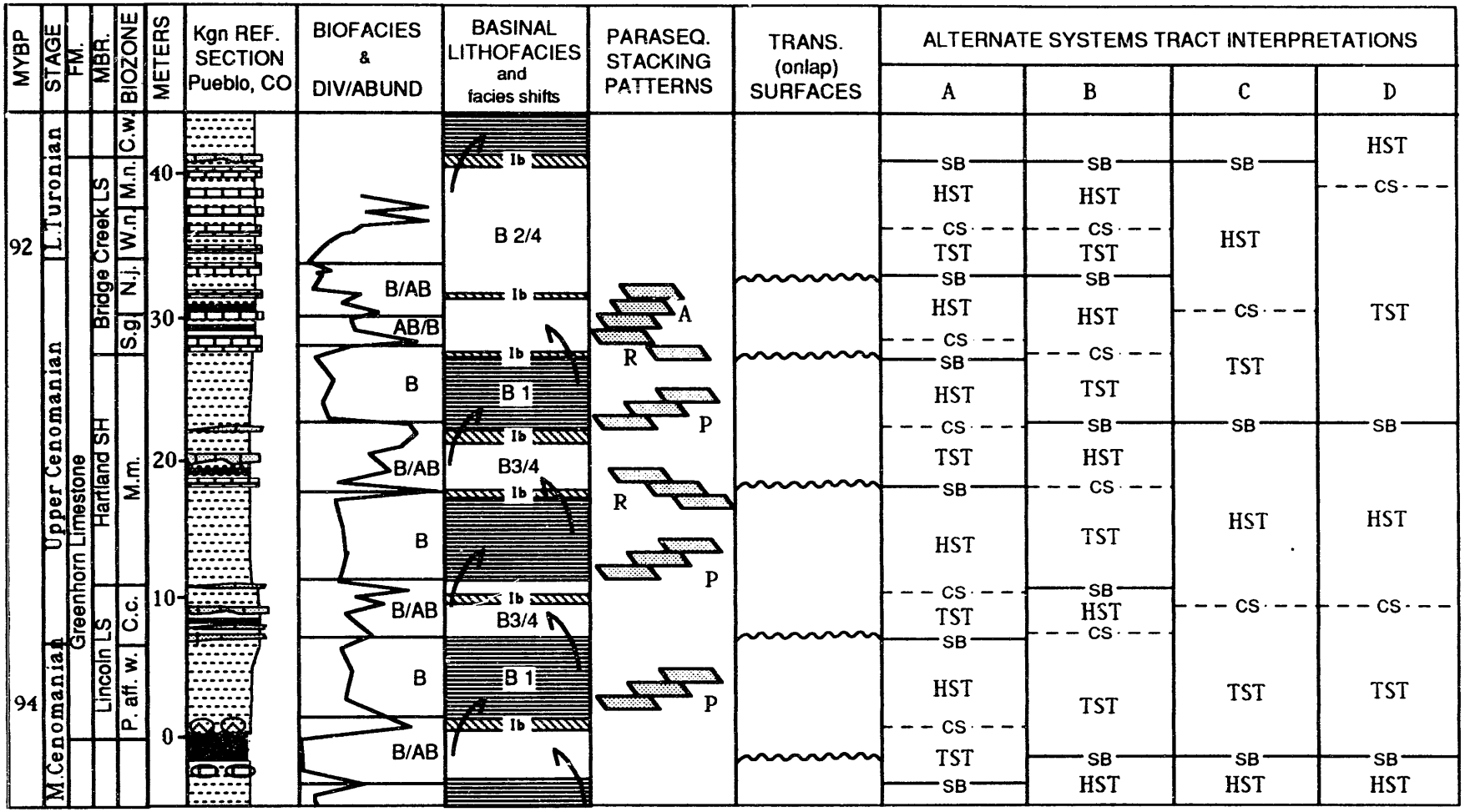

S1+S2 (mg HC/g rock)
0 2 4 6 8 10
Escalante
TOC
S1+S2
Depth (m)
0 20 40 60 80 100 120 140 160 180 200 220 240 260
0 0.5 1 1.5 2 2.5 3 3.5
% TOC-RE
% Total S
0 0.5 1 1.5
Escalante
0 20 40 60 80 100 120 140 160 180 200 220 240 260
0 0.5 1 1.5
% Total S

Figure 8



B Biofacies=Low div/epifaunal susp. feeders dominate.

AB Biofacies=High div/mixed epi/infaunal susp.-deposit feeders and other trophic groups.

B1 Lithofacies =Lam/org.-rich black shale

B3/4 Lithofacies= Skeletal Lmst or Lmst/Marlst

Ib Events=condensed beds/disconformities

KEY

Basinward shift in facies

Landward shift in facies

Paraseq. stacking { P=progradational, R=retrogradational, A=aggradational

HST=Highstand systems tract
TST=Transgressive systems tract
SB=Sequence boundary
CS=Condensed section

Case D= Haq, et al. (1986)

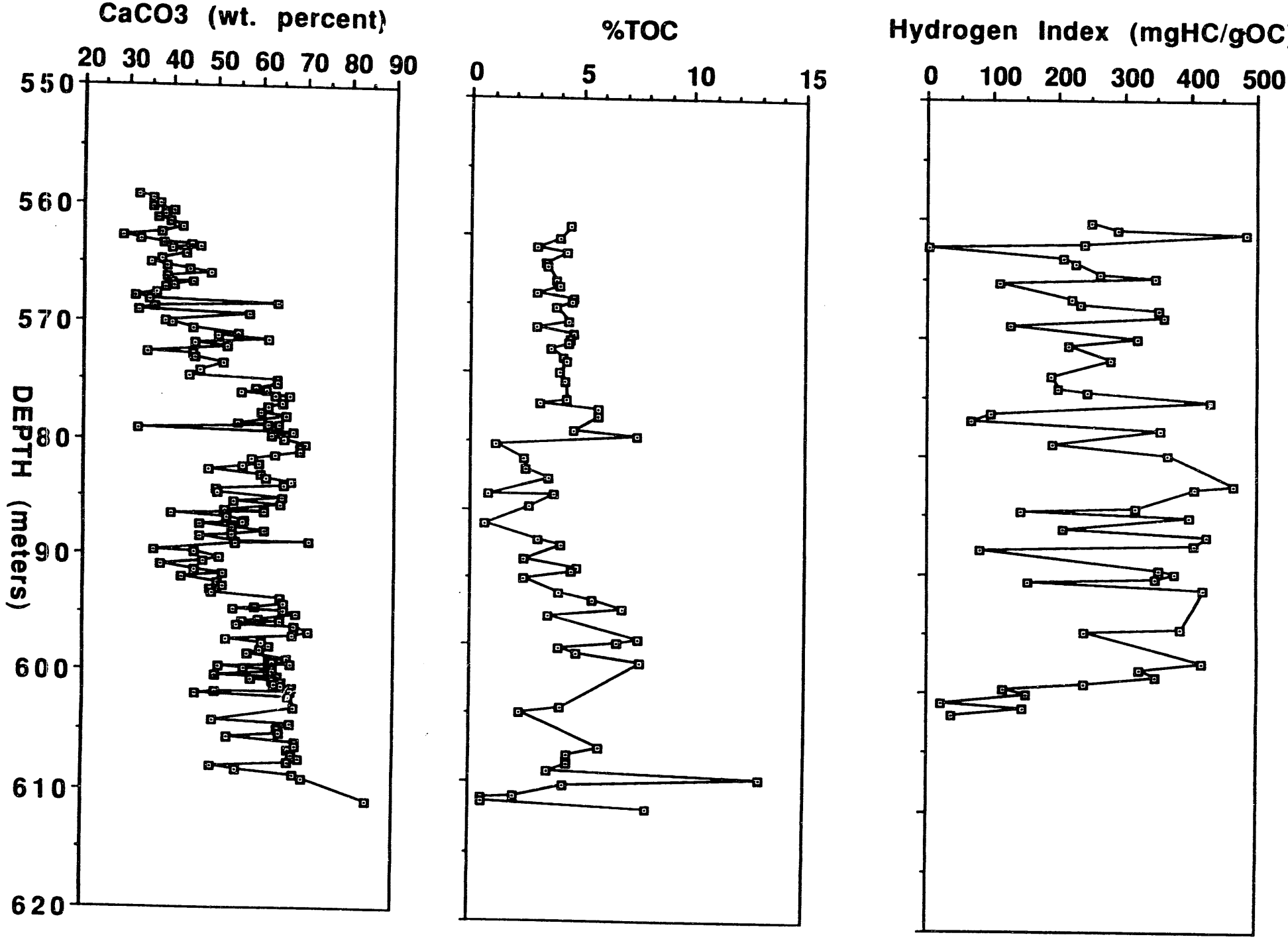

CaCO3 (wt. percent)
20 30 40 50 60 70 80 90
%TOC
0 5 10 15
Hydrogen Index (mgHC/gOC)
0 100 200 300 400 500
DEPTH (meters)
550
560
570
580
590
600
610
620

Figure 10

DOE PROJECT ACCOMPLISHMENTS
Year 1, The Pennsylvania State University
January, 1992 through December, 1993

Project Title: Cretaceous Shallow Drilling, U.S. Western Interior: Core Research

Overall Principal Project Investigators:

Dr. Michael A. Arthur
Department of Geosciences, Pennsylvania State University, University Park, PA 16802; phone: (814)863-6054; FAX: (814)863-7823; EMAIL: Omnet, M.Arthur; Bitnet, Arthur@geosc.psu.edu;

Dr. Walter E. Dean (not supported directly by PSU DOE grant)
U.S. Geological Survey, Branch of Sedimentary Processes, MS 939 Federal Center, Denver, CO 80225; phone: (303)236-5760; FAX: (303)236-0459; E-Mail: Omnet, W.Dean;

Additional Project Personnel: Accomplishments and Ongoing Work:

Below are listed the members of the Cretaceous Shallow Drilling working group coordinated by Arthur and Dean. These scientists are working in an integrated and collaborative way to collect and interpret data bearing on the main objectives of the Project. All of these workers are respected leaders in their fields of expertise.

Dr. Timothy Bralower (support from PSU DOE grant; 2 months 1992, travel)
Professor, Department of Geology, Univ. North Carolina

A. Role in project: paleontology/stratigraphy and paleoecology (calcareous nannofossils)
B. Principal areas of research and expertise: micropaleontology; biostratigraphy and zonation of WIS Cretaceous marine strata; paleoenvironment of WIS surface waters for Cenomanian through Campanian based on calcareous nannofossils

Dr. William Elder (not supported directly by PSU DOE grant)
Geologist, U.S. Geological Survey, Branch of Paleontology and Stratigraphy

A. Role in project: paleontology (macrofossils)
B. Principal areas of research and expertise: macrofaunal evolution and extinction in the Cenomanian/Turonian and biostratigraphy based on macrofauna--correlation of WIS project cores to outcrop away from transect.

Dr. Katherine Freeman (support from PSU DOE grant; 1 month 1992)
Asst. Professor, Department of Geosciences, Penn State Univ.

A. Role in project: organic geochemistry
B. Principal areas of research and expertise: biomarker compounds, stable isotopic compositions of biomarkers and paleoenvironmental indicators; main effort will be to identify contributions of marine organisms that did not necessarily leave a fossil record and to assess paleoproductivity
Freeman and graduate student **Richard Pancost** are collaborating with Arthur on the carbon isotopic record of the Cenomanian-Turonian interval; Pancost will also

separate and analyze biomarkers in this interval in all cores for inferences about paleoproductivity.

Dr. Erle Kauffman (support from PSU DOE grant; 1 month 1992)
Professor, Department of Geological Sciences, Univ. Colorado

A. Role in project: paleontology (macrofossils)/ stratigraphy
B. Principal areas of research and expertise: evolution and extinction of macrofossils, biofacies distributions and benthic paleoenvironment; main effort for western side of WIS and tying to WIS data base.

Dr. Mark Leckie (support from PSU DOE grant; for grad. student 1992, travel)
Assoc. Professor, Department of Geology, Univ. Massachusetts

A. Role in project: paleontology (foraminifera)
B. Principal areas of research and expertise: paleoecology of surface and bottom water masses, for the Cenomanian through Coniacian; ties to outcrop sequences on the western side of the basin. Supervises graduate student **Oona West** on aspect of bethic foraminiferal ecology of Cenomanian and Turonian in samples of cores

Dr. Elana Leighthold (not supported directly by PSU DOE grant; ancillary NSF)
Asst. Prof., Department of Marine, Earth, and Atmospheric Sciences, North Carolina State Univ.

A. Role in project: physical sedimentology
B. Principal areas of research and expertise: nearshore sedimentation and stratigraphy of prodeltaic strata; concentrating on western edge of WIS in Cenomanian-Turonian interval. Examining sequence stratigraphy and sea level variations. Lonnie was added to Project personnel at no extra cost after the proposal was funded and on the basis of her excellent ongoing work in the nearshore facies. We felt that she would be an important addition towards our overall goal of an onshore-offshore transect.

Dr. Michael Lewan (not supported directly by PSU DOE grant)
Chemist, U.S. Geological Survey, Branch of Petroleum Geology

A. Role in project: organic geochemistry
B. Principal areas of research and expertise: organic geochemistry, assessing organic preservation and maturity in cross basin burial transect

Dr. Phillip Nelson (not supported directly by PSU DOE grant)
U.S. Geological Survey, Branch of Geophysics

A. Role in project: logging and well-log analysis
B. Principal areas of research and expertise: formating, processing and interpreting geophysical logs from the WIS project drillsites.

Dr. Douglas Nichols (not supported directly by PSU DOE grant)
U.S. Geological Survey, Branch of Paleontology and Stratigraphy

A. Role in project: paleontology (palynomorphs, dinoflagellates)
B. Principal areas of research and expertise: biostratigraphy and marine- terrestrial link for paleoenvironment and paleoclimatic studies, mainly Cenomanian-Turonian interval.

Dr. John Obradovich (not supported directly by PSU DOE grant)
U.S. Geological Survey, Branch of Isotope Geology

A. Role in project: radiometric age dating
B. Principal areas of research and expertise: providing laser $^{39}Ar/^{40}Ar$ age dates on sanidines separated from the less altered ash beds in cores (and outcrops). This will provide an

unparalleled absolute age framework for the Western Interior Cretaceous (Cenomanian-Coniacian).

Mr. Richard Pollastro (not supported directly by PSU DOE grant)
Geologist, U.S. Geological Survey, Branch of Petroleum Geology

A. Role in project: mineralogy
B. Principal areas of research and expertise: x-ray mineralogy of selected samples for studies of clay minerals; these data will complement the inorganic geochemical data collected by Dean and Arthur and will allow inferences about variations in intensity of weathering, changes in clastic influx during cyclic variations in climate, and burial diagenesis.

Dr. Bradley Sagemen (support from PSU DOE grant; 2 months 1992, travel)
Asst. Professor, Department of Geology, Northwestern University

A. Role in project: sedimentology; cyclostratigreaphy and spectral analyses; trace fossils
B. Principal areas of research and expertise: working closely with Arthur, Dean, Kauffman on overall detailed core descriptions, assessment of biofacies and paleo-oxygenation, and cyclostratigraphy, including spectral analysis of limestone bedding data. Brad is an integral part of the main working group and will contribute greatly to the synthesis and writeup of the data

Dr. Charles Savrda (support from PSU DOE grant; 1 month 1992, travel)
Professor, Department of Geology, Auburn Univ.

A. Role in project: trace fossils
B. Principal areas of research and expertise:trace fossils; stratigraphy. In particular, Chuck is working on detailed assessment of benthic paleoecology across two critical intervals--the Bridge Creek Ls. Mbr. and the lower part of the Niobrara Fm. in which there appears to be evidence for periodic variations in bottom-water oxygenation. Trace fossils are very sensitive indicators of these variations.

Dr. William Sliter (not supported directly by PSU DOE grant)
Geologist, U.S. Geological Survey, Branch of Paleontology and Stratigraphy

A. Role in project: paleontology (foraminifera; world authority on identification of Cretaceous forams in thin section)
B. Principal areas of research and expertise: examining selected thin sections of limestone beds for paleoecology and biostratigraphy to complement work of Leckie and student, who mainly examine samples that can be disaggregated.

Ms. Oona West (supported by PSU DOE grant; stipend and travel through Leckie)
Graduate Student, Department of Geology, Univ. Massachusetts

A. Role in project: paleontology (foraminifera)
B. Principal areas of research and expertise: paleoecology of benthic foraminifers in the Cenomanian-Turonian and their response to changing oxygenation and sediment fluxes. This work will constitute the bulk of her PhD dissertation.

Mr. Timothy White (supported by PSU DOE grant; stipend, travel through Arthur)
Graduate Student, Department of Geosciences, Penn State Univ.

A. Role in project: sedimentology, stratigraphy, organic facies determinations
B. Principal areas of research and expertise: will be examining the regressive facies of upper part of Greenhorn cyclothem and tying core sequences to outcrops in the basin through additional field work. Will perform organic petrography, TOC, stable isotopes, pyrolysis on organic matter (working with Arthur and Freeman). This work will constitute part of his PhD dissertation.

Mr. Richard Pancost (supported by PSU DOE grant; analyses through Freeman)

Graduate Student, Department of Geosciences, Penn State Univ.

A. Role in project: organic geochemistry and stable isotopes

B. Principal areas of research and expertise: will be examining the Cenomanian-Turonian interval in all cores for organic biomarkers and stable isotopic compositions (working with Arthur and Freeman). His fellowship support is independant of DOE Project. This work will constitute part of his PhD dissertation.

END

DATE
FILMED
6/11/93