

DEPARTMENT OF THE INTERIOR

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Preliminary Results of Organic Geochemical and Stable Isotope Analyses of
Newark Supergroup Rocks in the Hartford and Newark Basins, Eastern U.S.

by

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INTRODUCTION

This study was initiated under the Early Mesozoic Basins Program with the intent to evaluate the sources, distribution, and amount of organic matter in Triassic and Jurassic strata in the exposed Mesozoic basins on the Atlantic Coastal Plain. The first phase of this study was focussed on the Hartford and Newark basins because there is an established stratigraphic (Fig. 1) and sedimentologic framework for these basins (e.g., Krynine, 1950; Van Houten, 1965, 1977; Glaeser, 1966; Cornet et al., 1973; Hubert et al., 1976; Hubert et al., 1978; Olsen, 1984). Organic geochemical information is important for understanding the role of sedimentary organic matter or migrated organic compounds during genesis of ore mineralization in these basins. Results of this study are also of interest for evaluation of thermal maturity and hydrocarbon potential of these basins.

Preliminary results have been published as an extended abstract and an abstract (Pratt et al., 1985, Pratt et al., 1986). This is our first report of detailed sample descriptions, sampling localities, Rock-Eval pyrolysis data, and stable isotope data on organic matter and carbonate. The purpose of this publication is to provide industry and the general geological community with a set of organic geochemical data on the Hartford and Newark basins, because there is little published data of this kind on Newark Supergroup rocks (Lawlor et al., 1968; Parnell, 1986). A brief interpretation of the analytical results is provided. A comprehensive discussion of these data will be formally published as soon as possible.

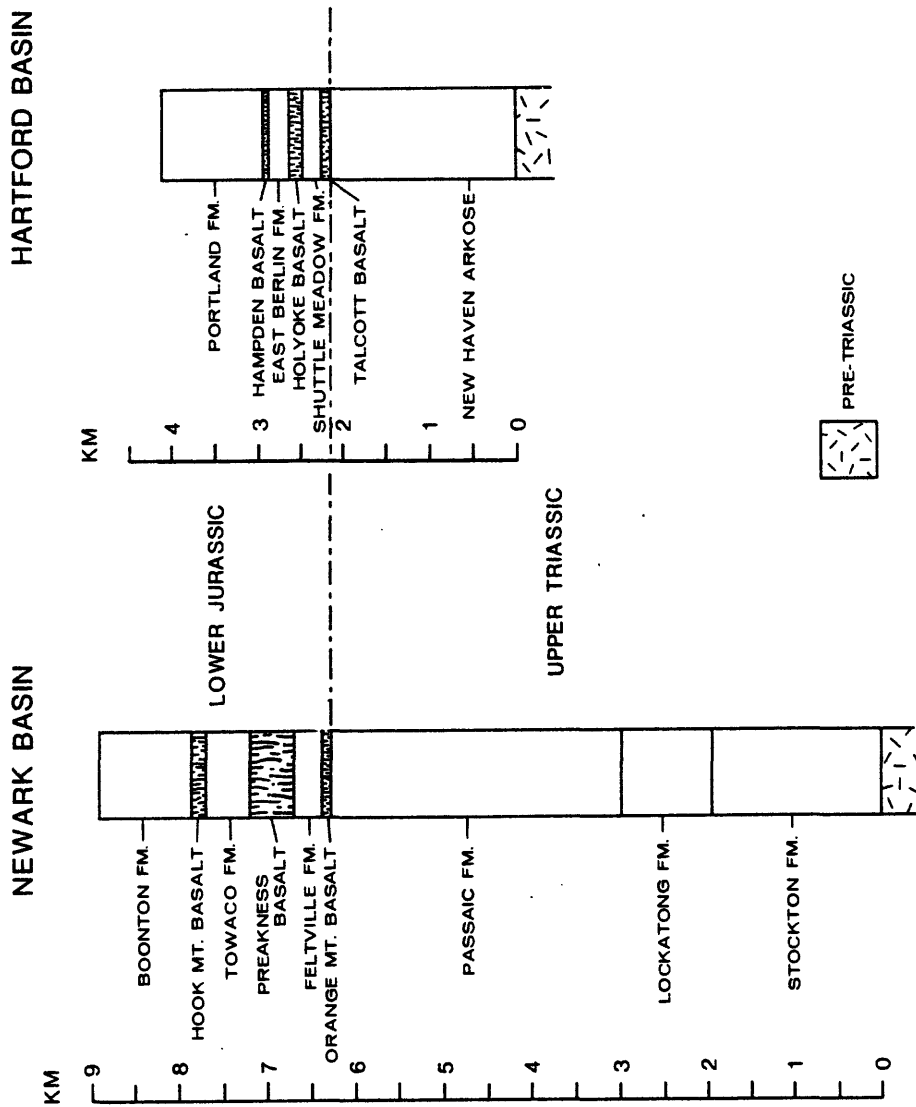


Figure 1--Generalized stratigraphic columns for Newark Supergroup strata in the Newark and Hartford basins. Names and thicknesses of stratigraphic units in the Newark basin are from Hubert et al. (1978) and Olsen (1984). Names and thicknesses of stratigraphic units in the Hartford basin are from Hubert et al. (1978).

DESCRIPTION OF SAMPLES AND SAMPLING LOCALITIES

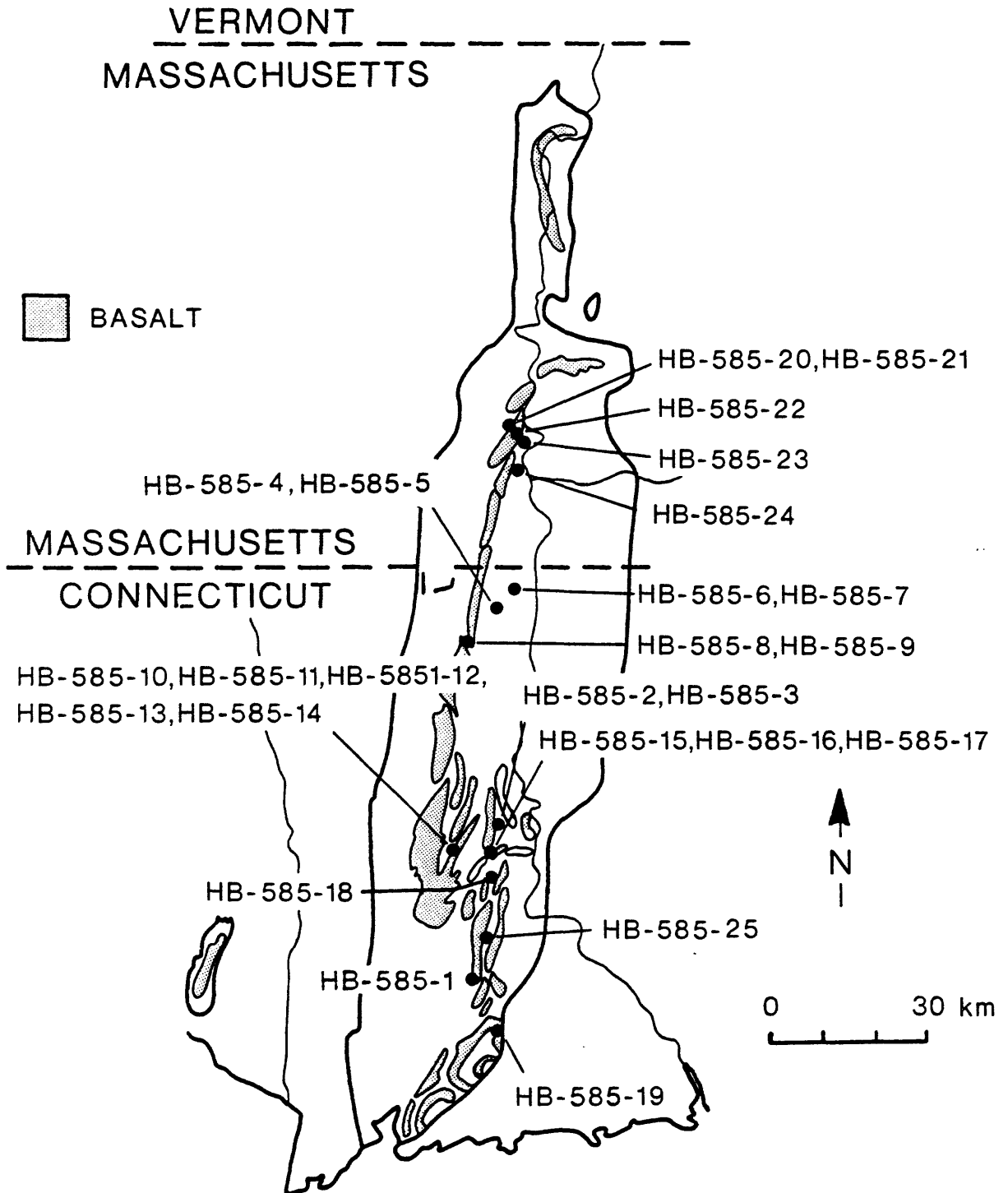
Field Trips

Samples used in this study were collected from natural exposures, road cuts, and railroad cuts in the Hartford and Newark basins (Fig. 2, 3). During late May and early June of 1984, P. E. Olsen (Lamont-Doherty Geological Observatory) led a field trip to collect samples of Triassic and Jurassic strata from the Newark basin. Samples obtained on this trip are designated NB-584-1 to NB-584-20 and NB-684-23 to NB-684-25. During May of 1985, P. E. Olsen led a field trip to collect additional samples from the Newark basin and to collect Triassic and Jurassic samples from the Hartford basin. Samples obtained on this second trip are designated NB-585-1 to NB-585-14 for the Newark basin and HB-585-1 to HB-585-25 for the Hartford basin.

The term "lacustrine cycle" is used in this report to refer to a vertical sequence of non-marine sediment types that is laterally persistent, occurs in a repetitive order, and contains a dark gray to black, organic-rich siltstone or shale. Base of a lacustrine cycle refers to the contact between the dark-colored organic-rich unit and the underlying lighter-colored mudstone, siltstone, or sandstone.

Correlation of members and beds is based on the detailed stratigraphic studies of Olsen (1982, 1984).

HARTFORD BASIN



NEWARK BASIN

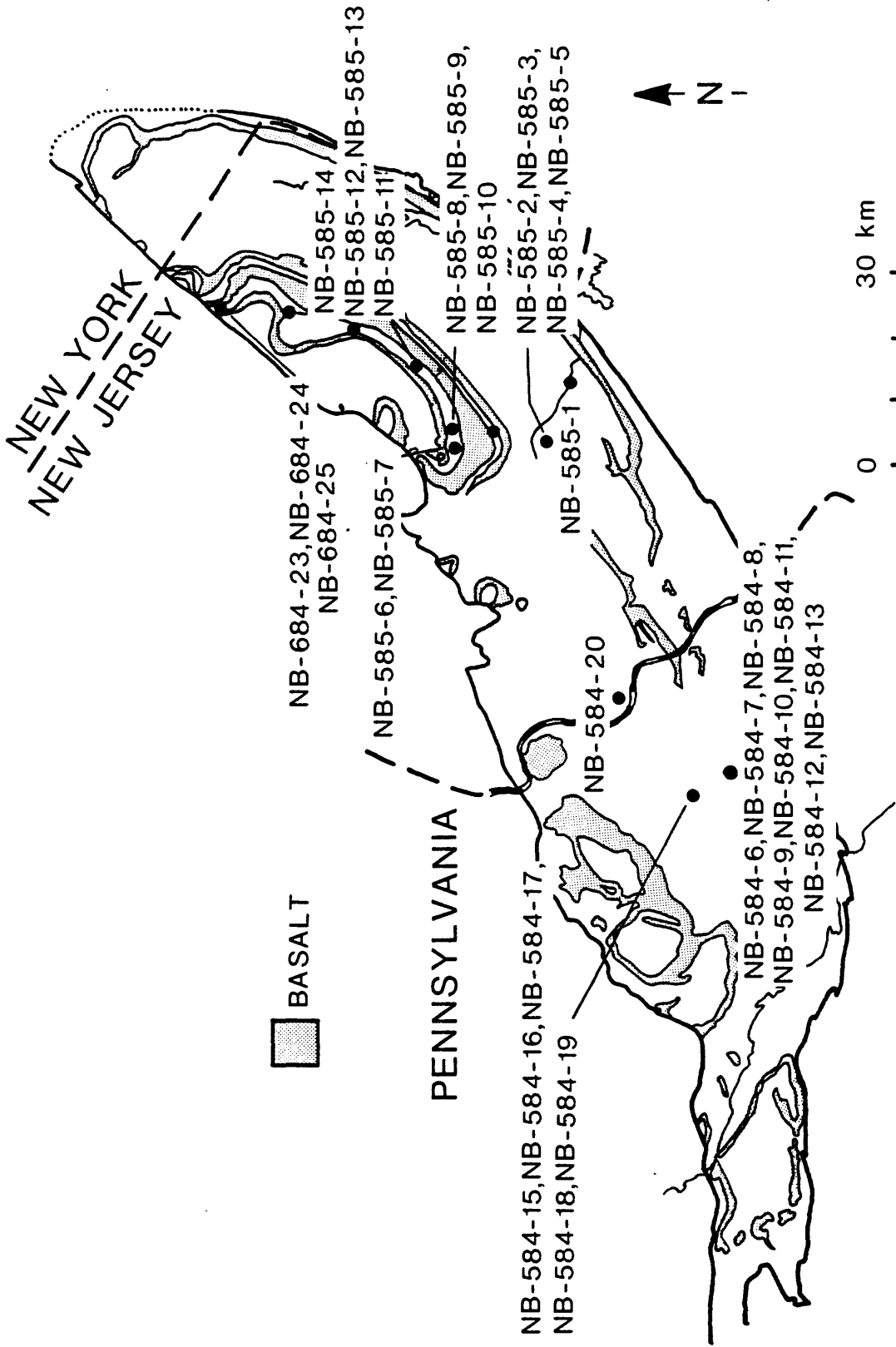


Figure 3--Sample numbers and sampling locations in the Newark basin. Base map showing undifferentiated extrusive and intrusive basalts is taken from Glaeser (1966) and Olsen (1984).

Hartford Basin Samples

HB-585-1, Shuttle Meadow Formation--One sample was collected from a roadcut through Higby Mountain along Interstate 91 northbound at Meriden, Connecticut. The sample is from a dark-gray, thinly bedded siltstone overlain by medium-gray thinly bedded sandstone, 0.2 m above the contact with the Talcott Basalt.

HB-585-2 and HB-585-3, Holyoke (? Hamden) basalt--Samples were collected from roadcuts within an unfinished cloverleaf interchange on Interstate 91 at Wethersfield, Connecticut. Sample HB-585-2 is black, resinous, solid bitumen that occurs as a coating on joint surfaces in the basalt. Sample HB-585-3 is calcite spar and intermingled solid bitumen that occurs as a vein-like filling within a joint in the basalt.

HB-585-4 and HB-585-5, Portland Formation--Samples were collected from recently blasted walls and rubble within the Kelsey-Ferguson Brick Quarry, Suffield, Connecticut. Sample HB-585-4 consists of coalified vascular plant stems in a matrix of copper mineralized sandstone. HB-585-5 sample is from a thin, lenticular, medium-gray claystone interbedded with red fissile mudstones and red sandstones.

HB-585-6 and HB-585-7, Portland Formation--Samples were collected from natural outcrops just north of a bridge on Route 195 over Stony Brook near Suffield, Connecticut. Sample HB-585-6 is from a dark-gray siltstone thinly interbedded with reddish brown sandstone. Sample HB-585-7 is a dark-gray resistant siltstone.

HB-585-8 and HB-585-9, East Berlin Formation--Samples were collected from natural outcrops along a tributary to the Farmington River near the intersection of Route 187 and Route 159, Tariffville, Connecticut. Sample HB-585-8 is from a dark-gray clayey shale containing flasers of silt. Sample HB-585-9 is from a medium-dark-gray siltstone. Both samples are from the first lacustrine cycle below the Hamden Basalt.

HB-585-10 to HB-585-14, East Berlin Formation--Samples were collected from roadcuts at the intersection of Route 15 and Route 72 near East Berlin,

Connecticut. Five lacustrine cycles each containing about a meter of well-developed, dark-gray to black, laminated shale are exposed at this location.

Samples HB-585-10A,B,C are from the fifth cycle below the Hamden Basalt. Sample HB-585-10A is from a finely laminated, dark-gray to black shale, 0.4 m above base of the lacustrine cycle defined by the contact with the underlying thickly bedded sandstone. Sample HB-585-10B is from a medium-dark gray, thinly bedded, silty shale, 0.9 m above the base of the cycle. Sample HB-585-10C is from a medium-gray, thinly bedded siltstone, 1.2 m above the base of the cycle.

Samples HB-585-11A,B,C are from the fourth cycle below the Hamden Basalt. Sample HB-585-11A is from a glossy black shale with undulatory, slickensided surfaces parallel to bedding, 0.1 m above the base of this cycle defined by the contact with the underlying medium-gray, thinly bedded siltstone. Sample HB-585-11B is from a dark-gray, fine-silty shale, 0.3 m above the base of the cycle. Sample HB-585-11C is from a dark-gray, shaley siltstone, 0.7 m above the base of the cycle.

Samples HB-585-12A,B,C,D are from the third cycle below the Hamden Basalt. Sample HB-585-12A is from a dark-gray, finely laminated shale, 0.15 m above the base of the cycle defined by the contact with the underlying thickly bedded sandstone. Sample HB-585-12B is from a dark-gray, finely laminated shale, 0.35 m above the base of the cycle. Sample HB-585-12C is from a dark-gray, silty shale, 0.65 m above the base of the cycle. Sample HB-585-12D is from a thinly bedded, medium-gray siltstone stained with bitumen along fractures, 0.9 m above the base of the cycle.

Sample HB-585-13 is from the second cycle below the Hamden Basalt. This sample is from a highly sheared and disrupted dark-gray shale that is angularly discordant with the adjacent siltstones.

Sample HB-585-14 is from a grayish-red to medium-gray silty shale about 5 cm below the Hamden Basalt.

HB-585-15 to HB-585-17, East Berlin Formation--Samples were collected from roadcuts within the unfinished cloverleaf interchange of Interstate 91 and Route 9 West, near Cromwell, Connecticut.

Samples HB-585-15A,B,C,D are from the third lacustrine cycle below the Hamden Basalt. Sample HB-585-15A is from a black fissile shale that parts into thin papery layers, 0.1 m above the base of the cycle defined by the contact

with the underlying wavy-bedded silty sandstone. Sample HB-585-15B is from a dark-gray silty shale, 0.6 m above the base of the cycle. Sample HB-585-15C is from a medium-gray siltstone, 0.8 m above the base of the cycle.

Sample HB-585-15D is from an acid-resistant, elongate concretion about 8 cm in diameter. The center of this concretions contains sticky bitumen with a petroliferous odor. The concretion is enclosed within a medium-gray siltstone, 0.8 m above the base of the cycle.

Samples HB-585-16A,B,C are from the second cycle below the Hamden Basalt. Sample HB-585-16A is from a dark-gray finely laminated shale with undulatory glossy surfaces that appears to be slightly disrupted, 0.1 m above the base of the cycle defined by the contact with the underlying thickly bedded sandstone. Sample HB-585-16B is from a thinly bedded to laminated dark-gray shale, 0.35 m above the base of the cycle. Sample HB-585-16C is from a thinly interbedded medium-gray siltstone and silty sandstone, 0.8 m above the base of the cycle.

Sample HB-585-17 is from a dark-gray shale in the first cycle below the Hamden Basalt.

HB-585-18A,B,C,D,E,F,G, East Berlin Formation--Samples were collected from natural exposures along West Miner Brook north of Westfield Village, Connecticut.

Samples HB-585-18A,B,C,D,E,F,G are from the fourth lacustrine cycle below the Hamden Basalt. Sample HB-585-18A is from a black laminated shale that separates into thin papery sheets, .05 m above the base of the cycle defined by the contact with the underlying thinly bedded sandstone. Sample HB-585-18B is from a dark-gray laminated silty shale, 0.5 m above the base of the cycle. Sample HB-585-18C is from a thin graded bed of sand and silt overlying a scoured surface, 0.9 m above the base of the cycle. Sample HB-585-18D is from a thinly bedded dark-gray shale, 1.0 m above the base of the cycle. Sample HB-585-18E is from a thinly bedded dark-gray shale containing abundant conchostracans (bivalve arthropods), 1.1 m above the base of the cycle. Sample HB-585-18F is from a thinly bedded dark-gray shale, 1.5 m above the base of the section. Sample HB-585-18G is from a thinly bedded silty shale, 2.0 m above the base of the cycle.

HB-585-19, East Berlin Formation--Samples were collected from natural exposures along a creek draining into Quonnipaug Lake between Bluff Head and

Quonnipaug Hill, near Rockland, Connecticut. Samples HB-585-19A,B are from a sequence of thinly interbedded siltstone, limestone, and medium- to dark-gray shale overlying the Holyoke Basalt. Sample HB-585-19A is from a nonlaminated dark-gray shale. Sample HB-585-19B is from a laminated dark-gray shale.

HB-585-20 and HB-585-21, East Berlin Formation--Samples were collected from roadcuts along the access road to Mount Tom Ski Area, Massachusetts and in exposures at the back of the main parking lot for Mount Tom Ski Area.

Samples HB-585-20A,B,C are from the fifth lacustrine cycle below the Hamden Basalt. Sample HB-585-20A is from a laminated dark-gray shale, 0.55 m above the base of the cycle defined by the contact of shale with the underlying wavy-bedded (possibly stromatolitic) carbonate. Sample HB-585-20B is from a thinly bedded dark-gray silty shale, 1.25 m above the base of the cycle. Sample HB-585-20C is from a thinly bedded fine-sandy siltstone, 2.1 m above the base of this cycle.

Samples HB-585-21A,B,C are from the fourth lacustrine cycle below the Hamden Basalt. Sample HB-585-21A is from a laminated black shale that separates into thin papery layers, 0.1 m above the base of this cycle. Sample HB-585-21B is from a thinly bedded dark-gray shale, 0.6 m above the base of this cycle. Sample HB-585-21C is from a homogeneous dark-gray claystone, 1.25 m above the base of this cycle.

HB-585-22, East Berlin Formation--Samples were collected from a roadcut at the exit of Interstate 91 to Mountain Park, Massachusetts. Samples HB-585-22A,B are from the second lacustrine cycle below the Hamden Basalt. Sample HB-585-22A is from a laminated dark-gray shale, 0.05 m above the base of this cycle. Sample HB-585-22B is from a thinly bedded dark-gray shale that contains abundant lenses and laminae of lighter colored clayey material, 0.4 m above the base of this cycle.

HB-585-23, lower Portland Formation--One sample was collected from a hillside exposed by construction behind the Holyoke Plaza Shopping Center off Route 5 at Holyoke, Massachusetts. This sample is from a thinly bedded dark-gray shale.

HB-585-24, East Berlin Formation--One sample was collected from a railroad cut on the Conrail line, about 1 kilometer south of Ashley Pond, near Holyoke,

Massachusetts. This sample is from a dark-gray shale in a sequence of thinly interbedded shale and limestone.

HB-585-25, lower Portland Formation--Samples were collected from natural exposures along Laurel Brook about 1 km west of Route 17 near Middlefield, Connecticut. Samples HB-585-25A,B,C,D are from a two-meter-thick coarsening-upward sequence composed of claystone, shale, siltstone, and sandstone. Sample HB-585-25A is from a thinly bedded, dark-gray, calcareous shale containing lenses and laminae of fine sand. Sample HB-585-25B is from a nodular to wavy bedded dark-gray shale, 0.5 m above sample 25A. HB-585-25C is from thinly interbedded silty shale and sandstone, 1.0 m above 25A. Sample HB-585-25D is from a pyritic, medium-gray claystone, 0.9 m below sample 25A.

Newark Basin Samples

NB-584-6 to NB-584-13, "Gwynedd member", Lockatong Formation--Samples were collected from railroad cuts just north of the Reading Railroad overpass over Route 202, near Gwynedd, Pennsylvania.

Sample NB-584-6 is from a dark gray calcareous shale in the lowest lacustrine cycle above an extensively faulted and fractured interval exposed at this locality. Sample NB-584-7 is from a medium gray calcareous shale overlying the shale sampled by NB-584-6.

Sample NB-584-8 is from a dark gray calcareous shale in the second lowest lacustrine cycle in this section. This lacustrine cycle was described in detail by Olsen (1984) and identified with a SW preface before the sample numbers. Sample NB-584-9 is from a dark gray, finely laminated, calcareous shale immediately below the shale sampled by NB-584-8 in the second lowest lacustrine cycle in this section.

Sample NB-584-10 is from a dark gray laminated, calcareous shale in the third lowest lacustrine cycle in this section. Sample NB-584-11 is from a medium dark gray shale immediately above the shale sampled by NB-584-10.

Sample NB-584-12 is from a dark gray shale in the uppermost lacustrine cycle exposed in this section.

Sample NB-584-13 is from a dark gray shale interbedded with reddish sandstones and siltstones, in the sequence above the well-developed lacustrine cycles.

NB-584-15 to NB-584-19, "Skunk Hollow member", Lockatong Formation--Samples were collected from exposures in the H and K Materials Quarry near Chalfont, Pennsylvania.

Samples NB-584-15A,B,C,D are from a relatively thick dark-gray shale in a lacustrine cycle exposed near the bottom of the upper quarry wall. This dark-gray shale is called the Skunk Hollow fish bed by Olsen (1984). Sample NB-584-15A is from a massive medium-gray siltstone just below the base of the dark-gray shale unit. Sample NB-584-15B is from a finely laminated interval in the dark-gray shale, 0.10 m above the base of the cycle. Sample NB-584-15C is from a finely laminated interval in the dark-gray shale, 0.17 m above the base of the cycle. Sample NB-584-15D is from a thinly bedded and coprolite-rich interval in the dark-gray shale, 0.29 m above the base of the cycle.

Samples NB-584-17, NB-584-18, and NB-584-19 were collected from a dark-gray shale and the underlying lighter gray shale and siltstone, about 100m above the Skunk Hollow fish bed sampled by NB-584-15 and just above first thin redbed. Sample NB-584-17 is from a dark-gray, thinly bedded, pyritic shale. Sample NB-584-18 is from a medium-gray pyritic shale, 0.42 m below sample NB-584-17. Sample NB-584-19 is from a medium-gray siltstone, 0.12 m below sample NB-584-18.

NB-584-20, "Skunk Hollow member", Locketong Formation--Samples were collected from natural exposures in bluffs above the Delaware River, along Route 29, about 4 km south of Frenchtown, New Jersey. Samples are from the Skunk Hollow fish bed and are stratigraphically equivalent to the shale sampled by NB-584-15.

Sample NB-584-20A is from a massive medium-gray siltstone, 0.07m below the base of the Skunk Hollow fish bed. Sample NB-584-20B is from a finely laminated dark-gray shale in the Skunk Hollow fish bed, 0.03m above the base of this lacustrine cycle. Sample NB-584-20C is from a finely laminated dark-gray shale in the Skunk Hollow fish bed, 0.25 m above the base of this lacustrine cycle. Sample NB-584-20D is from a finely laminated dark-gray shale in the Skunk Hollow fish bed, 0.48 m above the base of this lacustrine cycle.

NB-684-23 to NB-684-25, Towaco Formation--Samples were collected from natural exposures and from an excavation within a ravine at the Glenn in Pompton, New Jersey.

Sample NB-584-23 is from a light-gray siltstone in the uppermost portion of Towaco Formation. This sample was collected from the bed of a shallow stream.

Samples NB-684-24A,B,C are from the fifth lacustrine cycle below the top of the Towaco Formation. Samples were collected from the walls of a 3-meter-deep excavation. Sample NB-684-24A is from a finely laminated, dark-gray shale commonly containing fish fossils. This shale is 1.24 m above the base of this lacustrine cycle defined by the contact with the underlying cobble conglomerate. Sample NB-684-24B is from a poorly laminated, dark-gray shale without fish fossils that is 2.04 m above the base of this cycle. Sample NB-684-24C is from a poorly laminated, dark-gray shale that is 3.05 m above the base of this cycle. The measured thickness of dark-gray shale in this cycle is 3.95 m.

Sample NB-584-25 is from a dark-gray shale in the laminated portion of the lower Towaco.

NB-585-1, "Metlars Brook member" Passaic Formation--One sample was collected from bluffs along the west side of the Raritan Canal, below Highwood Road, Somerset, New Jersey. This sample is from a dark-gray, laminated, calcareous shale interbedded with lighter gray siltstones and sandstones.

NB-585-2 to NB-585-5, "Ukranian member" Passaic Formation--Samples were collected from construction excavations and a stream bed within Ukranian Village, near Franklin Park, New Jersey.

Sample NB-585-2 is from a dark-gray shale exposed in a one-meter-deep pit excavated by hand in a hillside.

Sample NB-585-4 is from a dark-gray shale exposed in construction excavations.

Sample NB-585-5 is a copper-mineralized dark-gray shale exposed in construction excavations.

NB-585-6 and NB-585-7, Towaco Formation--Samples were collected from natural exposures in bluffs on the south side of the Passaic River at Millington, New Jersey.

Sample NB-585-6 is from a finely laminated, dark-gray to brownish shale in the uppermost lacustrine cycle in the Towaco Formation. There is solid bitumen filling small (2-3 mm width) tension fractures in this shale.

Sample NB-585-7 is from a dark-gray to black, papery shale that underlies the shale sampled by NB-585-6.

NB-585-8 to NB-585-10, Towaco Formation--Samples were collected from a bluff on the west side of the Conrail line, about 0.7 km east of Northfield Road near Sterling, New Jersey.

Sample NB-585-8 is from a finely laminated, dark-gray to brownish shale in the middle Towaco Formation.

Sample NB-585-9 is from a finely laminated, dark-brownish-gray shale, about two meters higher in the section than the shale sampled by NB-582-8.

Sample NB-585-10 is from a highly fractured, dark-gray chert that overlies the shale sampled by NB-582-9. Solid bitumen fills many of the fractures in this chert.

NB-585-11, Towaco Formation--One sample was collected from a bluff on the west side of Central Avenue between River Road and Fairmont Road in Longhill,

New Jersey. Sample NB-585-11 is from a deeply weathered dark-gray shale that contains abundant dark-gray nodules and lenses of chert. This sample consists only of chert nodules.

NB-585-12 and NB-585-13, Towaco Formation--Samples were collected from the walls of an inactive quarry located in Rieke Park near Roseland, New Jersey.

Sample NB-585-12 is from a layer of dark-gray chert nodules in the uppermost lacustrine cycle of the Towaco Formation.

Sample NB-585-13 is from a poorly laminated, dark-brownish-gray shale that underlies the chert layer sampled by NB-585-12.

NB-585-14, Towaco Formation--One sample was collected from a bluff known as Tom's Point near Lincoln Park, New Jersey. Sample NB-582-14 is from a dark-gray shale that contains small (2-3 mm width) tension fractures filled with solid bitumen.

ANALYTICAL TECHNIQUES

Organic and Carbonate Carbon Contents

Organic and total carbon content were measured by combusting a sample of powdered rock in a LECO induction furnace with an infrared (IR) detector. Combusted carbon produces CO_2 (and a minor amount of CO which is catalytically converted to CO_2) which absorbs a specific infrared wavelength.

Sample preparation involved removal of weathered or contaminated surfaces with a dry rock saw and powdering of the trimmed samples in a steel ball mill. Prior to combustion of the organic carbon samples, a weighed fraction of powdered rock (between 0.1 and 1.0 grams based on the assumed carbon content) was leached in 100 ml of 2.0 N HCl for 24 hours to remove carbonate carbon. The insoluble residue was concentrated on a glass fiber filter, aspirated with distilled water to remove any remaining HCl, transferred to a combustion crucible, and dried in a 50°C oven. Preparation for combustion of total carbon samples required only that a weighed amount of dry, powdered rock be transferred to a standard LECO combustion crucible. Carbonate carbon values were calculated as the difference between the total carbon and organic carbon.

Rock-Eval Pyrolysis

Organic geochemical properties based on pyrolysis were measured with a Rock-Eval instrument that was calibrated by analysis of a synthetic standard ($n\text{-C}_{20}\text{H}_{42}$) and dry ice. S_1 is the integral of the first hydrocarbon peak detected after heating the powdered sample in flowing helium at 250°C for 5 min. This peak represents the free or adsorbed hydrocarbons in the rock and is roughly proportional to the content of organic matter that can be extracted from the rock with organic solvents. S_2 is the integral of the second hydrocarbon peak, produced mainly by cracking of solid organic matter when the rock is heated from 250°C to 550°C at 25°C per min. These hydrocarbons are probably produced by thermal cracking of the kerogen and to a small degree by the cracking of resins and asphaltenes (Espitalie et al, 1977). S_3 is the integral of the carbon dioxide peak measured on a split of the gas trapped during the heating interval from 250° to 390°C . This temperature range is lower than the temperature of thermal dissociation for carbonate minerals under most circumstances. Therefore, S_3 is considered to be a measure of the CO_2 produced by pyrolysis of the organic matter in the rock. S_1 , S_2 , and S_3 are reported in

milligrams of hydrocarbon or CO_2 per gram of dry rock.

The hydrogen index is defined as S_2 divided by the organic carbon content of the rock ($\text{mgHC/gC}_{\text{org}}$) and is reported in milligrams of hydrocarbon per gram of organic carbon. The oxygen index is defined as S_3 divided by the organic carbon content of the rock ($\text{mgCO}_2/\text{gC}_{\text{org}}$) and is reported in milligrams of CO_2 per gram of organic carbon.

Thermal maturity is interpreted from the temperature of maximum yield of pyrolytic hydrocarbons [$T_{\text{max}}(S_2)$]. In general, the transition from immature to mature petroleum source rocks is indicated by $T_{\text{max}}(S_2)$ values of about 435°C and production indices of about 0.1 (Tissot and Welte, 1978).

To minimize the effects of complicating factors on whole-rock pyrolysis (Katz, 1981; Orr, 1983), the amount of whole-rock powder that was pyrolyzed was varied such that each sample contained about 0.5 mg of organic carbon.

Carbon Isotope Ratios of Organic Matter

Preparation for determination of carbon isotopic ratio of organic matter ($\delta^{13}\text{C}_{\text{org}}$) required transferring approximately 5 g of dry powdered rock to a clean beaker, thoroughly wetting with distilled water, and leaching with 200 ml of 1.0 N HCl for 24 hours to remove carbonate minerals. After the initial acid leach, the acid was vacuum decanted with special attention paid to retaining the supernatant. The remaining residue was then leached a second time in 100 ml of warm 2.0 N HCl for 24 hours to remove any remaining carbonate carbon. The acid was then vacuum decanted and the residue neutralized through repeated suspensions in distilled water, centrifugation, and decanting. Following neutralization, each sample was dried in centrifuge tubes at 50°C , powdered, and transferred to 2 dram vials.

Stable carbon isotopic ratios were determined on the organic matter (decalcified residues) in a routine manner utilizing the following procedure. Organic matter is combusted in a quartz crucible at 1000°C using a LECO induction furnace with a 6 inch afterburner and a closed loop pumping system. This system promotes complete conversion of the organic carbon to carbon dioxide and water. Carbon dioxide is collected over a liquid oxygen trap which allows recirculation of oxygen. With the exception of water and oxygen, combustion by-products are removed by absorption onto a manganese dioxide trap. Complete conversion to carbon dioxide is insured by passing the gas stream through a second furnace containing a copper-oxide packing. The gas is further purified and dehydrated using cryogenic traps in a high-vacuum, gas-transfer line. The

carbon dioxide gas is expanded into a manometer and the volume determined by mercury displacement. Carbon isotopic ratios are determined for the purified gas using a Finnegan MAT 251, 90° sector isotope ratio mass spectrometer.

The carbon dioxide generated from the samples is directly compared with a working reference standard of carbon dioxide prepared from NBS-19 calcite. Ratios are reported in the standard per mil (‰) deviation relative to the Peedee belemnite standard (PDB):

$$\delta^{13}\text{C}^{\text{‰}} = [(R_{\text{sample}}/R_{\text{PDB}}) - 1] \times 10^3,$$

where $R = {}^{13}\text{C}/{}^{12}\text{C}$.

Carbon and Oxygen Isotopic Ratios of Carbonate

Carbonate minerals were analyzed for the stable isotopic ratios of carbon ($\delta^{13}\text{C}_{\text{carb}}$) and oxygen ($\delta^{18}\text{O}_{\text{carb}}$) in selected samples that contained greater than 0.1 wt. % carbonate carbon. Samples were prepared in a routine manner using the following procedure. A weighed amount of powdered whole-rock material is transferred to the bottom of a glass reaction vessel with a side arm. Anhydrous phosphoric acid (1.5 ml) is carefully pipetted into the side arm. The vessel is placed on a vacuum line and evacuated to 5–10 Torr for one hour. This procedure removes water and air from the vessel, thus minimizing contamination of the carbon and oxygen in the samples. The vessel is sealed with a stopcock and removed from the vacuum line. Acid is poured onto the samples by tipping the vessel and draining the sidearm. Samples containing only calcite are reacted for 24 hours in a 25°C water bath. Samples containing dolomite or other acid-resistant forms of carbonate are reacted for 96 hours in a 25°C water bath. Carbon dioxide gas generated from the sample is collected on a vacuum line using cryogenic traps. The carbon dioxide is purified and dehydrated using a dry ice-acetone slush trap on a high-vacuum gas-transfer line. The purified carbon dioxide is expanded into a manometer and the volume is determined by mercury displacement. The carbon dioxide is transferred to a sample-collection tube that is sealed with a stopcock. The carbon dioxide is then analyzed using a mass spectrometer as described in the section on carbon isotopic ratios of organic matter. Carbon isotopic ratios are expressed relative to the PDB standard using

the same equation as for carbon in organic matter. Oxygen isotopic ratios are expressed relative to the PDB standard using the following equation:

$$\delta^{18}\text{O}_{\text{carb}} = [(R_{\text{sample}}/R_{\text{PDB}}) - 1] \times 10^3$$

where $R = {}^{18}\text{O}/{}^{16}\text{O}$.

ANALYTICAL RESULTS

Pyrolysis results are shown in Table 1 (Hartford basin) and Table 2 (Newark basin). Data on stable isotopic composition of organic matter and carbonate are given in Table 3 (Hartford basin) and Table 4 (Newark basin).

Pyrolysis Data for Hartford Basin

Fifty-two samples from the Hartford basin were analyzed using Rock-Eval pyrolysis (Table 2). As can be seen from the sample descriptions, most of the analyzed samples are from lacustrine shales in the East Berlin Formation. This unit was extensively sampled in order to assess local and regional variations in thermal maturity that could be masked by variations in the type of organic matter.

Samples of dark-gray to black lacustrine shales in the East Berlin Formation have organic carbon contents of 1.2-3.8 wt. % and have hydrogen indices that range from less than 10 to 440 mg/g. The hydrogen indices vary inversely with temperature of maximum pyrolytic yield (T_{\max}). The systematic inverse relationship between hydrogen index and T_{\max} indicates a relatively uniform type of organic matter in these lacustrine shales. Based on samples with the lowest T_{\max} values initial hydrogen indices were probably 450 to 550 mg/g, indicating good source-rock potential for petroleum. East Berlin shales that are thermally mature with respect to petroleum generation ($T_{\max} = 435-460^{\circ}\text{C}$) have production indices in the range of 0.2 to 0.4, also indicating good source-rock potential for petroleum. East Berlin shales that are marginally mature with respect to petroleum generation ($T_{\max} = 425-435^{\circ}\text{C}$) were collected from large synclinal structures along the southeastern margin of the Hartford basin.

Pyrolysis Data for Newark Basin

Thirty-seven samples from the Newark Basin were analyzed using Rock-Eval pyrolysis (Table 2). The majority of the samples were collected from the Triassic Lockatong Formation and from the Jurassic Towaco Formation. As in the Hartford basin, samples were taken primarily from dark-colored lacustrine shales in order to minimize the effects of differing types of organic matter.

Samples of the Lockatong Formation are extensively thermally altered and are overmature with respect to petroleum generation and preservation. Samples from the central portion of the basin, however, appear to have some potential for gas generation and preservation.

Most samples of the Towaco Formation are immature to marginally mature with respect to petroleum generation, as shown by T_{\max} values generally less than 435°C and production indices generally less than 0.1. A few samples from the Towaco have T_{\max} values between 440°C and 450°C and have production indices of about 0.15. These samples are mature with respect to petroleum generation. Hydrogen indices for the dark-gray to black lacustrine shales range from 210 to 980 mg/g, with most values between 350 and 550 mg/g. Thus, the Towaco lacustrine shales have good to excellent source-rock potential for petroleum.

Stable Isotope Data for Hartford Basin

Fifty-two samples from the Hartford basin were analyzed for the stable isotopic composition of carbon in whole-rock organic matter and carbon and oxygen in whole-rock carbonate. Most of the East Berlin lacustrine shales have $\delta^{13}\text{C}_{\text{org}}$ values in the range of $-28.5^{\circ}/\text{oo}$ to $-30.0^{\circ}/\text{oo}$. Samples that are bitumen stained or contain solid bitumen have somewhat lighter $\delta^{13}\text{C}_{\text{org}}$ values and generally are in the range of $-30^{\circ}/\text{oo}$ to $-32^{\circ}/\text{oo}$. Most samples of fluvial shales and pieces of coalified wood have $\delta^{13}\text{C}_{\text{org}}$ values in the range of $-24^{\circ}/\text{oo}$ to $-27^{\circ}/\text{oo}$. Thus, the lacustrine organic matter is isotopically distinct from organic matter in the fluvial shales and from the woody organic matter. The relatively light carbon isotopic composition of the solid bitumens and bitumen-stained samples suggests that these are migrated hydrocarbons derived from lacustrine organic matter.

Carbon isotopic values of whole-rock carbonate from the East Berlin lacustrine shales are generally in the range of $+1.5^{\circ}/\text{oo}$ to $2.0^{\circ}/\text{oo}$. Most shales with more negative $\delta^{13}\text{C}_{\text{org}}$ values are sheared and disrupted or contain calcite-filled fractures. Samples of coarsely crystalline calcite from vein fillings have $\delta^{13}\text{C}_{\text{carb}}$ values that are $3-4^{\circ}/\text{oo}$ more negative (lighter) than the average shales. Oxygen isotopic ratios of whole-rock carbonate from the East Berlin lacustrine shales are widely variable but are generally in the range of $+2^{\circ}/\text{oo}$ to $-4^{\circ}/\text{oo}$. Lacustrine shales with more negative $\delta^{18}\text{O}_{\text{carb}}$ values usually contain concretionary cements or calcite-filled fractures. Samples of coarsely crystalline calcite intermingled with solid bitumen from vein fillings have $\delta^{18}\text{O}_{\text{carb}}$ values of about $-11^{\circ}/\text{oo}$.

Values of $\delta^{13}\text{C}_{\text{carb}}$ for the Portland Formation are similar to values for the East Berlin Formation; however, values of $\delta^{18}\text{O}_{\text{carb}}$ for the Portland are substantially more negative (lighter) than values for the East Berlin Formation.

TABLE 1

Hartford Basin Pyrolysis Results¹

Sample ID	Sample Type ²	Organic Carbon (wt. %)	S ₁ (mg/gm)	S ₂ (mg/gm)	S ₃ (mg/gm)	T _{max} (°C)	HI (mg/gm)	OI (mg/gm)	PI
HB-585-1	g.slt.	.12	.00	.01	.13	UD ³	8	110	UD
-2	s.bt.	58.4	10.2	120.9	.93	476	210	1	.08
-3	bt.cl.	3.60	1.3	4.5	.38	467	120	10	.22
-4	c.wd.	15.2	.22	1.4	17	457	8	110	.14
-5	r.sh.	.26	.00	.05	.05	UD	18	18	UD
HB-585-6	g.slt.	.15	.00	.01	.10	UD	6	66	UD
-7	g.slt.	.44	.00	.05	.11	UD	11	24	UD
-8	d.sh.	1.38	.22	.78	.44	457	55	31	.22
-9	g.slt.	.13	.00	.01	.11	UD	7	83	UD
-10A	d.sh.	1.73	.58	2.0	.43	445	110	24	.23
HB-585-10B	d.sh.	1.79	1.3	2.1	.37	443	120	20	.38
-10C	g.slt.	.25	.18	.10	.17	UD	39	67	.64
-11A	d.sh.	3.62	.56	4.5	.28	448	120	7	.11
-11B	d.sh.	3.76	.76	2.2	.25	450	57	7	.26
-11C	g.slt.	2.75	1.3	2.3	.06	450	84	2	.37
HB-585-12A	d.sh.	3.05	.74	3.2	.29	449	110	9	.19
-12B	d.sh.	1.67	.63	2.5	.24	447	150	14	.20
-12C	g.slt.	1.45	.40	2.1	.22	451	140	15	.16
-12D	bt.ss.	.70	.97	1.0	.56	373	140	79	.49
-13	d.sh.	2.49	.75	5.4	.32	451	220	12	.12
HB-585-14	r.slt.	.02	.00	.00	.17	UD	UD	UD	UD
-15A	d.sh.	2.19	1.4	3.2	.77	455	140	35	.30
-15B	d.sh.	2.53	.55	1.4	.18	455	55	7	.28
-15C	bt.slt.	.50	.91	.45	.26	358	110	51	.63
-15D	bt.cc.	3.08	1.24	16.6	.45	432	540	14	.07
HB-585-16A	d.sh.	2.21	.8	2.4	.42	459	110	18	.26
-16B	d.sh.	2.46	1.2	2.7	.61	459	110	24	.31
-16C	g.slt.	2.65	2.1	4.0	.50	455	150	18	.35
-17	d.sh.	2.16	2.1	2.8	.56	458	130	25	.42
-18A	d.sh.	1.26	.38	1.7	.73	445	130	58	.18
HB-585-18B	d.sh.	1.26	1.0	2.1	.41	439	160	32	.34
-18C	d.sh.	3.78	1.2	16.6	.61	421	440	16	.07
-18D	d.sh.	2.27	1.2	6.1	.38	428	270	16	.17
-18E	d.sh.	2.29	1.5	6.7	.33	434	290	13	.18
-18F	g.slt.	1.86	.83	3.6	.35	448	190	18	.19
HB-585-18G	g.slt.	1.22	.63	2.3	.38	446	190	31	.22
-19A	sh.lms.	.95	.19	1.9	.39	431	200	41	.09
-19B	sh.lms.	.59	.05	1.3	.26	422	210	44	.04
-20A	d.sh.	.86	.69	.36	.31	UD	40	35	.66
-20B	g.slt.	.35	.00	.04	.44	UD	11	130	UD
HB-585-20C	g.slt.	1.50	.18	.38	.84	487	25	55	.32
-21A	d.sh.	.89	.02	.27	.96	UD	29	110	.07
-21B	d.sh.	2.08	.00	.06	.73	UD	3	35	UD
-21C	d.sh.	.41	.04	.06	.20	UD	14	49	.40
-22A	d.sh.	1.76	.37	.68	.19	455	38	10	.36
HB-585-22B	d.sh.	2.02	.79	1.0	.24	459	50	12	.44
-23	d.sh.	1.94	.19	.31	.20	456	15	10	.38
-24	sh.lms.	.23	.00	.02	.46	UD	8	200	UD
-25A	d.sh.	2.09	.90	6.1	.21	440	290	9	.13
-25B	g.slt.	.74	.12	.64	.16	430	86	21	.16
HB-585-25C	g.slt.	.06	.00	.00	.09	UD	UD	150	UD
-25D	d.sh.	.29	.02	.05	.14	435	16	48	.33

1. See text for definitions of S₁, S₂, S₃, T_{max}, HI, OI, PI.

2. d.sh. = dark gray to black shale; r.sh. = reddish shale; sh.lms. = interbedded gray shale and limestone; g.slt. = medium to dark gray siltstone; r.slt. = reddish siltstone; s.bt. = solid bitumen; bt.cc. = bitumen-stained concretion; bt.ss. = bitumen-stained sandstone; bt.slt. = bitumen-stained siltstone; bt.cl. = solid bitumen intermingled with calcite; c.wd. = coalified woody stem.

3. UD = unable to determine due to low yield of pyrolytic products.

TABLE 2

Newark Basin Pyrolysis Results¹

Sample ID	Sample ² Type	Organic Carbon (wt. %)	S ₁ (mg/gm)	S ₂ (mg/gm)	S ₃ (mg/gm)	T _{max} (°C)	HI (mg/gm)	OI (mg/gm)	PI
NB-584-6	d.sh.	1.07	.00	.03	.23	UD ³	UD	21	UD
-7	d.sh.	.60	.00	.03	.07	UD	UD	12	UD
-8	d.sh.	2.19	.01	.04	.72	UD	UD	33	UD
-9	d.sh.(d) ⁴	3.22	.07	.13	6.2	522	1	94	.18
-10	d.sh.(d)	2.32	.32	.34	.28	580	8	7	.48
NB-584-11	d.sh.	.70	.01	.04	.14	UD	UD	20	UD
-12	d.sh.	1.07	.00	.02	.17	UD	UD	16	UD
-13	d.sh.	2.41	.00	.03	.20	UD	UD	8	UD
-15A	g.slt.	.47	.00	.03	.10	UD	UD	21	UD
-15B	d.sh.(d)	1.21	.05	.28	.25	475	10	9	.16
NB-584-15C	d.sh.	1.42	.00	.00	.32	UD	UD	23	UD
-15D	d.sh.	1.96	.06	.09	.36	481	5	18	.43
-17	d.sh.	3.02	.01	.01	.19	UD	UD	6	UD
-18	d.sh.	1.49	.01	.00	.07	UD	UD	5	UD
-19	g.slt.	.17	.01	.00	.03	UD	UD	30	UD
NB-584-20A	g.slt.	.85	.00	.00	.24	UD	UD	28	UD
-20B	d.sh.	3.52	.03	.54	.48	449	15	14	.04
-20C	d.sh.	2.38	.02	.03	.22	UD	UD	9	UD
-20D	d.sh.	1.78	.10	.02	.22	UD	UD	12	UD
NB-684-23	g.slt.	.82	.19	3.61	.16	432	440	20	.05
NB-684-24A	d.sh.	1.56	.32	7.1	.76	420	450	49	.04
-24B	d.sh.	1.50	.12	3.6	.69	423	240	46	.03
-24C	d.sh.	1.13	.07	2.4	.59	428	210	52	.03
-25	d.sh.	1.08	.53	4.6	.54	429	430	50	.10
NB-585-1	d.sh.	1.17	.01	.00	.74	UD	UD	48	UD
NB-585-2	d.sh.(d)	2.15	.01	.28	1.4	476	9	46	.04
-4	d.sh.	2.31	.05	.05	3.3	UD	UD	130	UD
-5	d.sh.	.39	.00	.03	.17	UD	UD	42	UD
-6	d.sh.	2.59	.78	25.3	1.1	437	980	41	.03
-7	d.sh.	3.31	1.1	12.9	.93	419	390	28	.08
NB-585-8	d.sh.	3.16	.65	10.9	.84	423	350	27	.06
-9	d.sh.	3.65	.89	16.6	.95	434	460	26	.05
-10	bt.ct.	1.52	.80	8.4	.28	421	550	18	.09
-11	ct.	.75	.21	2.8	.26	434	370	35	.07
-12	ct.	.90	.34	1.8	.12	437	200	13	.16
NB-585-13	d.sh.	2.97	1.7	9.4	.53	443	320	18	.15
-14	d.sh.	2.23	.62	11.0	.35	446	500	16	.05

1. See text for definitions of S₁, S₂, S₃, T_{max}, HI, OI, PI.

2. d.sh. = dark gray to black shale; g.slt. = medium to dark gray siltstone; ct. = chert; bt.ct. = bitumen-stained chert.

3. UD = unable to determine due to low yield of pyrolytic products.

4. (d) = decalcified residue, acid leached to concentrate organic matter.

If the $\delta^{18}\text{O}_{\text{carb}}$ values for the Portland in the range of $-6^{\circ}/\text{oo}$ to $-16^{\circ}/\text{oo}$ are primary then they reflect carbonate formation in fresh lacustrine and fluvial waters that were not isotopically fractionated by evaporation. Given the small number of samples analyzed from the Portland, it is uncertain whether these $\delta^{18}\text{O}_{\text{carb}}$ values are typical or unusual for this formation. The $\delta^{18}\text{O}_{\text{carb}}$ values for the East Berlin Formation in the range of $+2^{\circ}/\text{oo}$ to $-4^{\circ}/\text{oo}$ are interpreted to be primary and to reflect carbonate formation in lacustrine waters that were isotopically fractionated by extensive evaporation.

Stable Isotopic Data for Newark Basin

Thirty-seven samples from the Newark basin have been analyzed for stable carbon isotopic composition of whole-rock organic matter. Sixteen of these samples were analyzed for stable carbon and oxygen isotopic composition of whole-rock carbonate. Most of the Towaco lacustrine shales have $\delta^{13}\text{C}_{\text{org}}$ values in the range of $-29^{\circ}/\text{oo}$ to $-31.5^{\circ}/\text{oo}$ and are isotopically similar to the East Berlin lacustrine shales from the Hartford basin. Shale and chert samples from the Towaco that contain bitumen-filled fractures have $\delta^{13}\text{C}_{\text{org}}$ values in the range of $-32^{\circ}/\text{oo}$ to $-33^{\circ}/\text{oo}$. $\delta^{13}\text{C}_{\text{org}}$ values of the Lockatong lacustrine shales are significantly heavier than typical Towaco or East Berlin lacustrine shales. The Lockatong lacustrine shales generally have $\delta^{13}\text{C}_{\text{org}}$ values in the range of $-26^{\circ}/\text{oo}$ to $-28.5^{\circ}/\text{oo}$. All of the Lockatong samples are thermally overmature with respect to petroleum generation and, therefore, may have lost substantial amounts of isotopically light hydrocarbons due to thermal cracking and migration of products.

Carbon isotopic values of whole-rock carbonate from the Towaco lacustrine shales are generally in the range of $-1^{\circ}/\text{oo}$ to $-4^{\circ}/\text{oo}$ and are slightly more negative than typical values for the East Berlin lacustrine shales. Bitumen-stained shales and cherts from the Towaco have $\delta^{13}\text{C}_{\text{carb}}$ values in the range of $-4^{\circ}/\text{oo}$ to $-7^{\circ}/\text{oo}$. The $\delta^{13}\text{C}_{\text{carb}}$ values of three samples of the Lockatong are in the range of $+1.5^{\circ}/\text{oo}$ to $-0.5^{\circ}/\text{oo}$ and are isotopically heavier than typical Towaco lacustrine shales but are isotopically similar to East Berlin lacustrine shales.

Oxygen isotopic values of whole-rock carbonate from Towaco lacustrine shales are widely variable but generally are in the range of $+3^{\circ}/\text{oo}$ to $-3^{\circ}/\text{oo}$. Bitumen-stained shales and cherts from the Towaco tend to have more negative $\delta^{18}\text{O}_{\text{carb}}$ values than nonstained samples. The $\delta^{18}\text{O}_{\text{carb}}$ of bitumen-stained

TABLE 3

Hartford Basin Stable Isotope Values

Sample	Organic Carbon (wt.%)	$\delta^{13}\text{C}_{\text{org}}$ (‰)	Carbonate Carbon (wt.%)	$\delta^{13}\text{C}_{\text{carb}}$ (‰)	$\delta^{18}\text{O}_{\text{carb}}$ (‰)
HB-585-1	0.12	-26.5	2.81	- 3.4	- 8.7
2	58.4	-30.5	4.05	- 5.0	-11.8
3	3.60	-30.4	9.19	- 4.9	-10.4
4	15.2	-22.9	1.05	-15.6	- 6.1
5	0.26	-24.2	0.31	- 6.3	- 3.7
6	0.15	-24.1	1.05	- 7.2	- 6.8
7	0.44	-27.7	1.11	- 6.3	- 6.5
8	1.38	-29.3	3.15	- 0.7	- 4.3
9	0.13	-26.5	1.88	- 0.1	+ 0.4
10A	1.73	-30.1	5.73	- 1.1	- 1.1
10B	1.79	-29.1	3.66	- 1.2	+ 0.1
10C	0.25	-28.7	1.94	+ 0.1	- 1.6
11A	3.62	-26.3	1.57	- 2.1	- 4.8
11B	3.76	-24.9	2.88	+ 1.4	+ 2.9
11C	2.75	-30.0	2.83	+ 1.0	+ 1.6
12A	3.05	-23.1	2.59	- 0.6	- 1.6
12B	1.67	-29.5	4.18	+ 0.2	- 0.9
12C	1.45	-29.8	7.15	- 0.3	+ 1.7
12D	0.70	-30.1	3.96	0.0	- 5.3
13	2.49	-31.1	3.53	- 0.2	- 7.3
14	0.02	-28.9	0.19	- 2.3	- 7.3
15A	2.19	-28.8	4.31	+ 1.2	+ 0.6
15B	2.53	-27.6	3.97	+ 1.1	+ 0.2
15C	0.50	-29.5	3.15	+ 0.2	- 0.7
15D	3.08	-31.9	3.29	- 0.7	- 6.2
16A	2.21	-30.4	2.94	+ 0.6	+ 0.7
16B	2.46	-26.6	4.05	+ 1.0	- 2.0
16C	2.65	-28.7	4.73	+ 1.0	- 2.7
17	2.16	-29.5	3.36	+ 1.3	- 2.4
18A	1.26	-29.5	3.63	- 1.0	+ 2.0
18B	1.26	-29.2	5.63	- 2.6	0.0
18C	3.78	-29.6	3.72	- 2.7	- 3.9
18D	2.27	-29.5	5.64	- 1.1	- 0.7
18E	2.29	-29.4	5.01	- 0.4	- 1.7
18F	1.86	-29.8	4.29	- 1.3	- 2.6
18G	1.22	-29.5	7.44	- 0.3	- 1.9
19A	0.95	-31.8	3.61	- 1.6	- 4.8
19B	0.59	-31.6	4.80	- 1.5	- 3.6
20A	0.86	-28.9	3.00	+ 0.9	- 1.9
20B	0.35	-27.6	0.02	UD	UD
20C	1.50	-29.6	3.53	+ 0.4	- 4.7
21A	0.89	-27.7	2.36		
21B	2.08	-28.6	0.61	- 1.3	+ 1.3
21C	0.41	-27.3	2.12	+ 1.3	- 0.2
22A	1.76	-29.7	4.82	- 0.6	- 2.3
22B	2.02	-30.1	2.63	- 0.2	- 3.0
23	1.94	-29.5	4.79	- 2.0	+ 1.0
24	0.23	-23.4	6.23	- 2.3	-10.7
25A	2.09	-28.5	1.19	- 2.3	-15.6
25B	0.74	-27.1	1.37	- 2.6	-15.2
25C	0.06	-26.4	0.01		
25D	0.29	-26.7	0.66	- 6.4	- 7.5

TABLE 4

Newark Basin Stable Isotope Values

Sample	Organic Carbon (wt. %)	$\delta^{13}\text{C}_{\text{org}}$ (‰)	Carbonate Carbon (wt. %)	$\delta^{13}\text{C}_{\text{carb}}$ (‰)	$\delta^{18}\text{O}_{\text{carb}}$ (‰)
NB-584-6	1.1	-28.2	6.2		
7	0.6	-28.1	2.4		
8	2.2	-26.6	6.6	0.2	-2.2
9	3.2	-26.1	6.3		
10	2.3	-26.4	7.8	1.1	-3.6
11	0.7	-26.6	5.5		
12	1.1	-27.0	2.4		
13	2.4	-25.5	3.5		
15A	0.5	-27.3	2.9		
15B	1.2	-27.8	5.2		
15C	1.4	-27.4	4.9	-0.3	+3.4
15D	0.4	-23.3	9.4		
17	3.0	-29.4	1.5		
18	1.5	-28.9	2.1		
19	0.2	-27.4	0.7		
20A	0.8	-26.6	5.0		
20B	3.5	-26.7	7.8		
20C	2.4	-26.4	3.8		
20D	1.8	-26.5	3.0		
NB-684-23	0.8	-31.7	2.7	-1.8	-2.4
24A	1.6	-30.8	3.3	-3.0	-2.5
24B	1.5	-30.6	0.8	-2.9	-2.1
24C	1.1	-30.4	0.3	-1.1	-2.8
25	1.1	-30.9	4.7	-3.8	-0.2
NB-585-1	1.17	-30.3	4.68	+1.7	-2.8
2	2.15	-29.4	0.23		
4	2.32	-30.6	0.15		
5	0.39	-28.8	0.35	-2.9	+0.2
6	2.59	-32.3	5.01	-1.5	+2.8
7	3.31	-31.9	2.14	-1.2	+0.1
8	3.16	-31.5	2.69	-1.6	-1.2
9	3.65	-31.8	0.45		
10	1.52	-32.6	0.03		
11	0.75	-30.9	1.12	-6.7	-4.2
12	0.90	-31.3	0.09		
13	2.97	-31.5	1.10	-3.8	-1.6
14	2.23	-31.4	4.01	-4.3	-5.8

samples are generally in the range of $-3.5^{\circ}/\text{oo}$ to $-7^{\circ}/\text{oo}$. Oxygen isotopic values of whole-rock carbonate from three samples of the Lockatong are in the range of $+3.5^{\circ}/\text{oo}$ to $-4.0^{\circ}/\text{oo}$.

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