Cambrian Saint Croixan and early Early Ordovician Canadian. It is bounded below by the unconformity on the Precambrian basement and above by the Knox unconformity. The Sauk sequence was deposited throughout the study area of northern Ohio, which includes the western portion of the Appalachian basin, the Ohio-Indiana platform to the west, and the southernmost portion of the Michigan basin northwest of the Ohio-Indiana platform. The major lithostratigraphic units, all in the subsurface, are the Cambrian Mount Simon Sandstone, Shady Dolomite, Eau Clair Formation, Rome Formation, Conasauga Formation, and Kerbel Formation, and the Cambrian-Ordovician Knox Group.

Stratigraphic interpretations generally show that the Sauk sequence begins with clastic deposition occurring in the north-central and western portions of Ohio and predominantly carbonate and open-marine clastic deposition occurring in eastern and south-central Ohio. The location of the present Cincinnati arch marks a transition zone between the two sedimentary regimes. The final stage of Sauk sequence deposition was marked by a major marine transgression that resulted in deposition of the Knox Dolomite over the entire study area.

Producing reservoirs occur in four stratigraphic-structural settings. The Copper Ridge Dolomite (Knox Group) on the eastern edge of the Ohio-Indiana platform has oil production from glauconitic sandstone reservoirs.

Basinward, the Cambrian dolomitic Rose Run Sandstone Member occurs at the top of the Copper Ridge Dolomite. Mainly gas has been discovered in the Rose Run in secondary reservoirs formed during erosion of the Knox unconformity. Middle Ordovician shales and impermeable limestones are the seals.

The majority of hydrocarbon production from the Knox Dolomite is located in central Ohio's Morrow County where erosional remnants of vuggy dolomite on the Knox unconformity form paleotopographic highs with Middle Ordovician shale as the seal. Other small pools consist of vuggy dolomite reservoirs with small structural closures.

Although no significant amounts of hydrocarbons have been discovered below the Copper Ridge Dolomite, high porosities and permeabilities in the Mount Simon Sandstone and Eau Claire Formation lend potential to these rocks for liquid waste disposal.

MARTIN, ANTHONY J., WAYNE D. MARTIN, and JOHN K. POPE, Miami Univ., Oxford, OH

Genesis of Phosphatic Sediments in Cincinnatian Series (Upper Ordovician), Southeastern Indiana and Southwestern Ohio

Few workers have considered the origin of lower Paleozoic phosphate-rich strata, especially in the light of recently proposed phosphorite depositional models. Selected samples of limestones and shales from the Cincinnatian Series have been examined to determine the environmental factors contributing to the accumulation of phosphatic sediments.

The conditions of phosphate accumulation have been interpreted from a detailed description of the stratigraphic sequence, sedimentary structures, textures, and fossil content of each locality. Microfacies analysis of the limestones revealed that phosphate is largely confined to intragranular pores of bioclasts (echinoderm debris, juvenile mollusks, bryozoan zooecia). The phosphatized bioclasts are concentrated as basal lag deposits above discontinuity surfaces, as starved ripples within shale beds, and as burrow infillings. The zones of phosphatic concentration directly overlie bioclastic wackestones.

The original phosphatization process probably occurred within the sediments that formed the bioclastic wackestones. The ichnofossils (and, in part, the body fossils) indicate that there was a low rate of sedimentation, high organic input, high initial water content (> 50%), normal oxygen concentrations, and pervasive bioturbation of a muddy substrate. The confining microenvironments necessary for the reducing conditions of phosphate precipitation were the intragranular pores of bioclasts, such as bryozoans, filled with organic-rich muds. Early diagenesis of phosphate took place within the pores, and these relatively denser allochems were subsequently winnowed from the unconsolidated muddy substrate by episodic high-energy events. The resultant deposits were phosphatic sands that also underwent biogenic disturbance and further physical redeposition.

MARTIN, D. W., A. H. COOGAN, R. SHADRACH, B. A. URIAN, and A. WIECKOWSKI, *Kent State Univ., Kent, OH*

Depositional Trends of Clinton Section in East-Central Ohio

The Lower Silurian Clinton section in east-central Ohio is a clastic wedge of sandstones, shales, and carbonates. Previous studies have shown that the Clinton section was deposited as a delta prograding westward over reworked clastics of the Ordovician Queenston Shale.

Geophysical log data were used to construct total Clinton sandstone and sandstone cleanliness maps of the delta margin. Clean-sand maps show the distribution of sand and shale in an offshore bar system in west-central Holmes County. Similar studies in adjoining counties indicate an extension of this bar system, which coincides with the Newburg pool in southern Medina County. Stratigraphic cross sections show the intertonguing relationship of sand, shale, and carbonate lithosomes typical of a deltaic system. The clastics of the upper Cabot Head grade westward into calcareous sands and thickening carbonates. Slice maps show the distribution of these deposits during time.

Production of oil and gas in Holmes County has been concentrated along the north-trending thick sands of the delta-margin bar system. Sand isopach maps, cross sections, and a porosity foot map show the distribution of thinner fluvial and fluvial delta-margin sands in western Holmes County.

MATTHEWS, R. DAVID, Inst. of Gas Technology, Chicago, IL

Relationship of Fracture-Induced Gas Reservoirs to Stratigraphic Controls in Eastern Devonian Shales

A new exploration method is advanced based on the hypothesis that some fractured shale reservoirs are related to a stratigraphic-type trapping mechanism at lithofacies boundaries where gray shales grade laterally into dark, radioactive shales having different physical and chemical characteristics. Hydrocarbons are postulated to move through these indurated, fine-grained shales as they do during late primary migration. Whatever mechanisms are operating at shale lithofacies, facies changes are systematic depositional events that can be mapped using conventional subsurface geologic methods. Shale gas fields associated with the mapped position of shale facies changes are found in all three eastern basins.

Gas occurrences from 139 wells were projected into a stratigraphic test section in Kentucky and West Virginia. Several facies changes and 232 gas occurrences are documented; they show a trend of gas occurrences near shale facies changes. For example, the middle Huron, more than 200 ft (61 m) thick, changes from 88% black to 2% within 17.2 mi (28 km); 87% of reported gas in the unit occurs in that same distance. Of 66 major shows or increases (> 100 mcf or 2,830 m^3) in the Ohio Shale, 88% fall within the 17.2 mi (28 km) in which the total unit changes from 86% black to 16%.

Facies changes appear to define trends of shale gas potential within specific beds; thus, a new element has been added to shale gas exploration methodology. The methods developed can be used to test the applicability of the hypothesis to the eastern basins.

MAXWELL, TIMOTHY C., and RICHARD SMOSNA, West Virginia Univ., Morgantown, WV

Sedimentology, Diagenesis, and Porosity Development of Middle Silurian Lockport Dolomite, Johnson County, Kentucky

A complete core of the Lockport Dolomite reveals the presence of five distinct lithofacies. Proceeding upsection from the underlying littoral Keefer Sandstone, these units are: (1) extensively burrowed and sparsely fossiliferous mudstone-wackestone (initial transgression); (2) thinly bedded, crinoidal packstone-grainstone (open shelf); (3) stromatoporoid-coral-crinoidal packstone (open shelf); (4) oolitic-peloidal packstone-grainstone (shoal); and (5) finely laminated mudstone (tidal flat). The middle to upper sections reflect a shoaling-upward sequence that grades into the overlying Salina Formation sabkha sediments.

Original rock textures have been veiled for the most part by dolomitization. Petrographic analysis indicates that dolomite occurs in two forms: (1) as a fine to medium crystalline replacement mineral, and (2) as a coarse crystalline cement (including saddle dolomite) filling vugs and fractures. The first variety is eogenetic, having formed primarily as a result of freshwater/seawater mixing during occasional subaerial exposure of sediments. The coarser dolomite is of late (mesogenetic) origin.

Historically, the Lockport has been an important oil and gas producer in eastern Kentucky. Secondary porosity development is significant and appears to have been a function of sedimentary facies and early dolomitization, coupled with freshwater invasion and solution. Intercrystalline (dolomitic) and vuggy (solution) porosity are present throughout the section but are particularly conspicuous in the open-shelf and shoal facies where they reach values of 6-10%. These particular facies had a higher relative abundance of mineralogically metastable skeletal grains and accommodated greater pore-water flow during early diagenesis. Reservoir quality in these facies has been significantly enhanced by good fracture permeability.

MCCARTAN, LUCY, and GEORGE ANDREWS, U.S. Geol. Survey, Reston, VA

Variations in Diatom Abundance in Chesapeake Group (Miocene-Pliocene) in Maryland and Virginia: A Reflection of Changes in Water Circulation and Tectonics

Diatoms are abundant in much of the Calvert and Choptank Formations (lower to middle Miocene), and are not abundant in the Eastover Formation (upper Miocene). No significant accumulations of diatoms have been observed in the St. Marys Formation (middle and upper Miocene), Yorktown Formation (lower and middle Pliocene), and sub-Chesapeake deposits. The distribution and abundance of diatoms in the Salisbury embayment were probably affected by two main factors: availability of nutrients and dilution by deposition of terrigenous clastic sediments. Beginning during the early Miocene, massive, long-term diatom blooms may have been supported by a steady, abundant supply of silica, nitrogen, phosphorus, and other nutrients transported by upwelling cold water from northern regions. The diatom-rich, silty-sand deposits also indicate a relatively slow influx of terrigenous sediment. The paucity of diatoms in some Miocene and Pliocene deposits is primarily due to increased sedimentation resulting from tectonic uplift in the Piedmont and Appalachian source areas adjacent to the Salisbury embayment. Other factors that affect diatom abundance are environment of deposition (proximity to beach or river mouth), an increase in clastic sedimentation coincident with a sea level drop due to Antarctic glaciation, and postdepositional intrastratal solution of diatoms by circulating ground water.

MCKINNEY, RICHARD B., and VICTOR V. CAVAROC, North Carolina State Univ., Raleigh NC, and CHARLES C. ALMY, Guilford College, Greensboro, NC

Subsurface Geology of the Pamlico Sound Area, Coastal North Carolina

The subsurface of the Pamlico Sound area in North Carolina contains the state's thickest drilled succession of Mesozoic-Cenozoic strata. The subsurface geology of approximately 1,800 mi^2 of northern Pamlico Sound was investigated using logs and cuttings from seven wells and about 135 mi of multichannel reflection seismic line.

Crystalline basement rocks dip about 1.2° east-southeast. The overlying strata, which range in thickness from 5,145 ft (Albemarle Sound area) to 9,860 ft downdip (Cape Hatteras), are not significantly affected by faulting. Jurassic(?) through Eocene sediments all appear to have accumulated within a gently subsiding, marine-shelf environment. Four distinct lithofacies characterize these strata. The basal Unit 1 (La Casitan-Trinitian) reflects a westward transgression of coastal sandstone, outer shelf mud, and carbonate across shallow shelf to lagoonal deposits. Unit 2 (Trinitian-Washitan) is an upward-coarsening detrital sequence which terminates with discontinuous, marine-shelf sandstones that reflect a northerly source. An abrupt transition into marine-shelf mudstones and limestones marks the base of Unit 3 (Woodbinian-Austinian); these are abruptly overlain by interbedded shelf sandstones that merge to the southwest. Unit 4 (Tayloran-Claibornian), the uppermost interval studied, is characterized by thick, widespread marl, which grades into glauconitic sandstone and finally marine limestone.

Continuous seismic reflectors occur at the basement interface and the top of Units 2 and 4. A reflector, possibly a stratigraphic discontinuity, occurs at the top of the Cretaceous in Unit 4. Well-developed prograding seismic sequences occur above Unit 4.

MCKINSEY, TIMOTHY R., and ROY C. KEPFERLE, Eastern Kentucky Univ., Richmond, KY

X-Radiography of New Albany and Chattanooga Shales (Devonian) Along Cincinnati Arch in Kentucky

Sedimentary structures and composition in the New Albany and Chattanooga Shales (Devonian) along the western flank of the Cincinnati arch in Kentucky help define seven lithofacies. These lithofacies, recognized by x-radiography, are: (1) organic-rich laminated shale, (2) bioturbated greenish-gray shale, (3) indistinctly laminated greenish-gray shale, (4) siltstone, (5) fine-grained sandstone, (6) carbonate, and (7) authigenic mineral phases. The organic-rich laminated shale is dominant and can be divided into three subfacies: (a) organic-rich thinly laminated shale, (b) organic-rich thickly laminated shale, and (c) organic-rich laminated shale with current stratification. This current stratification is in the form of discontinuous laminae, ripples, cross-beds, and scour surfaces. The carbonate and authigenic mineral phases refer to early (diagenetic?) formation of carbonates, sulfates, sulfides, and phosphates.

Areal and vertical distribution of these lithofacies in the New Albany and Chattanooga Shales in western-central Kentucky are interpreted to show the influence of the paleo-Cincinnati arch. The organic-rich, thinly laminated shale is dominant in the basins on the flanks of the arch and occurs on the arch. This facies records episodic deposition in quiet, anaerobic waters. The organic-rich thinly laminated shale with current stratification is dominant on the arch and is interpreted as evidence of episodic deposition in an anaerobic environment with weak bottom currents. Indistinctly laminated, greenish-gray shale and bioturbated greenish-gray shale facies are representative of a dysaerobic environment. Siltstone and fine-grained sandstone facies are also present in small amounts, mainly near the base of the section. Carbonate and authigenic minerals are indicators of paleosalinity, oxygen content, and conditions of Eh, and support interpretations of the other associated lithofacies.

MIKESELL, JON L., FRANK E. SENFTLE, and ALLAN B. TANNER, U.S. Geol. Survey, Reston, VA

In-Situ Elemental Analysis of Coal and Strategic Metals by Neutron Activation

Starting in 1969, the U.S. Geological Survey (USGS) developed neutron techniques for borehole measurement of the elemental composition of ores, and it successfully made a borehole ultimate analysis of coal in 1977. Borehole measurements permit real-time evaluation of ore quality without the expense of coring or the delays and expense associated with laboratory analyses. Two technological innovations have made such measurements possible: the availability of small californium-252 fission neutron sources from the Savannah River Operations Office of the Department of Energy, and the development, by USGS and Princeton Gamma-Tech, of the melting-cryogen-cooled high-purity germanium borehole gamma-ray detector. A technique of relating mass fractions to measured gamma-ray intensities, which eliminates the need for detailed knowledge of the geometry of the neutron distribution, was used to calculate elemental compositions without using test pits or computer borehole modeling. Most of the common elements in the earth's crust can be detected by neutron techniques. In coal all of the major constituents except oxygen (C, H, N, S, Si, Al, Fe, Ti) can be determined quantitatively by thermal neutron capture gamma-ray spectroscopy. The latest innovation in this field is the replacement of the ^{252}Cf neutron source with a neutron generator, a type of ion accelerator. These generators, used for many years by the petroleum logging industry, produce neutrons having an energy of 14 MeV. The neutron generator is a safer tool than californium, because no radiation is emitted by the device until it is turned on in the borehole. Coupling a neutron generator with a high-resolution detector to form a borehole measuring system was pioneered by workers at Sandia National Laboratories. USGS has built and put into service one neutron generator based on the Sandia design, and now is building a second. This new device enables the experimenter to use higher energy (n,n′), (n,p), (n,2n), and (n,α) reactions as well as the (n,γ) thermal neutron capture reaction. Both the (n,n′) and the (n,p) reactions on ^{16}O permit quantitative measurement of oxygen, and the inelastic scattering excitation of carbon in coal provides increased sensitivity over that of the (n,γ) reaction. Reactions caused by 14 MeV-neutron irradiation that are used in exploration for strategic metals such as Cr, Ni, Mn, V, Co, Ti, and W are tabulated.