PLAY Dho: FRACTURED MIDDLE DEVONIAN HUNTERSVILLE CHERT AND LOWER DEVONIAN ORISKANY SANDSTONE

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Location

The fractured Middle Devonian Huntersville Chert and Lower Devonian Oriskany Sandstone have produced significant quantities of natural gas from anticlinal structures within the Allegheny Plateau Physiographic Province of the Appalachian basin. Gas production extends from northern Clearfield County in Pennsylvania to Greenbrier County, West Virginia, along a northeast-southwest trend (Figure Dho-1). The proven area of this predominantly structural play occupies approximately 167,000 acres extending across parts of Maryland, Pennsylvania, and West Virginia. The actual play includes an estimated 11,800,000 acres: 4,400,000 acres in Pennsylvania, 250,000 acres in Maryland, and 7,150,000 acres in West Virginia.

Production History

The Huntersville Chert was first drilled and produced in Ligonier Township, Westmoreland County, Pennsylvania. Peoples Natural Gas Company spudded the No. 1 Booth and Flinn well in March 1919. Located on Chestnut Ridge, the well site was selected as a practical application of the anticlinal theory of gas accumulation in the deeper formations near an area of shallow gas production. Peoples Natural Gas was searching for "fresh supplies of fuel for its consumers after it had become evident that all present known gas-bearing sands were being depleted, as it was explained by John B. Tonkin, vice president and general manager of the Peoples Natural Gas Company" (Anonymous newspaper article, 1924). Thus, McCance pool of Lycippus field (Figure Dho-2) was discovered on March 3, 1920 with the completion of the No. 1 Booth and Flinn well having a natural open flow of 450 Mcf and a rock pressure estimated to be 3,600 psi. Peoples Natural Gas attempted to define the trend of this new discovery by spudding a second well in 1920, targeting the Huntersville and Oriskany. Although these formations were tight and dry, some commercial gas was found in a sandstone unit in the deeper Helderberg Group. Historical information is sketchy, but it seems the two wells produced for approximately six years before abandonment.

Summit field, in Fayette County, Pennsylvania (Figure Dho-2), was the first field to be drilled and developed in the combined Huntersville and Oriskany reservoir. By the time Summit field was discovered by W.E. Snee and New Penn Development Corporation's No. 1 Heyn well in 1937, the Oriskany Sandstone was already a major gas play in New York, Ohio, north-central Pennsylvania, and West Virginia. The No. 1 Heyn was an attempt to duplicate the success operators were realizing in developing the north-central Pennsylvania Oriskany gas fields. Drilling was completed April 23, 1937, with an initial open flow of 1,800 Mcf from 18 feet into the Huntersville Chert at 6,611 feet. Although many wells lacking initial flow were drilled and abandoned, within 10 years the fractured Huntersville/Oriskany reservoir was the target of numerous successful prospects drilled on anticlinal structures, and exploration had spread from south-central Pennsylvania to Maryland and West Virginia. As the reservoir became better understood and the hydraulic fracturing techniques of the mid 1950s were applied, operators realized that a well with little or no natural open flow, which previously would have been abandoned as a dry hole, could be stimulated into a well with high initial flow. These factors combined to make the play quite popular.

Total cumulative production since discovery in 1920 through 1993 from the Huntersville/Oriskany fractured reservoir play exceeds 650 bcf from about 60 fields in the Appalachian basin.

Stratigraphy

The producing formations of the play are the Lower and Middle Devonain Huntersville Chert and the Lower Devonian Oriskany Sandstone. The generalized stratigraphic chart in Figure Dho-3 illustrates regional relationships between the formations.

The regionally widespread Oriskany Sandstone overlies the Helderberg Group and is overlain by a sequence of laterally changing facies which, from east to west, consist of the Needmore Shale, the Huntersville Chert, the Bois Blanc Formation, and a portion of the overlying Onondaga Formation (Basan and others, 1980). Many Appalachian basin researchers have recognized the stratigraphic, geographic, and lateral facies changes in the lower part of the Middle Devonian (Patchen, 1968b; Inners, 1979; Basan and others, 1980; Cardwell, 1982b). Basan and others (1980) described three primary facies: eastern clastic facies, central basin chert facies, and western carbonate facies. The eastern clastic facies, represented by the Needmore Shale, has been characterized as "variously... dark, noncalcareous shale, calcareous silty shale, calcareous siltstone, argillaceous and silty or sandy limestone, and a subordinate amount of glauconitic or conglomeratic quartz sandstone" (Basan and others, 1980, p. 42). The lateral extent of the Huntersville Chert facies types is illustrated in Figure Dho-4. From Clearfield County, Pennsylvania, southward through Somerset County, Pennsylvania, western Maryland, and eastern and south-central West Virginia, these strata comprise the Needmore Shale (Figures Dho-2, Dho-4). The Needmore lies upon the Oriskany, and commonly includes grains of reworked Oriskany quartz sand and associated minerals (Basan and others, 1980). West of the eastern clastic facies, the central basin chert facies occupies the central part of the Appalachian basin from Forest and Elk counties, Pennsylvania, to Smyth County, Virginia (Figures Dho-2, Dho-4). In areas where the chert overlies the Oriskany Sandstone, the chert contains well-rounded

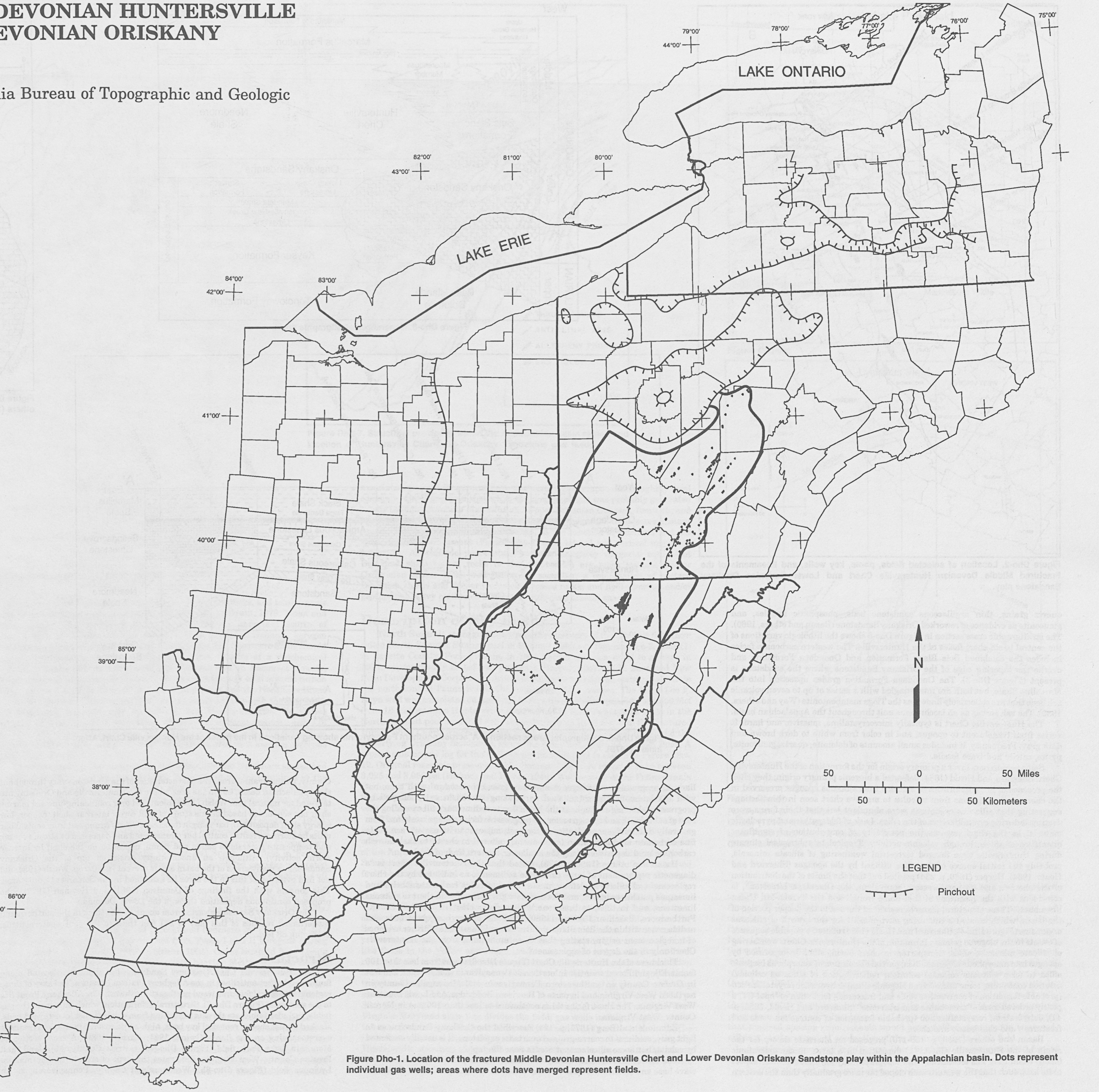

Figure Dho-1. Location of the fractured Middle Devonian Huntersville Chert and Lower Devonian Oriskany Sandstone play within the Appalachian basin. Dots represent individual gas wells; areas where dots have merged represent fields.

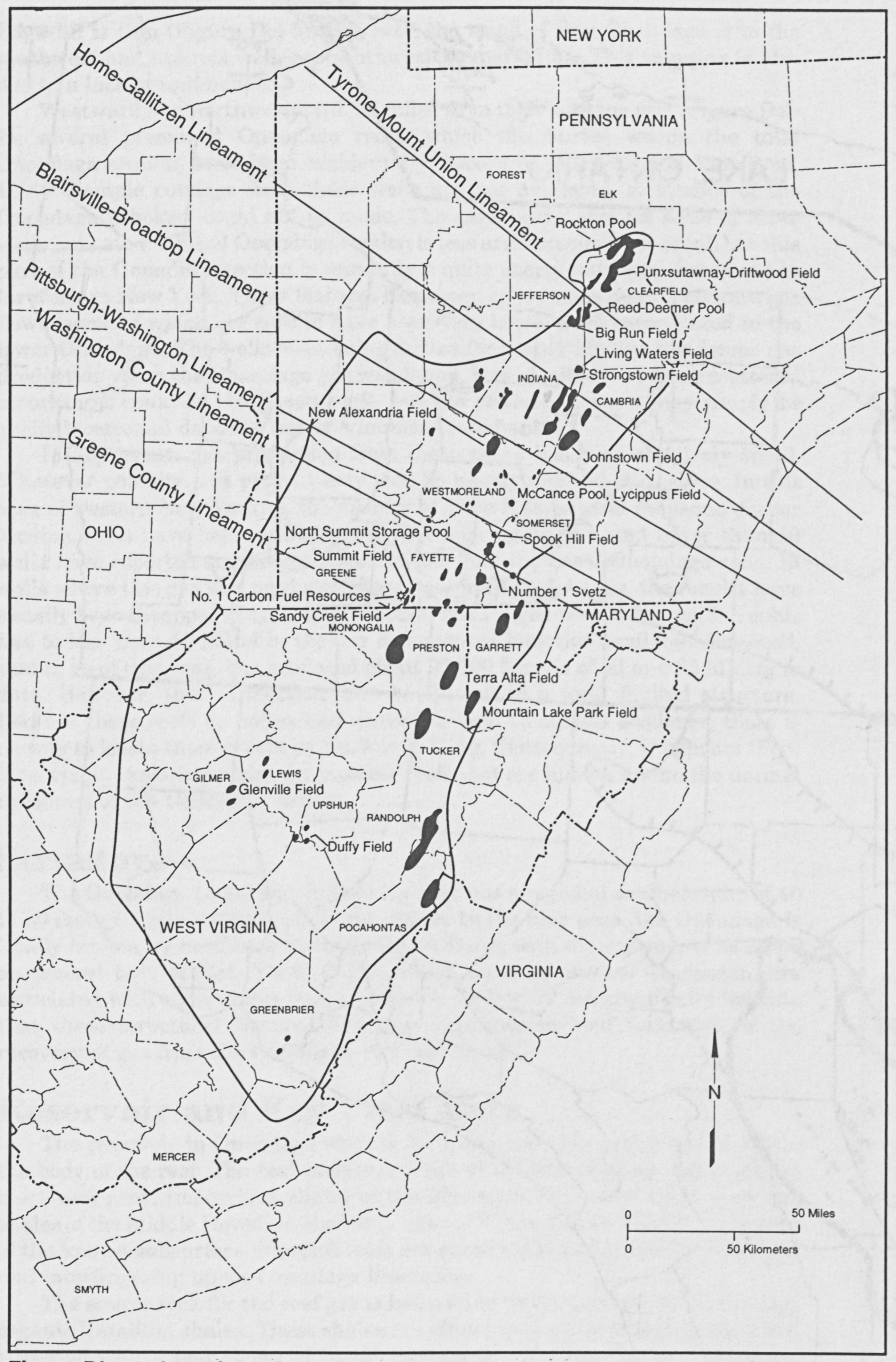

Figure Dho-2. Location of selected fields, pools, key wells, and lineaments of the Fractured Middle Devonian Huntersville Chert and Lower Devonian Oriskany Sandstone play.

quartz grains, thin argillaceous sandstone beds, phosphatic nodules, and glauconite as evidence of reworked Oriskany Sandstone (Basan and others, 1980). The stratigraphic cross section in Figure Dho-5 shows the lithologic variations of the central basin chert facies of the Huntersville. The western carbonate facies includes the combined Bois Blanc Formation and Onondaga Formation and overlie the tapering edge of the Oriskany Sandstone where the sandstone is present (Figure Dho-3). The Onondaga Formation grades upsection into the Marcellus Shale, but both are intermingled with a series of up to seven volcanic ash beds that are collectively known as the Tioga metabentonite (Way and others, 1986). The ash serves as an isochronous unit throughout the Appalachian basin.

The Huntersville Chert is typically microcrystalline, massive, and hard. It varies from translucent to opaque, and in color from white to dark brown and dark gray. Frequently, it includes small amounts of dolomite, quartz, glauconite, pyrite, calcite and trace fossils.

Some researchers favor a primary origin for the formation of the Huntersville Chert. Sherrard and Heald (1984) defended a biogenic primary origin; they cited the presence of large quantities of spicules from siliceous sponges preserved in the chert, and gradations from spicules to massive chert seen in thin sections suggesting that siliceous organisms were abundant but that their forms were destroyed during crystallization of the silica. Lack of feldspathic and pyroclastic material in the chert negates the possibility of contribution of significant quantities of silica through volcanic activity. Tropical to subtropical climate during Huntersville time favored terrestrial weathering of silicate minerals, probably the initial source of the silica utilized by the sponges (Sherrard and Heald, 1984). Harper (1989, p. 234) pointed out that the limits of the distribution of the chert "...and its northwestern equivalent, the Onondaga Limestone, is coincident with the [positions of the] Rome trough and the Tyrone-Mt. Union lineament." These structural features restricted the sea to the deeper portion of the basin, which created a nurturing environment for the growth of siliceous organisms (Figure Dho-4). Sherrard and Heald (1984) offered a possible sequence of events in the biogenic primary formation of the Huntersville Chert: weathering of silicate minerals; silica transported to chert basin; silica incorporated by sponges into amorphous biogenic silica; partial dissolution of amorphous biogenic silica to form siliceous colloidal solution; redistribution of silica as colloidal solution containing some undissolved biogenic silica; dehydration; crystallization (probable formation of contraction voids and fractures); formation of "opal-CT, a poorly ordered form of cristobalite and tridymite" (Sherrard and Heald, 1984, p. 41); dehydration; recrystallization (probable formation of contraction voids and fractures); and chalcedony and chert.

Basan and others (1980, p. 169-170) proposed an alternate theory for the origin of the Huntersville Chert: "1) deposition in a large, linear epicratonic (shelf) basin that was tectonically and topographically asymmetric with respect to its axis, such that the western limb sloped far more gradually than the eastern

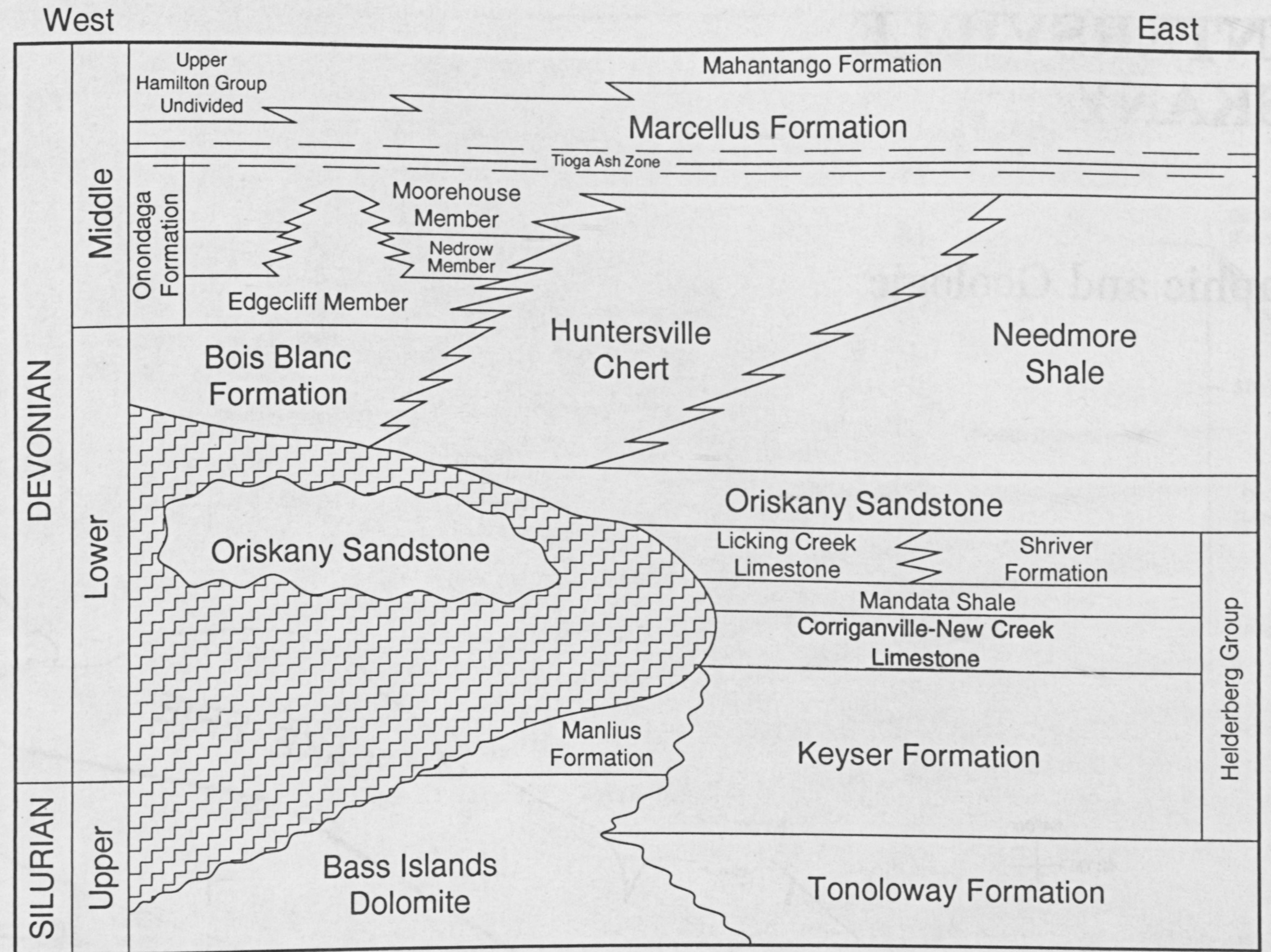

Figure Dho-3. Generalized stratigraphic chart.

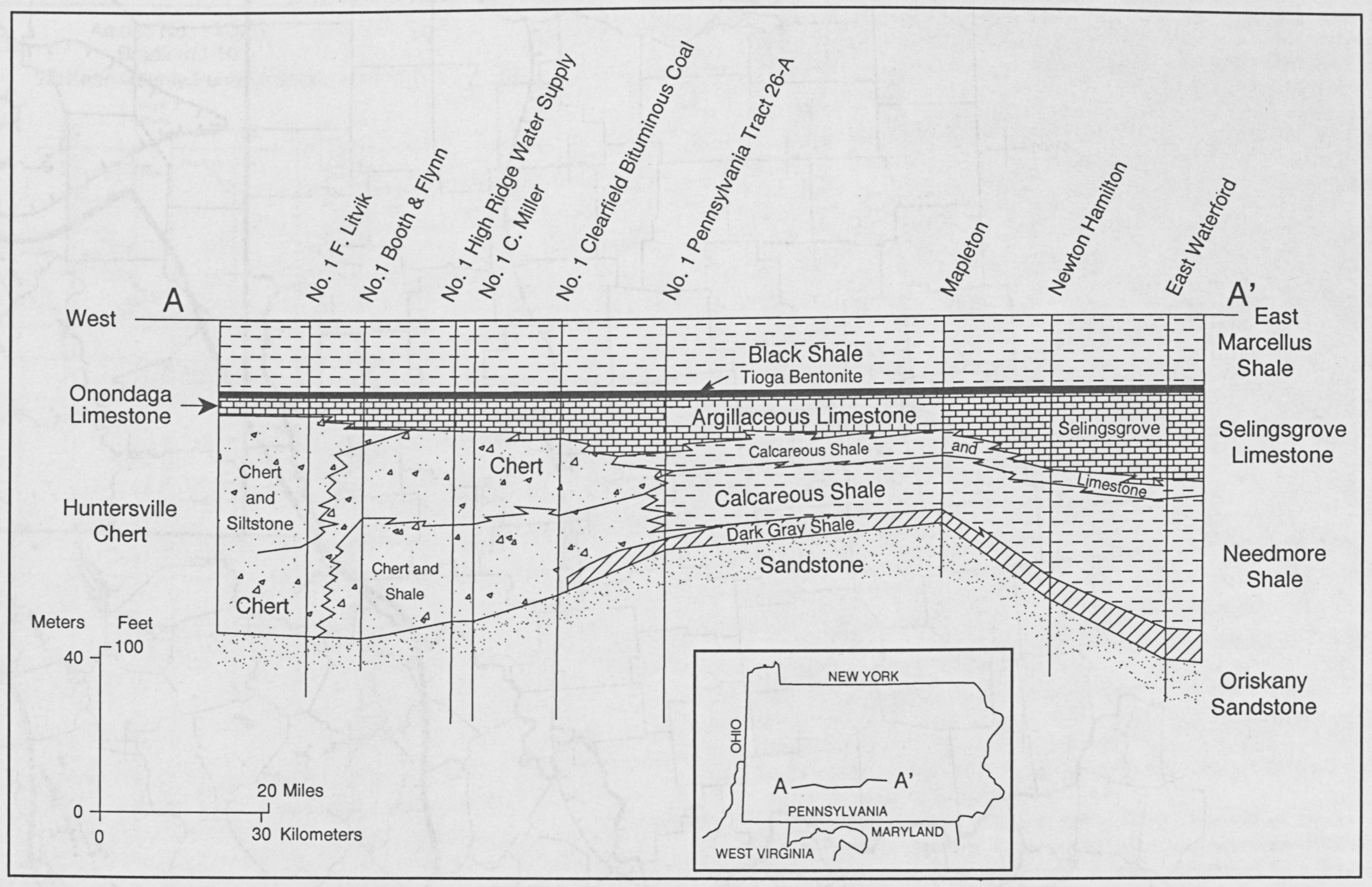

Figure Dho-5. Stratigraphic cross section A-A' across southern Pennsylvania showing variations in the facies of the Huntersville Chert. After Inners (1979).

limb; 2) progressive submergence and transgression westward with time, but with maximum depths established early along the basin axis, followed by progressive shoaling throughout the basin due to sedimentary fill exceeding the rate of subsidence and transgression; 3) progressive facies change westward from generally fine terrigenous clastics in the east, adjacent to its eastern source, to fine carbonate mud deposition (subsequently altered to chert), to skeletal-rich carbonate mud deposition along the shallower western limb of the basin."

Basan and others (1980, p. 173), stated that the Huntersville Chert is "a diagenetic replacement of large carbonate sediments, as indicated by the chert replacement of calcite skeletons, preservation of relict carbonate fabrics and limestone patches or lenses, and the complete gradation of solid chert to siliceous limestone, and in turn, to limestone with nodular chert in the Bois Blanc." Furthermore, Basan and others (1980) used the presence of chert beds and nodule zones within the Bois Blanc and Onondaga Limestone as further evidence of a replacement origin, stating that these units differ from the Huntersville Chert only in the degree of replacement.

Thickness of the Huntersville Chert (Figure Dho-6) varies from less than 100 feet in Elk and Forest counties in northwest Pennsylvania to more than 250 feet in Greene County in southwestern Pennsylvania and Monongalia County in northern West Virginia and in parts of Harrison, Doddridge, and Lewis counties, West Virginia. The chert facies thins southward to less than 100 feet in Mercer County, West Virginia.

Edmunds and Berg (1971, p. 124) described the Oriskany Sandstone as "a light gray, medium- to coarse-grained quartzose sandstone; it is usually cemented by calcite, but some silica cement occurs near the top" .

The Lower Devonian Oriskany Sandstone was deposited between normal wave base and storm wave base (Welsh, 1984) in the gas-productive Somerset County, Pennsylvania, area. The characteristics of the sandstone vary throughout the Appalachian basin, but in the area where the Huntersville and Oriskany are targeted for natural gas, Welsh (1984) identified four coarsening-upward marine shelf bar sequences based on his study of drill cores: interbar shelf (deeper, low energy shelf deposition); bar margin (bioclastic debris winnowed from central bar units by storm currents); central bar (transported and deposited by storm events); and tempestite (nearshore sands and fauna, deposited on the shelf by intense storm activity). Although an unconformity exists on top of the Oriskany Sandstone in many areas of the basin and is present in outcrop, Welsh (1984) did not find evidence of this in the cores he examined in the Somerset County area. This concurs with the findings of Dennison (1961) and Heyman (1977), who proposed continuous deposition through the Lower Devonian.

The Oriskany Sandstone varies from about 17 feet thick in the northern and westernmost reaches of this play to 241 feet thick in the southeastern fields, averaging 68 feet.

Structure

The Huntersville Chert/Oriskany Sandstone gas fields are located along faulted and offset anticlines in the Allegheny Plateau Province. The axes of these regional structural features trend northeast-southwest. The Allegheny Front lies to the southeast (Figure Dho-7). Structural deformation, which influences the gas fields, includes imbricate thrusts branching from a sole thrust, overturned beds, stacked thrust sheets, repeated key beds, high-angle reverse faults, and frequent oversteepening on one flank (Gwinn, 1964; Harper, 1989). A cross section of Mountain Lake Park field (Figure Dho-8a), Garrett County, Maryland, and Preston County, West Virginia, illustrates this type of structural deformation. Lycippus field (Figure Dho-8b), Westmoreland County, Pennsylvania, is an

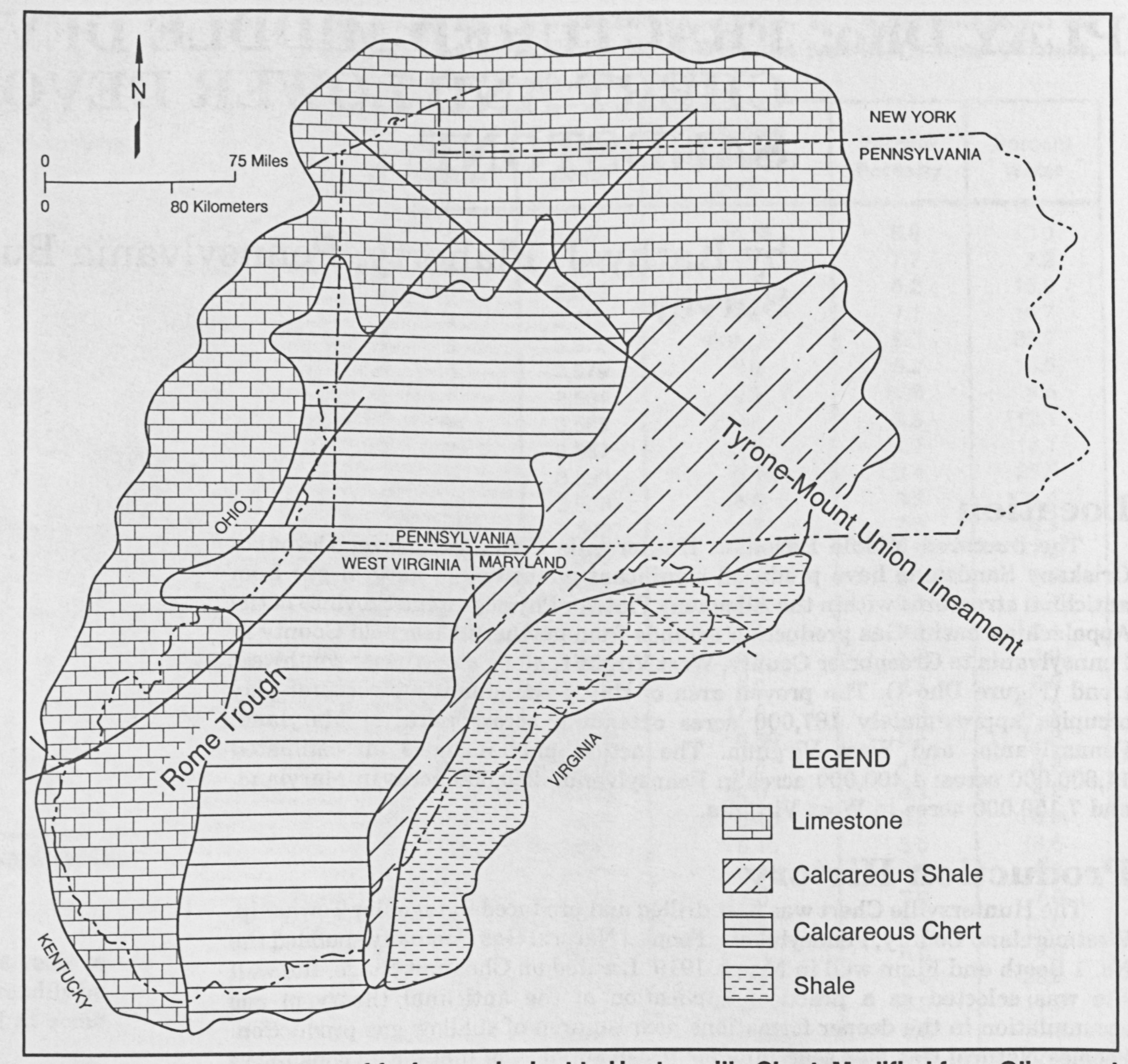

Figure Dho-4. Lateral extent of facies equivalent to Huntersville Chert. Modified from Oliver and others (1971) and Harper (1989).

example of a field characterized by a second type of structural deformation. At the Huntersville Chert/Oriskany Sandstone horizon on the anticline, the axis appears as a relatively down-faulted depression because of overthrusting limbs. The faults bounding the "depressed" zone are reverse faults, throw is greater on the northwest-dipping faults, anticlines are steeper on the southeast limbs, and vertical displacement of the Oriskany is up to 700 feet near the Allegheny Front, decreasing westward (Gwinn, 1964; Harper, 1989).

Further complicating the structure in the region are lineaments or cross-strike structural discontinuities (CSDs) that may correspond to wrench faults in the basement or within detached zones in the Paleozoic cover (Gwinn, 1964; Harper, 1989). The CSDs intersect and offset anticlines, provide fracturing and fluid migration paths, and they significantly affect the distribution and thickness of the Oriskany Sandstone in the northwestern corner of Pennsylvania as well as the Huntersville Chert north of the Tyrone-Mt. Union lineament (Figure Dho-4), where it is replaced by cherty limestone as previously mentioned (Harper, 1989). Some fields are terminated at their juncture with lineaments. Strongstown field in Indiana County, Pennsylvania, and New Alexandria field in Westmoreland County, Pennsylvania, terminate at the Home-Gallitzen and Blairsville-Broadtop lineaments, respectively (Figure Dho-2).

Reservoir

Fields producing from the Huntersville Chert and Oriskany Sandstone in this play are structurally controlled, and occur on isolated fault blocks with gas produced from a network of fractures. Summit field in Fayette County, Pennsylvania, and Terra Alta field in Preston County, West Virginia, are excellent examples. Some fields, however, have additional stratigraphic considerations. Fractured chert overlying porous Oriskany Sandstone, combined with the positive structural relief of an anticline, comprise the most favorable trap for natural gas. The Rockton pool in Punxsutawney-Driftwood field, Clearfield County, Pennsylvania (Figure Dho-2), is an example of a stratigraphic and structural trap.

In an extensive study of five cores from wells in the north-central West Virginia, central Pennsylvania, and western Maryland region, Sherrard and Heald (1984) obtained detailed information on the nature of porosity in the Huntersville Chert. They found that the fractures provide the best effective porosity, and are better developed in brittle pure chert, dying out in the more argillaceous chert. Sherrard and Heald (1984) also observed that spicules, spines, and vugs are more common in the more pure chert. They saw evidence of irregular fragments serving as props holding fractures open, fossils contributing to porosity due to void space resulting from hollow spines and spicules, silica contraction, and incomplete quartz filling. Sherrard and Heald used the presence of golden brown staining in the pores between fibers in the chalcedony to conclude that hydrocarbon had migrated through the chalcedony vugs and openings in fractures.

Sherrard and Heald (1984) noted salt crusts on cores taken through the chert and determined that the presence of the salts may indicate local variations in porosity. They observed solid salt crusts on the argillaceous zones, minor amounts of salt on the impure chert, and no salts present on the tight chert. Sherrard and Heald (1984) theorized that the cores contain connate water, and when the fresh core is left to dry, evaporation and capillary action in the more porous argillaceous and impure zones concentrates the salts on the surface of the core.

Extensive fracture networks allowed hydrocarbons generated in the overlying or adjacent organic-rich shales to migrate. The brittle fractured chert accumulated gas more readily than did the underlying sandstone, although the chert fractures probably functioned as a conduit between the source rocks and Oriskany Sandstone. Diecchio (1985) suggested that the less fractured sandstone was tighter and resisted gas accumulation, resulting in several fields that produce from Huntersville only with no contribution of gas from the Oriskany

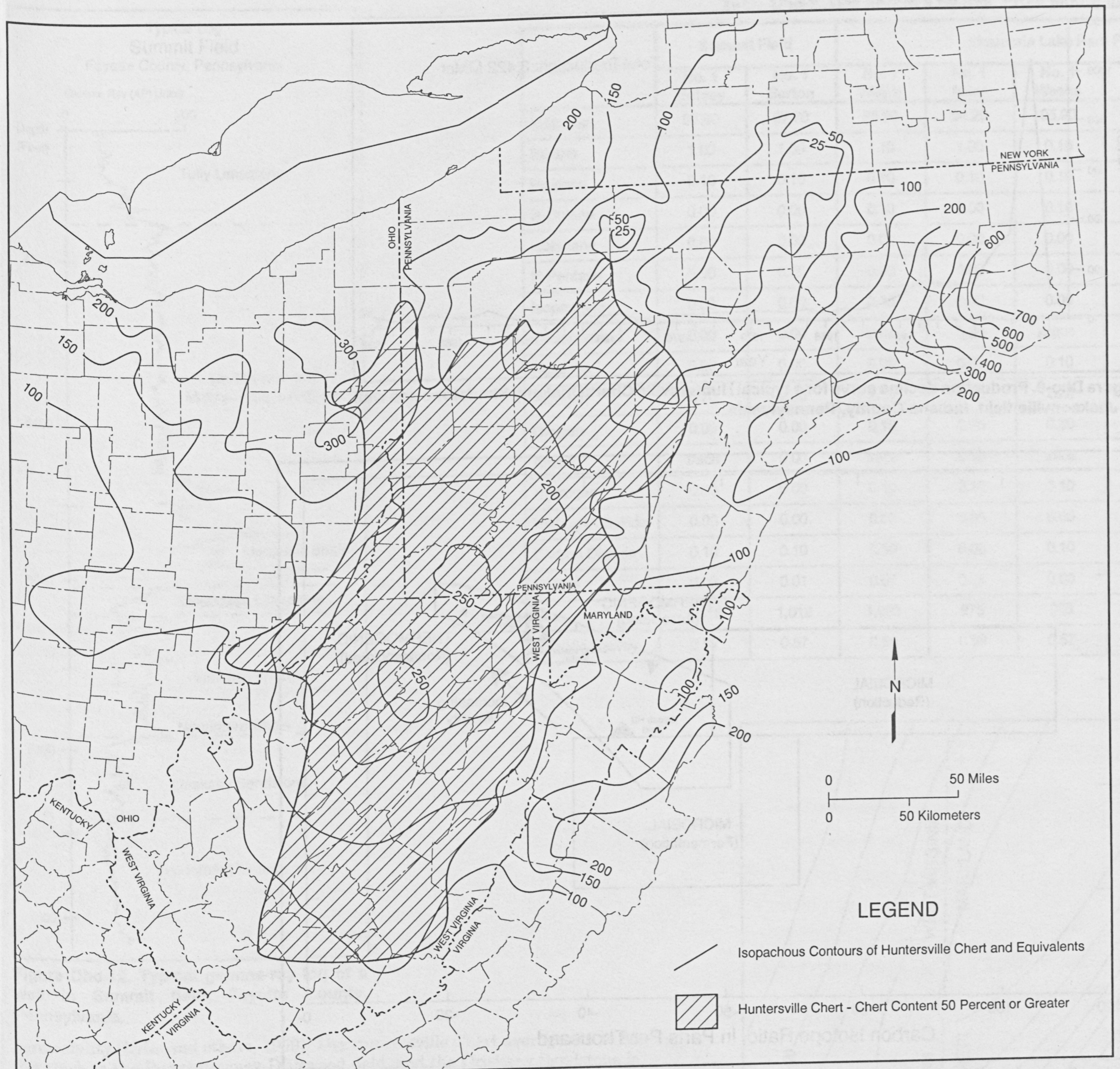

Figure Dho-6. Isopach map of facies equivalent to Huntersville Chert showing areal extent where the chert content is 50 percent or greater. Modified after Oliver and others (1971). Contour interval is variable.

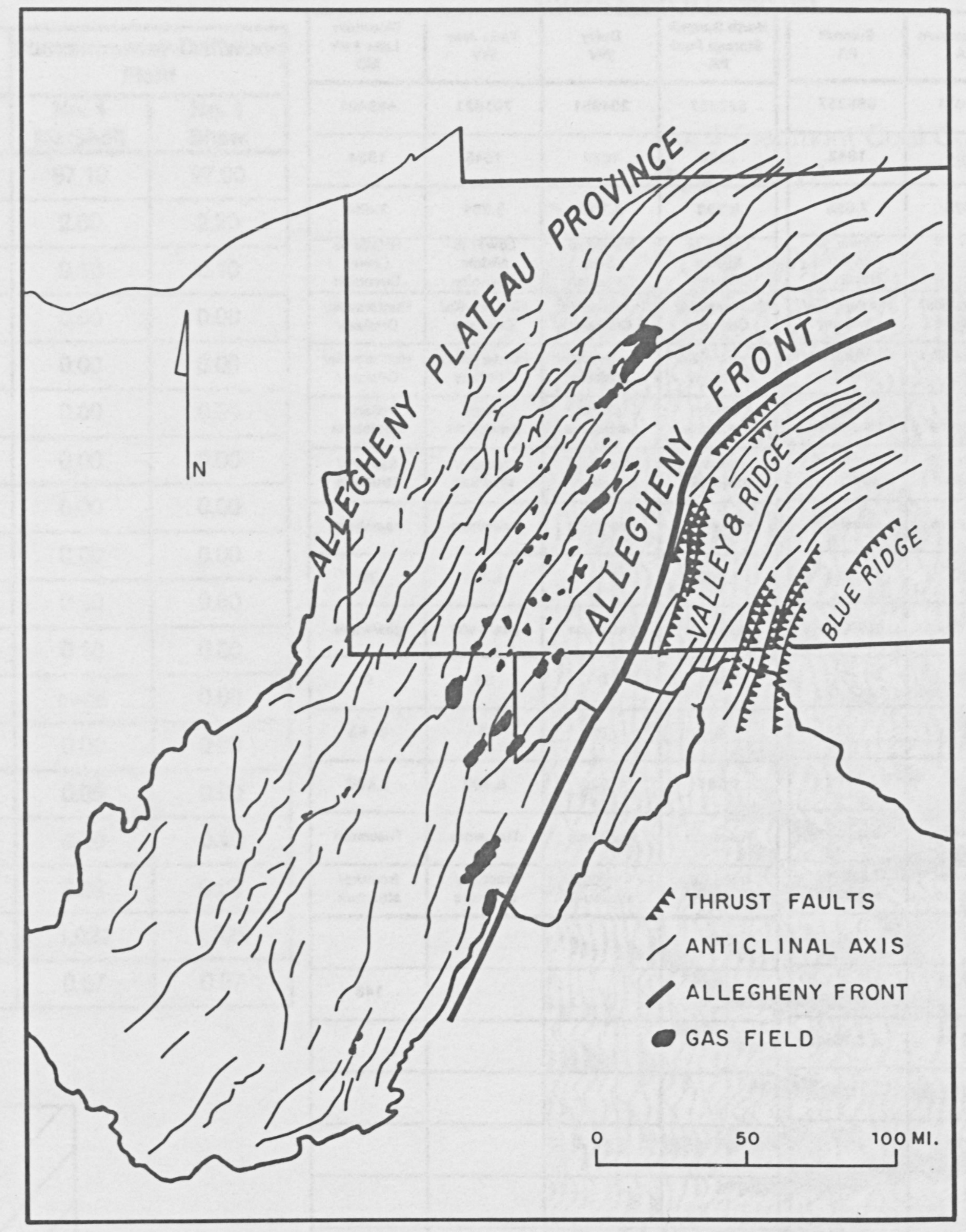

Figure Dho-7. Structural provinces within the Appalachian basin region and location of Huntersville Chert and Oriskany Sandstone gas fields.

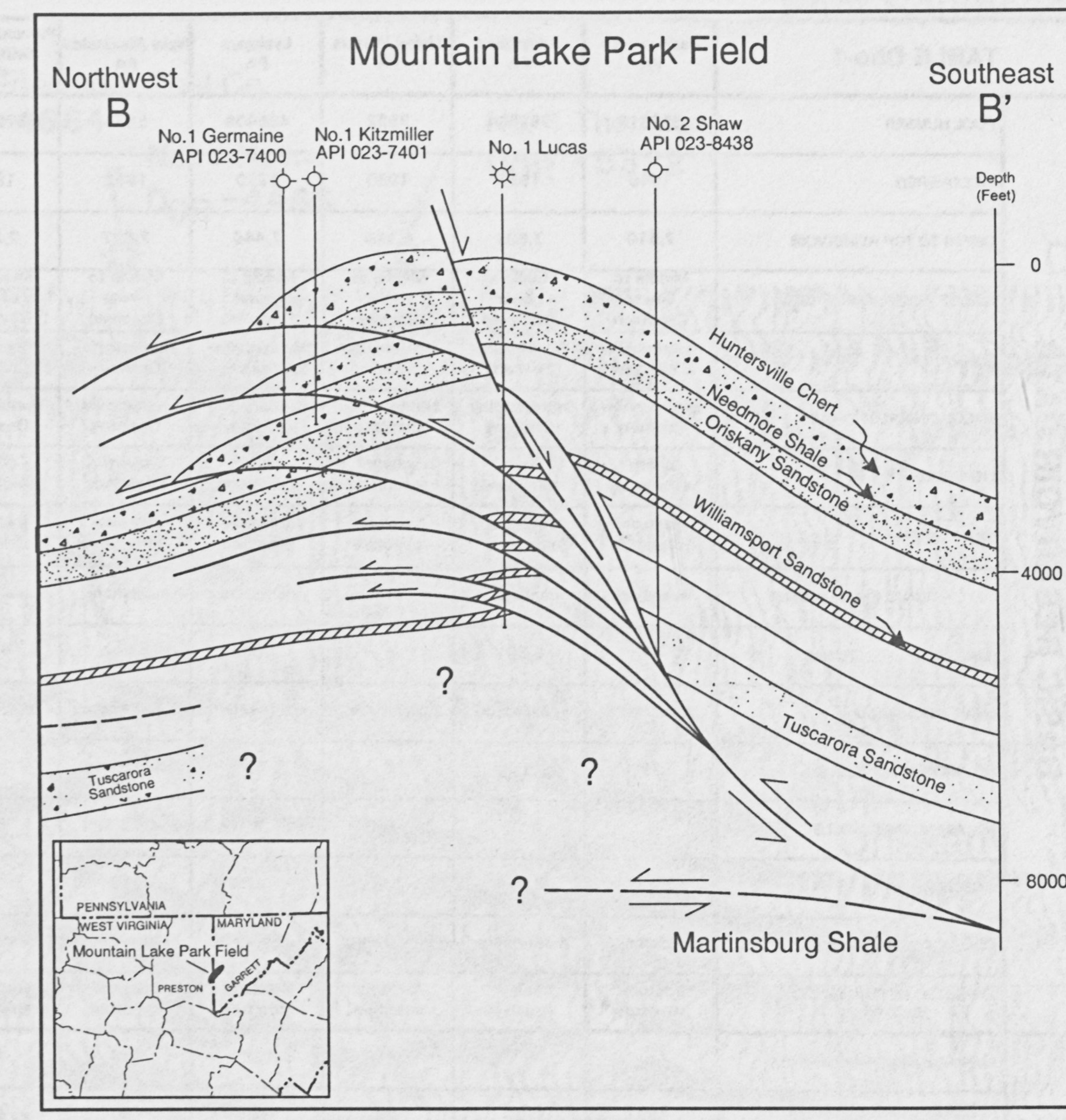

Figure Dho-8a.

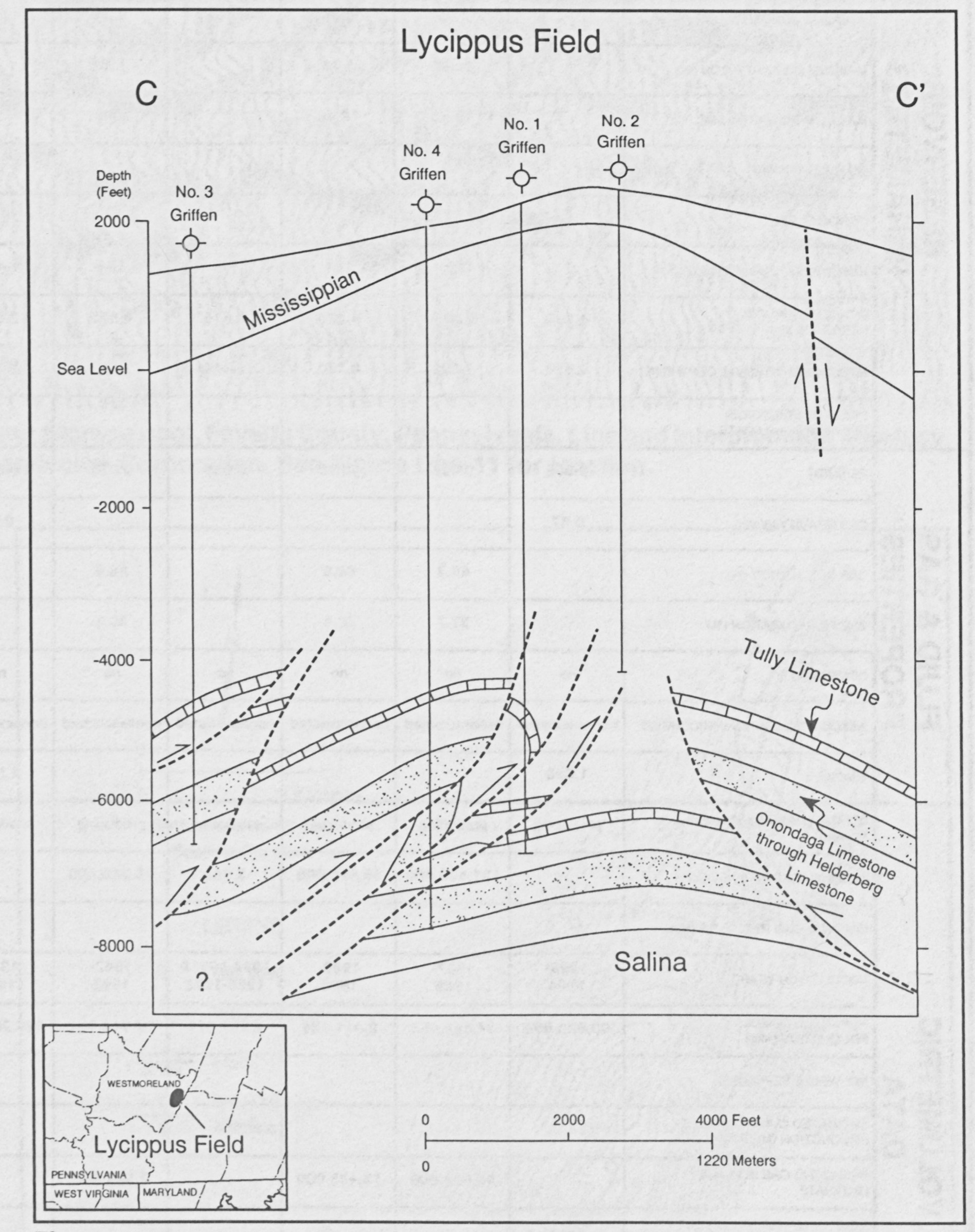

Figure Dho-8b.

Figure Dho-8. Imbricate thrust faulting in Huntersville/Oriskany play. From Gwinn (1964). Dho-8a. Cross section B-B' of Deer Park anticline, Mountain Lake Park field, Garrett County, Maryland. Dho-8b. Cross section C-C' of Chestnut Ridge anticline, Lycippus field, Westmoreland County, Pennsylvania.

(Lycippus field and Quebec Run pool in Sandy Creek field in Pennsylvania; Glenville and Duffy fields in West Virginia) (Figure Dho-2). Volume and pressure changes during the thermal cracking of oil to gas in the reservoir may also have influenced the relative distributions of gas in Huntersville and Oriskany reservoirs (Barker, 1990).

The top of the Huntersville Chert pay zone ranges from about 2,900 feet in Garrett County, Maryland, to 8,688 feet in Somerset County, Pennsylvania. Thickness of the pay zone is more difficult to determine with this play because of the communication within the fracture network characteristic of this reservoir. Well depth is likely to be determined in part by intersection of the well with the extensive fractures, which allow a significantly increased drainage area regardless of the amount of chert that was penetrated by the drill. In some fields, wells were acidized from the top of the chert to the total depth of the well, and in others, specific zones within the chert and Oriskany Sandstone were targeted for hydraulic fracture. Some wells were drilled through the chert; some were drilled through the Oriskany; and others just nicked the top of the chert. The thickness of the pay zone, therefore, varies from just a few feet to the entire thickness of the Huntersville and Oriskany sections, which measure up to 508 feet (probably due to fault-duplicated section) in Summit field, Fayette County, Pennsylvania. Average thickness is 155 feet for productive fields.

Initial rock pressures ranged from 200 to 4,310 psi and averaged 3,300 psi. The fields closer to the Allegheny Front have considerably lower rock pressure (Table Dho-1).

Initial open flows prior to any completion treatment ranged from no show of gas at all to 72,000 Mcf for one well in the Summit field. Three of the wells in the Rockton pool of Punxsutawney-Driftwood field had very high initial open flows of 45,000 Mcf, 60,000 Mcf, and 70,000 Mcf (Lytle and others, 1959). Average initial open flow for Huntersville Chert/Oriskany Sandstone wells was 1,938 Mcf. Many wells with significant natural open flows of gas were not treated, but of those that were, the average after treatment flow was 3,500 Mcf with a range of less than 50 Mcf to more than 41,000 Mcf.

Treatment and completion strategies have changed over time as better techniques evolved. The initial wells in the 1940s and 1950s were shot with nitroglycerine. In the middle 1950s through the 1960s, hydraulic fracturing was found to be much more effective with this reservoir. More recently, treatment with acid, sometimes combined with hydraulic fracturing, has become the most common method of completion.

Natural gas reserves are variable due to the variations in size, shape, orientation, and concentration of fractures of fractured fault block traps. Individual wells for which annual production is available indicate a range of total cumulative production from 234 MMcf to 10 bcf with an average near 400 MMcf over 20 to 35 years with various periods of shut-in. Figure Dho-9 illustrates an actual production decline curve.

A total organic carbon concentration of 0.5 to 1.0 weight percent is considered to have a fair generative potential for source rocks, and total organic carbon concentration exceeding 1.0 is good to very good (Hunt, 1979; Tissot and Welte, 1984). The Marcellus Shale is regarded an important source of hydrocarbons in the Appalachian basin in terms of organic richness, kerogen type, and sediment volume (Basan and others, 1980). The Needmore Shale should also be considered as a key hydrocarbon source. Results of a geochemical evaluation performed on the Amoco No. 1 Svetz well in Somerset County, Pennsylvania (Figure Dho-10), indicate the present average total organic carbon (TOC) for the Marcellus Shale to be 3.5 weight percent and the Needmore Shale is 2 weight percent. The original TOC was probably higher; both the Marcellus and Needmore are thermally overmature, and the hydrocarbon generative potential of these shales is diminished. Evidence of extreme maturity exists in the values for vitrinite reflectance (Ro), thermal alteration index (TAI), bitumen to TOC (Bit/TOC) ratio, and production indices calculated from kerogen pyrolysis data (Table Dho-2).

Prior to reaching overmaturation, the Marcellus and Needmore shales had considerable oil as well as gas potential. The organic matter contained in the shales is both marine and terrestrial; relative amounts of each depends on paleogeography and stratigraphic position. Generally, the organic matter is mixed (Type II), but nearly pure (70 to 80 percent) end members (Type I, Type III) occur in some samples (Basan and others, 1980; C.D. Laughrey, oral commun., 1993). Crossplots (Figure Dho-10) of stable carbon and hydrogen isotope ratios for gas samples from Huntersville Chert/Oriskany Sandstone reservoirs in Strongstown and Living Waters fields in Indiana County and Spook Hill field in Fayette County demonstrate that the gas is thermogenic associated gas (gas generated with the oil in the source rocks and/or gas formed from thermal cracking of oil in the reservoir).

There is a marked variation in the results of the analysis for the three fields. Spook Hill field gas is less thermally mature than gases in the other two fields. It was probably generated from marine organic matter within the oil window; the methane carbon isotope ratio of -46 percent and hydrogen isotope ratio of -241 percent are characteristic of gas cracked from Types I and II kerogens during peak oil generation (Schoell, 1983; Whiticar, 1994). Gases sampled from Living Waters and Strongstown fields are isotopically heavier. Methane carbon isotope ratio and hydrogen isotope ratio average -34.7 and -163.6 percent, respectively. These values are characteristic of gases associated with condensate that were generated from overmature Types I and II kerogens (Schoell, 1983; Whiticar, 1994).

The gases extracted and analyzed from wells in the Strongstown and Living Waters fields are distinctly different from Spook Hill field. Whereas methane is typically lighter (more negative) than ethane and propane from the same source, in the Strongstown field, for example, the methane is heavier. This isotopic reversal indicates that the gas is a mixture of very mature, dry, thermogenic gas and a less mature oil-associated gas. In Strongstown field, the ratio is 20 percent associated gas and 80 percent post-mature dry gas component. Laughrey (oral commun., 1994) proposed that while the associated gas was probably generated locally (Middle Devonian Marcellus and Upper Devonian Geneseo, Renwick, and Middlesex shales), the post-mature component migrated from some distant source. The location of Strongstown field, at the junction of fractures and the Home-Gallitzen lineament (Figure Dho-2) adds lateral and vertical migration pathways. As possible post-mature sources, Laughrey suggests: equivalent Devonian shale source rocks to the east which are more mature; deeper Ordovician source rocks well below the reservoir; a combination of eastern Devonian shales and deeper Ordovician source rocks; and hydrothermal and/or geothermal heavy methanes associated with deep crustal gases.

Description of Key Fields

North Summit storage pool: From the discovery of the Summit field (now called North Summit Storage pool in Summit field; see Figures Dho-2, Dho-11) in Fayette County, Pennsylvania, in 1937 until it was converted to storage in 1991, approximately 22 bcf was produced (Harper, 1987). W.E. Snee and New Penn Development Corporation drilled the discovery well in an attempt to imitate the north-central Pennsylvania Oriskany gas field successes. The No. 1 Leo F. Heyn well was completed on April 23, 1937, with an initial open flow of 1,800 Mcf from 18 feet into the Huntersville Chert at 6,611 feet. Twenty-one wells in the North Summit pool produced gas primarily from 40 to 70 feet into the fractured Huntersville Chert, which averages 6,713 feet deep and 197 feet thick, and the underlying Oriskany Sandstone, averaging 6,910 feet deep and 100 feet thick. A typical gamma-ray log for the wells in the Summit field is shown in Figure Dho-12. Original reservoir pressures in the Summit field were reported to be between 3,025 and 3,050 psi (Hickock and Moyer, 1940). Well records at the Pennsylvania Bureau of Topographic and Geologic Survey office indicate the average natural initial open flow was 2,752 Mcf and ranged from 132 Mcf to 11,700 Mcf. The Btu value of the gas is 1,018 with a specific gravity of 0.567 (Table Dho-3).

The North Summit pool is located on the crest of the Summit dome along the axis of the Chestnut Ridge anticline. A seismic line (Figure Dho-13) shows not only the reverse faults which are so typical of the anticlinal structures and domes of the Appalachian basin, but also the optimal positioning of wells in the North Summit pool with respect to structural features including the faults, isolated fault blocks, and closure between the blocks.

Mountain Lake Park field: The Mountain Lake Park field is located in Garrett County, Maryland, and extends southwestward into West Virginia. (Figures Dho-2, Dho-14) It is situated on the southern end of Deer Park anticline, and occupies approximately 3,400 acres. Gwinn (1964) called this region the Southeastern High Plateau Zone. Structural style in this area differs from that previously described. "The southeastern folds are steep on their northwest limbs like those in the Valley and Ridge...and many appear to lack northwest-flank reverse faults at the Oriskany level....[M]ode and style of subsurface deformation is similar to that along the Structural Front and in the Valley and Ridge province in general to the southeast, inasmuch as it is characterized by concentric folding at the surface and low-angle detachment thrusting at depth" (Gwinn, 1964, p. 824) (Figure Dho-8a). A northwest-southeast trending tear fault near the West Virginia-Maryland state line divides the field; gas wells in West Virginia are on the east flank of Deer Park anticline and are positioned south of the fault. The immediate vicinity surrounding the fault appears as a depression on the Huntersville structure (Figure Dho-14). The Maryland portion of the Mountain Lake Park field is on the east flank and north of the fault (Gwinn, 1964; Patchen, 1968b).

The first well drilled to the chert in Mountain Lake Park field was completed in 1948 by Columbian Carbon Company and tested 750 Mcf natural which blew down to 75 Mcf. The well quickly began to produce water and was plugged and abandoned, never having produced. The first successful well was the No. 1 Beachy, drilled and completed in 1949 by the Cumberland Oil and Gas Company. Initial reports indicated 380 Mcf after acidizing. After a second acid treatment, the well tested 432 Mcf at 1,600 psi. A year later, in 1950, the second successful well was drilled. This well, the Columbian Carbon No. 1 Welch, was completed with an open flow of 8,029 Mcf at a pressure of 1,610 psi after seven hours (Amsden, 1954). Within the next six months, there were 13 producing wells; by the end of 1953, the Mountain Lake Park field had produced 7.3 bcf from 42 wells (Amsden, 1954). Rapid overdevelopment of the field resulted in poor spacing and premature decline and abandonment of some wells. Amsden (1954) was stated that unitized spacing requirements would have yielded significantly improved, efficient, and economical production of the Mountain Lake Park field.

A typical gamma-ray log (Figure Dho-15) shows approximately 80 feet of Huntersville Chert and 80 feet of Oriskany Sandstone.

In 1954, the field was extended southwestward into Preston County, West

TABLE Dho-1		Jacksonville PA	Johnstown PA	Living Waters PA	Lycippus PA	New Alexandria PA	Punxsutawney-Driftwood PA	Spook Hill PA	Strongstown PA	Summit PA	North Summit Storage Pool PA	Duffy WV	Terra Alta WV	Mountain Lake Park MD
BASIC RESERVOIR DATA	POOL NUMBER	353316	362634	8552	435403	5931	575168	13423	685071	688357	688357	204951	701821	489401
	DISCOVERED	1956	1957	1980	1920	1962	1955	1988	1954	1942	1936	1967	1945	1954
	DEPTH TO TOP RESERVOIR	7,510	7,591	8,180	7,446	7,637	7,282	8,196	8,075	7,095	6,593	6,740	5,294	3,634
	AGE OF RESERVOIR	Middle to Lower Devonian	Middle to Lower Devonian	Middle to Lower Devonian	Middle to Lower Devonian	Middle to Lower Devonian	Middle to Lower Devonian	Middle to Lower Devonian	Lower to Middle Devonian	Lower to Middle Devonian	Lower to Middle Devonian	Middle to Lower Devonian	Lower to Middle Devonian	Middle to Lower Devonian
	FORMATION	Huntersville/ Oriskany	Huntersville/ Oriskany	Huntersville/ Oriskany	Huntersville/ Oriskany	Huntersville/ Oriskany	Huntersville/ Oriskany	Huntersville/ Oriskany	Huntersville/ Oriskany	Huntersville/ Oriskany	Huntersville/ Oriskany	Huntersville/ Oriskany	Huntersville/ Oriskany	Huntersville/ Oriskany
	PRODUCING RESERVOIR	Huntersville/ Oriskany	Huntersville/ Oriskany	Huntersville/ Oriskany	Huntersville/ Oriskany	Huntersville/ Oriskany	Huntersville/ Oriskany	Huntersville/ Oriskany	Huntersville/ Oriskany	Huntersville/ Oriskany	Huntersville/ Oriskany	Huntersville/ Oriskany	Huntersville/ Oriskany	Huntersville/ Oriskany
	LITHOLOGY	chert/ sandstone	chert/ sandstone	chert/ sandstone	chert/ sandstone	chert/ sandstone	chert/ sandstone	chert/ sandstone	chert/ sandstone	chert/ sandstone	chert/ sandstone	chert/ sandstone	chert/ sandstone	chert/ sandstone
	TRAP TYPE	fracture/ structure	fracture/ structure	fracture/ structure	fracture/ structure	fracture/ structure	fracture/ structure	fracture/ structure	fracture/ structure	fracture/ structure	fracture/ structure	fracture/ structure	fracture/ structure	fracture/ structure
	DEPOSITIONAL ENVIRONMENT	nearshore	nearshore	nearshore	nearshore	nearshore	nearshore	nearshore	nearshore	nearshore	nearshore	nearshore	nearshore	nearshore
	DISCOVERY WELL IP (Mcf)	179	6,501		400	6,000	515	0	480	1,784	1,900		4,355	70
	DRIVE MECHANISM	gas/water	gas/water	gas/water	gas/water	gas/water	gas/water	gas/water	gas/water	gas/water	gas/water	gas/water	gas/water	gas/water
	NO. PRODUCING WELLS	29	11	5	10	6	133	1	31	17	14	0	53	9
	NO. ABANDONED WELLS	6	5	0	9	3	64	1	1	1	0	3	3	> 53
	AREA (acreage)	2,713	2,218	533	1,292	710	26,691	160	7,307	770	1,081	1,920	6,400	3,400
	OLDEST FORMATION PENETRATED	Helderberg	Helderberg	Helderberg	Salina	Helderberg	Helderberg	Helderberg	Helderberg	Lockport	Tuscarora	McKenzie	Tuscarora	Tuscarora
	EXPECTED HETEROGENEITY DUE TO:	fracture/ structure	fracture/ structure	fracture/ structure	fracture/ structure	fracture/ structure	fracture/ structure	fracture/ structure	fracture/ structure	fracture/ structure	fracture/ structure	fracture/ structure	fracture/ structure	fracture/ structure
RESERVOIR PARAMETERS	AVERAGE PAY THICKNESS (ft.)			110	129	180	82	131	167	301	297		54	
	AVERAGE COMPLETION THICKNESS (ft.)	164	129	40		180	82							148
	AVERAGE POROSITY–LOG (%)		7.29	8.88		8.21		5.45	6.97	2.79				
	MINIMUM POROSITY–LOG (%)		1.24	3.73		1.80		2.24	4.10	1.76				
	MAXIMUM POROSITY–LOG (%)		15.53	12.40		20.50		9.27	11.15	3.51				
	NO. DATA POINTS								2					
	POROSITY FEET													
	RESERVOIR TEMPERATURE (°F)		130	164	171	164		138	160	152				136
	INITIAL RESERVOIR PRESSURE (psi)	4,230	2,810	4,225	3,875	3,875	2,985	3,165	3,250	3,280	4,478	2,250	2,365	1,875
	PRODUCING INTERVAL DEPTHS (ft.)	7,510	7,591	8,180	7,446	7,637	7,276	8,196	8,076	7,095	6,713	6,740	5,294	3,634
	PRESENT RESERVOIR PRESSURE (psi) / DATE													
FLUID & GAS PROPERTIES	Rw (Ωm)	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035		0.035	0.035
	GAS GRAVITY (g/cc)	0.57					0.57				0.566			0.576
	GAS SATURATION (%)		66.3	69.5		69.5		48	58.32	54.2				
	WATER SATURATION (%)		33.7	30.5		30.5		52	41.68	45.8				
	COMMINGLED	no	no	no	no	no	no	no	no	no	no		no	no
	ASSOCIATED OR NONASSOCIATED	nonassociated	nonassociated	nonassociated	nonassociated	nonassociated	nonassociated	nonassociated	nonassociated	nonassociated	nonassociated		nonassociated	nonassociated
	Btu/scf	1,026					1,023				1,018			1,003
VOLUMETRIC DATA	STATUS (producing, abandoned, storage)	producing	producing	producing	producing	producing	producing	producing	producing	producing	storage	abandoned	storage	producing
	ORIGINAL GAS IN PLACE (Mcf)		101,420,000	15,846,000	3,880	15,288,000		1,804,000	57,128,000	35,900,000	22,800,000			
	ORIGINAL GAS RESERVES (Mcf)												59,100,000	
	PRODUCTION YEARS	1956-1994	1957-1989	1980-1993	1924-1931& 1956-1992	1962-1992	1955-1992	1988-1992	1954-1992	1942-1992	1936-1986	1967-1973	1945-1959	1954-1992
	REPORTED CUMULATIVE PRODUCTION (Mcf)	30,923,555	34,868,452	2,411,196	6,167,077	12,744,721	133,204,405	84,000	28,455,613	23,079,925	21,975,214		47,010,000	17,726,869
	NO. WELLS REPORTED													
	ESTIMATED CUMULATIVE PRODUCTION (Mcf)											1,000,000		
	REMAINING GAS IN PLACE (Mcf)/DATE		66,552,000	13,435,000		2,543,000		1,720,000	28,673,000	13,309,000		1,000,000		
	REMAINING GAS RESERVES (Mcf)/DATE												12,090,000	
	RECOVERY FACTOR (%)		34	15		83		5	50	63				
	INITIAL OPEN FLOW (Mcf/d)	380	3,359		1,759	353	2,975	0	2,272	1,217	2,752		4,009	524
	FINAL OPEN FLOW (Mcf/d)	2,142	4,712	1,046	4,465	3,881	5,121	3,100	3,114	9,800		9,550	1,707	1,782

Virginia, whereupon a total of five wells were drilled: two dry holes and three gas wells (Cardwell, 1982b). Initial open flows before treatment in Mountain Lake Park field ranged from no gas to 5,700 Mcf. After treatment, most commonly acidizing, open flows ranged from no gas and salt water to more than 12,000 Mcf. Although total production from the Maryland portion of the Mountain Lake Park field through 1992 was reportedly 15.8 bcf (K. Schwarz, Maryland Geological Survey, oral commun., 1993), many operators believe 20 bcf may be closer to actual production. An average Btu of 995 and gas gravity of 0.57 were measured (Table Dho-3). The seven wells remaining in production in the field are those highest on structure and in closest proximity to the tear fault near the southwestern end of the field.

Wells in West Virginia produced approximately 2 bcf through 1973 with an average Btu value of 1,015 and average gas gravity of 0.561 (Table Dho-3).

Terra Alta field: Snee and Eberly Drilling Company's No. 2 Sisler well, drilled in 1945, discovered Terra Alta field in Preston County, West Virginia (Figure Dho-2). Natural open flow from the Huntersville and Oriskany totaled 57 Mcf at 2,340 psi. After acidizing, the initial potential increased to 100 Mcf. The area had been tested in 1925 by Hope Natural Gas Company's No. 1 Gordon well, which, although targeting the Oriskany Sandstone, was abandoned before reaching the Oriskany. In 1944, the William E. Snee Company's No. 1 Sisler reached the Helderberg limestone with a show of 24 Mcf from the combined Huntersville Chert and Oriskany Sandstone. This well also was abandoned. Completion of the No. 3 Sisler well in 1946 by William E. Snee Company resulted in a natural open flow of 4.3 MMcf from the Huntersville Chert. According to Haught and McCord (1960), 40 of the 60 wells drilled in the field were productive, averaging 1.6 MMcf per well and ranging up to an initial production of 17 MMcf. Initial reservoir pressure was 2,365 psi, and the total depth of wells reached 5,100 to 6,250 feet. Cumulative production from Terra Alta was 47 bcf before conversion to storage in 1960.

Terra Alta field is located on the crest of the Briery Mountain anticline in Preston County, West Virginia. Although it is only about 8 miles west of Mountain Lake Park field, structurally Terra Alta more closely resembles Summit field, which is 25 miles north. The crest of the anticline is depressed and bound by reverse faults resulting in parallel isolated fault blocks with structural closure (Figure Dho-16).

The Huntersville chert as described from well cuttings in Terra Alta field is

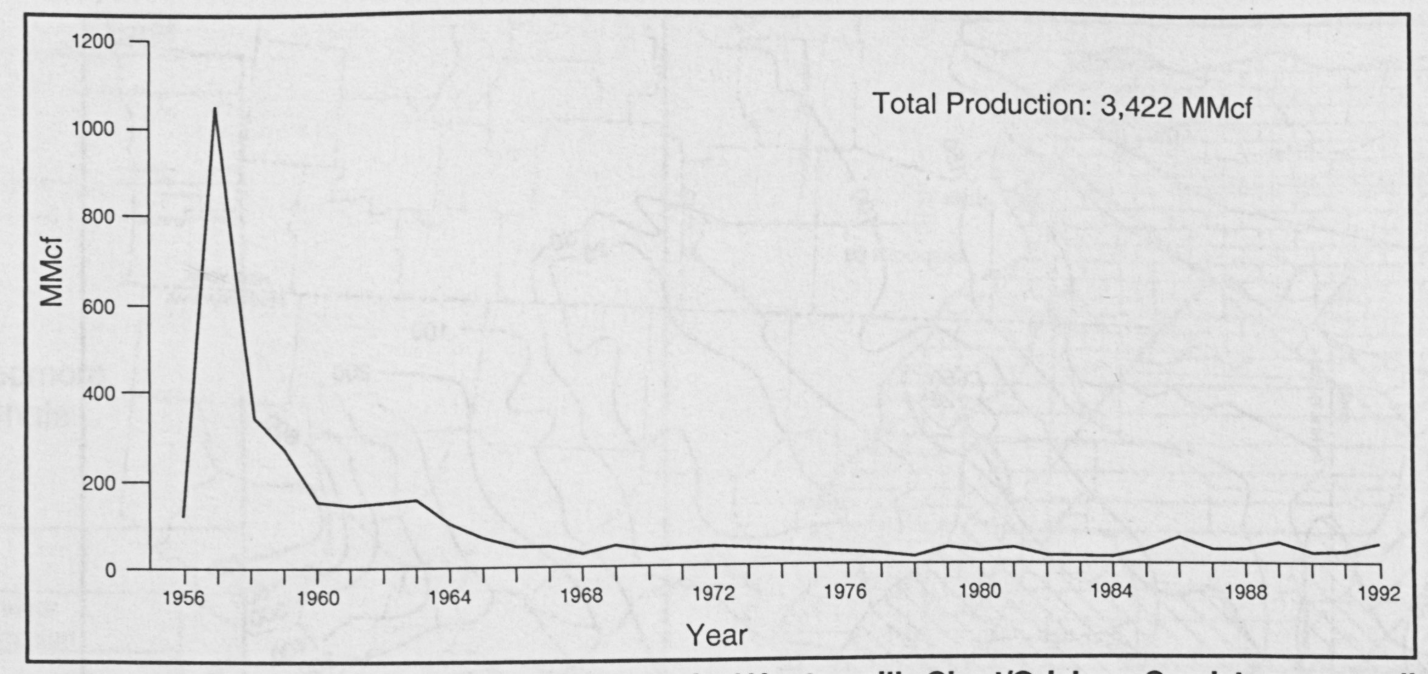

Figure Dho-9. Production decline curve for a typical Huntersville Chert/Oriskany Sandstone gas well in Jacksonville field, Indiana County, Pennsylvania.

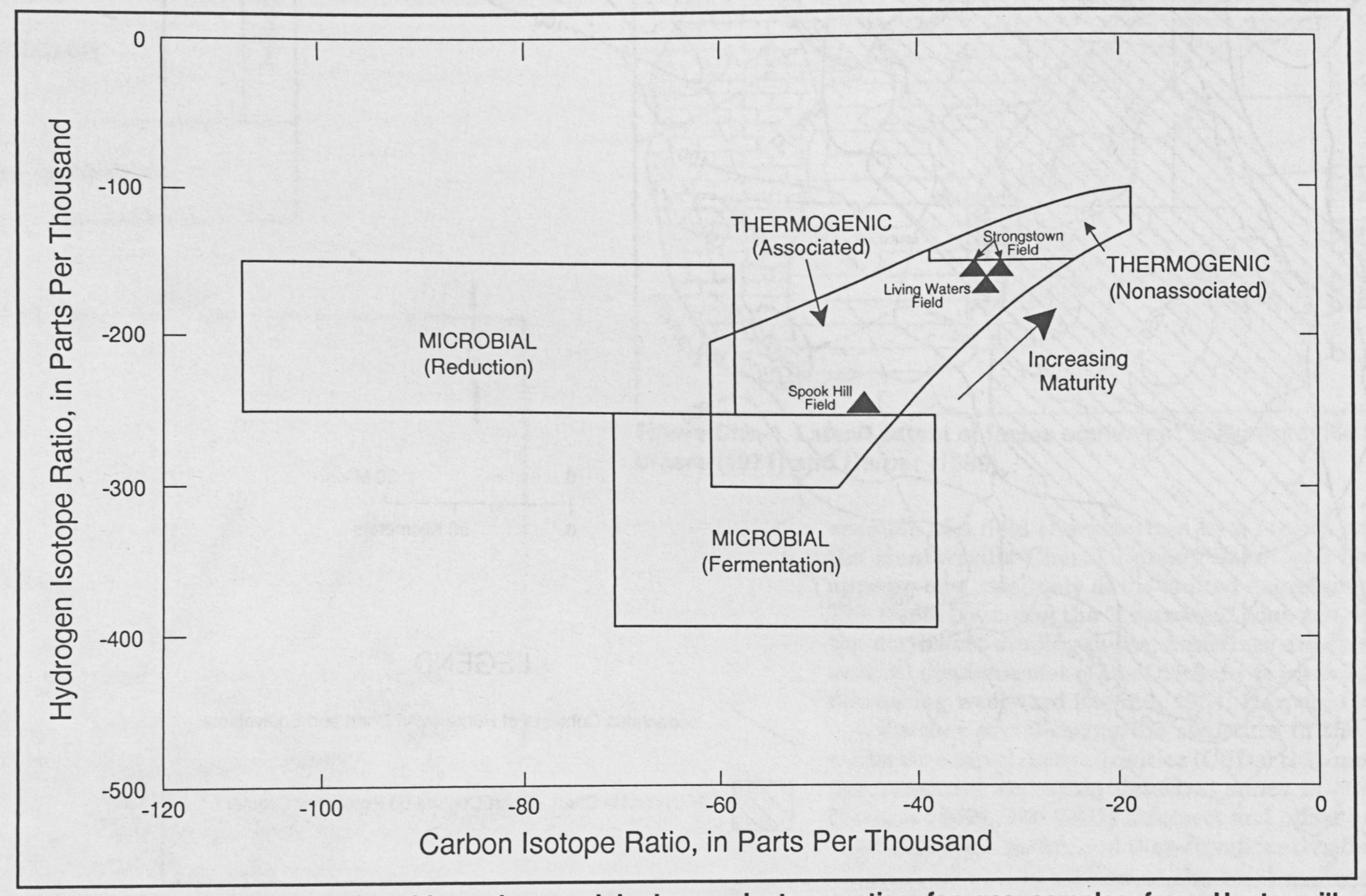

Figure Dho-10. Crossplot of stable carbon and hydrogen isotope ratios for gas samples from Huntersville Chert/Oriskany Sandstone reservoirs in Spook Hill field, Somerset County, Pennsylvania, and Living Waters and Strongstown fields, Indiana County, Pennsylvania. From Laughrey and Baldassare (1992).

Table Dho-2. Rock evaluation pyrolysis including information for the Marcellus Shale of the No. 1 Svetz well in Somerset County, Pennsylvania. After Peters and Moldowan (1993).

Maturation Level	PI	C	Ro%	TAI	Bit/TOC
Beginning Oil Window	0.1	435-445	0.6	1.5-2.6	0.05-0.1
Peak Oil Window	0.25	445-450	0.9	2.9-3	0.15-0.25
End Oil Window	0.4	470	1.4	> 3.2	< 0.1
Marcellus Shale No. 1 Svetz	0.63-0.69	332-339**	3.28	4.2	0.026

** The temperature measurement is invalid because the hydrocarbons from kerogen pyrolysis yields were too low. Thus the maximum generated hydrocarbons were at this low temperature and therefore invalid for these testing purposes.

a brownish-gray to milky, translucent to nearly transparent, slightly calcareous chert containing sponge spicules, and occasional inclusions of highly silicified, phosphatic, glauconitic, silty, sandy or shaley chert. It ranges from 120 to 140 feet thick. The underlying Oriskany sandstone, which varies from 100 to 250 feet thick, is a fine- to coarse-grained, well-sorted, light to medium brownish-gray, highly calcareous, quartzitic, fossiliferous sandstone, containing thin, silty to sandy limestone interbeds. Figure Dho-17 is a typical gamma-ray log of a well in the Terra Alta field.

Punxsutawney-Driftwood and Big Run fields: The portions of the Punxsutawney-Driftwood field and Big Run field that produce gas from both the Huntersville Chert and Oriskany Sandstone occupy 26,691 acres in Clearfield County, Pennsylvania (Figure Dho-2). Punxsutawney-Driftwood and Big Run fields combine elements of stratigraphic and structural trapping mechanisms. Edmunds and Berg (1971) observed that the boundaries of these fields coincide with deep, high-angle reverse faults on the northwest flank of the Chestnut Ridge anticline, separating the fields into pools (Figure Dho-18). Vertical displacement on either side of these faults is approximately 200 feet (Roberts, 1960). Gas accumulation is affected by deep fractures as well as reservoir porosity and

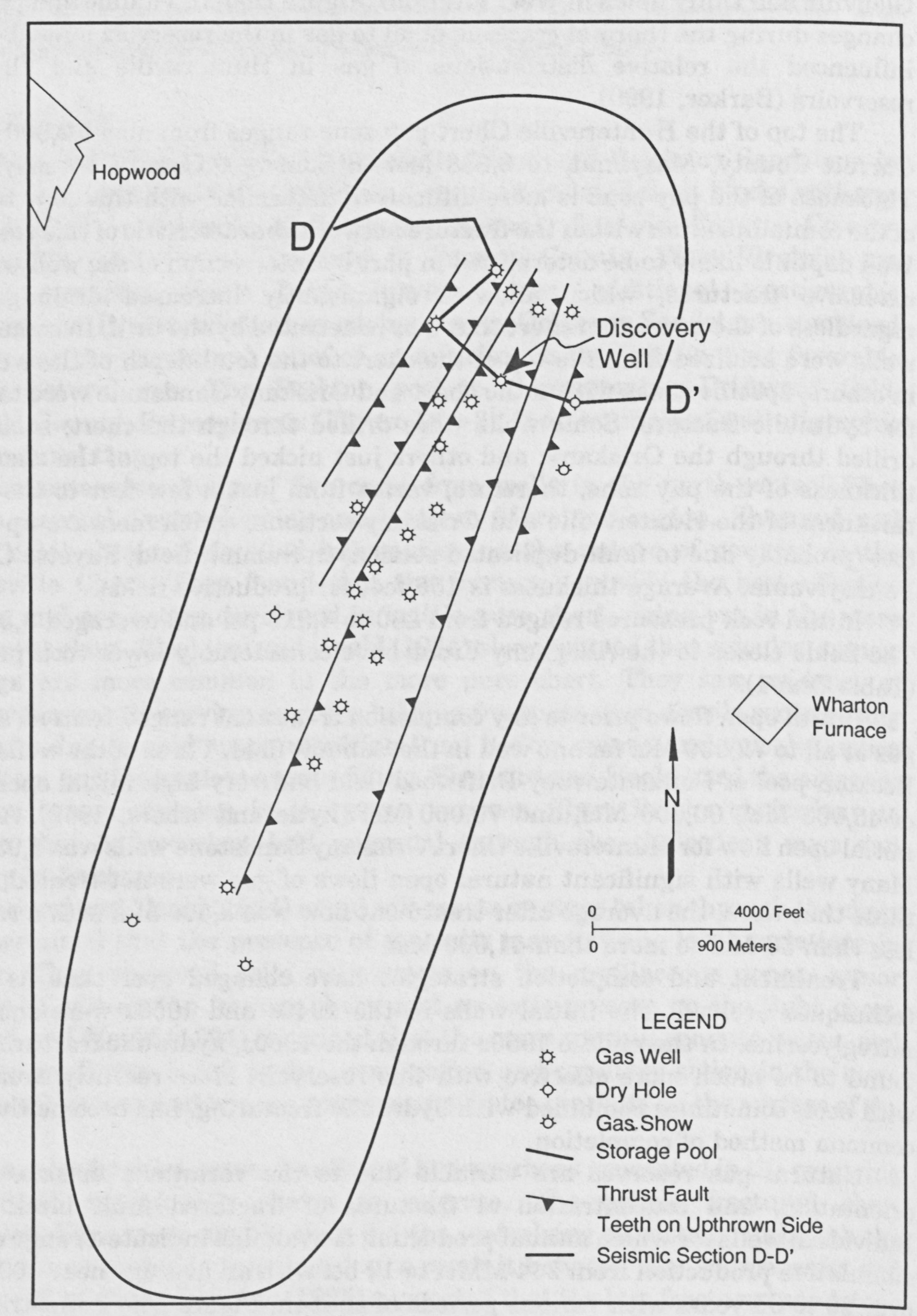

Figure Dho-11. Summit field, North Summit Storage pool. Location of seismic section D-D' (Figure Dho-13) is also shown.

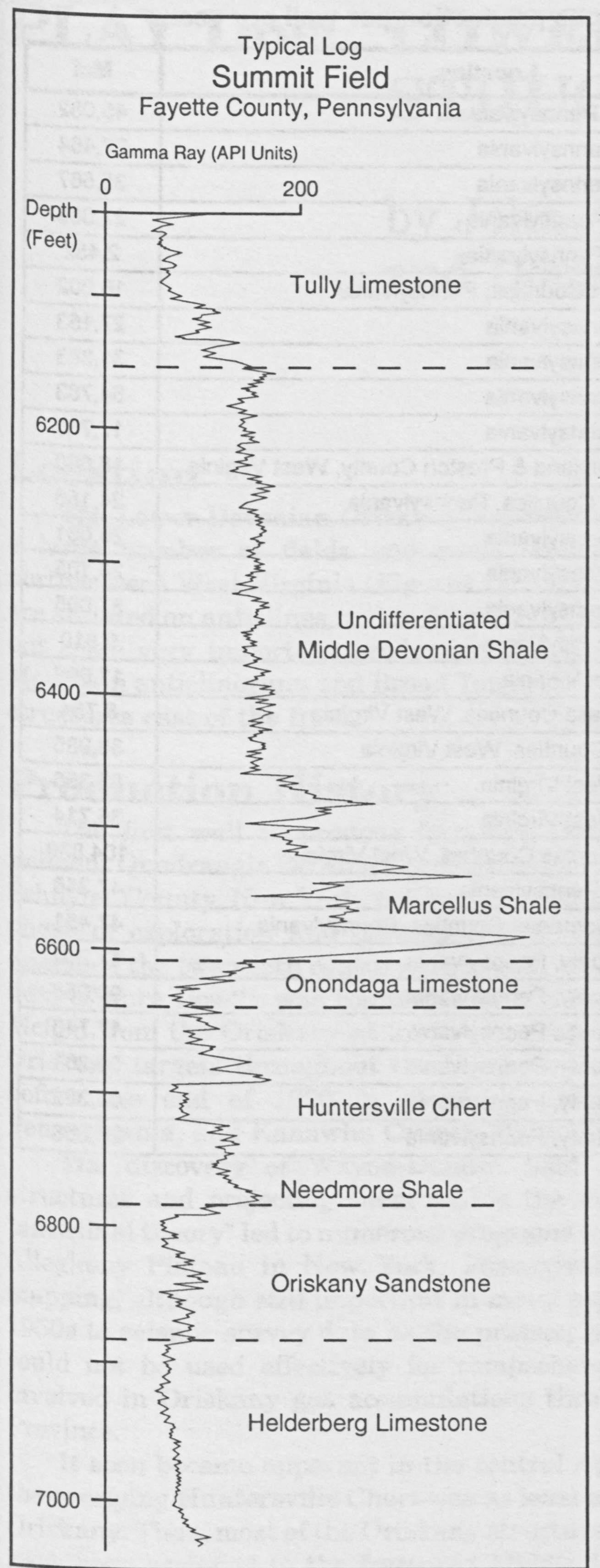

Figure Dho-12. Typical gamma-ray log of a well in Summit field, Fayette County, Pennsylvania.

Table Dho-3. Gas analysis figures. From Moore and Sigler (1987a).

Component	Summit Field		Mountain Lake Park Field					Punxsutawney-Driftwood Field	
	No. 1 Eutsey	No. 1 Barton	No. 1 Welch	No. 1 Miler	No. 1 Weeks	No. 2 Riley	No. 1 Burger	No. 1 Marshall	No. 1 Shaw
Methane	97.60	97.70	95.90	94.20	95.90	96.20	98.20	97.10	97.00
Ethane	1.50	1.50	1.10	1.00	0.10	1.00	1.00	2.00	2.20
Propane	0.10	0.10	0.10	0.10	0.10	0.00	0.10	0.10	0.10
N-Butane	0.00	0.00	0.10	0.00	0.10	0.00	0.00	0.00	0.00
Isobutane	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N-Pentane	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Isopentane	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00
Cyclopentane	0.00	0.00	trace	0.00	trace	0.00	0.00	0.00	0.00
Hexanes	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
Nitrogen	0.70	0.60	2.10	4.30	2.20	2.60	0.50	0.50	0.60
Oxygen	0.00	0.00	0.10	0.20	0.20	0.10	0.00	0.10	0.00
Argon	trace	0.00	trace	0.10	trace	0.00	0.00	trace	0.00
Hydrogen	0.00	0.00	0.10	0.10	0.10	trace	trace	0.00	0.00
Hydrogen Sulfide	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Carbon Dioxide	0.10	0.10	0.30	0.00	0.10	trace	0.00	0.20	0.10
Helium	0.02	0.01	0.07	0.08	0.08	0.08	0.10	0.02	0.02
Btu	1,018	1,019	1,003	975	985	992	1,015	1,022	1,025
Specific Gravity	0.57	0.57	0.58	0.58	0.57	0.57	0.56	0.57	0.57

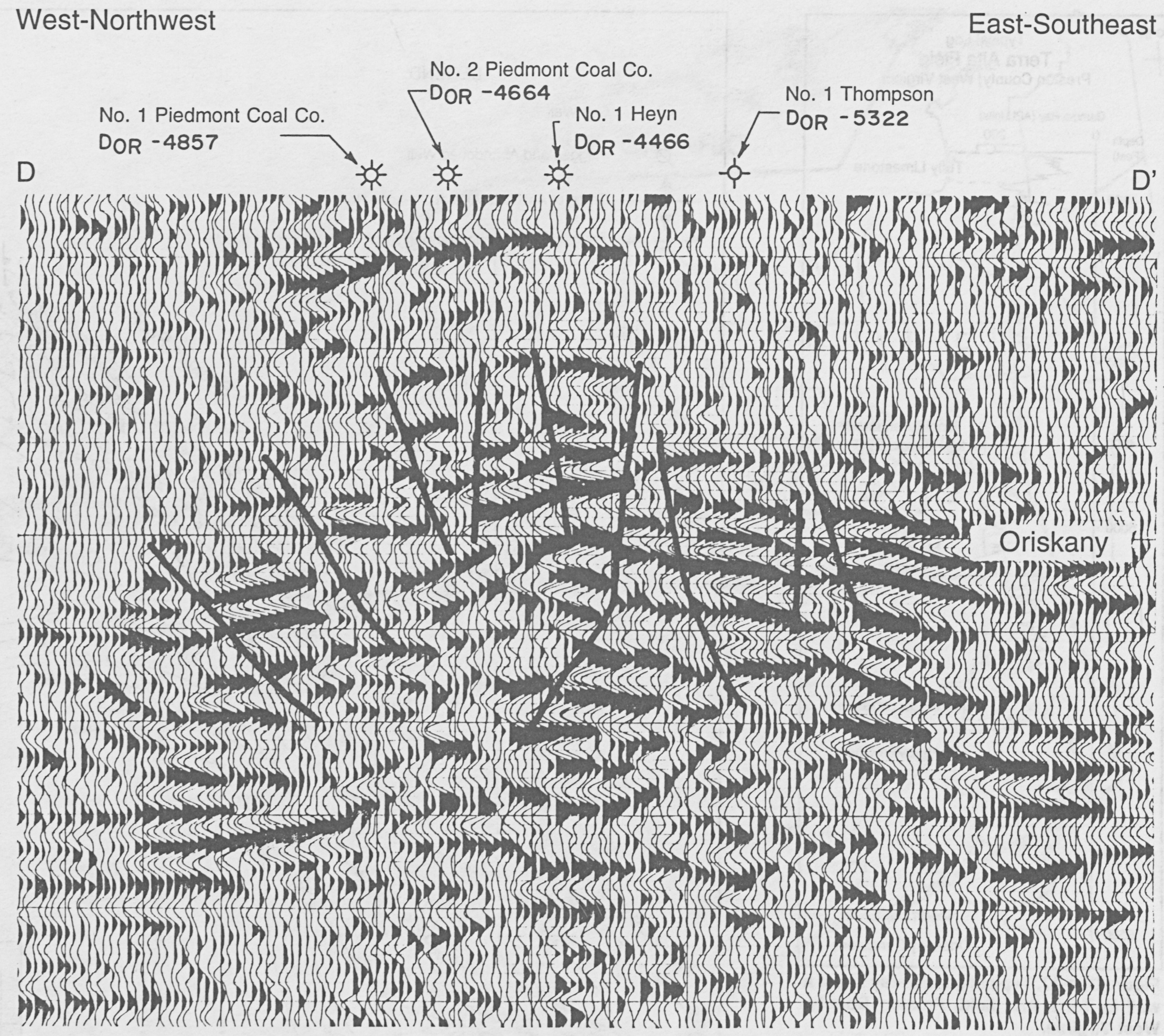

Figure Dho-13. Seismic line D-D' across the North Summit Storage pool, Fayette County, Pennsylvania. Line and interpretation courtesy of R. Beardsley and R. Campbell, Columbia Gas Transmission Corporation. See Figure Dho-11 for location.

permeability (Lytle and others, 1959). The Huntersville Chert averages 40 to 80 feet thick in the Punxsutawney-Driftwood field, and the Oriskany Sandstone is 10 to 20 feet in thickness (Berg and Glover, 1976), as shown on the gamma-ray log typical of wells in the area (Figure Dho-19).

The chert observed in this field is described as "brownish gray, slightly silty, usually non-calcareous, bedded chert with some dark siliceous shales in the lower part" (Edmunds and Berg, 1971, p. 124). The Oriskany is a "light gray, medium- to coarse-grained quartzose sandstone... cemented by calcite but some silica cement occurs near the top. Sufficient pore space has been retained to make the sandstone body an easily exploitable reservoir" (Edmunds and Berg, 1971, p. 124). Lytle and others (1959) observed that gas is not encountered until the Oriskany is penetrated, and the chert does not yield gas until both units have been stimulated.

F.C. Deemer was disappointed with the results of the No. 10 Irwin well he drilled in Bell Township, Clearfield County, Pennsylvania, while he was exploring for what would later be developed as Reed-Deemer pool in Big Run field. "[T]here was just a trace of the Oriskany Sand, and where the sand should have been was just limestone and shell life" (F.C. Deemer, written commun. to the Pennsylvania Bureau of Topographic and Geologic Survey, 1950). The well reached the Lower Devonian strata in November 1946. From that time until January 1949, the well was subjected to episodes of drilling deeper, shutting down, reaming, and was finally plugged back and shot twice with nitroglycerine to capitalize on the 13 gas shows they experienced while drilling through the lower portion of the Hamilton shales and Huntersville Chert. Unable to coax gas from the well, Deemer abandoned it but remained convinced that commercial quantities of gas existed in the area. He built a second location and spudded a new well 5,400 feet northwest of the No. 10, on the northwest flank of the Chestnut Ridge anticline. This well, the No. 13 Irwin, was completed in December 1953 and was the discovery well for the Deemer pool (now the Reed-Deemer pool in Big Run field). Seventy-two feet of Huntersville Chert and 6 feet of Oriskany Sandstone were penetrated. Only the top 2 feet of the Oriskany were fine- to medium-grained quartzose sandstone. The remaining 4 feet consisted of a fine- to coarse-grained, light gray to gray clastic limestone, sandy, containing occasional rounded and polished quartz grains and brachiopod shells. There was no show of gas during drilling, but after shooting, the well tested at 700 Mcf (Fettke, 1954) and experienced almost no decline in production for the first year the well was on line (Fettke and Lytle, 1956). Original reservoir pressure was 3,900 psi (Fettke and Lytle, 1956). The pool currently produces from 15 wells with nine holes abandoned. Average initial pressure was 3,182 psi and average initial open flow was 1,312 Mcf. Average depth to the top of the productive Huntersville-Oriskany interval is 7,452 feet. The Btu value of the gas is 1,023 with a specific gravity of 0.570 (Table Dho-3).

Guidance offered by unsuccessful tests on the eastern flank of the Chestnut Ridge anticline and the success of Deemer's No. 13 Irwin on the northwestern flank led to further drilling activity in the area. About 8 miles northeast of the Reed-Deemer pool, Rockton Drilling Company discovered the Rockton pool of the Punxsutawney-Driftwood field with the successful completion of the No. 1 Eva Moore well. The No. 1 Moore had an initial open flow of 515 Mcf after hydraulic

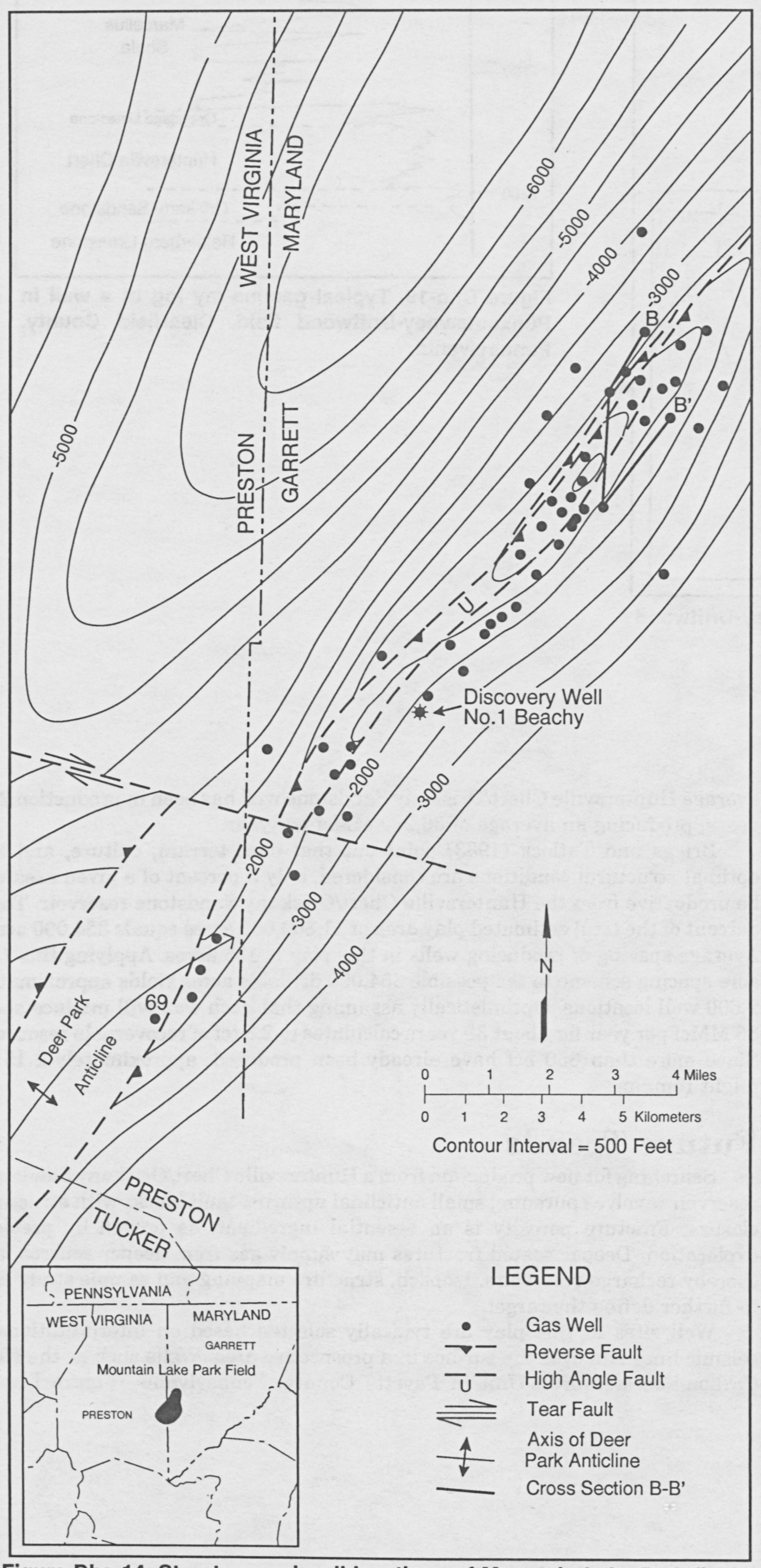

Figure Dho-14. Structure and well locations of Mountain Lake Park field, Garrett County, Maryland, and Preston County, West Virginia. From Gwinn (1964).

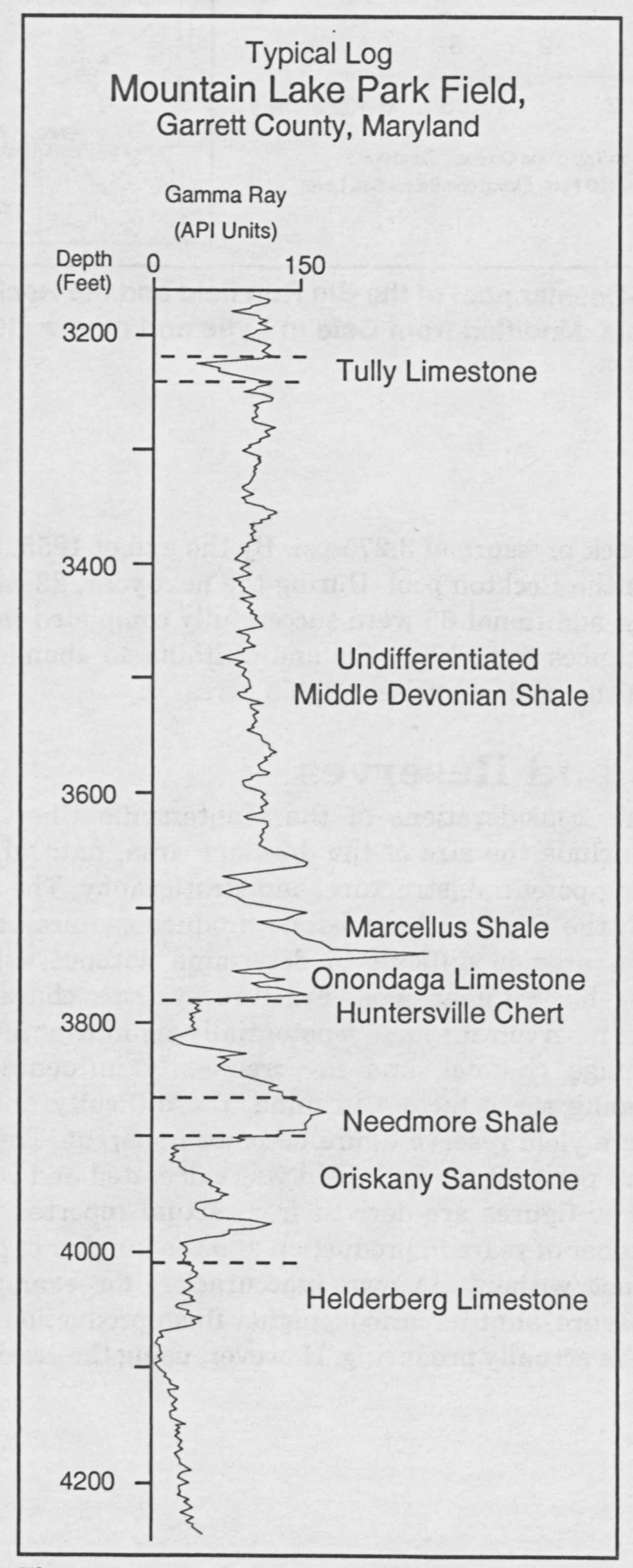

Figure Dho-15. Typical gamma-ray log of a well in Mountain Lake Park field, Garrett County, Maryland, and Preston County, West Virginia.

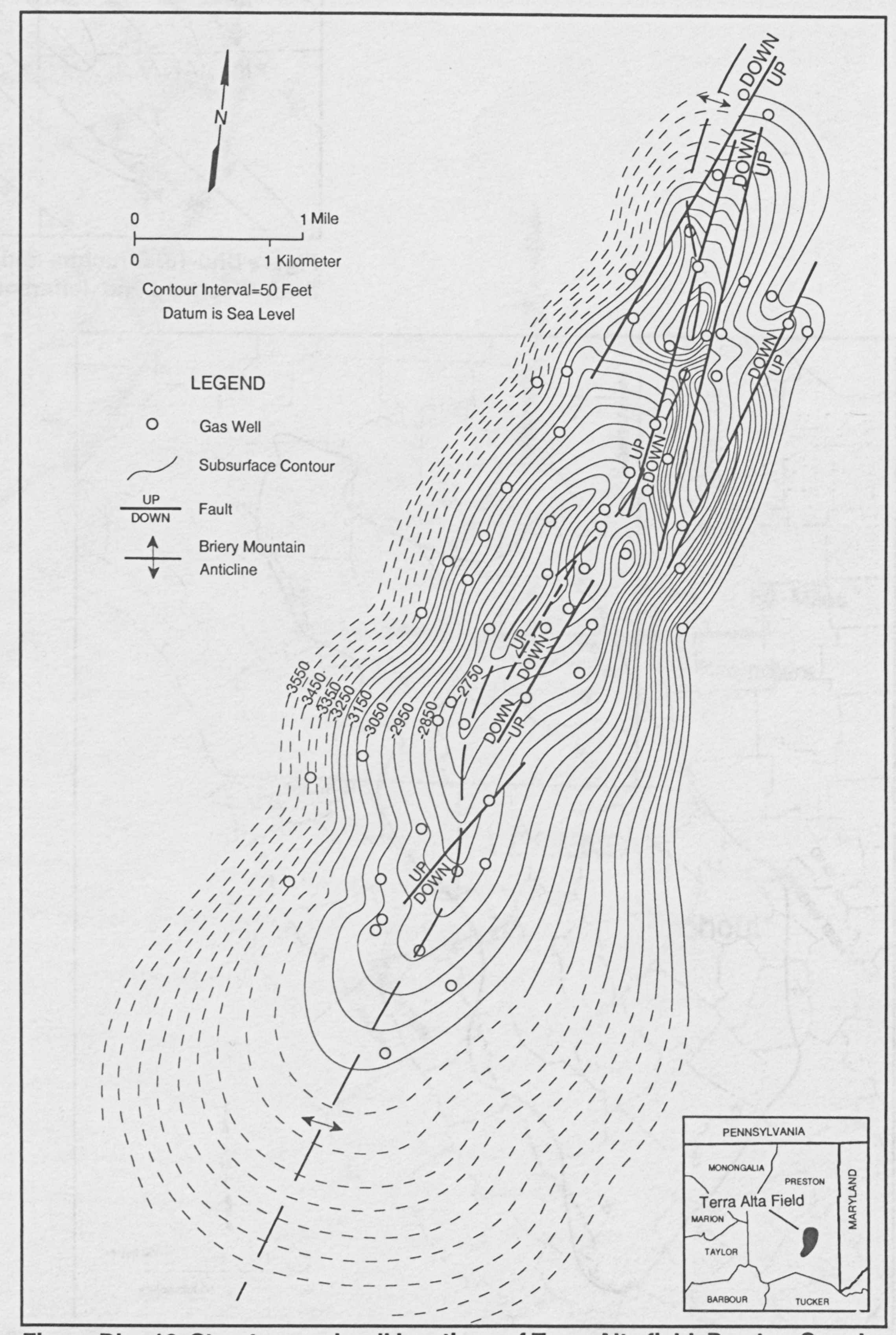

Figure Dho-16. Structure and well locations of Terra Alta field, Preston County, West Virginia. From Cardea (1959).

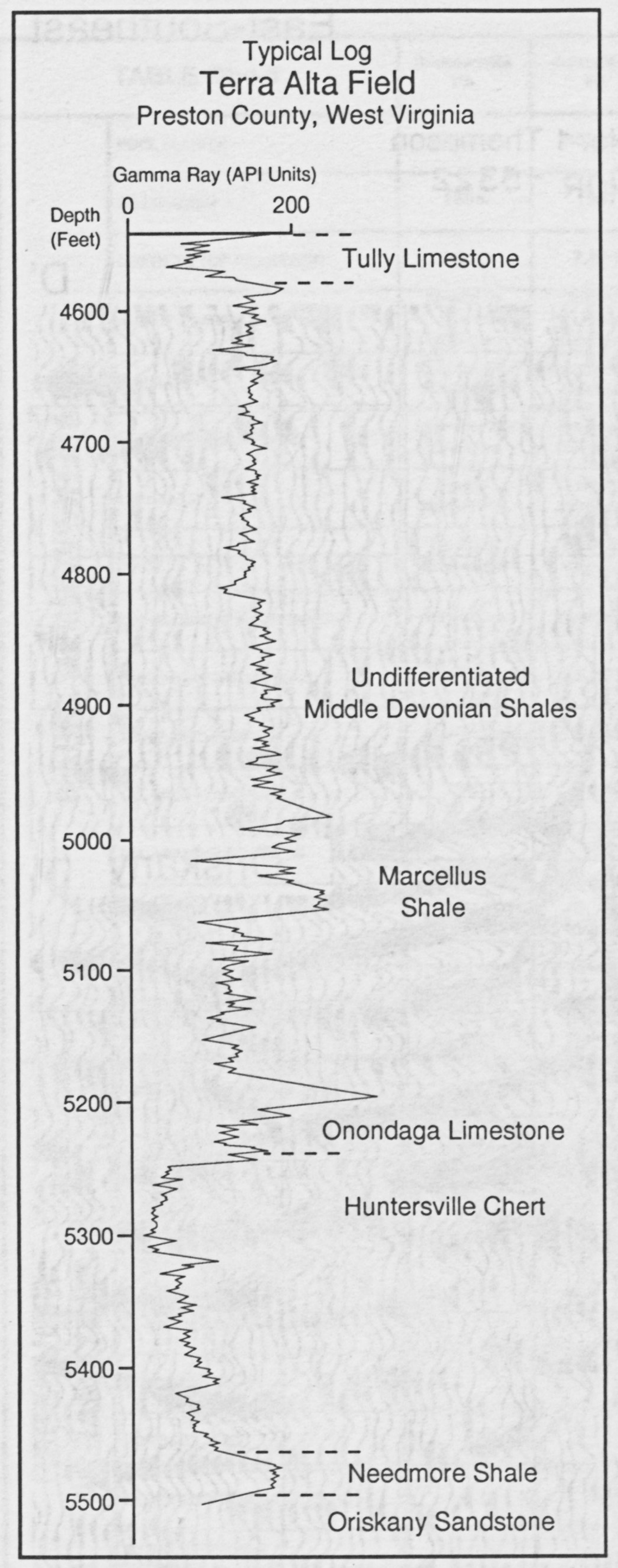

Figure Dho-17. Typical gamma-ray log of a well in Terra Alta field, Preston County, West Virginia.

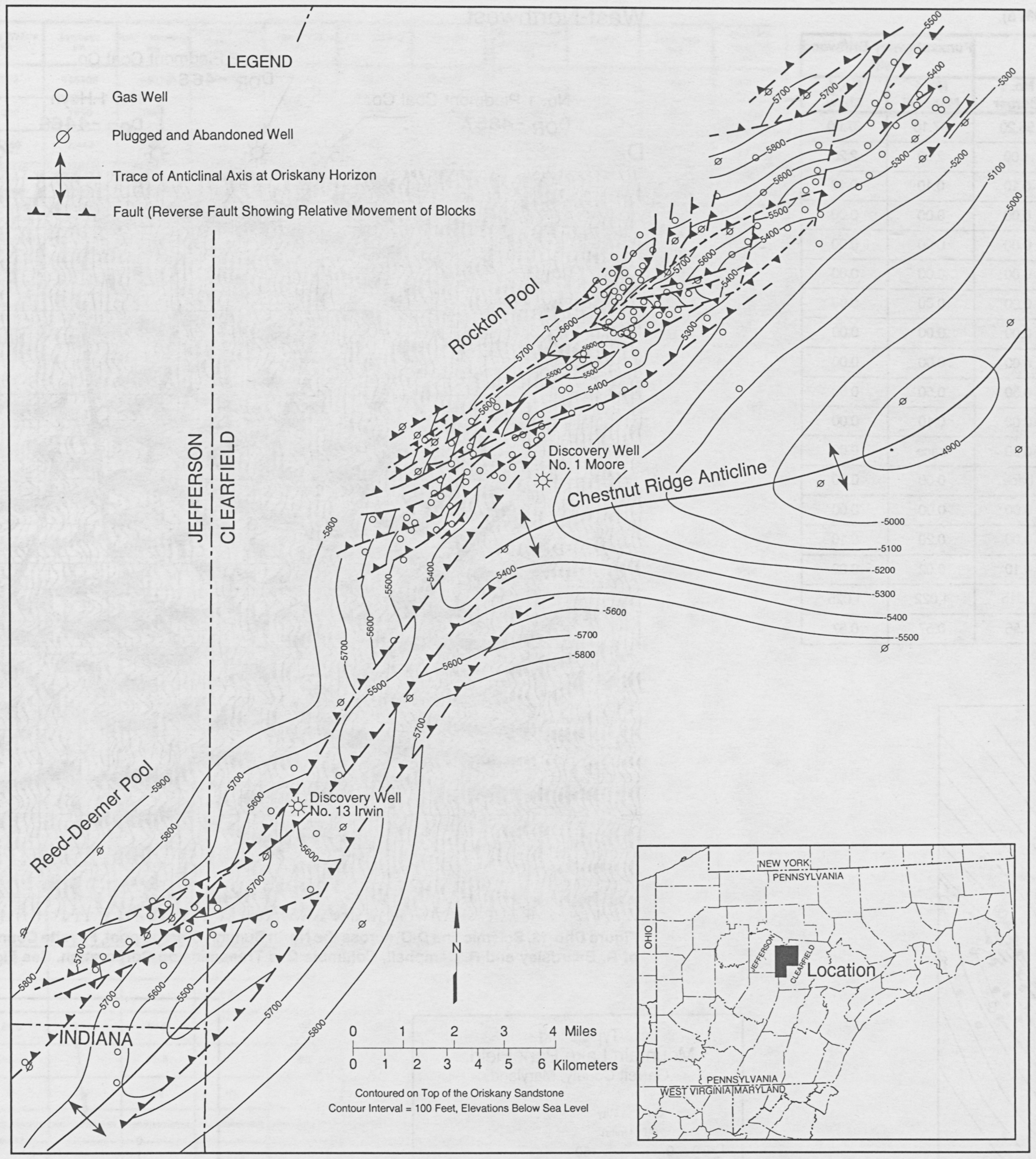

Figure Dho-18. Structure and well locations of Reed-Deemer pool of the Big Run field and the Rockton pool, Punxsutawney-Driftwood field, Clearfield and Jefferson counties, Pennsylvania. Modified from Cate in Lytle and others (1959).

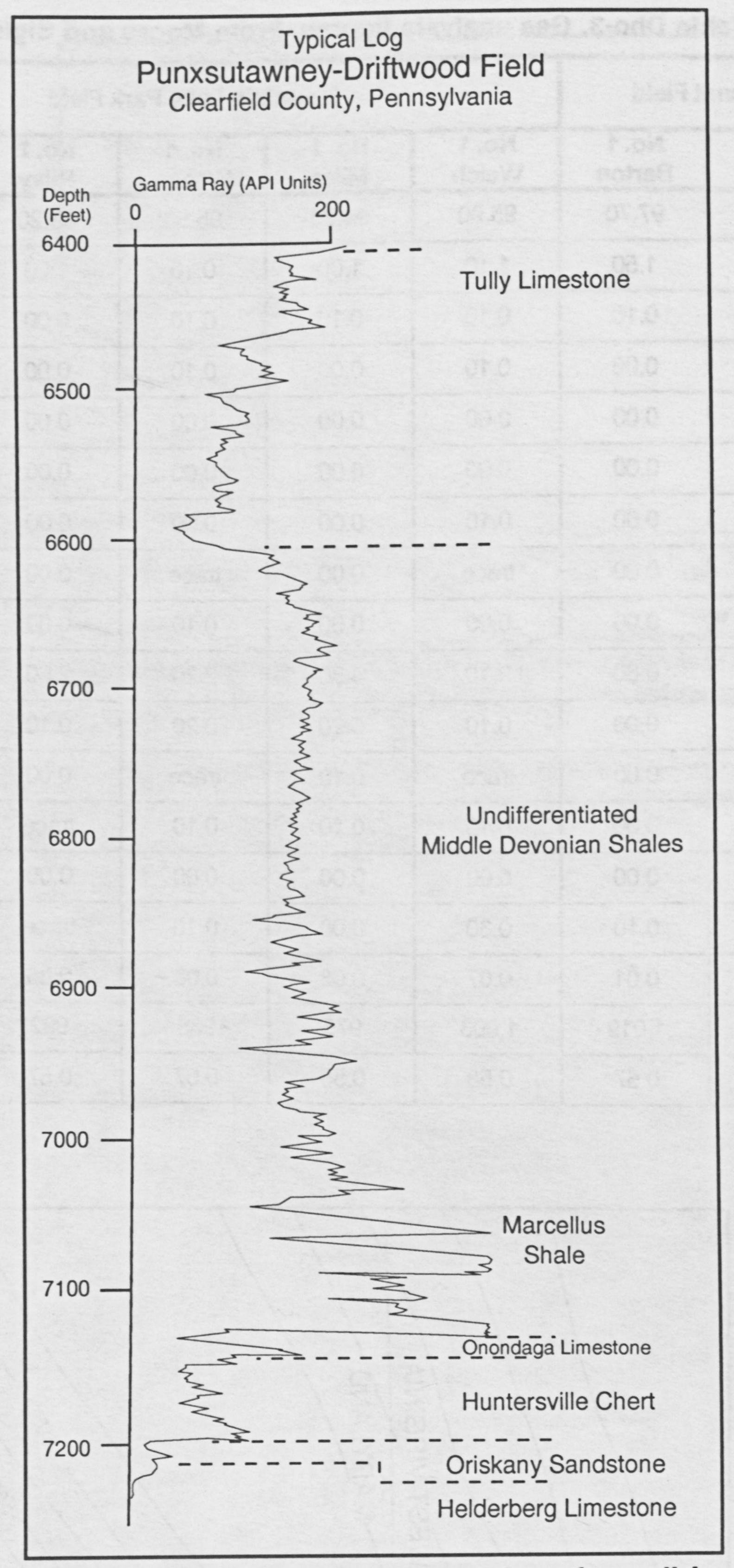

Figure Dho-19. Typical gamma-ray log of a well in Punxsutawney-Driftwood field, Clearfield County, Pennsylvania.

Table Dho-4. Average natural gas production per well per year.

Field	Location	Mcf
Roaring Run	Armstrong County, Pennsylvania	45,082
Carrolltown	Cambria County, Pennsylvania	27,464
Rager Mountain	Cambria County, Pennsylvania	35,567
Punxsutawney-Driftwood	Clearfield County, Pennsylvania	27,069
Penfield	Clearfield County, Pennsylvania	2,452
Ohiopyle	Fayette & Somerset Counties, Pennsylvania	16,002
Summit	Fayette County, Pennsylvania	27,153
North Summit	Fayette County, Pennsylvania	31,393
Spruell	Fayette County, Pennsylvania	54,763
Mill Run	Fayette County, Pennsylvania	17,765
Mt. Lake Park	Garrett County, Maryland & Preston County, West Virginia	18,660
Strongstown	Indiana & Cambria Counties, Pennsylvania	24,156
Jacksonville	Indiana County, Pennsylvania	28,061
Nolo	Indiana County, Pennsylvania	26,105
Living Waters	Indiana County, Pennsylvania	37,095
Cherry Hill	Indiana County, Pennsylvania	9,910
Murphy Creek	Lewis County, West Virginia	17,699
South Burns Chapel	Preston & Monongalia Counties, West Virginia	8,754
Etam	Preston & Tucker Counties, West Virginia	36,985
Terra Alta	Preston County, West Virginia	63,356
Concord	Preston County, West Virginia	35,714
Glady	Randolph & Pocahontas Counties, West Virginia	104,839
Boswell	Somerset County, Pennsylvania	47,348
Seven Springs	Westmoreland & Somerset Counties, Pennsylvania	47,451
New Alexandria	Westmoreland County, Pennsylvania	47,202
Johnstown	Westmoreland County, Pennsylvania	99,058
Crabtree	Westmoreland County, Pennsylvania	17,743
Jacobs Creek	Westmoreland County, Pennsylvania	38,261
Lycippus	Westmoreland County, Pennsylvania	66,392
Linn Run	Westmoreland County, Pennsylvania	28,868

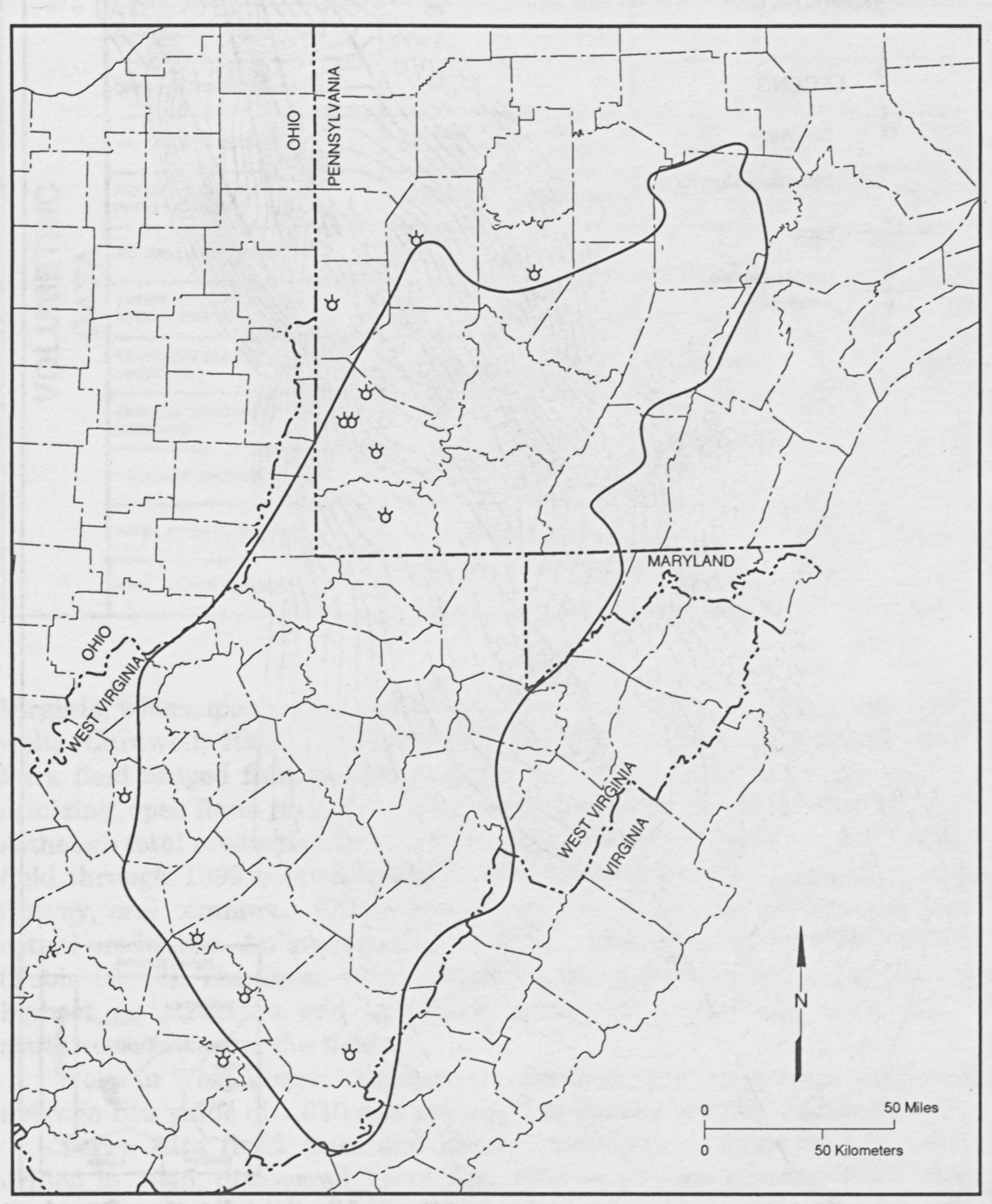

Figure Dho-20. Map showing outine of Huntersville Chert/Oriskany Sandstone play area with wells having gas shows.

fracturing and a rock pressure of 3,275 psi. By the end of 1955, there were four producing wells in the Rockton pool. During the next year, 22 wells were added to the pool, and an additional 65 were successfully completed in 1957. Rockton pool presently produces from 109 wells and contains 43 abandoned wells. The productive area of the pool comprises 21,458 acres.

Resources and Reserves

Main economic considerations of the Huntersville Chert and Oriskany sandstones play include the size of the drainage area, natural fracturing and hydraulic fracturing potential, structure, and stratigraphy. The size of the fault blocks from which the chert and sandstone produce gas are variable. Lateral extent of drainage area is difficult to determine without extensive seismic coverage to define block dimensions. Fracture systems characteristic of the Huntersville Chert reservoir may add a potentially significant multidimensional natural gas drainage channel, and are frequently influenced by the local stratigraphy. Keeping these factors in mind, the difficulty and inaccuracy of assigning a per-acre yield reserve figure becomes apparent. Therefore, average production per well per year for each field was calculated and results are listed in Table Dho-4. The figures are derived from actual reported gas production, divided by the number of years in production and the number of producing wells. This method is not without its own inaccuracies, for example, fluctuating gathering line pressure, shut-in periods, higher flush production in initial years, and number of wells actually producing. However, using the available data, the average Huntersville Chert/Oriskany Sandstone well has been in production 29.5 years, producing an average of 36,280 MMcf per year.

Briggs and Tatlock (1983) point out that once terrain, culture, and less optimal structural conditions are considered, only 3 percent of a given area will be productive from the Huntersville Chert/Oriskany Sandstone reservoir. Three percent of the total estimated play area of 11,800,000 acres equals 354,000 acres. Average spacing of producing wells in this play is 135 acres. Applying this 135-acre spacing scheme to the possible 354,000 drillable acres yields approximately 2,600 well locations. Optimistically assuming that each well will produce about 36 MMcf per year for about 30 years calculates to 2.8 tcf of recoverable resources. Since more than 650 bcf have already been produced, approximately 2.15 tcf might remain.

Future Trends

Searching for new production from a Huntersville Chert/Oriskany Sandstone reservoir involves pursuing small anticlinal upthrust fault blocks with structural closure. Fracture porosity is an essential ingredient, as proven by previous exploration. Deeper seated fractures may supply gas from deeper sources, and thereby recharge reservoirs. Isopach, structure mapping and sample study help to further define the target.

Well sites in this play are typically selected based on interpretations of seismic lines run over the surface in a prospective area. Wells such as the No. 1 Carbon Fuel Resources Unit in Fayette County, Pennsylvania (Figure Dho-2), drilled by R.E. Fox and Associates, Inc. in October 1993, show the results of optimal placement with respect to fractures, structure, and lithology. This well was located on the western flank of the Chestnut Ridge anticline, approximately 8,000 feet west of the South Summit pool of Summit field. Drilling through the Huntersville Chert/Oriskany Sandstone at 7,120 feet resulted in a natural open flow of 72 MMcf from gas-filled fractures intersected by the well bore. Similar small, isolated, untested fault blocks occur along the flanks of the anticlines in southwestern Pennsylvania, northern West Virginia, and western Maryland.

Aside from the more traditional defined structure prospects, less tested exploration possibilities exist along the edges of the present chert play. The northern and western edges of the play boundary, where the chert facies gradually alters to include limestone and more porous sediments, should be considered for gas potential. Shows of natural gas have been observed and recorded in the Huntersville Chert along the western edge of the play outline (Figure Dho-20). Drillers' records indicate that the lithology consists of chert and cherty limestone. Quantities of natural gas reported varied between ungauged shows of gas and 1 MMcfg/d from the combined chert and Oriskany sandstone after treatment.

Depleted fields and pools may be considered for gas storage purposes. The typical structurally closed, isolated blocks serve as good storage reservoirs. North Summit and Terra Alta fields have been successfully converted to underground gas storage.