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Thermal maturity patterns (CAI and %R_o) in the Ordovician and Devonian rocks of the Appalachian basin in Pennsylvania

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature. Any use of trade names is for descriptive purposes only and does not imply endorsement by the USGS.

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Introduction

This report presents a series of new thermal maturation maps for Pennsylvania, based on conodont color alteration index (CAI) and vitrinite reflectance (%R_o). Also, RockEval and total organic carbon (TOC) data are included in the report. Two Paleozoic intervals were studied: Middle Ordovician carbonate rocks and Lower and Middle Devonian carbonate rocks and black shale. These intervals were chosen for several reasons: A) they represent target reservoir zones for most of the oil and gas exploration and drilling in Pennsylvania; B) they are stratigraphically near probable source rocks for the oil and gas; C) they include contiguous geologic formations that extend across most of Pennsylvania; D) they contain carbonate grainstone/packstone which give a reasonable to good probability of recovery of conodont elements from small samples of drill cuttings; and E) the Middle Devonian black shale contains large amounts of organic matter for geochemical analysis.

The maps presented herein complement, and in some areas replace, the Pennsylvania part of the CAI-based thermal maturation maps for the Appalachian Basin of Harris and others (1978). The maps of Harris and others were pioneering efforts in applying the concepts and techniques of CAI analysis developed by Epstein and others (1977). Our maps differ in that the CAI data used is derived entirely from subsurface samples whereas the CAI data used by Harris and others (1978) was almost entirely from outcrop samples. Because of the sampling methods, there is little geographic overlap in the two data sets, with the new data presented herein mostly from the Appalachian

Plateau province and most of the data of Harris and others being from the Valley and Ridge province.

Several vitrinite reflectance ($\%R_o$) maps are available for evaluating thermal maturity patterns in the Appalachian Basin but they are limited to smaller areas than the CAI-based maps. Examples of vitrinite reflectance maps that apply to Pennsylvania are those for Upper Devonian black shale by Streib (1981) and T. Hamilton-Smith (in Boswell, 1996) and for Pennsylvanian coal beds by Hower and Davis (1981), Chyi and others (1987), and Zhang and Davis (1993). RockEval/TOC-derived maps for Appalachian Ordovician black shale are available in Wallace and Roen (1989).

Thermal maturity patterns of the Middle Ordovician Trenton Group are evaluated here because they are expected to closely approximate those of the overlying Ordovician Utica (Antes) Shale that is the probable source rock for oil and gas in Upper Cambrian sandstone, Lower Ordovician carbonate, and Lower Silurian sandstone (Laughrey and Baldassare, 1998; Ryder and others, 1998) and for new gas discoveries in the Trenton and Black River Group carbonate (Schwochow, 2000). Improved CAI-based thermal maturity maps are important to identify areas of optimum gas generation from the Utica (Antes) Shale and to constraint the origin and distribution of oil and gas in the Lower Silurian regional accumulation (Ryder, 1998). Also, thermal maturity maps of the Ordovician may have a role in understanding the origin and distribution of gas in Trenton and Black River carbonate reservoirs. Thermal maturity maps of the Devonian will constrain burial history - petroleum generation models of the Ordovician Utica (Antes) Shale, as well as provide a better understanding of the origin and distribution of regional oil and gas accumulations in Upper Devonian sandstone, self-sourced gas in Middle to Upper Devonian black shale, and conventional gas in Lower Devonian sandstone.

New CAI and %R_o maps presented in this report also contain information that relates to the thermal and tectonic evolution of the Appalachian Basin. Important in this regard are the character of thermal maturity patterns across specific tectonic features, comparison of thermal maturity and overburden patterns, changes in paleogeothermal gradient with time for a given area, and proposed geological/geophysical causes of regional thermal maturity anomalies.

New York State was the first area in the Appalachian Basin where the collection, processing, and analysis of subsurface drill-hole cuttings and core samples have resulted in new CAI and %R_o maps (Weary and others, 2000, 2001). The present study was a cooperative effort between the U.S. Geological Survey (USGS) and the Pennsylvania Geological Survey. Additional investigations in West Virginia (USGS-West Virginia Geological and Economic Survey), Ohio (USGS-Ohio Division of Geological Survey), Kentucky (USGS-Kentucky Geological Survey), and Virginia (USGS-Virginia Division of Natural Resources) are at various stages of completion.

Methods

Seventy-five samples were collected, processed, and analyzed for conodont color alteration index (CAI) for this study. Of these 49 were Devonian and 27 were Ordovician. The Devonian samples were from 48 drill holes; 40 samples consisted of cuttings and 10 were core splits (one sample comprised both cuttings and core). These yielded 24 new

Devonian CAI points for Pennsylvania. The Ordovician samples were obtained from 24 drill holes; 22 samples were cuttings, one was core, and 4 were splits of sidewall cores from one well. In all, these resulted in 23 new Ordovician CAI points.

An additional 36 samples were collected from Devonian black shales. These black shales were sent to Humble Geochemical Services,[1] Humble, Texas, for processing and analysis for total organic carbon (TOC), RockEval parameters, and vitrinite reflectance.

Samples for this study were collected by one of us (JH) from drill core and cuttings in the repository holdings of the Pennsylvania Geological Survey, at Penfield, Clearfield County, PA. Devonian conodonts from one additional well, already on file at USGS, were re-analyzed for this study. In all, 85 drill holes in 47 counties were sampled (Fig. 1). We also included one sample site from Lake Erie, from a drill hole in southern Ontario, Canada, kindly provided to us by Bob Bonnar, Talisman Energy Co., Calgary, Alberta. The sidewall core samples were provided by Bob Heim, Atlas Resources, Pittsburgh, Pennsylvania.

Where possible (n=23 holes), we sampled the different target intervals from the same drill hole (well). In most of these cases, the sampled pair was the Devonian black shale and Devonian carbonate rocks. The total collection (n=111) consists of: 1) carbonate (limestone) samples from the Middle-Late Ordovician Black River and Trenton Groups (n=27); 2) carbonate (chiefly limestone, with minor dolostone) samples from selected Devonian formations (n=49); and 3) black shale samples from the Middle Devonian Marcellus Shale (n=36). The samples averaged about 120 g, with a range from 2.1 to several hundred g, and consisted of rock fragments >20-mesh. Most samples were

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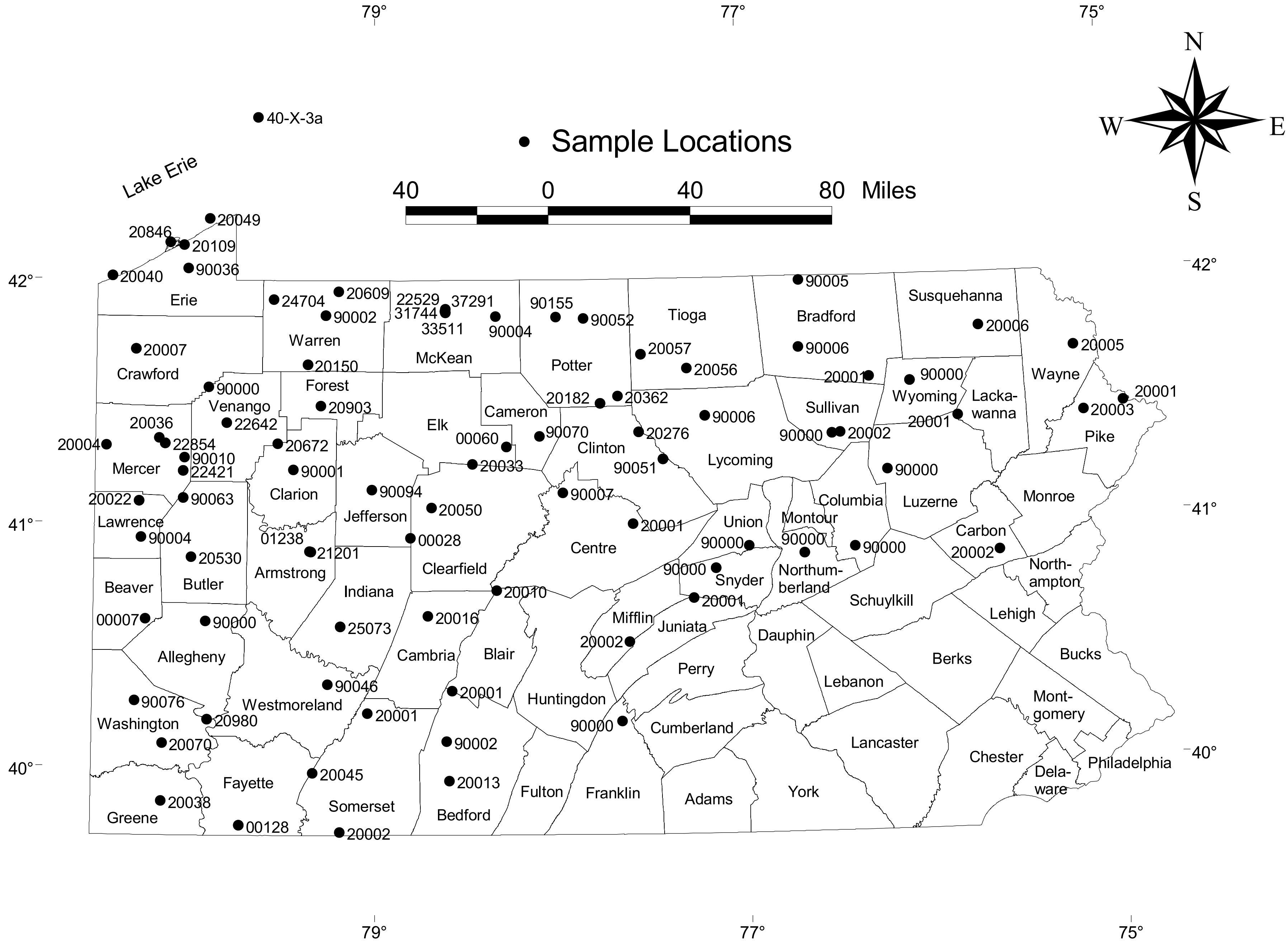


Figure 1. Location of wells and surface localities sampled for conodonts and (or) vitrinite in this study.

composites representing from about 100 to several hundred feet of stratigraphic section. The carbonate samples were shipped to the USGS in Reston, Virginia. There they were processed for conodonts using standard chemical and physical extraction procedures (Harris & Sweet, 1989).

Conodonts recovered were visually compared with a set of conodont color standards of approximately the same age (to Period), provided by A.G. Harris (USGS-Emeritus), and assigned a conodont alteration index (CAI) value. Samples exhibiting a range in CAI values and samples with very few individual conodont elements or only a few element fragments were assigned a minimum and maximum value. We chose to use the maximum CAI value for plotting the isograds on the accompanying maps (Figs. 4-6, 8-10) to maintain consistency with the procedures used by Harris and others, 1978, for their Appalachian CAI maps. In effect, if a host rock experienced at least the magnitude and duration of heating to raise any of the contained conodont elements to the higher CAI value in an observed range of values, then any associated hydrocarbons also would have experienced those temperatures as well. The conodonts used in this study are reposited in the collections of the U.S. Geological Survey in Reston, Virginia, and are curated using the USGS Cambrian-Ordovician (CO) and Silurian-Devonian (SD) fossil collection/locality numbers. (Tables 1 and 2). Tables 1 and 2 also provide faunal lists, biostratigraphic ages or age ranges for the recovered conodonts from each productive sample, and details of the processed residues for the Ordovician and Devonian carbonate sample sets, respectively. Summaries of notable minerals and fossils seen in the heavy fraction (sp. gr. >2.87) of the insoluble residues are given in Table 3.

All of the maps were constructed by plotting points in ARC/VIEW over a digital base map, using latitude/longitude coordinates from the Pennsylvania Geological Survey well database. The points were then attributed with American Petroleum Institute (API) numbers, minimum and maximum CAI values, RockEval parameter values, and $\%R_o$ values. Data points and CAI isograd contours from Harris and others (1978) were captured and replotted by tracing and attributing the points and lines in ARC/INFO. The coverages were exported to ARC/VIEW version 3.1 for ease of manipulation and graphic display.

Stratigraphy of Sampled Intervals

All Ordovician samples used in this study were identified from well logs as either Trenton Group or Trenton plus Black River Group by the Pennsylvania Geological Survey. One side wall core (from well 037-085-22421) was identified by the well logger as Black River Group. No attempt was made to further refine these assignments to formation level. All but four of the 27 Ordovician samples were productive of conodonts, yielding from one to 81 elements or fragments identifiable as conodonts. Analysis of the total possible biostratigraphic ranges for each fauna indicates that they all are consistent with the lithostratigraphic determinations, even though most of these possible age ranges extend above or below the range of the identified lithostratigraphic unit. The lithostratigraphy of the studied interval, modified from Berg and others (1983), and the biostratigraphic ranges of the conodonts are shown on Figure 2. Because of long-standing usage in North America, we have used the traditional level of the Middle/Upper Ordovician boundary, even though the International Commission on Stratigraphy has

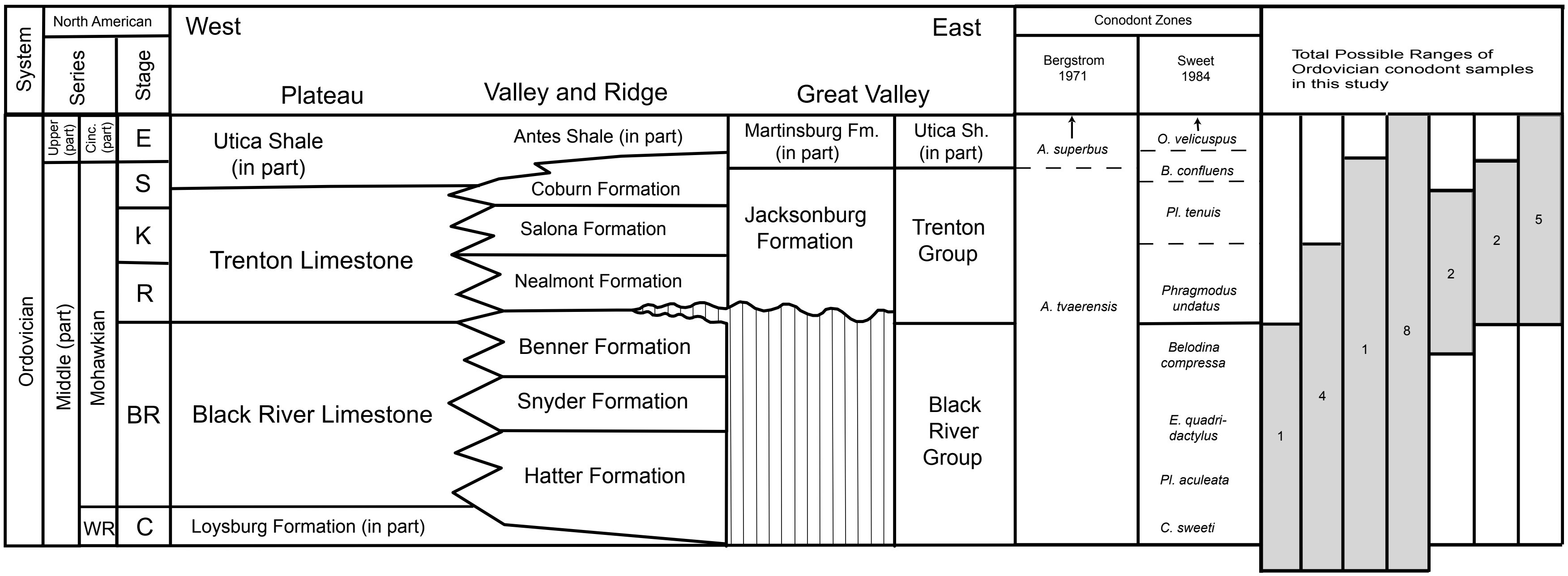


Figure 2 - Stratigraphic relationships of Ordovician rocks (part) in Pennsylvania with total possible biostratigraphic ranges of conodont sample collections recovered in this study. Numbers in shaded bars indicate numbers of samples representing each range. Range bars extending below Blackriveran indicate base-of-range beginning in upper Whiterockian Series or Chazyan Stage. Total Ordovician samples with recovered conodonts = 23.
(E - Edenian; BR - Blackriverian; C - Chazyan; K - Kirkfieldian; R - Rocklandian; S - Shermanian; WR - Whiterockian)

recently standardized the base of the Middle Ordovician at a significantly lower level (Webby, 1998). The new usage includes all strata above a level in the middle part of the Chazy Group in the Upper Ordovician, i.e., all of the samples used in this study would be considered to be of Late Ordovician age. Table 1 shows detailed faunal composition, abundance, biostratigraphic range, CAI, and other data from the Ordovician conodont samples analyzed.

Devonian samples were selected where carbonate rocks could be located, identified stratigraphically with reasonable confidence, and sampled in suitable quantity. Where possible, samples comprise a single carbonate lithostratigraphic unit. However, commonly we had to composite cuttings from more than one unit. Twenty-four of the 48 samples yielded conodonts, with element abundances ranging from a single element to 112 elements or fragments identifiable as conodonts. The sample suite as a whole was limited to the Lower and Middle Devonian, thereby obtaining CAI data reasonably close stratigraphically to the the samples from the black shales of the Marcellus Formation that were selected and analyzed for vitrinite reflectance and RockEval/TOC data. Figure 3 shows the stratigraphic framework for the studied part of the Devonian of the Plateau and Valley and Ridge provinces of Pennsylvania (modified from Berg and others (1983), as well as the positions of the conodont samples, both productive and barren. Details of the faunal compositions, element counts, biostratigraphic positions, CAI, and other data, for each of the Devonian conodont samples used in this study are shown in Table 2.

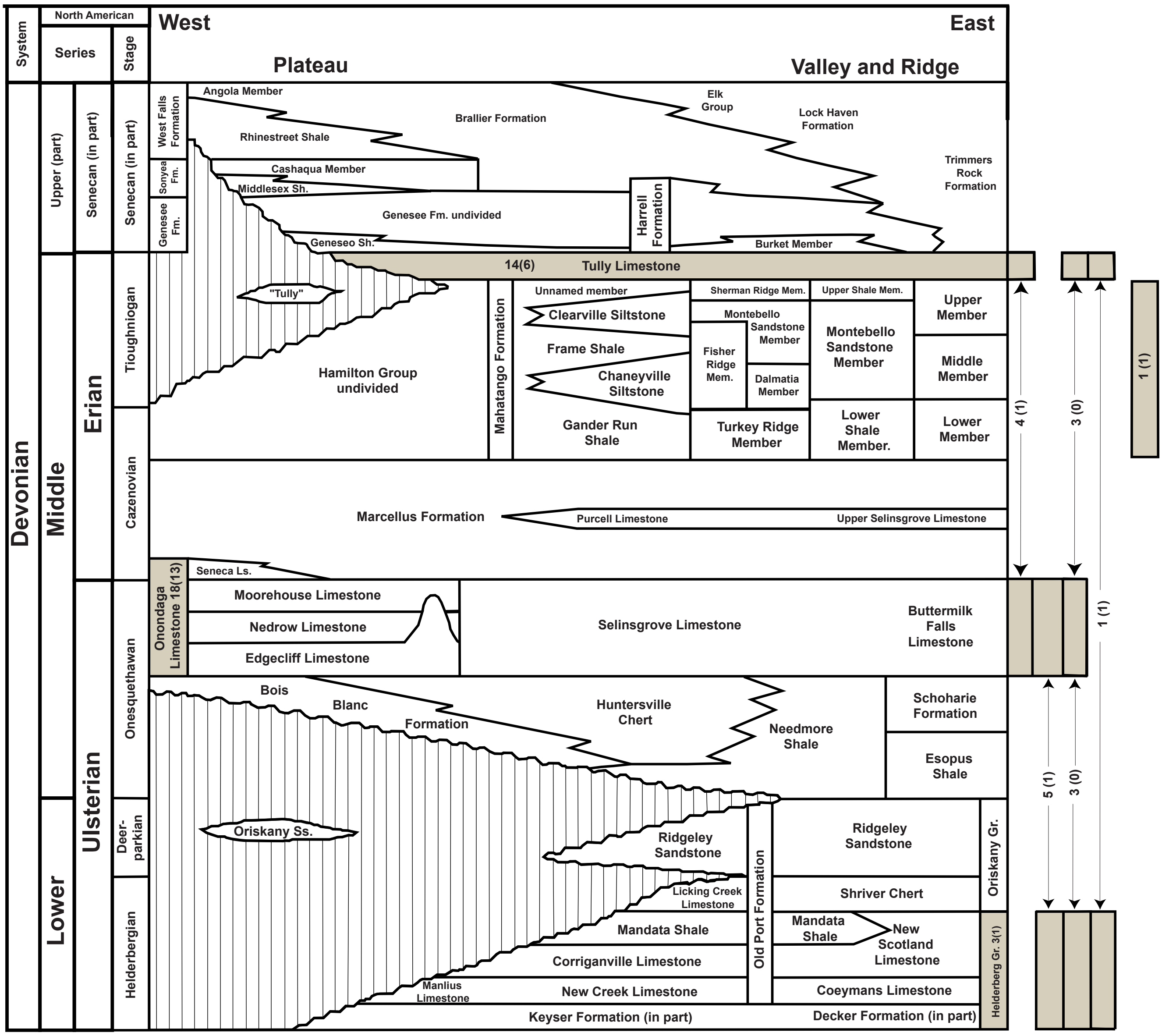


Figure 3 - Stratigraphic relationships of Lower, Middle, and Upper (part) Devonian rocks in Pennsylvania with conodont sample collections recovered in this study. Vertical bars indicate stratigraphic intervals of samples; number of conodont samples from each unit in plain numerals; samples yielding conodonts in parentheses. Total Devonian samples with recovered conodonts: 24.

Thermal Maturity of Ordovician Strata

The Ordovician CAI data for the new subsurface samples (Tables 1 and 3) are plotted in Figures 4 and 5 and contoured as isograds. All Ordovician isograds are based on maximum CAI values for a given control point. The majority of the samples with recoverable conodont elements are located in the Plateau province (18 of 21) with the remainder located in the Valley and Ridge province (Fig. 4). CAI_{max} values in our collection range between 1.5 and 5. The CAI 5 isograd defines a narrow, northeast-trending region of high thermal maturity that extends from Fayette County in southwest Pennsylvania to Lycoming County in central Pennsylvania. Northeast of Lycoming County, the region of high thermal maturity broadens considerably to where it is represented by two closed CAI 5 isograds centered in Wyoming and Bradford Counties. The northern region of CAI 5 isograd closure is based on data from south-central New York (Weary and others, 2000, 2001). The region of high thermal maturity defined by CAI 5 isograds coincides with a broad region of extended crust that includes the Rome trough, a Middle Cambrian graben beneath the eastern part of the Plateau province that involves Proterozoic crystalline basement rocks (Harper, 1989; Shumaker, 1996; Beardsley and others, 1999)(Fig. 5). In addition, the northeastern extremity of the region of high thermal maturity overlaps part of the Scranton gravity high where early Paleozoic and(or) early Mesozoic crustal extension and associated volcanism probably occurred (Diment and others, 1972)(Fig. 5).

The location of the Rome trough in northern Pennsylvania as shown by Shumaker (1996) differs from the location shown by Harper (1989) and Beardsley and others

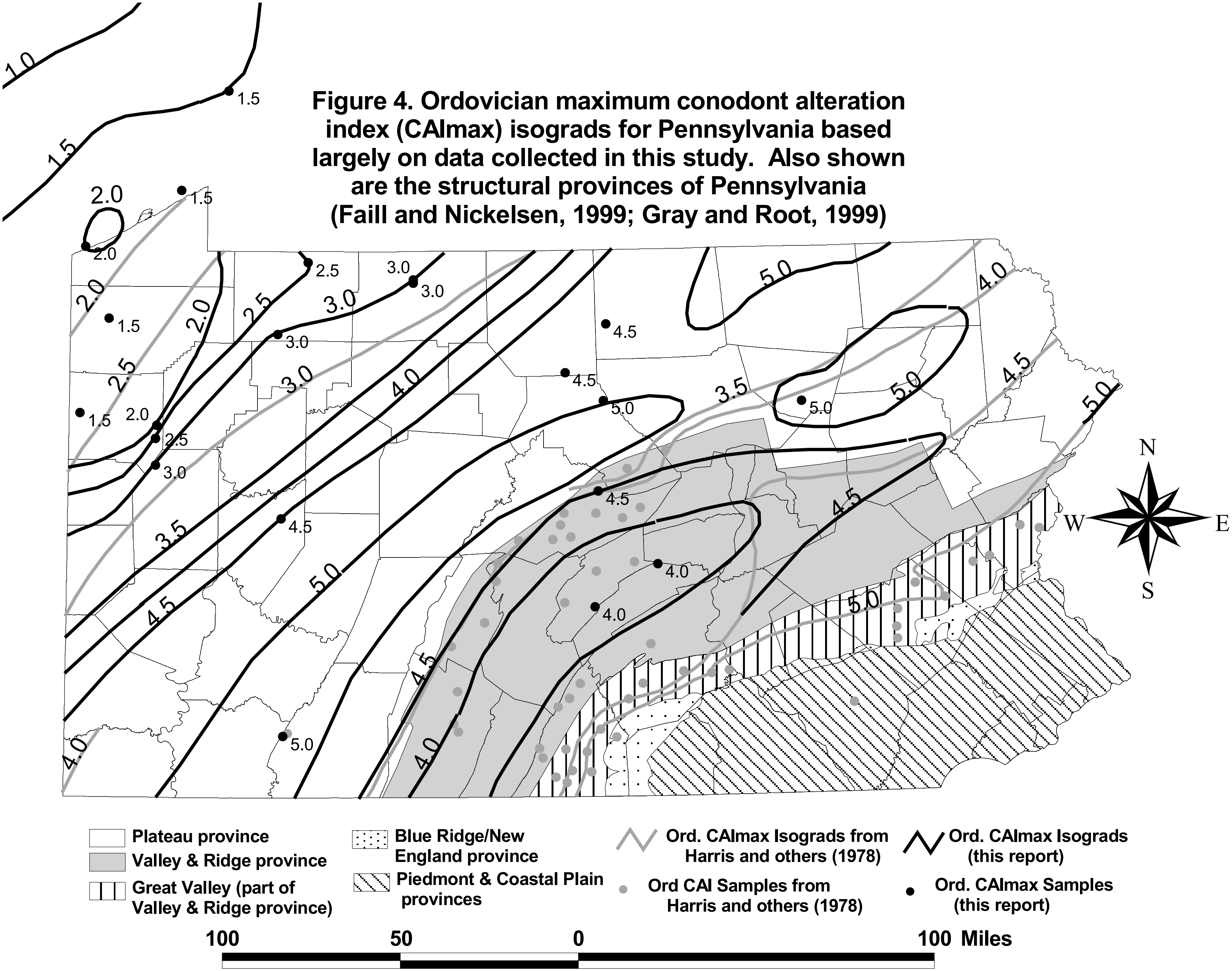


Figure 4. Ordovician maximum conodont alteration index (CAImax) isograds for Pennsylvania based largely on data collected in this study. Also shown are the structural provinces of Pennsylvania (Faill and Nickelsen, 1999; Gray and Root, 1999)

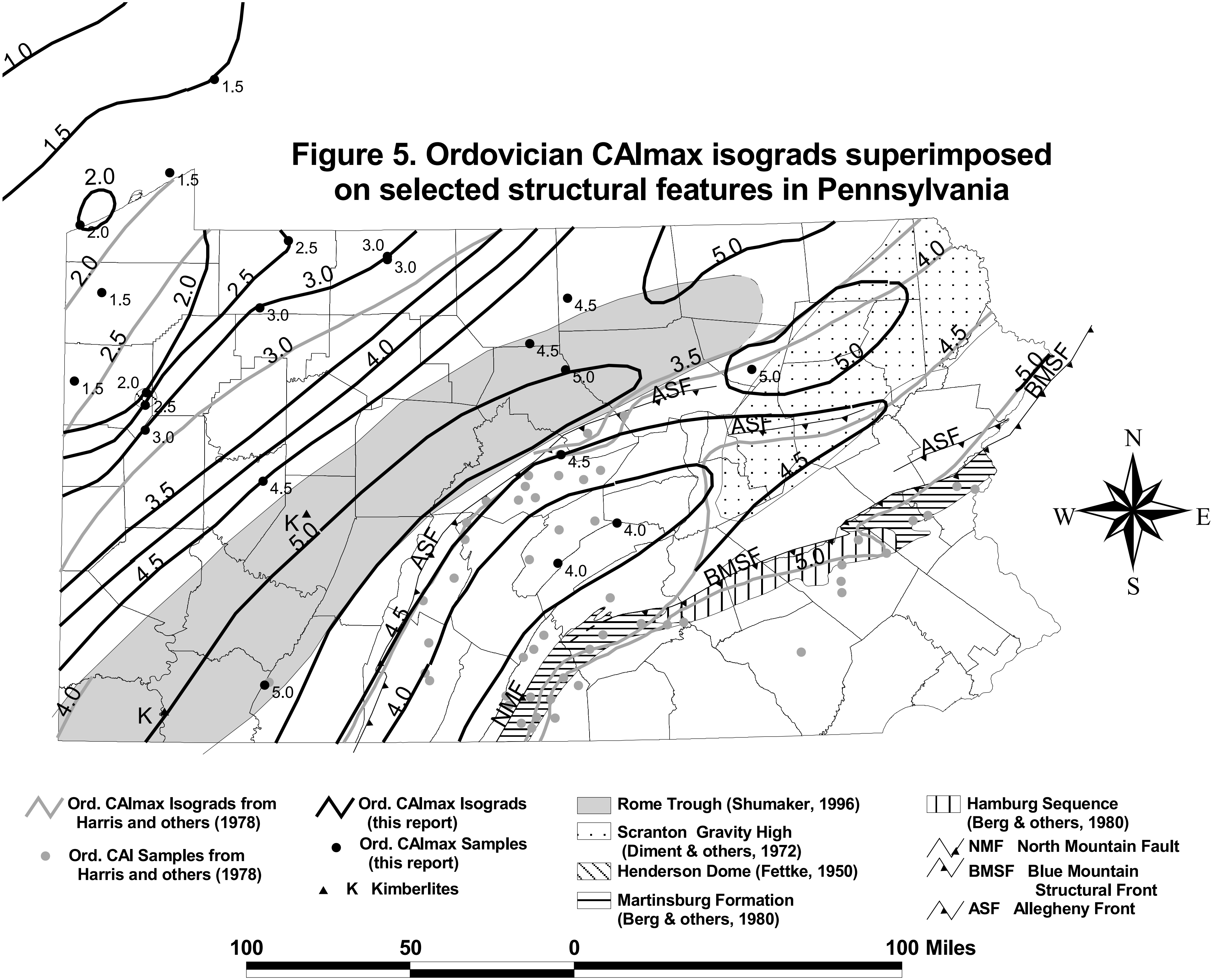


Figure 5. Ordovician CAImax isograds superimposed on selected structural features in Pennsylvania

(1999). Harper (1989) and Beardsley and others (1999) indicated that the Rome trough maintains a northeastward trend across Pennsylvania and extends into southern New York State, whereas Shumaker (1996) suggested that the Rome trough changes to a more easterly trend in central Pennsylvania and continues into northeastern Pennsylvania. We use Shumaker's (1996) regional basement structure map to provide a consistent location of the Rome trough in the 6-state area of the thermal maturity study of which this is a part. The precise location of the Rome trough in each state is not as critical to this reconnaissance-level investigation as knowing its approximate location and extensional character. As more thermal maturity data become available, a more exact location of the Rome trough will be desirable.

Lower isograds that flank the CAI 5 isograds maintain the same dominant northeast trend (Figs. 4, 5). In the Plateau province isograds diminish in value from CAI 4.5 to 1.5 in a northwest direction whereas in the Valley and Ridge province they diminish less dramatically in a southeast direction from CAI 4.5 to 4. The CAI 3.5 to 4.5 isograds in northwestern Pennsylvania appear to be an extension of tightly grouped isograds that are well documented by Weary and others (2000, 2001) in south-central New York. Although the CAI 3.5 to 4.5 isograds are drawn here to mimic the tight grouping of equivalent isograds in New York, they are less well constrained. Additional tightly grouped isograds, in this case between CAI 2 and 3, are identified near the Henderson dome (Fettke, 1950) in Butler and Mercer Counties (Fig. 5). East and southeast of Juniata and Mifflin Counties in the central Valley and Ridge province, isograds show a reversal of their western-Valley-and-Ridge trend and increase to CAI 4.5 and 5 as reported by Harris and others (1978).

For a comparison to our CAI isograd trends, Ordovician CAI isograds from Harris and others (1978) were plotted on Figures 4 and 5. Except for a single subsurface collection in western Somerset County, Harris and others (1978) based the Pennsylvania part of their map on outcrop collections from the Valley and Ridge province and the adjoining Great Valley. Ordovician CAI isograds defined here are consistent with those of Harris and others (1978) in northwestern and southeastern Pennsylvania but differ significantly in the 50- to 100-mi-wide, northeast-trending central zone that coincides with the Rome trough and Scranton gravity high. Although Harris and others (1978) recognized the strong influence of the Rome trough on regional thermal maturity patterns they lacked the subsurface data to document specific trends. For example, their map in Pennsylvania was limited to a CAI 5 value in Somerset County and to a CAI 4 isograd in Greene County projected from data in adjoining West Virginia. Likewise, the underestimated CAI isograds reported by Harris and others (1978) for northeastern Pennsylvania resulted from incomplete subsurface data. The CAI 5 isograd in the Great Valley of southeastern Pennsylvania is adopted here as originally defined by Harris and others (1978).

The isograd trends shown in Figures 4 and 5 broadly match the isopach trends in overlying Devonian through Permian strata (de Witt and others, 1975; Harris and others, 1978; Fig. 8 herein). However, there are several regions where significant departures occur: 1) the northeast-trending group of Ordovician CAI 3 to 4.5 isograds cross the Devonian through Permian isopachs at a high angle in north-central Pennsylvania and adjoining New York (Harris and others, 1978; Weary and others, 2000, 2001); 2) the CAI 5 isograd closure along the Pennsylvania-New York border represents an abnormally high thermal maturity compared to rocks in northwestern Pennsylvania having an equivalent overburden thickness of 6,000 to 8,000 ft; and 3) the CAI 4 isograd that characterizes central Valley and Ridge rocks has a corresponding overburden that is about 4,000 ft thicker than for flanking western Valley and Ridge rocks characterized by the CAI 4.5 isograd.

Lower Silurian Medina Group gas fields in northwestern Pennsylvania with associated oil and condensate are located between the CAI 1.5 to 3 isograds (fig. 6). These CAI values correspond with $\%R_o$ values of <1 to 2 (Fig. 7) and, thus, occupy the range of thermal maturity indices commonly associated with the “window” of oil, wet gas, and early dry gas generation and preservation (Dow, 1977; Harris and others, 1978; Tissot and Welte, 1984). Considering that Ordovician black shale directly overlying conodont-bearing Ordovician limestone of this study is the probable source rock (Laughrey and Baldassare, 1998; Ryder and others, 1998) for the hydrocarbons, the predominance of natural gas in the Medina Group (Pennsylvania Topographic and Geologic Survey, 1994; Wandrey and others, 1997) is inconsistent with the relatively low thermal maturity values reported here. Stable isotope studies by Laughrey and Baldassare (1998) and Jenden and others (1993) provide further evidence that the Medina Group gases have a higher thermal maturity (source rock $\%R_o$= 1.5 to 3) than underlying Ordovician black shale. These analyses suggest that the Medina Group gases were generated from deeper in the basin from an Ordovician source rock and migrated to their present location. Likewise, natural gas trapped in Upper Cambrian sandstone and lower Ordovician dolomite in northwestern Pennsylvania (fig. 6) probably migrated from an Ordovician shale source rock deeper in the basin.

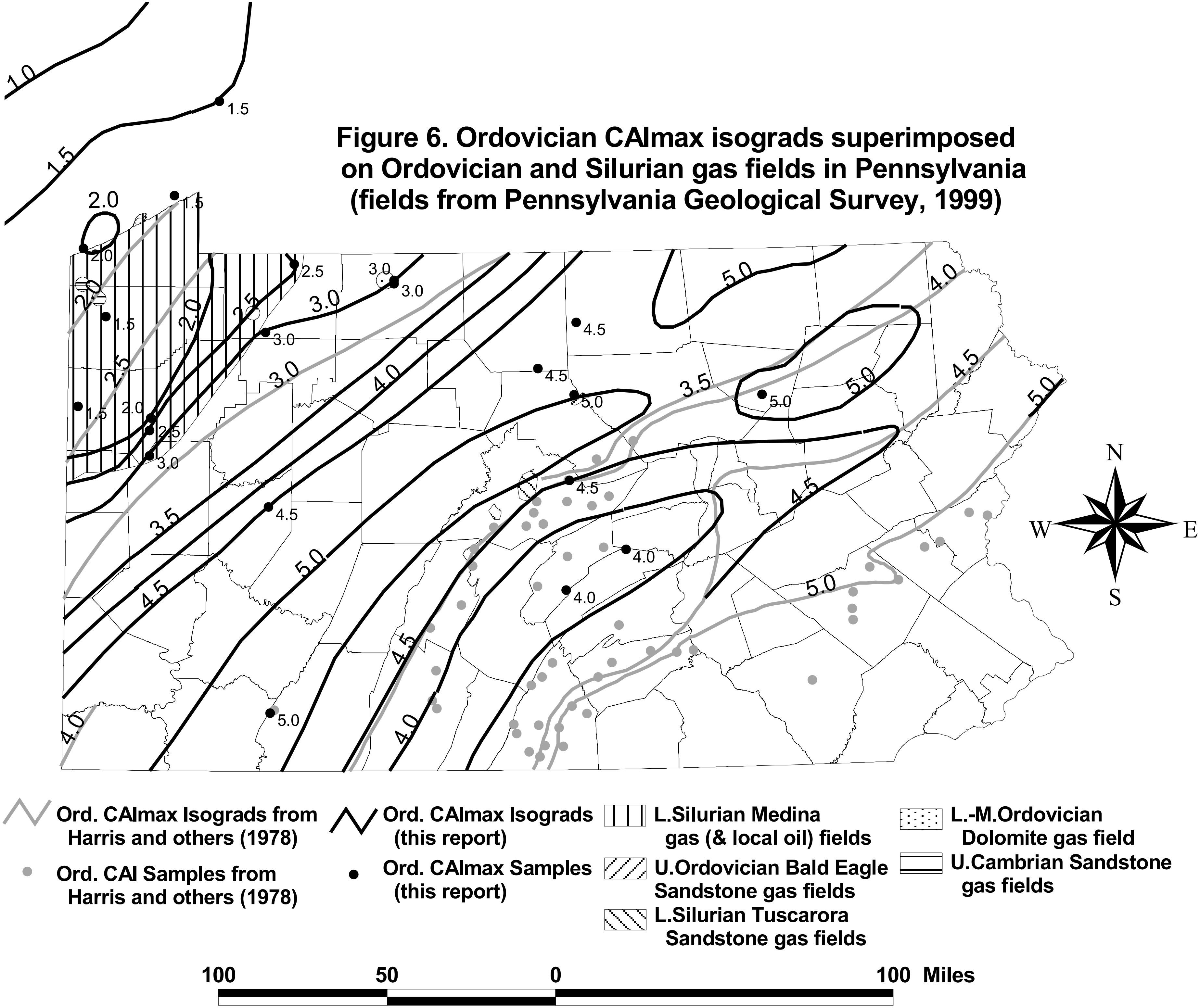


Figure 6. Ordovician CAImax isograds superimposed on Ordovician and Silurian gas fields in Pennsylvania (fields from Pennsylvania Geological Survey, 1999)

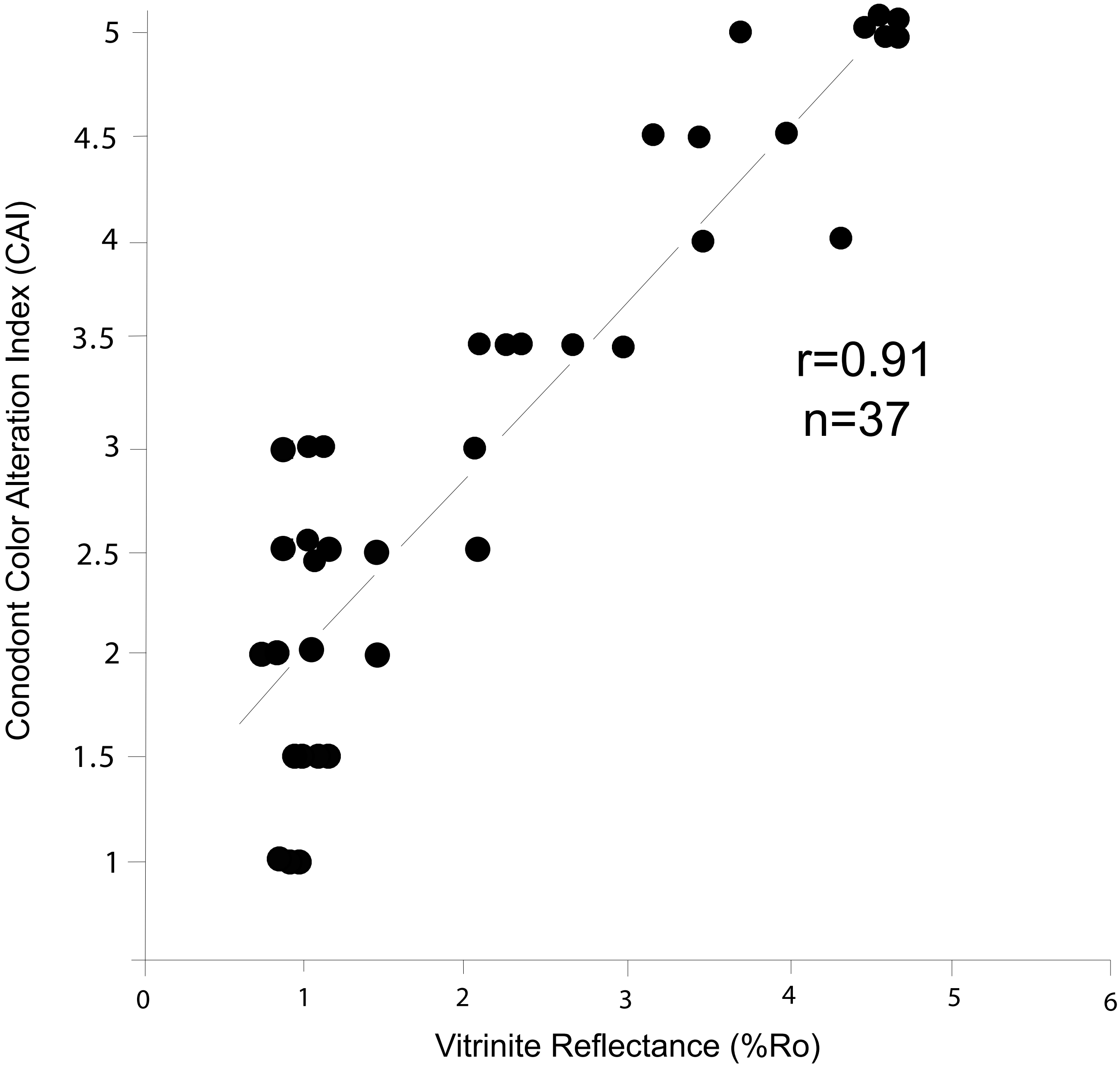


Figure 7. Correlation of vitrinite reflectance and CAI values (after Nöth, 1991)

Central Pennsylvania gas fields in the Upper Ordovician Bald Eagle Sandstone and Lower Silurian Tuscarora Sandstone are located near the CAI5 isograd (%R_o4) (fig. 6). Stable isotope values for the Bald Eagle gas indicate a source rock %R_o>4 (Laughrey and Baldassare, 1998) which is consistent with the high level of thermal maturity measured for Ordovician strata in this locality. However, stable isotope values indicate a source rock %R_o= 2 for the Tuscarora gas that is considerably lower than the thermal maturity of Ordovician strata in the vicinity. We have no explanation for the abnormally low thermal maturity of the Tuscarora gas except that the gas appears to have escaped advanced thermogenic processes after entrapment.

Thermal Maturity of Devonian Strata

The Devonian CAI data for the new subsurface samples (Tables 2 and 3) are plotted in Figures 8 and 9 and contoured as isograds. All Devonian isograds are based on maximum CAI values for a given control point. The majority of the samples with recoverable conodont elements are located in the Plateau province (22 of 24) with a single sample located in the Valley and Ridge province (fig. 8). CAI_{max} values in our collection range between 1.5 and 5. The CAI 5 isograd defines a northeast-trending, oval-shaped region of high thermal maturity in northeastern Pennsylvania centered in Sullivan County. This region of high thermal maturity coincides with the east end of the Rome trough and part of the Scranton gravity high (fig. 9). Concentric, tightly spaced CAI 3.5 to 4.5 isograds further define the northern and western sides of the closed CAI 5 isograd. West of this region of high thermal maturity, CAI isograds decrease to a low of

Figure 8. Devonian maximum conodont alteration index (CAImax) isograds for Pennsylvania based largely on data collected in this study. Also shown are the structural provinces of Pennsylvania (Faill and Nickelson, 1999; Gray and Root, 1999)

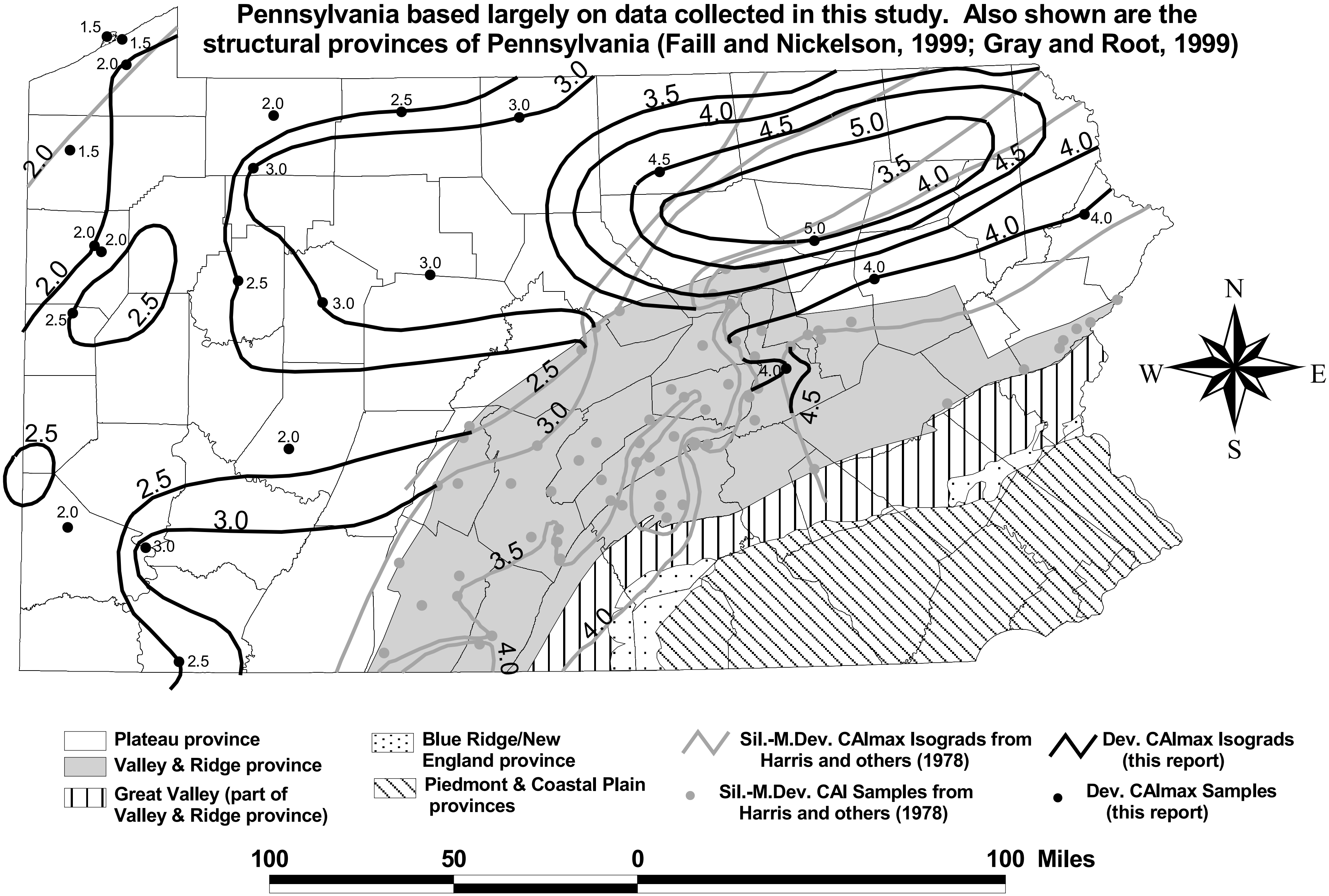
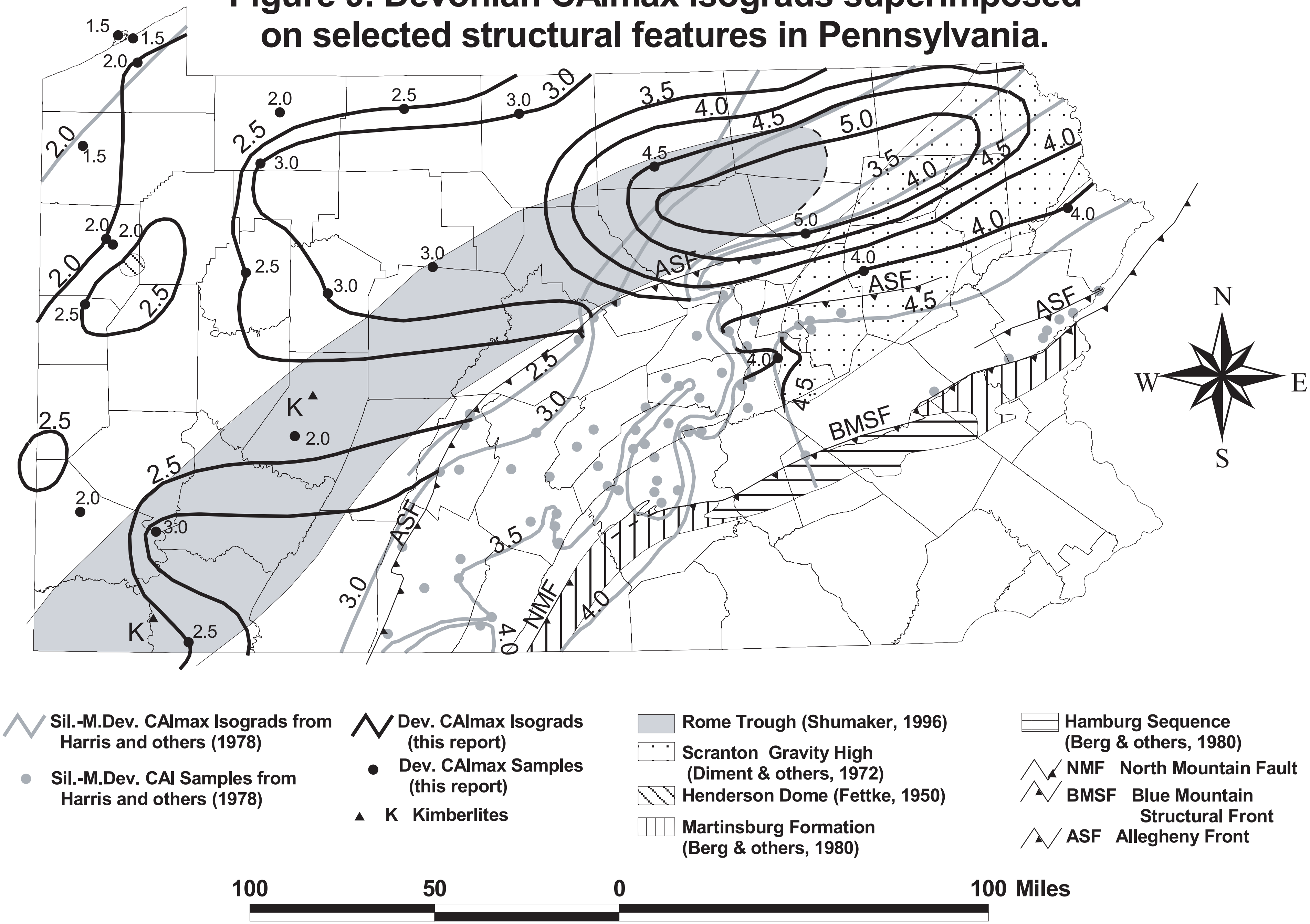


Figure 9. Devonian CAImax isograds superimposed on selected structural features in Pennsylvania.



CAI 1.5 in northwestern Pennsylvania. The intervening CAI 2.5 to 3 isograds closely conform to one another and identify two large, westward-protruding salients of higher thermal maturity (Figs. 8 and 9). Perhaps significantly, the northern salient conforms with the west end of the CAI 3.5 to 5 anomaly. Isograds south of the CAI 3.5 to 5 anomaly are less well constrained but decrease in magnitude to CAI 4 before increasing to CAI 4.5 as reported by Harris and others (1978).

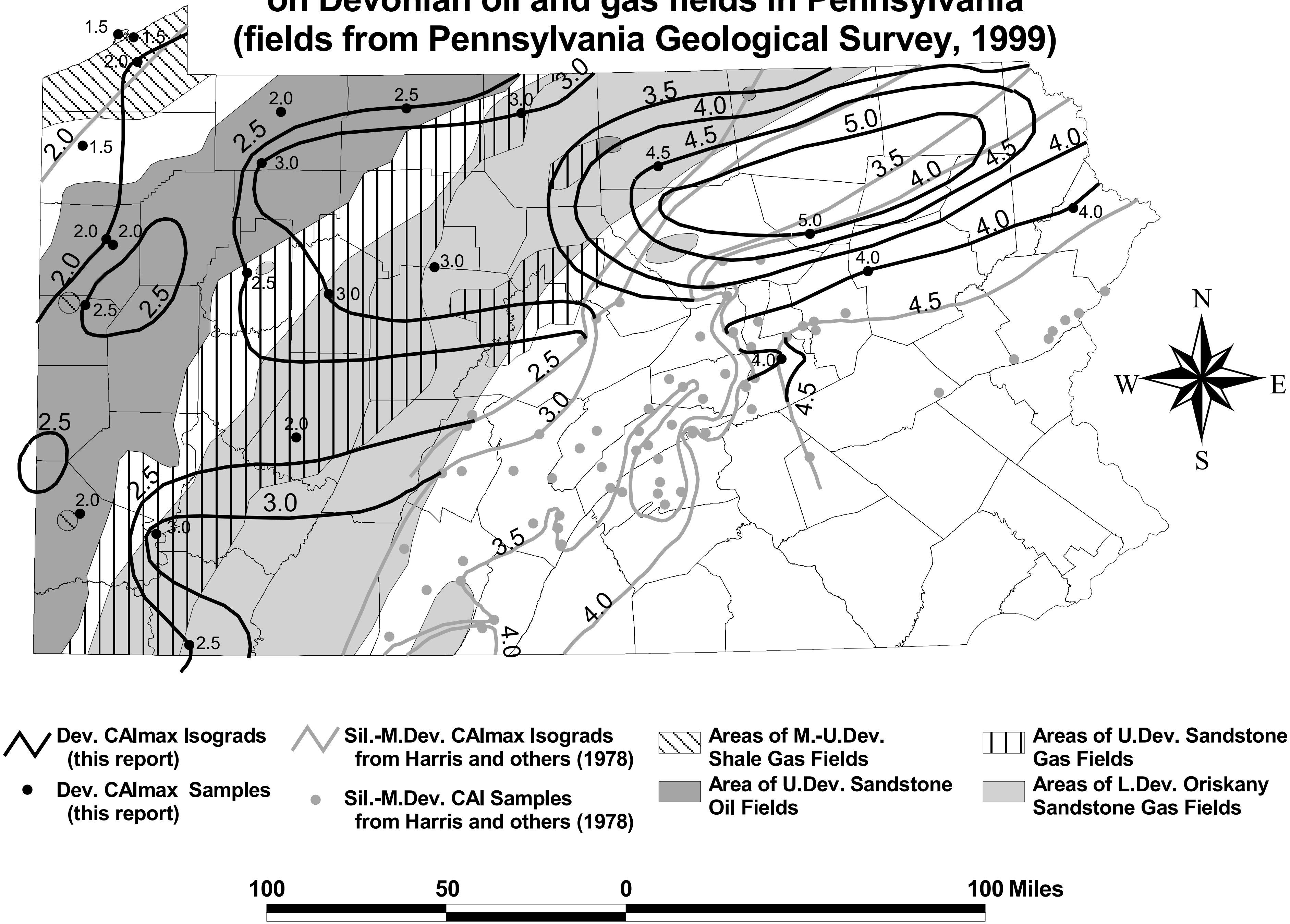
For a comparison to our CAI isograd trends, Silurian through Middle Devonian CAI isograds from Harris and others (1978) were plotted on Figures 8 and 9. This isograd map of Harris and others (1978) was used for a comparison because it most closely approximates the Devonian intervals that we sampled. Harris and others (1978) based the Pennsylvania part of their map exclusively on outcrop collections from the Valley and Ridge province (Fig. 8). Devonian CAI isograds defined here are consistent with those of Harris and others (1978) except in northeastern Pennsylvania where the CAI 3.5 to 5 thermal maturity occurs. This area and adjoining southeastern New York (Weary and others, 2000, 2001; Harris and others, 1978) lacked the necessary subsurface data to document specific trends.

The distribution of CAI isograds in the Plateau province (Figs. 8 and 9) diverge markedly from isopach trends in the Devonian through Permian overburden (de Witt and others, 1975; Harris and others, 1978). For example, in most areas the CAI 2 to 3 isograds cross the isopachs at a high angle. Moreover, the CAI 5 and surrounding isograds in northeastern Pennsylvania indicate a much higher level of thermal maturity than rocks in southwestern Pennsylvania having an equivalent overburden thickness of 8,000 to 10,000 ft. The distribution of Devonian isograd patterns in the Valley and Ridge province (Harris and others, 1978) are generally consistent with eastward thickening overburden isopachs except where a major reentrant of CAI 3 values in south-central Pennsylvania cuts at a high angle across northeast-trending isopachs.

Oil and gas fields in Upper Devonian sandstones and associated CAI isograds in northwestern Pennsylvania are plotted in Figure 10. The oil fields are largely confined to a zone marked by CAI 1.5 to 2.5 isograds whereas the gas fields, located farther eastward, are largely confined to a zone marked by CAI 2.5 to 3.5 isograds. The CAI values correspond with $\%R_o<1$ to 1.5 for oil fields and $\%R_o$ 1.5 to 3 for gas fields (Fig. 7) and are consistent with thermal maturity indices commonly used to define the "window" of oil, wet gas, and dry gas generation and preservation (Dow, 1977; Harris and others, 1978; Tissot and Welte, 1984). Considering that Middle and Upper Devonian black shale, either underlying or laterally equivalent to conodont-bearing Devonian limestone of this study, are probable source rocks for the hydrocarbons in these fields (Laughrey and Baldassare, 1998), the close correlation between CAI isograds and hydrocarbon type implies that the oil and gas in the fields were generated near their respective regions of entrapment. However, stable isotope studies suggest a more complex origin for Upper Devonian sandstone gases that involve mixing of thermogenic and microbial gas (Laughrey and Baldassare, 1998).

Two small Upper Devonian sandstone oil fields in Tioga and Bradford Counties (Fig. 10) are located in a region where dry gas is the expected hydrocarbon type (CAI 3.5; $\%R_o$ 3). These anomalous oil occurrences imply either that locally the oil escaped from being converted to gas or that oil migrated into the region after the main phase of gas generation.

Figure 10. Devonian CAImax isograds superimposed on Devonian oil and gas fields in Pennsylvania (fields from Pennsylvania Geological Survey, 1999)



In general, natural gas fields in the Lower Devonian Oriskany Sandstone of west-central Pennsylvania occupy a region of higher thermal maturity (CAI 3 to 4; $\%R_o$ 2 to 3.5) than the Upper Devonian sandstone gas fields (Fig. 10). Consistent with the higher thermal maturity is the high methane content of the Oriskany gas (Moore, 1982) and stable isotope compositions that indicate a thermogenic origin (Laughrey and Baldassare, 1998). Probably minimal migration was required for the Oriskany gas before entrapment because of its close proximity to the overlying Middle Devonian Marcellus Formation source rock (Harper and Patchen, 1996) that has a thermal maturity similar to the gases ($\%R_o$ 3) (Laughrey and Baldassare, 1998).

Small areas of natural gas accumulation in self-sourced Middle and Upper Devonian black shale in western Pennsylvania are characterized by CAI 1.5 to 2 isograds ($\%R_o$ <1 to 1) which correspond roughly with thermal maturity values expected for a wet thermogenic gas (Fig. 10). The high C_{2+} (wet) composition of the Devonian shale gas is based on a single analysis in Erie County (Laughrey and Baldassare, 1998). The stable isotope composition of the Erie County Devonian shale gas suggests a thermogenic origin with a possible microbial component (Laughrey and Baldassare, 1998).

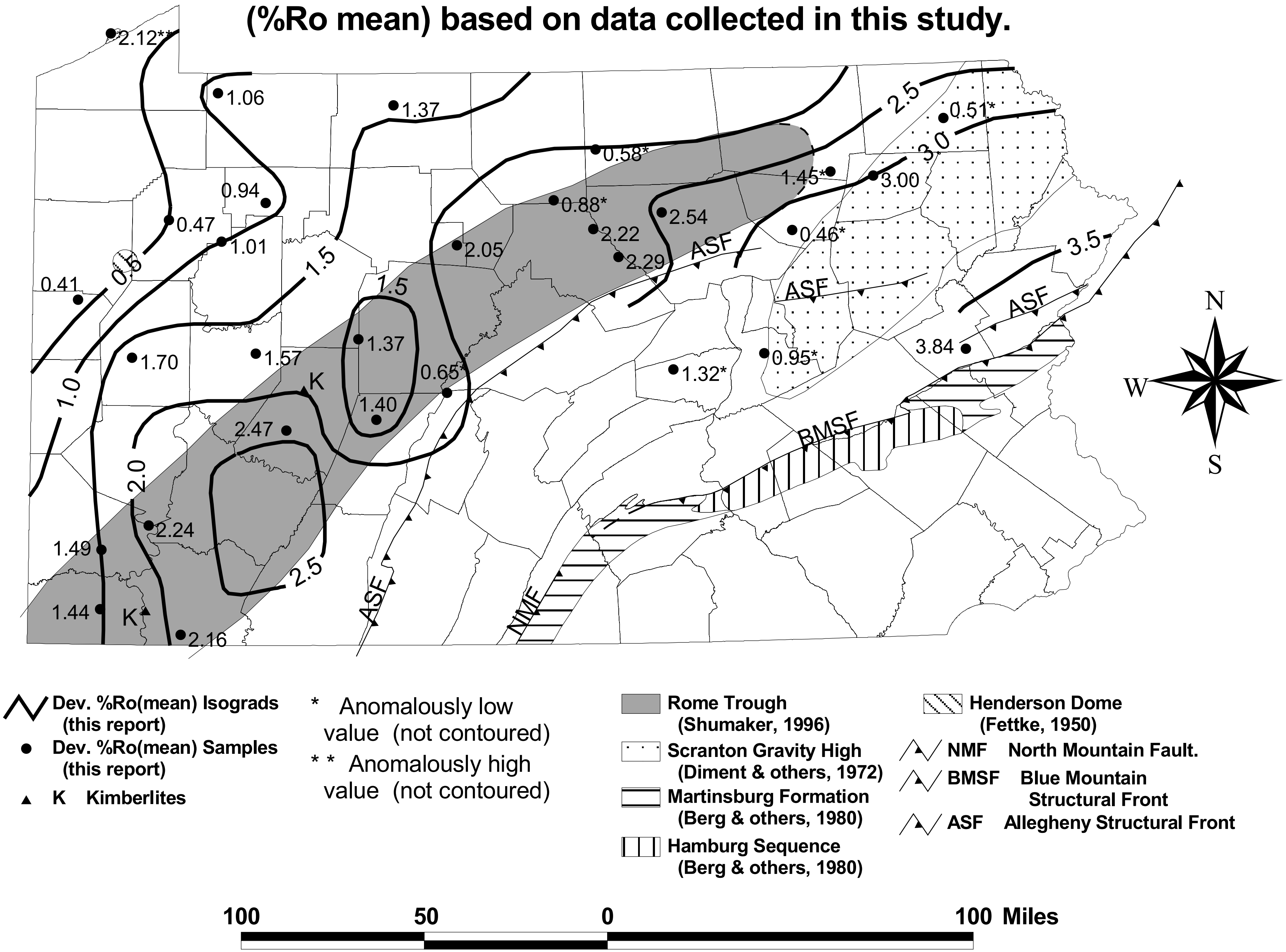
Mean vitrinite reflectance values of Devonian black shale samples (largely Marcellus Formation) are listed in Table 3 and plotted in Figure 11. Of the 30 Devonian shale samples having sufficient dispersed organic matter for analysis, 21 were suitable for identifying regionally consistent isoreflectance lines (Fig. 11). Eight of the nine rejected vitrinite reflectance values were considered anomalously low for a consistent regional pattern whereas one value was considered anomalously high. A low number of readings (2 to 8) may explain anomalous values for 4 of the 9 rejected samples (Table 3).

The trends of the isoreflectance lines are compatible with the Devonian CAI isograds including the westward-bulging salients of higher thermal maturity in northwestern Pennsylvania (Figs. 9 and 11). Also, for a given area, the $\%R_o$ values indicate approximately the same level of thermal maturity as the CAI values. The major difference between the Devonian CAI and $\%R_o$ maps is that the region of high thermal maturity defined by the CAI 5 isograd in northeastern Pennsylvania was not identified by our vitrinite data. Our Devonian vitrinite reflectance map (Fig. 11) is consistent with the vitrinite reflectance map compiled by T. Hamilton-Smith (in Boswell, 1996) and the Thermal Alteration Index (TAI) map of Laughrey and Baldassare (1998). In contrast to other related investigations, our vitrinite reflectance map indicates a slightly higher thermal maturity for the Devonian shale of northwestern Pennsylvania than the map of Streib (1981), and, in Clinton County, central Pennsylvania, our reported $\%R_o$ values (2.22 and 2.29) are slightly below the $\%R_o$ 3 value reported by Laughrey and Harper (1996).

Discussion

Ordovician CAI isograds and Devonian CAI isograds/$\%R_o$ isoreflectance lines identified in this investigation indicate much greater paleotemperatures than can be explained by the existing overburden. Other thermal maturity investigations in Pennsylvania have led to similar conclusions: fluid inclusions (Nickelsen, 1983; Orkan and Voight, 1985; Lacazette, 1991; Evans, 1995), $\%R_o$/coal rank (Levine, 1983, 1986; Zhang and Davis, 1993), and apatite fission tracks (Roden and Miller, 1989). Several

Figure 11. Devonian vitrinite reflectance values (%Ro mean) based on data collected in this study.



explanations may account for the discrepancies in thermal maturity values and accompanying present-day overburden: 1) deep burial beneath thick Carboniferous and Permian overburden that has since been removed by Mesozoic and Tertiary erosion; 2) high heat flow caused by crustal thinning and igneous activity; 3) high heat flow caused by hot, migrating basinal fluids; and 4) an additional increase in temperature of the basin caused by insulating properties of beds with low thermal conductivity.

Harris and others (1978) favored the excess overburden explanation because of similar trends in CAI isograds and overburden isopachs. Moreover, MacLachlan (1999) favored this hypothesis based on coal-rank maps that show a southeastward increase in maximum coal-bed overburden from 2 km in northwestern Pennsylvania to over 8 km in eastern Pennsylvania and that conform to the northeast-trending structural grain of the state. Similarly, Levine (1986) reported former overburden thicknesses of 6 to 8 km in the Anthracite region (Lackawanna and Luzerne Counties) of eastern Pennsylvania. These interpreted overburden thicknesses are atypical for molasse overburden thicknesses and suggested to Levine (1986) either rapid sedimentation or large-scale tectonic displacement such as the Anthracite thrust sheet (nappe) proposed by Orkan and Voight (1985) and MacLachlan (1999).

Although overburden thickness is a very important control on the distribution of thermal maturity values identified in this study, marked differences between CAI isograds and overburden isopachs — previously described in the Results sections — argue for an additional mechanism. We suggest that an elevated geothermal flux caused by crustal thinning and the emplacement of mantle-derived rocks is a contributing factor. Paleogeothermal gradients between 31^{o} and 40^{o} C/km (Hower and Davis, 1983; Levine, 1983; Orkan and Voight, 1985; Lacazette, 1991), which exceed those in typical foreland basins, support our hypothesis. Ordovician CAI 5 isograd patterns in this report suggest that high heat flow was introduced through extended crust in the vicinity of the Rome trough and Scranton gravity high (Fig. 5). Elevated heat flow values probably were greatest during the initial phases of rifting in the Middle Cambrian and tapered off gradually into the Late Ordovician. Early Mesozoic reactivation of the Rome trough and Scranton gravity high in the early Mesozoic may have introduced a second phase of high heat flow. Additional high heat flow may have been concentrated in Mercer and Butler Counties where closely spaced CAI 2 to 3 isograds are recorded (Fig. 5). This possible heat-flow anomaly could be related to the structural events accompanying the complex Henderson dome (Kuminecz and Gorham, 1993) or the western limit of extended crust (Beardsley and others, 1999).

The Devonian CAI 5 isograd in northeastern Pennsylvania (Fig. 9) may have resulted from high heat flow during Mesozoic extension and probable reactivation of the Rome trough and structures associated with the Scranton gravity high. Mesozoic kimberlite intrusions exposed in southwestern Pennsylvania along the trend of the Rome trough (Parrish and Lavin, 1982; Phipps, 1988; Shultz, 1999) are consistent with these suggested events. In outcrop, the kimberlites are small and have a minor alteration halo but at depth they may merge with larger igneous bodies that have regional thermal influence. Such magmatic bodies may underlie the Scranton gravity high (Diment and others, 1972; Hawman and Phinney, 1992) and the Rome trough of southwestern and northeastern Pennsylvania as suggested by high-intensity aeromagnetic anomalies (Zeitz and others, 1980). The proposed magmatism could be Cambrian/Ordovician and (or)

Mezozoic in age. Apatite fission-track studies in the Plateau province indicate a Jurassic-Early Cretaceous thermal event that may have resulted from kimberlite intrusion (Roden and Miller, 1989).

Westward-bulging salients in the Devonian CAI 2.5 and 3 isograds (Fig. 9) may represent migration routes of hot, basin-derived fluids. Curiously, the southern salient is very close to a high thermal maturity anomaly in the Kittanning coal bed perhaps caused by a post-Pennsylvanian phase of fluid flow (Zhang and Davis, 1993). Based on model studies, Zhang and Davis (1993) proposed that the fluid-flow event was associated with a geothermal gradient of 31^{o} to 33^{o}C/km. If these salients in the Devonian CAI isograds are indeed caused by the shelfward flow of hot, basin-derived fluids, the prevailing concept that considers their flow rates to be too high to leave a measurable CAI imprint is in need of revision (Dorobek, 1989).

Cercone and others (1996) suggested that coal- and carbonaceous shale-bearing Carboniferous strata had an important effect on the temperature history of the Appalachian Basin. They proposed that the coal and carbonaceous shale units acted as an insulator, thereby increasing the temperature of underlying rocks to a degree that may account for anomalous thermal maturity values in the basin. Although plausible, this mechanism must be tested with burial history models to determine the range of thermal maturity indices that would be expected under given insulating conditions.

Reasons are obscure for the thermal isolation of the central Valley and Ridge province, characterized by Ordovician CAI 4 values, from surrounding areas having CAI 4.5 to 5 values (Fig. 5). Perhaps the central Valley and Ridge represents a more stable tectonic block that escaped major crustal extension and magmatic intrusion. A similar pattern occurs regarding the distribution of Devonian CAI 3 values in the central Valley and Ridge province except here the zone of lower CAI values is less confined and cuts northward across the Allegheny structural front into the Plateau province.

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TABLE 1. Conodont data from Ordovician samples from the subsurface of Pennsylvania.

COUNTY API number[1] USGS Collection Number	WELL NAME; FOOTAGE (Latitude North/ Longitude West)	STRATIGRAPHIC UNIT (Based on picks provided by the Pennsylvania Department of Natural Resources)	CORE? OR CUTTINGS	CONODONT FAUNA	AGE RANGE OF CONODONTS	CAI	REMARKS
Armstrong 005-21201 11911-CO	No. 1 Nellie Martin; 12280-12400 40.88483/ -79.34708	Black River	cuttings	1 *Phragmodus inflexus* Stauffer; P element 1 unassigned oistodontiform element 2 indeterminate fragments	Middle Ordovician; *C. sweeti* - *P. undatus* Zone (late Chazyan to Rocklandian)	4-4.5	2.1 g of rock processed (trace of insoluble residue remained)
Bedford 009-20013 no USGS colln #	Mary Martin; 1490-1700 39.94557/ -78.60438	Trenton	cuttings	BARREN	Not determined	n/a	106 g rock processed (37.8 g +20-mesh, and 8 g 20-200 mesh insoluble residue
Bedford 009-90002 no USGS colln #	Jessie Miller; 7913-8130 40.10688/ -78.61926	Trenton	cuttings	BARREN	Not determined	n/a	117.1 g rock processed (22.9 g +20-mesh, and 6 g 20-200 mesh insoluble residue
Butler 019-90063 11912-CO	Hockenberry; 8812-9202 41.10660/ -80.04028	Trenton & Black River	cuttings	2 fragments of coniform elements; indet. to gen. & sp.	Middle or Late Ordovician	2-3	105.3 g rock processed (12.6 g +20-mesh, and 2 g 20-200 mesh insoluble residue)
Centre 027-20001 11913-CO	Long; 14,850-14,960 40.99410/ -77.60144	Trenton	cuttings	1 *Pseudooneotodus mitratus* (Moskalenko) element, with basal "funnel" attached 1 unassigned oistodontiform element 1 indet. hyaline element process fragment 1 indet. albid element fragment	Middle or Late Ordovician	4.5	117.1 g rock processed (34.2 g +20-mesh, and 6 g 20-200 mesh insoluble residue). One fragment of a hindeodelloid element fragment in this sample, w/somewhat lower CAI, is considered downhole contaminant.
Clinton 035-20276 11914-CO	No. 1 PA Tract 285; 14,5000-14,670 41.37129/ -77.56662	Trenton	cuttings	*Phragmodus undatus* Branson & Mehl 2 P, 3 S, 1 M elements 4 indet. gen. & spp.; element fragments 4 indet. fragments.	late Middle or Late Ordovician; *Ph. undatus* Zone to end of Ordovician (latest Blackriveran to latest Gamachian)	4.5-5	118.5 g rock processed (10.6 g +20-mesh, and 7 g 20-200 mesh insoluble residue).

[1]Because all samples are from Pennsylvania, the state API prefix, 037-, was omitted for brevity.

COUNTY API number[1] USGS Collection Number	WELL NAME; FOOTAGE (Latitude North/ Longitude West)	STRATIGRAPHIC UNIT (Based on picks provided by the Pennsylvania Department of Natural Resources)	CORE? OR CUTTINGS	CONODONT FAUNA	AGE RANGE OF CONODONTS	CAI	REMARKS
Crawford 039-20007 11915-CO	Kardosh; 6290-6400 41.71556/ -80.30705	Trenton	cuttings	2 *Belodina compressa* (Branson & Mehl) elements 1 *Panderodus gracilis* (Branson & Mehl) element 2 *Panderodus* sp. elements *Phragmodus undatus* Branson & Mehl 4 P, 7 S elements 1 *Polyplacognathus ramosus* Stauffer 2 *Polyplacognathus* or *Cahabagnathus* sp. element fragments 1 indet. gen. & sp. fragment 4 indet. conodont fragments	late, but not latest, Middle Ordovician; *Ph. undatus* Zone to lowest *B. confluens* Zone (= latest Blackriveran - middle Shermanian)	1.5	110 g rock processed (18 g +20-mesh, and 2 g 20-200 mesh insoluble residue). Sample contains about 20 fish fragments.
Erie 049-20040 11916-CO	PA Forest & Waters Block 1; 4291-4756 42.01422/ -80.44298	Trenton & Black River	cuttings	2 *Panderodus gracilis* (Branson & Mehl) elements 1 unassigned oistodontiform (M) element 7 indet. conodont fragments	Middle or Late Ordovician; *C. friendsvillensis* Zone to end of Ordovician (Chazyan to latest Gamachian)	1.5-2	116 g rock processed (28.5 g +20-mesh, and 2 g 20-200 mesh insoluble residue). One polygnathid P element fragment in this sample, w/CAI of 1.5, is considered most likely downhole contaminant.
Erie 049-20049 11917-CO	PA Forest & Waters Block 2; 4181-4308 42.25160/ -79.91120	Trenton	cuttings	1 *Belodina compressa* (Branson & Mehl) element 2 *Drepanoistodus suberectus* (Branson & Mehl) ; drepanodontiform elements *Phragmodus undatus* Branson & Mehl 2 P, 2 S, 1 M elements 1 *"Oistodus" pseudoabundans* Schopf 1 unassigned coniform element 1 indet. coniform element 1 indet. conodont element fragment	late, but not latest, Middle Ordovician; *Ph. undatus* Zone to lowest *B. confluens* Zone (= latest Blackriveran - middle Shermanian)	1.5	112 g rock processed (1 g 20-200 mesh insoluble residue). Sample contains about 9 fish fragments.
Franklin 055-90000 no USGS colln #	#2 Amerile; 1478-1598 40.18459/ -77.67705	Trenton	cuttings	BARREN	Not determined	n/a	120 g rock processed (20 g +20-mesh, and 8 g 20-200 mesh insoluble residue).
Juniata 067-20001 11918-CO	Shade Mt.; 3870-3970 40.68637/ -7728083	Trenton	cuttings	1 *Drepanoistodus*? sp. indet.; drepanodontiform element fragment 3 *Phragmodus* sp. indet.; S elements 2 indet. conodont element fragments	Middle or Late Ordovician; *Histiodella holodentata* Zone to end of Ordovician (late Whiterockian to latest Gamachian)	4	108 g rock processed (16 g +20-mesh, and 2 g 20-200 mesh insoluble residue).

COUNTY API number[1] USGS Collection Number	WELL NAME; FOOTAGE (Latitude North/ Longitude West)	STRATIGRAPHIC UNIT (Based on picks provided by the Pennsylvania Department of Natural Resources)	CORE? OR CUTTINGS	CONODONT FAUNA	AGE RANGE OF CONODONTS	CAI	REMARKS
McKean 083-33511 11919-CO	Say; 9400-9590 41.86731/ -78.61435	Trenton/ Black River	cuttings	1 *Panderodus gracilis* (Branson & Mehl) 1 *Panderodus*? sp. element fragment *Plectodina*? sp. or *Aphelognathus*? sp. 1 Sb element 3 indet. element fragments	Middle or Late Ordovician; *C. friendsvillensis* Zone to end Ordovician (Chazyan through Gamachian)	2.5-3	220.1 g rock processed (28.6 g +20-mesh, and 21 g of 20-200 mesh insoluble residue).
McKean 083-22529 11920-CO	Minard Run #1 Moody Lot 9050-9480 41.88214/ -78.61509	Trenton/ Black River	cuttings	1 *Phragmodus* cf. *Ph. undatus* Branson & Mehl; S element 1 *Phragmodus* sp., *Plectodina* sp., or *Aphelognathus* sp.; Sc element fragment 3 indet. element fragments	Late Middle or Late Ordovician; most likely *Ph. undatus* Zone to end of Ordovician (= latest Blackriveran through Gamachian)	2.5-3	50.8 g rock processed (9 g +20-mesh, and 2 g of 20-200 mesh insoluble residue).
Mercer 085-20004 11921-CO	McKnight; 6844 ft 41.31989/ -80.46161	Trenton	core	1 *Dapsilodus* cf. *D. mutatus* (Branson & Mehl) element *Phragmodus undatus* Branson & Mehl 4 S, 1 M elements 2 indet. conodont element fragments	late, but not latest, Middle or Late Ordovician; *Ph. undatus* Zone to end of Ordovician (= latest Blackriveran - middle Shermanian)	1.5	159.5 g rock processed (1.5 g +20-mesh, and 3 g 20-200 mesh insoluble residue).
Mercer 085-22421 11907-CO	#4 Montgomery; 8495 ft 41.21769/ -80.04119	Trenton	sidewall core	1 *Eoplacognathus*? sp. or *Polyplacognathus ramosus* Stauffer; distal process fragment 1 *Erismodus*? sp.; distal process fragment	Middle to earliest Late Ordovician (Chazyan to lower part of *B. confluens* Zone). Age-range partially constrained by underlying samples.	~2	26 g rock processed (21 g 20-200 mesh insoluble residue).
Mercer 085-22421 11908-CO	#4 Montgomery; 8530 ft 41.21769/ -80.04119	Trenton	sidewall core	1 *Ansella* sp. element 1 *Drepanoistodus* sp.; drepanodontiform element 1 *"Oistodus" venustus* Stauffer element 8 *Panderodus gracilis* (Branson & Mehl) *Phragmodus inflexus* Stauffer; 4 Pb elements *Phragmodus undatus* Branson & Mehl; 17 P; 34 S; 15 M elements	Middle Ordovician (late-Chazyan to Rocklandian; *C. sweeti* to *Ph. undatus* Zone)	2 - 2.5	18 g rock processed (1.5 g 20-200 mesh insoluble residue).
Mercer 085-22421 11909-CO	#4 Montgomery; 8600 ft 41.21769/ -80.04119	Trenton	sidewall core	1 *Drepanoistodus* sp.; drepanodontiform element 4 *Panderodus* cf. *P. gracilis* (Branson & Mehl) 1 genus & species indet.; P element frag. 1 indet. conodont element fragment	Mid- to late Middle Ordovician (mid-Chazyan to Rocklandian). Age constrained by samples above and below.	2-2.5	23 g rock processed (2.4 g 20-200 mesh insoluble residue).

COUNTY API number[1] USGS Collection Number	WELL NAME; FOOTAGE (Latitude North/ Longitude West)	STRATIGRAPHIC UNIT (Based on picks provided by the Pennsylvania Department of Natural Resources)	CORE? OR CUTTINGS	CONODONT FAUNA	AGE RANGE OF CONODONTS	CAI	REMARKS
Mercer 085-22421 11910-CO	#4 Montgomery; 9019 ft 41.21769/ -80.04119	Black River Gp.	sidewall core	1 *Coleodus*? sp.; small posterior fragment 1 *Drepanoistodus* cf. *D. angulensis* (Harris); M element 2 *Drepanoistodus*? sp.; fragments 1 *Microzarkodina*? sp.; P element 1 *Phragmodus inflexus* Stauffer; Pa element 1 indet. genus & species 1 indet. hyaline sp.; distal process fragment 6 indet. element fragments	Mid- to late Middle Ordovician (mid-Chazyan to Blackriveran)	2.5	16 g rock processed (15 g 20-200 mesh insoluble residue).
Mercer 085-90010 11922-CO	Maude Davidson 8220-8380 ft 41.27245/ -80.01601	Trenton	cuttings	1 *Phragmodus* sp., cf. *Ph. undatus* Branson & Mehl; P element	Middle or Late Ordovician; most likely *Ph. undatus* Zone to end of Ordovician (= latest Blackriveran through Gamachian)	2	119.6 g rock processed (51.1 g +20-mesh, and 2 g 20-200 mesh insoluble residue).
Mifflin 085-20002 11923-CO	PA tract 377 5300-5390 ft 40.51161/ -77.62851	Trenton	cuttings	1 *Ansella*? sp. 2 *Dapsilodus*? cf. *D. mutatus* (Branson & Mehl); costate coniform elements 1 *Drepanoistodus suberectus* (Branson & Mehl); homocurvatiform element *Phragmodus inflexus* Stauffer or *Ph. undatus* Branson & Mehl; 1 P element fragment; 1 M element 2 indet. element fragments	Middle or Late Ordovician; *C. sweeti* Zone to end of Ordovician (late Chazyan to Gamachian)	4	121.8 g rock processed (82 g +20-mesh, and 2 g 20-200 mesh insoluble residue).
Potter 105-20182 11924-CO	No. 1 PA tract 129 13,600-13,695 ft 41.48929/ -77.77445	Trenton	cuttings	1 *Icriodella* sp.; Sb element 3 *Phragmodus* sp.; S element fragments 1 indet. element frag.	Middle or Late Ordovician; most likely *Ph. undatus* Zone to end of Ordovician (= latest Blackriveran through Gamachian)	4.5	120 g rock processed (63.2 g +20-mesh, and 3 g 20-200 mesh insoluble residue).
Somerset 111-20045 10750--52-CO	Svetz 15,400-15,900 ft 39.97776/ -79.33387	Trenton & Black River	cuttings	3 *Phragmodus* sp. indet. or *Plectodina* sp. indet.; P elements 1 unassigned M element	Middle or Late Ordovician; *Phragmodus pre-flexuosus* Zone to end of Ordovician (late Whiterockian to latest Gamachian)	5	Compilation of three samples, of 100 to 200 g each; reported in Ryder and others, 1992 (USGS Bulletin 1839-K, p. K7).
Sullivan 113-20002 11925-CO	Dieffenbach 16,470-16,610 ft 41.35469/ -76.46890	Trenton	cuttings	1 oistodontiform (M) element, cf. *Phragmodus* sp.	Middle or Late Ordovician; *Phragmodus pre-flexuosus* Zone to end of Ordovician (late Whiterockian to latest Gamachian)	5	119.3 g rock processed (53 g +20-mesh, and 7 g 20-200 mesh insoluble residue).

COUNTY API number[1] USGS Collection Number	WELL NAME; FOOTAGE (Latitude North/ Longitude West)	STRATIGRAPHIC UNIT (Based on picks provided by the Pennsylvania Department of Natural Resources)	CORE? OR CUTTINGS	CONODONT FAUNA	AGE RANGE OF CONODONTS	CAI	REMARKS
Tioga 117-20057 11926-CO	No. 1 Dewey 11,880-12,020 ft 41.68940/ -77.54698	Trenton	cuttings	1 *Belodina compressa* (Branson & Mehl) 1 *Dapsilodus* sp. or *Besselodus* sp.; costate coniform element *Phragmodus* sp. cf. *Ph. undatus* Branson & Mehl; 3 P and 1 S elements 8 indet. conodont element fragments	late Middle Ordovician; *B. compressa* to *Pl. tenuis* Zone (mid-Blackriveran to mid-Shermanian Stage)	4.5	118.4 g rock processed (16.8 g +20-mesh, and 8 g 20-200 mesh insoluble residue). Heavy-fraction residue also contains 7 fish fragments and 1 phosphatized scolecodont frag.
Union 119-90000 no USGS foss. #	Solomon 5951-6273 ft 40.89736/ -76.97566	Trenton & Black River	cuttings	BARREN	Not determined	n/a	119.7 g rock processed (32.6 g +20-mesh, and 11 g 20-200 mesh insoluble residue).
Warren 123-20150 11927-CO	Shaw 8333-8452 ft 41.65390/ -79.36919	Trenton	cuttings	*Drepanoistodus* cf. *D. angulensis* (Harris); 2 drepanodontiform, 1 oistodontiform elements 2 *"Oistodus" venustus* Stauffer elements *Phragmodus inflexus* Stauffer; 1 P element *Phragmodus inflexus* or *Ph. undatus* Branson & Mehl; 3 P, 9 S, 6 M elements 8 indet. conodont element fragments	Middle Ordovician (late-Chazyan to Rocklandian; *C. sweeti* to *Ph. undatus* Zone)	2.5-3	118.9 g rock processed (27 g +20-mesh, and 2 g 20-200 mesh insoluble residue). Heavy-fraction residue also contains 8 fish fragments
Warren 123-20609 11928-CO	Marsh Childs 7020-7360 ft 41.95339/ -79.20122	Trenton	cuttings	1 *Ansella* sp. indet. 1 *Belodina* cf. *B. compressa* (Branson & Mehl) *Phragmodus* sp. or *Plectodina* sp.; 2 P elements 1 indeterminate (M?) element 1 indet. conodont element fragment	Middle Ordovician; most likely *B. compressa* to *Pl. tenuis* Zone (mid- Blackriveran to mid-Shermanian Stage)	2-2.5	118.5 g rock processed (24.7 g +20-mesh, and 5 g 20-200 mesh insoluble residue). Heavy-fraction residue also contains 4 fish fragments

TABLE 2. Conodont data from Devonian samples from the subsurface of Pennsylvania.

COUNTY API number[1] USGS Collection Number	WELL NAME; FOOTAGE (Latitude North/ Longitude West)	STRATIGRAPHIC UNIT (Based on picks provided by the Pennsylvania Department of Natural Resources)	CORE OR CUTTINGS	CONODONT FAUNA	AGE RANGE OF CONODONTS	CAI	REMARKS
Allegheny 003-20980 13001-SD	No. 1 Combustion Engineering; 7495 ft 40.19721/ -79.90056	Onondaga	core	5 *Polygnathus* sp.; P elements of the *Po. costatus* group 1 unassigned M element 1 unassigned S element 10 indet. conodont element fragments	Middle Devonian	3	245.3 g rock processed (ca. 6 g 20-200 mesh insoluble residue)
Allegheny **003-90000** **no USGS colln #**	Backhaus; 6040-6090 ft 6335-6370 ft 6470-6622 ft 40.59995/ -79.91389	Tully, Onondaga, & Helderberg	cuttings	BARREN	Not determined	n/a	117.8 g rock processed 90 g +20-mesh, and 6 g 20-200 mesh insoluble residue)
Armstrong 005-01238 no USGS colln.#	#4 Lowry Martin; 6120-6181 ft 6560-6576 ft 6691-6729 ft 40.88819/ -79.35467	Tully, Onondaga, & Helderberg	cuttings	BARREN	Not determined	n/a	104.9 g rock processed 69.7 g +20-mesh, and 5 g 20-200 mesh insoluble residue)
Beaver 007-00007 no USGS colln.#	Jones & Laughlin Steel; 5255 ft 40.60894/ -80.23967	Onondaga	core	BARREN	Not determined	n/a	344 g rock processed 154.3 g +20-mesh, and 8 g 20-200 mesh insoluble residue)
Blair 013-20001 no USGS colln.#	PA Tract 26A; 6775-6785 ft 6940-6960 ft 40.31535/ -78.58459	Onondaga & Helderberg	cuttings	BARREN	Not determined	n/a	122.8 g rock processed 69.5 g +20-mesh, and 4 g 20-200 mesh insoluble residue)

[1]Because all samples are from Pennsylvania, the state API prefix, 037-, was omitted for brevity.

COUNTY API number[1] USGS Collection Number	WELL NAME; FOOTAGE (Latitude North/ Longitude West)	STRATIGRAPHIC UNIT (Based on picks provided by the Pennsylvania Department of Natural Resources)	CORE OR CUTTINGS	CONODONT FAUNA	AGE RANGE OF CONODONTS	CAI	REMARKS
Bradford 015-90005 no USGS colln.#	Carver; 4216-4267 ft 4544-4601 ft 41.98216/ -76.67825	Onondaga & Helderberg	cuttings	BARREN	Not determined	n/a	120.2 g rock processed 22.3 g +20-mesh, and 7 g 20-200 mesh insoluble residue)
Bradford 015-90006 no USGS colln.#	French; 2837-3054 ft 41.70710/ -76.68608	Tully	cuttings	BARREN	Not determined	n/a	101.7 g rock processed 44 g +20-mesh, and 2 g 20-200 mesh insoluble residue)
Butler 019-90063 no USGS colln #	Hockenberry; 4483-4540 ft 4702-4828 ft 4841-4987 ft 41.10660/ -80.04028	Tully, Onondaga, & Helderberg	cuttings	BARREN	Not determined	n/a	97.4 g rock processed (54.7 g +20-mesh, and 20 g 20-200 mesh insoluble residue).
Cameron 023-90070 no USGS colln #	Dodge Lumber Co.; 5376-5471 ft 41.35798/ -78.10573	Tully	cuttings	BARREN	Not determined	n/a	118.4 g rock processed (27.1 g +20-mesh, and 13 g 20-200 mesh insoluble residue).
Centre 027-90007 no USGS colln #	City of Philadelphia; 7125-7312 ft 41.12486/ -77.98011	Tully	cuttings	BARREN	Not determined	n/a	113.2 g rock processed (48.6 g +20-mesh, and 11 g 20-200 mesh insoluble residue).
Clarion 031-90001 13002-SD	#33 Bryner; 5214-5250 ft 5528-5529 ft 41.22228/ -79.44284	Tully & Onondaga	cuttings	2 indeterminate conodont element fragments	Post-Early Ordovician Paleozoic	2-2.5	117.6 g rock processed (76.4 g +20-mesh, and 2 g 20-200 mesh insoluble residue).
Clearfield 033-20050 no USGS colln #	#6 Hopkins; 7222-7358 ft 41.06590/ -78.69477	Helderberg	cuttings	BARREN	Not determined	n/a	110.2 g rock processed (79.1 g +20-mesh, and 7 g 20-200 mesh insoluble residue).

COUNTY API number[1] USGS Collection Number	WELL NAME; FOOTAGE (Latitude North/ Longitude West)	STRATIGRAPHIC UNIT (Based on picks provided by the Pennsylvania Department of Natural Resources)	CORE OR CUTTINGS	CONODONT FAUNA	AGE RANGE OF CONODONTS	CAI	REMARKS
Clinton 035-90051 no USGS colln #	No. 1 Chatham Water Works; 7304-7388 41.25873/ -77.43576	Tully	cuttings	BARREN	Not determined	n/a	119.5 g rock processed (64.5 g +20-mesh, and 3 g 20-200 mesh insoluble residue).
Columbia 037-90000 no USGS colln #	Knarr; 6230-6358 ft 6478-6501 ft 40.88540/ -76.40415	Onondaga & Helderberg	cuttings	BARREN	Not determined	n/a	115 g rock processed (81 g +20-mesh, and 2 g 20-200 mesh insoluble residue).
Crawford 039-20007 13003-SD	Kardosh; 2860-2960 ft 41.71556/ -80.30705	Onondaga	cuttings	2 indet. probable conodont element fragments	Post-medial Late Cambrian Paleozoic	1.5	116.4 g rock processed (42.6 g +20-mesh, and 7 g 20-200 mesh insoluble residue).
Elk 047-00060 no USGS colln #	No. 1 PA Tract 26A; 6175-6294 ft 41.31466/ -78.28713	Tully	cuttings	BARREN	Not determined	n/a	122.4 g rock processed (75.9 g +20-mesh, and 3 g 20-200 mesh insoluble residue).
Elk 047-20033 13004-SD	PA Tract 83; 6487 ft 41.24437/ -78.47030	Onondaga	core	1 *Belodella* sp. element 2 robust prioniodinid elements; 1 Sb, 1 Sc 3 indet. denticulate bar element fragments	Silurian to Late Devonian (Frasnian)	3	214.8 g rock processed (61.8 g +20-mesh, and 6 g 20-200 mesh insoluble residue).
Erie 049-20040 no USGS colln #	PA Forest & Waters Block 1; 1103-1149 ft 1270-1478 ft 42.01422/ -80.44298	Tully & Onondaga	cuttings	BARREN	Not determined	n/a	21.7 g rock processed (3 g 20-200 mesh insoluble residue).
Erie 049-20109 13005-SD	#2 Hammermill; 1390-1590 ft 42.14278/ -80.04756	Onondaga	cuttings	1 *Icriodus* sp.; P element fragment 1 ozarkodinid P element fragment 2 indet. denticulate bar element fragments: 1 Sa, I P or Sc element	Devonian	1.5	103.4 g rock processed (30.3 g +20-mesh, and 2 g 20-200 mesh insoluble residue).

COUNTY API number[1] USGS Collection Number	WELL NAME; FOOTAGE (Latitude North/ Longitude West)	STRATIGRAPHIC UNIT (Based on picks provided by the Pennsylvania Department of Natural Resources)	CORE OR CUTTINGS	CONODONT FAUNA	AGE RANGE OF CONODONTS	CAI	REMARKS
Erie 049-20846 10207- 10214-SD, + 5 more SD's	Presque Isle State Park--EGSP-PA 3; 1041-1049.6 ft - (core) 1050-1176 ft - (cuttings) 42.15341/ -80.12695	"Moscow or Ludlowville" = "drillers' Tully" or Hamilton Group	core and cuttings	*Polygnathus linguiformis linguiformis* Hinde gamma morphotype: 18 Pa, 4 Pb, 2 M, 20 S elements *Polygnathus varcus* Stauffer: 3 P, 2 S elements *Polygnathus* sp. (post-latest Early Devonian morphotype): 1 P element fragment *Tortodus intermedius* (Bultynck): 1 Pb, 1 S element 60 indet. bar & blade element fragments	late Middle Devonian, probably earliest late Middle Dev. (*varcus* Zone, probably lower part of zone)	1.5	9 cored intervals comprising 5.47 kg processed (199 g 20-200 mesh insoluble residue), and 24 cuttings intervals comprising 1613 g (195 g insoluble residue). Samples processed and analyzed by A.G. Harris in unpub. USGS internal fossil examination & report (E & R) nos. O&G-80-9 and O&G-80-10
Erie 049-90036 13006-SD	Goodwill-Curley; 2330 ft 42.04683/ -80.02467	Onondaga	core	2 *Icriodus* sp.; P element fragments	Devonian	1.5-2	221.5 g rock processed (183.7 g +20-mesh, and 14 g 20-200 mesh insoluble residue).
Fayette 051-00128 13007-SD	No. 8 Barton Estate; 6510-6652 ft 7401-7500 ft 39.76174/ -79.72861	Tully & Helderberg	cuttings	1 indet. conodont element fragment	Post-medial Late Cambrian Paleozoic	2.5	117.3 g rock processed (68 g +20-mesh, and 2 g 20-200 mesh insoluble residue).
Indiana 063-25073 13008-SD	No. 5 McCall; 7616 ft 40.57894/ -79.18593	Tully	core	1 indet. conodont element fragment	Post-medial Late Cambrian Paleozoic	1.5-2	239.5 g rock processed (2 g 20-200 mesh insoluble residue).
Jefferson 065-90094 13009 -SD	Verstein & Klein; 6077-6101 ft 6181-6226 ft 41.14059/ -79.01815	Onondaga & Helderberg	cuttings	1 *Icriodus* sp.; P element 1 *Polygnathus linguiformis* Hinde, subsp. not determined; Pa element 2 indet. conodont element fragments	Devonian	2.5-3	104.8 g rock processed (56.7 g +20-mesh, and 4 g 20-200 mesh insoluble residue).
Lackawanna 069-20001 no USGS colln #	Richards; 7443-7701 ft 41.41172/ -75.82407	Onondaga	cuttings	BARREN	Not determined	n/a	117.3 g rock processed (36.3 g +20-mesh, and 4 g 20-200 mesh insoluble residue).
Lawrence 073-20022 13010-SD	No. 1 Sokevitz; 3984 ft 41.09201/ -80.28192	Tully	core	2 P element fragments, gen. & sp. indet. 6 indet. conodont element fragments	post-Ordovician Paleozoic	2	172.1 g rock processed (127 g +20-mesh, and 2 g 20-200 mesh insoluble residue).

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Lawrence 073-90004 no USGS colln #	Miller & Myer; 4517-4672 ft 4717-4737 ft 40.94315/ -80.26737	Onondaga & Helderberg	cuttings	BARREN	Not determined	n/a	72.3 g rock processed (58.7 g +20-mesh, and 2 g 20-200 mesh insoluble residue).
Luzerne 079-90000 13011-SD	Galey #1 Harrison; 4800-4906 ft 41.19810/ -76.21936	Helderberg	core	1 indet. conodont element fragment	Post-medial Late Cambrian Paleozoic	3.5-4	223.8 g rock processed (140 g +20-mesh, and 13 g 20-200 mesh insoluble residue).
Lycoming 081-90006 no USGS colln #	No. 1 Hughes; 6212-6258 ft 7410-7420 ft 41.43431/ -77.20386	Tully & Onondaga	cuttings	BARREN	Not determined	n/a	113.6 g rock processed (64 g +20-mesh, and 2 g 20-200 mesh insoluble residue).
McKean 083-37291 13012-SD	Minard Run Oil Co.; 5213 ft 41.86882/ -78.61270	Onondaga	core	1 indet., robust, conodont bar element fragment	Middle Ordovician or later Paleozoic	2.5	201.9 g rock processed (130.4 g +20-mesh, and 2 g 20-200 mesh insoluble residue).
McKean 083-90004 no USGS colln #	#2 Nunn; 3935-3955 ft 4460-4469 ft 41.84989/ -78.33858	Tully & Onondaga	cuttings	BARREN	Not determined	n/a	114.8 g rock processed (73 g +20-mesh, and 1 g 20-200 mesh insoluble residue).
Mercer 085-20036 13013-SD	Temple; 3840-4000 ft 41.35126/ -80.17643	Onondaga	cuttings	1 *Icriodus* sp. indet.; posterior fragment of P element 3 indet. conodont element fragments	Devonian	1.5-2	101.4 g rock processed (53.2 g +20-mesh, and 5 g 20-200 mesh insoluble residue).
Mercer 085-22854 12801-SD	#1 Psensky; 3828-3885 ft 41.32861/ -80.14139	Tully	cuttings	6 indet. conodont element fragments	Ordovician or later Paleozoic	1.5-2	17.2 g of 20-200 mesh air-drilled cuttings (wet-sieved; not acidized) processed through heavy liquid.

COUNTY API number[1] USGS Collection Number	WELL NAME; FOOTAGE (Latitude North/ Longitude West)	STRATIGRAPHIC UNIT (Based on picks provided by the Pennsylvania Department of Natural Resources)	CORE OR CUTTINGS	CONODONT FAUNA	AGE RANGE OF CONODONTS	CAI	REMARKS
Mercer 085-22854 12802-SD	#1 Psensky; 3990-4045 ft 41.32861/ -80.14139	Onondaga	cuttings	48 indet. conodont element fragments	Ordovician or later Paleozoic	1.5-2	32 g of 20-200 mesh air-drilled cuttings (wet-sieved; not acidized) processed through heavy liquid.
Northumberland 097-90000 13014-SD	No. 1 Fox; 1062-1114 ft 40.86429/ -76.68004	Onondaga	cuttings	1 *Belodella* sp. *Icriodus* sp. indet.; 1 P, 1 coniform element fragment	Devonian	4	112.8 g rock processed (21.5 g +20-mesh, and 1 g 20-200 mesh insoluble residue).
Pike 103-20003 13015-SD	PA Tract 163, Texaco # C-1; 8040-8160 ft 41.41653/ -75.14159	Onondaga	cuttings	3 indet. conodont element fragments	Ordovician or later Paleozoic	3.5-4	206.4 g rock processed (152.7 g +20-mesh, and 11 g 20-200 mesh insoluble residue).
Potter 105-20362 no USGS colln #	#5 PA Tract 58; 6688-6690 ft 41.51861/ -77.67726	Helderberg	cuttings	BARREN	Not determined	n/a	127.8 g rock processed (2.7 g +20-mesh, and 2 g 20-200 mesh insoluble residue).
Potter 105-90052 no USGS colln #	Lewis; 4382-4436 ft 41.83892/ -77.85915	Tully	cuttings	BARREN	Not determined	n/a	112.5 g rock processed (52 g +20-mesh, and 2 g 20-200 mesh insoluble residue).
Potter 105-90155 13016-SD	Simpson; 4908-4941 41.84559/ -78.01016	Tully	cuttings	*Polygnathus* sp(p).; 3 Pa, 1 Pb element fragments 2 indet. genus & sp., element fragments 8 indet. conodont element fragments	Devonian	2.5	121.5 g rock processed (70.1 g +20-mesh, and 3 g 20-200 mesh insoluble residue).
Snyder 109-90000 no USGS colln #	No. 1 Albert; 1355-1415 ft 40.80863/ -77.15787	Onondaga	cuttings	BARREN	Not determined	n/a	115.6 g rock processed (49.4 g +20-mesh, and 2 g 20-200 mesh insoluble residue).
Somerset 111-20002 no USGS colln #	Bender; 8305-8333 ft 39.73545/ -79.18871	Onondaga	cuttings	BARREN	Not determined	n/a	103.6 g rock processed (76.6 g +20-mesh, and 2 g 20-200 mesh insoluble residue).

COUNTY API number[1] USGS Collection Number	WELL NAME; FOOTAGE (Latitude North/ Longitude West)	STRATIGRAPHIC UNIT (Based on picks provided by the Pennsylvania Department of Natural Resources)	CORE OR CUTTINGS	CONODONT FAUNA	AGE RANGE OF CONODONTS	CAI	REMARKS
Sullivan 113-90000 13017-SD	No. 1 Bennett 8375 ft 41.35208/ -76.51584	Onondaga	core	*Icriodus* sp(p).; 3 Pa element fragments, 1 M element	Devonian	4.5-5	164 g rock processed (23.2 g +20-mesh, and 2 g 20-200 mesh insoluble residue).
Tioga 117-20056 13018 -SD	S & S Coal Co.; 6250-6320 ft 41.62934/ -77.29862	Tully	cuttings	2 indeterminate conodont element fragments	Post-medial Late Cambrian Paleozoic	4-4.5	120.8 g rock processed (92.5 g +20-mesh, and 1 g 20-200 mesh insoluble residue).
Venango 121-90000 no USGS colln #	Van Camp; 3951-4022 ft 41.55986/ -79.90856	Onondaga	cuttings	BARREN	Not determined	n/a	113.4 g rock processed (74 g +20-mesh, and 4 g 20-200 mesh insoluble residue).
Warren 123-20150 13019-SD	Shaw; 4459-4508 ft 41.65390/ -79.36919	Onondaga	cuttings	1 indet. conodont; denticulate bar element fragment	Ordovician or later Paleozoic	2.5-3	101 g rock processed (67.5 g +20-mesh, and 6 g 20-200 mesh insoluble residue).
Warren 123-90002 13020-SD	No. 1 Keester; 3474-3595 ft 41.85524/ -79.26945	Onondaga	cuttings	1 indeterminate conodont element fragment	Post-medial Late Cambrian Paleozoic	2	107.4 g rock processed (76 g +20-mesh, and 5 g 20-200 mesh insoluble residue).
Washington 125-90076 13021-SD	McBurney; 6198-6253 ft 40.27191/ -80.29244	Tully	cuttings	1 indet. conodont; denticulate bar element fragment	Ordovician or later Paleozoic	2	102.2 g rock processed (43.4 g +20-mesh, and 1 g 20-200 mesh insoluble residue).
Westmoreland 129-90046 no USGS colln #	#3 Giffen; 6332-6378 ft 40.34206/ -79.25717	Tully	cuttings	BARREN	Not determined	n/a	111.8 g rock processed (71 g +20-mesh, and 1 g 20-200 mesh insoluble residue).
Wyoming 131-90000 no USGS colln #	No. 1 Sheehan; 5880-5948 ft 41.55863/ -76.08076	Tully	cuttings	BARREN	Not determined	n/a	118 g rock processed (71.2 g +20-mesh, and 3 g 20-200 mesh insoluble residue).

Table 3. Thermal maturity (CAI, %Ro) and RockEval/TOC data from Ordovician and Devonian samples collected from the subsurface of Pennsylvania.

API NUMBER	COUNTY	QUADRANGLE	LATITUDE (DEC DEG)	LONGITUDE (DEC DEG)	LEASE NAME	FORMATION	SERIES / SYSTEM	CORE	CUTTINGS	INTERVAL SAMPLED	AMOUNT (in grams)
037-003-20980	Allegheny	Monongahela	40.197213	-79.900556	No. 1 Combustion Eng.	MARCELLUS	M. Devonian	X		7494.0	247.0
037-003-20980	Allegheny	Monongahela	40.197213	-79.900556	No. 1 Combustion Eng.	ONONDAGA	M. Devonian	X		7495.0	245.3
037-003-90000	Allegheny	Glenshaw	40.599947	-79.913890	Backhaus	TULLY, ONONDAGA, & HELDERBERG	M. and L. Devonian		X	6040 to 6090, 6335 to 6370, 6470 to 6622	117.8
037-005-01238	Armstrong	Distant	40.888188	-79.354671	#4 Lowrey Martin	TULLY, ONONDAGA, & HELDERBERG	M. and L. Devonian		X	6120 to 6181, 6560 to 6576, 6691 to 6729	104.9
037-005-21201	Armstrong	Distant	40.884827	-79.347075	No.1 Nellie Martin	MARCELLUS	M. Devonian		X	6260 to 6380	57.4
037-005-21201	Armstrong	Distant	40.884827	-79.347075	No.1 Nellie Martin	BLACK RIVER	Ordovician		X	12280 to 12400	2.1
037-007-00007	Beaver	Ambridge	40.608938	-80.239666	Jones & Laughlin Steel	ONONDAGA	M. Devonian	X		5255.0	344.0
037-009-20013	Bedford	Rainsburg	39.945566	-78.604375	Mary Martin	TRENTON	Ordovician		X	1490 to 1700	106.0
037-009-90002	Bedford	Bedford	40.106877	-78.619260	Jessie Miller	TRENTON	Ordovician		X	7913 to 8130	117.1
037-013-20001	Blair	Blue Knob	40.315354	-78.584588	PA Tract 26A	ONONDAGA & HELDERBERG	M. and L. Devonian		X	6775 to 6785, 6940 to 6960	122.8
037-013-20010	Blair	Tipton	40.726696	-78.346141	No.1 Blair Gap Water	MARCELLUS	M. Devonian	X		7049.0	176.1
037-015-20001	Bradford	Colley	41.580615	-76.305884	No.1 Blemle	MARCELLUS	M. Devonian		X	7430 to 7520	114.8
037-015-90005	Bradford	Bentley Creek	41.982162	-76.678252	Carver	ONONDAGA & HELDERBERG	M. and L. Devonian		X	4216 to 4267, 4544 to 4601	120.2
037-015-90006	Bradford	Leroy	41.707097	-76.686076	French	TULLY	M. Devonian		X	2837 to 3054	101.7
037-019-20530	Butler	Butler	40.864015	-79.996474	No.2 Rozic	MARCELLUS	M. Devonian		X	5137 to 5250	119.2
037-019-90063	Butler	Slippery Rock	41.106604	-80.040276	Hockenberry	TULLY, ONONDAGA, & HELDERBERG	M. and L. Devonian		X	4483 to 4540, 4702 to 4828, 4841 to 4987	97.4
037-019-90063	Butler	Slippery Rock	41.106604	-80.040276	Hockenberry	TRENTON & BLACK RIVER	Ordovician		X	8812 to 9202	105.3
037-021-20016	Cambria	Carrolltown	40.621431	-78.715898	No.1 Shero	MARCELLUS	M. Devonian		X	8175 to 8200	113.0
037-023-90070	Cameron	Sinnemahoning	41.357982	-78.105734	Dodge Lumber Co.	TULLY	M. Devonian		X	5376 to 5471	118.4
037-025-20002	Carbon	Palmerton	40.855917	-75.624253	No.1 Graver Estate	MARCELLUS	M. Devonian		X	3140 to 3200	116.7
037-027-20001	Centre	Madisonburg	40.994098	-77.601445	Long	TRENTON	Ordovician		X	14850 to 14960	117.1
037-027-90007	Centre	Snow Shoe	41.124861	-77.980110	City of Philadelphia	TULLY	M. Devonian		X	7125 to 7312	113.2
037-031-20672	Clarion	Kossuth	41.328499	-79.530255	No.2 UNG	MARCELLUS	M. Devonian		X	5080 to 5140	106.4
037-031-90001	Clarion	Clarion	41.222277	-79.442838	#33 Bryner	TULLY & ONONDAGA	M. Devonian		X	5214 to 5250, 5528 to 5529	117.6
037-033-20050	Clearfield	Luthersburg	41.065901	-78.694770	#6 Hopkins	HELDERBERG	L. Devonian		X	7222 to 7358	110.2
037-035-20276	Clinton	Glen Union	41.371292	-77.566622	No.1 PA Tract 285	MARCELLUS	M. Devonian		X	8050 to 8200	101.8
037-035-20276	Clinton	Glen Union	41.371292	-77.566622	No.1 PA Tract 285	TRENTON	Ordovician		X	14500 to 14670	118.5
037-035-90051	Clinton	Jersey Mills	41.258731	-77.435760	No. 1 Chatham Water Works	TULLY	M. Devonian		X	7304 to 7388	119.5
037-035-90051	Clinton	Jersey Mills	41.258731	-77.435760	No. 1 Chatham Water Works	MARCELLUS	M. Devonian		X	8344 to 8383	118.2
037-037-90000	Columbia	Catawissa	40.885401	-76.404148	Knarr	ONONDAGA & HELDERBERG	M. and L. Devonian		X	6230 to 6358, 6478 to 6501	115.0
037-039-20007	Crawford	Harmonsburg	41.715558	-80.307049	Kardosh	ONONDAGA	M. Devonian		X	2860 to 2960	116.4
037-039-20007	Crawford	Harmonsburg	41.715558	-80.307049	Kardosh	TRENTON	Ordovician		X	6290 to 6400	110.0
037-047-00060	Elk	Dents Run	41.314665	-78.287128	No. 1 PA Tract 26	TULLY	M. Devonian		X	6175 to 6294	122.4
037-047-00060	Elk	Dents Run	41.314665	-78.287128	No. 1 PA Tract 26	MARCELLUS	M. Devonian		X	6775 to 6850	122.8

Table 3. Thermal maturity (CAI, %Ro) and RockEval/TOC data from Ordovician and Devonian samples collected from the subsurface of Pennsylvania.

API NUMBER	TOC	S1	S2	S3	Tmax	HI	OI	PI	% Ro(mean)	Number of Ro Readings	Min CAI	Max CAI	Comments Regarding Insoluble Heavy Fraction Mineralogy & Fossils; Other Comments
037-003-20980	5.38	0.13	0.22	0.37	585.00	4.00	7.00	0.37	2.24	15	n/a	n/a	n/a
037-003-20980											3.0	3.0	pyrite(euhedral,fine crystalline)
037-003-90000											n/a	n/a	pyrite(fine crystalline, framboidal, replaced fossils(rods & spines), euhedral), sphalerite, reddish felsitic/arkosic lith fragments, fish fragments(2), silica sponge spicules(2)
037-005-01238											n/a	n/a	pyrite(euhedral, fine crystalline, framboidal, replaced fossils), sphalerite(?)
037-005-21201	5.26	0.63	0.43	0.30	417.00	8.00	6.00	0.59	1.57	14	n/a	n/a	n/a
037-005-21201											4.0	4.5	pyrite(fine crystalline), clear zircons(?), phosphatic bryozoans, silica bryozoans, tubes, ostracodes, dolomitic crinoid columnal
037-007-00007											n/a	n/a	sphalerite, pyrite(euhedral,fine crystalline)
037-009-20013											n/a	n/a	sphalerite, fluorite, pyrite(euhedral,fine crystalline)
037-009-90002											n/a	n/a	pyrite(euhedral,fine crystalline, replaced fossils (echinoderm spicules), sphalerite
037-013-20001											n/a	n/a	pyrite(euhedral, fine crystalline, replaced fossils(rods & spines), framboidal), sphalerite(orange), white mica, detrital pink zircons(?)
037-013-20010	0.26	0.03	0.02	0.33	326.00	8.00	127.00	0.60	0.65	24	n/a	n/a	n/a
037-015-20001	3.23	0.58	0.12	0.29	351.00	4.00	9.00	0.83	1.45	4	n/a	n/a	n/a
037-015-90005											n/a	n/a	pyrite (euhedral, fine crystalline, replaced fossils(rare spines & shelly fragments)), sphalerite(trace)
037-015-90006											n/a	n/a	pyrite(euhedral, fine crystalline, framboidal, replaced fossils(echinoderm spines & rods)), clear fluorite(?), silica echinoderm spines & rods
037-019-20530	0.79	0.29	0.38	0.14	472.00	48.00	18.00	0.43	1.70	21	n/a	n/a	n/a
037-019-90063											n/a	n/a	pyrite(framboidal,fine crystalline), sphalerite, zircon, fluorite/barite, one fish tooth
037-019-90063											2.0	3.0	pyrite(euhedral,fine crystalline), sphalerite,fluorite/barite
037-021-20016	3.03	1.05	0.55	0.49	372.00	18.00	16.00	0.66	1.40	7	n/a	n/a	n/a
037-023-90070											n/a	n/a	pyrite(euhedral,fine crystalline,framboidal,replaced fossils(ostracodes, spines)), sphalerite(trace), chitinozoans, bivalves
037-025-20002	1.46	0.29	0.56	0.20	410.00	38.00	14.00	0.34	3.84	20	n/a	n/a	n/a
037-027-20001											4.5	4.5	pyrite(euhedral,fine crystalline), barite/fluorite, sphalerite
037-027-90007											n/a	n/a	pyrite(fine crystalline,replaced fossils(tapered spines)), sphalerite, barite(trace)
037-031-20672	3.98	1.74	2.01	0.84	443.00	51.00	21.00	0.46	1.01	30	n/a	n/a	n/a
037-031-90001											2.0	2.5	pyrite (fine crystalline, replaced fossils(bryozoans, rods & spines)), sphalerite (tr), silica bryozoans, rods & spines
037-033-20050											n/a	n/a	pyrite(fine crystalline, euhedral, framboidal), sphalerite, barite(?), phosphatic brachiopod(?) shards, phosphatic bryozoan infills
037-035-20276	3.10	0.30	0.13	0.83	358.00	4.00	27.00	0.70	2.22	23	n/a	n/a	n/a
037-035-20276											4.5	5.0	pyrite(euhedral,fine crystalline)
037-035-90051											n/a	n/a	pyrite(euhedral, fine crystalline, replaced fossils(spines, tubes)), silica spines & tubes
037-035-90051	3.56	0.56	0.21	0.73	355.00	6.00	21.00	0.73	2.29	13	n/a	n/a	n/a
037-037-90000											n/a	n/a	pyrite(fine crystalline, euhedral, spheroids, replaced fossils(rods & spines)), sphalerite(tr)
037-039-20007											1.5	1.5	pyrite(euhedral,fine crystalline,spheroidal, framboidal), sphalerite(trace), fluorite
037-039-20007											1.5	1.5	pyrite(euhedral,fine crystalline,replaced fossils, ostracodes(rare)), euhedral dark brown mica, phosphatic fossil fragments common(brachiopods, bryozoan infilling, fish fragments (?), echinoderms, ostracodes, & bivalves)
037-047-00060											n/a	n/a	pyrite(euhedral, fine crystalline, replaced fossils(echinoderm rods & spines), framboidal), sphalerite, fibrous clear mineral; single fragment, probably not conodont
037-047-00060	5.13	1.23	0.39	0.42	352.00	8.00	8.00	0.76	2.05	28	n/a	n/a	n/a

Table 3. Thermal maturity (CAI, %Ro) and RockEval/TOC data from Ordovician and Devonian samples collected from the subsurface of Pennsylvania.

API NUMBER	COUNTY	QUADRANGLE	LATITUDE (DEC DEG)	LONGITUDE (DEC DEG)	LEASE NAME	FORMATION	SERIES / SYSTEM	CORE	CUTTINGS	INTERVAL SAMPLED	AMOUNT (in grams)
037-047-20033	Elk	Huntley	41.244373	-78.470296	PA Tract 83	ONONDAGA	M. Devonian	X		6487.0	214.8
037-049-20040	Erie	Fairview SW	42.014222	-80.442976	PA Forest & Waters Block 1	TULLY & ONONDAGA	M. Devonian		X	1103 to 1149, 1270 to 1478	21.7
037-049-20040	Erie	Fairview SW	42.014222	-80.442976	PA Forest & Waters Block 1	TRENTON & BLACK RIVER	Ordovician		X	4291 to 4756	116.0
037-049-20049	Erie	North of North East	42.251598	-79.911195	PA Forest & Waters Block 2	TRENTON	Ordovician		X	4181 to 4308	111.9
037-049-20109	Erie	Erie North	42.142783	-80.047563	#2 Hammermill	ONONDAGA	M. Devonian		X	1390 to 1590	103.4
037-049-20846	Erie	Erie North	42.153413	-80.126954	Presque Isle State Park	MOSCOW OR LUDLOWVILLE	M. Devonian	X	X	1041 to 1049.6, 1050-1176	708.3
037-049-20846	Erie	Erie North	42.153413	-80.126954	Presque Isle State Park	MARCELLUS	M. Devonian	X		1236.0	160.6
037-049-90036	Erie	Erie South	42.046833	-80.024666	Goodwill-Curley	ONONDAGA	M. Devonian	X		2330.0	221.5
037-051-00128	Fayette	Brownfield	39.761742	-79.728608	No.8 Barton Estate	TULLY & HELDERBERG	M. and L. Devonian		X	6510 to 6652, 7401 to 7500	117.3
037-051-00128	Fayette	Brownfield	39.761742	-79.728608	No.8 Barton Estate	MARCELLUS	M. Devonian		X	7030 to 7105	115.4
037-053-20903	Forest	Tylersburg	41.484631	-79.296776	No.1 Collins-Clinger	MARCELLUS	M. Devonian		X	4970 to 5020	102.1
037-055-90000	Franklin	Doylesburg	40.184588	-77.677045	#2 Amerile	TRENTON	Ordovician		X	1478 to 1598	119.7
037-059-20038	Greene	Oak Forest	39.860586	-80.146016	No.1 Gordon	MARCELLUS	M. Devonian		X	7860 to 7960	101.5
037-063-25073	Indiana	Indiana	40.578940	-79.185926	No.5 McCall	TULLY	M. Devonian	X		7616.0	239.5
037-063-25073	Indiana	Indiana	40.578940	-79.185926	No.5 McCall	MARCELLUS	M. Devonian	X		7801.0	108.0
037-065-00028	Jefferson	McGees Mills	40.941589	-78.809402	No.1 McClure	MARCELLUS	M. Devonian		X	7845 to 7940	113.8
037-065-90094	Jefferson	Brookville	41.140592	-79.018152	Verstein & Klein	ONONDAGA & HELDERBERG	M. and L. Devonian		X	6077 to 6101, 6181 to 6226	104.8
037-067-20001	Juniata	McClure	40.686371	-77.280828	Shade Mt.	TRENTON	Ordovician		X	3870 to 3970	108.2
037-069-20001	Lackawanna	Ransom	41.411722	-75.824074	Richards	ONONDAGA	M. Devonian		X	7443 to 7701	117.3
037-073-20022	Lawrence	New Castle North	41.092005	-80.281924	No.1 Sokevitz	TULLY	M. Devonian	X		3984.0	172.1
037-073-20022	Lawrence	New Castle North	41.092005	-80.281924	No.1 Sokevitz	MARCELLUS	M. Devonian	X		4124.0	173.2
037-073-90004	Lawrence	New Castle South	40.943154	-80.267374	Miller & Myer	ONONDAGA & HELDERBERG	M. and L. Devonian		X	4517 to 4672, 4717 to 4737	72.3
037-079-90000	Luzerne	Shickshinney	41.198101	-76.219365	Galey #1 Harrison	HELDERBERG	L. Devonian	X		4800 to 4906	223.8
037-081-90006	Lycoming	White Pine	41.434313	-77.203863	No.1 Hughes	MARCELLUS	M. Devonian		X	7364 to 7390	111.6
037-081-90006	Lycoming	White Pine	41.434313	-77.203863	No.1 Hughes	TULLY & ONONDAGA	M. Devonian		X	6212 to 6258, 7410 to 7420	113.6
037-083-31744	McKean	Cyclone	41.871976	-78.618396	No.2 Minard Run Tr.6295	MARCELLUS	M. Devonian		X	5030 to 5090	100.2
037-083-22529	McKean	Derrick City	41.882137	-78.615093	Minard Run Track #1, Mood	TRENTON & BLACK RIVER	Ordovician		X	9050 to 9480	50.8
037-083-33511	McKean	Cyclone	41.867312	-78.614355	Minard Run #1 Say	TRENTON & BLACK RIVER	Ordovician		X	9400 to 9580	220.1
037-083-37291	McKean	Cyclone	41.868822	-78.612703	Minard Run Oil Co.	ONONDAGA	M. Devonian	X		5213.0	201.9
037-083-90004	McKean	Port Allegany	41.849890	-78.338582	#2 Nunn	TULLY & ONONDAGA	M. Devonian		X	3935 to 3955, 4460 to 4469	114.8
037-085-20004	Mercer	Sharpsville	41.319885	-80.461609	McKnight	TRENTON	Ordovician	X		6844.0	159.5
037-085-20036	Mercer	Jackson Center	41.351260	-80.176427	Temple	ONONDAGA	M. Devonian		X	3840 to 4000	101.4
037-085-22421	Mercer	Grove City	41.217694	-80.041194	#4 Montgomery	TRENTON	Ordovician	X		8495 to 8600	67.0
037-085-22421	Mercer	Grove City	41.217694	-80.041194	#4 Montgomery	BLACK RIVER	Ordovician	X		9019.0	16.0
037-085-22854	Mercer	Jackson Center	41.328611	-80.141389	#1 Psensky	TULLY	M. Devonian		X	3828 to 3885	17.2
037-085-22854	Mercer	Jackson Center	41.328611	-80.141389	#1 Psensky	ONONDAGA	M. Devonian		X	3990 to 4045	32.0
037-085-22854	Mercer	Jackson Center	41.328611	-80.141389	#1 Psensky	MARCELLUS	M. Devonian		X	3955 to 3960	
037-085-22854	Mercer	Jackson Center	41.328611	-80.141389	#1 Psensky	MARCELLUS	M. Devonian		X	3960 to 3965	
037-085-90010	Mercer	Sandy Lake	41.272449	-80.036013	Maude Davidson	TRENTON	Ordovician		X	8200 to 8380	119.6
037-087-20002	Mifflin	Belleville	40.511610	-77.628506	PA Tract 377	TRENTON	Ordovician		X	5300 to 5390	121.8

Table 3. Thermal maturity (CAI, %Ro) and RockEval/TOC data from Ordovician and Devonian samples collected from the subsurface of Pennsylvania.

API NUMBER	TOC	S1	S2	S3	Tmax	HI	OI	PI	% Ro(mean)	Number of Ro Readings	Min CAI	Max CAI	Comments Regarding Insoluble Heavy Fraction Mineralogy & Fossils; Other Comments
037-047-20033											3.0	3.0	pyrite(euhedral,fine crystalline,replaced fossils(spines & rods)), sphalerite(trace), unknown clear grains (barite?, celestite?)
037-049-20040											n/a	n/a	pyrite(euhedral,fine crystalline,replaced fossils(non-tapering solid & hollow tubes/spines)), barite or fluorite(trace)
037-049-20040											1.5	2.0	pyrite(fine crystalline,framboidal,replaced fossils(rods)), fluorite(?), biotite euhedra(rare), phosphatic bryozoans infills
037-049-20049											1.5	1.5	pyrite(euhedral,fine crystalline,replaced fossils(snails)), biotite euhedra(rare), phosphatic fragments of brachiopods, fish fragments, bryozoan infills, snail infills
037-049-20109											1.5	1.5	phosphatic & silica(?) spines & fossil fragments
037-049-20846											1.5	1.5	Reported by A.G. Harris (U.S.G.S. unpub. report O&G-80-9/O&G-80-10
037-049-20846	8.55	2.67	33.58	0.48	448.00	393.00	6.00	0.07	2.12	2	n/a	n/a	n/a
037-049-90036											1.5	2.0	pyrite(euhedral,fine crystalline,replaced fossils(rods/spines/triaxon)), sphalerite(?), glauconite, apatite(?), phosphatic brachiopod shards, silica sponge spicules
037-051-00128											2.5	2.5	pyrite (euhedral, fine crystalline, framboidal, replaced fossils(coral/bryozoan fragment)), garnet(?) sand grain, phosphatic shell fragments,
037-051-00128	4.74	0.90	0.18	0.70	382.00	4.00	15.00	0.83	2.16	30	n/a	n/a	n/a
037-053-20903	6.10	2.53	3.19	0.62	454.00	52.00	10.00	0.44	0.94	40	n/a	n/a	n/a
037-055-90000											n/a	n/a	pyrite(euhedral,fine crystalline,replaced fossils(spines & gastropods)), barite(?), silica spicules & ostracodes
037-059-20038	5.92	1.15	3.07	0.56	406.00	52.00	9.00	0.27	1.44	5	n/a	n/a	n/a
037-063-25073											1.5	2.0	pyrite(euhedral,fine crystalline), sphalerite, barite(?)
037-063-25073	0.23	0.03	0.03	0.29	415.00	13.00	126.00	0.50	2.47	7	n/a	n/a	n/a
037-065-00028	3.71	0.83	0.48	0.53	350.00	13.00	14.00	0.63	1.37	2	n/a	n/a	n/a
037-065-90094											2.5	3.0	pyrite(euhedral, fine crystalline, spheres, framboidal, replaced fossils(echinoderm spines & rods)), sphalerite, silica echinoderm spines & rods, gastropods
037-067-20001											4.0	4.0	pyrite(euhedral fine crystalline, replaced fossils(spines,rods)), phosphatic brachiopod fragments
037-069-20001											n/a	n/a	pyrite(euhedral,fine crystalline,replaced fossils(rods/filled tubes)), sphalerite
037-073-20022											2.0	2.5	pyrite(fine crystalline,euhedral), unknown clear mineral, phosphatic spine
037-073-20022	4.54	3.26	6.94	0.48	440.00	153.00	11.00	0.32	0.41	55	n/a	n/a	n/a
037-073-90004											n/a	n/a	pyrite (euhedral), sphalerite(?, trace)
037-079-90000											3.5	4.0	
037-081-90006	3.07	0.81	0.96	0.70	365.00	31.00	23.00	0.46	2.54	10	n/a	n/a	n/a
037-081-90006											n/a	n/a	pyrite(euhedral, fine crystalline, replaced fossils(echinoderm spines & rods)), sphalerite(trace)
037-083-31744	2.86	1.03	1.79	0.43	454.00	63.00	15.00	0.37	1.37	6	n/a	n/a	n/a
037-083-22529											2.5	3.0	
037-083-33511											2.5	3.0	pyrite(euhedral,fine crystalline,rare), sphalerite(rare), silica ostracodes(2), phosphatic tube
037-083-37291											2.5	2.5	pyrite(fine crystalline,euhedral, spheroidal,replaced fossils(rods/tubes, gastropods)), sphalerite(common), silica spines
037-083-90004											n/a	n/a	pyrite(fine crystalline,euhedral, replaced fossils(rods & spines)), silica rods & spines
037-085-20004											1.0	1.5	pyrite(euhedral,fine crystalline), sphalerite(trace), phosphatic brachiopod fragments
037-085-20036											1.5	2.0	pyrite(fine crystalline,replaced fossils), glauconite(common, diagenetic), silica sponge spicules & bryozoan infills, phosphatic bits
037-085-22421											2.0	2.5	pyrite (irregular & euhedral grains, sponge spicules), sphalerite (trace), brown mica (abraded), glauconite (rare), phosphatic fossils (fish, sponge spicules, ostracode, bryozoan steinkerns, brachiopod fragments)
037-085-22421											2.5	2.5	pyrite (irregular & euhedral grains, replaced bryozoans & scolecodont frags), phosphatic fossil fragments
037-085-22854											1.5	2.0	20- to 200 mesh cuttings picked; not acidized
037-085-22854											1.5	2.0	20- to 200 mesh cuttings picked; not acidized
037-085-22854	5.01	2.70	11.35	0.33	4.34	227.00	7.00	0.19			n/a	n/a	n/a
037-085-22854	3.36	2.05	6.79	0.50	4.36	202.00	15.00	0.23			n/a	n/a	n/a
037-085-90010											2.0	2.0	pyrite(euhedral,fine crystalline,replaced fossils(spines, triaxon, others)), unknown clear mineral, phosphatic bits
037-087-20002											4.0	4.0	pyrite(euhedral, fine crystalline), chlorite(?), silica fragments, brachiopods(?), ostracodes(?)

Table 3. Thermal maturity (CAI, %Ro) and RockEval/TOC data from Ordovician and Devonian samples collected from the subsurface of Pennsylvania.

API NUMBER	COUNTY	QUADRANGLE	LATITUDE (DEC DEG)	LONGITUDE (DEC DEG)	LEASE NAME	FORMATION	SERIES / SYSTEM	CORE	CUTTINGS	INTERVAL SAMPLED	AMOUNT (in grams)
037-097-90000	Northumberland	Trevorton	40.864295	-76.680043	No.1 Fox	ONONDAGA	M. Devonian		X	1062 to 1114	112.8
037-097-90000	Northumberland	Trevorton	40.864295	-76.680043	No.1 Fox	MARCELLUS	M. Devonian		X	995 to 1049	117.8
037-103-20001	Pike	Shohola	41.449166	-74.924618	No.1 Hess	MARCELLUS	M. Devonian		X	6310 to 6428	108.3
037-103-20003	Pike	Hawley	41.416528	-75.141588	Texaco #C-1 State Forest	ONONDAGA	M. Devonian		X	8040 to 8160	206.4
037-105-20182	Potter	Tamarack	41.489294	-77.774453	No.1 PA Tract 129	MARCELLUS	M. Devonian		X	6250 to 6345	100.3
037-105-20182	Potter	Tamarack	41.489294	-77.774453	No.1 PA Tract 129	TRENTON	Ordovician		X	13600 to 13695	120.0
037-105-20362	Potter	Oleona	41.518613	-77.677256	#5 PA Tract 58	HELDERBERG	L. Devonian		X	6688 to 6690	127.8
037-105-90052	Potter	Brookland	41.838924	-77.859145	Lewis	TULLY	M. Devonian		X	4382 to 4436	112.5
037-105-90155	Potter	Coudersport	41.845595	-78.010162	Simpson	TULLY	M. Devonian		X	4908 to 4941	121.5
037-109-90000	Snyder	Beavertown	40.808626	-77.157871	No.1 Albert	MARCELLUS	M. Devonian		X	1274 to 1342	113.1
037-109-90000	Snyder	Beavertown	40.808626	-77.157871	No.1 Albert	ONONDAGA	M. Devonian		X	1355 to 1415	115.6
037-111-20001	Somerset	Boswell	40.221994	-79.040106	No.2 Williams	MARCELLUS	M. Devonian		X	7900 to 7963	118.3
037-111-20002	Somerset	Grantsville	39.735448	-79.188711	Bender	ONONDAGA	M. Devonian		X	8305 to 8333	103.6
037-111-20045	Somerset	Kingwood	39.977764	-79.333868	Svetz	TRENTON & BLACK RIVER	Ordovician		X	15400 to 15900	49.1
037-113-20002	Sullivan	Elk Grove	41.354690	-76.468896	Dieffenbach	TRENTON	Ordovician		X	16470 to 16610	119.3
037-113-90000	Sullivan	Sonestown	41.352082	-76.515843	No.1 Bennett	MARCELLUS	M. Devonian	X		8364.0	298.3
037-113-90000	Sullivan	Sonestown	41.352082	-76.515843	No.1 Bennett	ONONDAGA	M. Devonian	X		8375.0	164.0
037-115-20006	Susquehanna	Harford	41.777666	-75.697828	No.1 Peace	MARCELLUS	M. Devonian		X	6600 to 6650	117.6
037-117-20056	Tioga	Antrim	41.629343	-77.298616	S & S Coal Company	TULLY	M. Devonian		X	6250 to 6320	120.8
037-117-20057	Tioga	Marshlands	41.689397	-77.546975	No.1 Dewey	MARCELLUS	M. Devonian		X	5540 to 5630	104.5
037-117-20057	Tioga	Marshlands	41.689397	-77.546975	No.1 Dewey	TRENTON	Ordovician		X	11880 to 12020	118.4
037-119-90000	Union	Lewisburg	40.897356	-76.975659	Solomon	TRENTON & BLACK RIVER	Ordovician		X	5951 to 6273	119.7
037-121-22642	Venango	Franklin	41.414195	-79.809348	No.348 Grant Fee	MARCELLUS	M. Devonian		X	4320 to 4350	110.5
037-121-90000	Venango	Sugar Lake	41.559864	-79.908559	Van Camp	ONONDAGA	M. Devonian		X	3951 to 4022	113.4
037-123-20150	Warren	Cobham	41.653900	-79.369192	Shaw	ONONDAGA	M. Devonian		X	4459 to 4508	101.0
037-123-20150	Warren	Cobham	41.653900	-79.369192	Shaw	TRENTON	Ordovician		X	8333 to 8452	118.9
037-123-20609	Warren	Russell	41.953388	-79.201222	Marsh Childs	TRENTON	Ordovician		X	7020 to 7360	118.5
037-123-24704	Warren	Columbus	41.920600	-79.552689	No.1 Christensen	MARCELLUS	M. Devonian		X	3170 to 3230	117.5
037-123-90002	Warren	Youngsville	41.855240	-79.269454	No.1 Keester	MARCELLUS	M. Devonian		X	3393 to 3474	
037-123-90002	Warren	Youngsville	41.855240	-79.269454	No.1 Keester	ONONDAGA	M. Devonian		X	3474 to 3595	107.4
037-125-20070	Washington	Amity	40.098108	-80.143093	No.1 Connor	MARCELLUS	M. Devonian		X	7450 to 7500	112.1
037-125-90076	Washington	Midway	40.271913	-80.292441	McBurney	TULLY	M. Devonian		X	6198 to 6253	102.2
037-127-20005	Wayne	Galilee	41.682124	-75.180760	No.1 Rodolfy	MARCELLUS	M. Devonian		X	7880 to 7900	120.7
037-129-90046	Westmoreland	Derry	40.342060	-79.257174	#3 Giffin	TULLY	M. Devonian		X	6332 to 6378	111.8
037-131-90000	Wyoming	Meshoppen	41.558627	-76.080761	No.1 Sheehan	TULLY	M. Devonian		X	5880 to 5948	118.0
037-131-90000	Wyoming	Meshoppen	41.558627	-76.080761	No.1 Sheehan	MARCELLUS	M. Devonian		X	6650 to 6726	116.4
(Canada)	n/a	n/a	42.667278	-79.649253	40-X-3a	TRENTON	Ordovician		X	3018 to 3074 (920 to 937m)	500.0

Table 3. Thermal maturity (CAI, %Ro) and RockEval/TOC data from Ordovician and Devonian samples collected from the subsurface of Pennsylvania.

API NUMBER	TOC	S1	S2	S3	Tmax	HI	OI	PI	% Ro(mean)	Number of Ro Readings	Min CAI	Max CAI	Comments Regarding Insoluble Heavy Fraction Mineralogy & Fossils; Other Comments
037-097-90000											4.0	4.0	pyrite(euhedral, fine crystalline, replaced fossils(rods, spines, tubes)), sphalerite, unknown clear grains, silica sponge spicules, phosphatic brachiopods
037-097-90000	6.20	1.22	0.47	0.81	416.00	8.00	13.00	0.72	0.95	8	n/a	n/a	n/a
037-103-20001	1.16	0.41	0.51	0.32	392.00	44.00	28.00	0.45	nd	nd	n/a	n/a	n/a
037-103-20003											3.5	4.0	
037-105-20182	3.43	0.43	0.35	0.51	345.00	10.00	15.00	0.55	0.88	5	n/a	n/a	n/a
037-105-20182											4.5	4.5	pyrite(euhedral,fine crystalline,replaced fossils), garnet(?, trace), sphalerite
037-105-20362											n/a	n/a	chlorite, fluorite, unknown clear glassy mineral, detrital pink zircons
037-105-90052											n/a	n/a	pyrite(fine crystalline,replaced fossils(rods),framboidal,euhedral), sphalerite, pale green pyroxene(?), silica spine, shell fragments
037-105-90155											3.0	3.0	pyrite(fine crystalline,framboidal,replaced fossils(spines/rods, bivalves),euhedral grains), barite(?, trace), sphalerite(trace), silica spines
037-109-90000	4.76	0.99	1.15	0.78	349.00	24.00	16.00	0.46	1.32	26	n/a	n/a	n/a
037-109-90000											n/a	n/a	pyrite(euhedral,fine crystalline,replaced fossils(spines & rods)), sphalerite(common, spines & rods), barite(?), silica fossil bits
037-111-20001	5.07	1.27	1.39	0.79	371.00	27.00	16.00	0.48	nd	nd	n/a	n/a	n/a
037-111-20002											n/a	n/a	pyrite(euhedral,fine crystalline,replaced fossils), sphalerite
037-111-20045											5.0	5.0	pyrite(euhedral,fine crystalline, replaced fossils(trilobite fragment, bryozoan fragments)), silica ostracodes, phosphatic bryozoan fragments; Published in U.S.G.S. Bulletin #1839
037-113-20002											5.0	5.0	pyrite(euhedral,fine crystalline,framboidal,replaced fossils(bivalve)), sphalerite(?), chlorite(?), silica(?) spines, phosphatic fish fragments & brachiopods
037-113-90000	3.41	1.31	0.86	0.39	377.00	25.00	11.00	0.60	0.46	50	n/a	n/a	n/a
037-113-90000											4.5	5.0	pyrite(euhedral,fine crystalline,replaced fossils,spheroidal), sphalerite
037-115-20006	1.76	0.48	0.20	0.36	407.00	11.00	20.00	0.71	0.51	50	n/a	n/a	
037-117-20056											4.0	4.5	pyrite(fine crystalline,replaced fossils(rods/tubes)), unknown clear mineral, silica "spines"
037-117-20057	4.68	1.79	2.61	1.14	400.00	56.00	24.00	0.41	0.58	50	n/a	n/a	n/a
037-117-20057											4.5	4.5	pyrite(euhedral,fine crystalline,replaced fossils), phosphatic fossil fragments, fish fragments, brachiopods, silica corals, echinoderms, steinkerns
037-119-90000											n/a	n/a	pyrite(fine crystalline,euhedral,framboidal,replaced fossils), sphalerite
037-121-22642	4.60	3.78	7.48	0.43	436.00	163.00	9.00	0.34	0.47	52	n/a	n/a	n/a
037-121-90000											n/a	n/a	pyrite(euhedral,fine crystalline,replaced fossils(rod/spine)), sphalerite or yellow fluorite
037-123-20150											2.5	3.0	pyrite(fine crystalline,euhedral,spheroids),sphalerite,barite(?)
037-123-20150											2.5	3.0	pyrite(euhedral,fine crystalline,replaced fossils),chlorite(?), fish fragments, phosphatic brachiopods, bryozoans, gastropods
037-123-20609											2.0	2.5	pyrite(euhedral,fine crystalline,framboidal(?)),sphalerite, phosphatic bryozoans, brachiopods, echinoderms, fish fragments(?)
037-123-24704	1.92	1.34	4.36	0.43	438.00	227.00	22.00	0.24	1.06	3	n/a	n/a	n/a
037-123-90002	3.99	2.30	6.51	0.56	437.00	163.00	14.00	0.26	nd	nd	n/a	n/a	n/a
037-123-90002											2.0	2.0	pyrite(fine crystalline, replaced fossils(snail fragment, spines)), barite(?), sphalerite, glauconite
037-125-20070	3.35	1.72	1.80	0.57	374.00	54.00	17.00	0.49	1.49	13	n/a	n/a	n/a
037-125-90076											2.0	2.0	pyrite(fine crystalline,euhedral,replaced fossils(rods/spines),spheroids), clear barite or fluorite, phosphatic rods/fillings, silica sponge spicules
037-127-20005	1.86	0.49	0.29	0.43	354.00	16.00	23.00	0.63	nd	nd	n/a	n/a	n/a
037-129-90046											n/a	n/a	pyrite(euhedral,fine crystalline,replaced fossils(spines)), unknown clear grains, phosphatic brachiopod shard
037-131-90000											n/a	n/a	pyrite(fine crystalline,euhedral,replaced fossils(echinoderm spines & rods),framboidal), barite, phosphatic brachiopods
037-131-90000	0.42	0.33	0.08	0.20	354.00	19.00	48.00	0.80	3.00	49	n/a	n/a	n/a
(Canada)											1.0	1.5	Canadian sample from Lake Erie, no API #, county, or quad names