THE BASAL SANDSTONE IN THE STAHL NO. 1 WELL, WYOMING COUNTY, NEW YORK: IS IT A CORRELATIVE OF THE ROSE RUN SANDSTONE?

FINAL REPORT

by

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NOTICE

ABSTRACT

The Belden and Blake Corporation Stahl #1 (API #31-121-22520) well is located in the Town of Arcade, Wyoming County, New York. The Stahl well was drilled to a total depth of 6,021 feet (1836 m) to the Cambrian Theresa Formation. Twenty-one sidewall cores were recovered from the well between 5378 feet (1640 m) and 6009 feet (1832 m) depth. The sidewall core at 5378 feet (1640 m) depth is in the Ordovician Black River Formation and the remainder of the samples are from the Cambrian Little Falls and the Theresa formations. The cores were sent to Omni Laboratories, Inc. for petrographic study. This report compares the results of that study with the published information on the Rose Run in Ohio, the Upper Sandy Member of the Gatesburg Formation in Pennsylvania, and the Theresa Formation in New York. This comparison indicates a strong lithostratigraphic correlation between the Theresa in the Stahl well and the Upper Sandy Member of the Gatesburg and the Rose Run. Cross-sections also demonstrate the possible correlations among the Lower Ordovician and Upper Cambrian units, including the Rose Run and the Theresa between Ohio and New York. This study supports the proposed correlation by Wagner (1961) and Riley, et al., (1993) between the Rose Run in Ohio and the Theresa in New York, and demonstrates the presence of reservoir quality sandstone in the Theresa in New York.

INTRODUCTION

The Stahl #1 (API Permit No. 31-121-22655) was drilled by Belden & Blake Corporation in October, 1996 to a total depth of 6,021 feet (1836 m). Other joint participants in the prospect are US Energy Development Corporation, Ardent Resources, Inc. and Nornew, Inc. The well is located in the Town of Arcade, Wyoming County, New York. Figure 1 shows the location of the Stahl and other deep wells used for correlations in this study. A 3-dimensional seismic survey (4207-ERTER-ER-96), a high-resolution aeromagnetic survey and detailed subsurface mapping defined the prospect.

In the Stahl #1 well, carbonate of the Cambrian Little Falls Formation was encountered at a depth of 5932 feet (1808 m) to 5961 feet (1817 m), and an underlying sandstone section was encountered between 5961 feet (1817 m) and 6021 feet (1836 m) (TD). Based on comparison with similar sandstones in nearby wells that were assigned to the Theresa Formation (Flagler, 1966), this report concludes that the basal sandstones are part of the Theresa Formation. Twenty-one rotary sidewall cores were retrieved from the well. Twenty of these cores were from the Little Falls and Theresa formations between 5,950 feet (1814 m) and 6,009 feet (1832 m) depth. The cores were sent to Omni Laboratories, Inc. for core property and petrographic analysis. This report summarizes Omni Laboratories' petrographic analysis.

In light of the prolific play in the Rose Run in Ohio, and the recent increase in exploratory efforts in the Theresa of New York, it is important to test the validity of the proposed correlation between the Rose Run and Theresa formations in the context of the basal sandstone encountered in the Stahl #1. This report uses electric logs from the Stahl #1 and other wells in New York to construct a cross section that ties into a previous cross section (Riley et al., 1993) that extends northeast from Ohio; in combination, these cross sections demonstrate the possibility of a Rose Run/Theresa correlation. The report also compares the petrography and proposed depositional environment of the basal sandstone in the Stahl #1 with the Theresa in New York, the Rose Run in Ohio, and the correlative Upper Sandy Member of the Gatesburg Formation in Pennsylvania. This report supersedes an earlier preliminary report by Jacobi and a slide presentation by Loewenstein at the 1997 annual meeting of the Independent Oil & Gas Association of New York held in Buffalo.

ROSE RUN BACKGROUND

The Upper Cambrian Rose Run Sandstone is a poorly sorted sandstone that is about 70 feet (21 m) thick (Figure 2) where it was first encountered in northeast Kentucky. There, the Rose Run was originally included within the Chepultepec Dolomite, the lowest member of the Ordovician Beekmantown Formation (Freeman, 1949).

In Ohio, more recent research (e.g., Janssens, 1973) suggest that the Rose Run is Upper Cambrian in age, and lies below the Beekmantown (Figure 3). In both the original model proposed by Freeman (1949), and the more recent work by Janssens (1973), the underlying unit is the Copper Ridge Dolomite. The Copper Ridge, Rose Run and Beekmantown together comprise the Knox Group. Uplift along the north-striking Waverly Arch was coeval with the generation of the Knox unconformity, which truncates the uplifted units, including the Rose Run (Figures 4a and 4b). Most of the producing pools in the Rose Run and overlying Beekmantown/Mines are located along the subcrop of those units at the Knox unconformity.

The Rose Run is correlated with the Upper Sandy Member of the Gatesburg Formation

(Conococheague Group) in Pennsylvania (Figures 3 and 5; Riley et al. 1993) and with the Theresa Formation in New York (Figure 3; Wagner, 1961; Riley, et al.,1993). In New York State, the Theresa Formation (Cushing, 1908) is regarded as a transitional series of Upper Cambrian to Lower Ordovician interbedded calcareous siltstones, quartz sandstones, and sandy dolostones that lie between the sandstones of the underlying Potsdam Formation and the dolostones of the overlying Ogdensburg Dolostone (Fisher,1956; Flager,1966; Selleck,1984). In Pennsylvania, the Upper Sandy Member of the Gatesburg is characterized by interbedded dolostones and thickly-bedded sandstones.

ARE THE BASAL SANDSTONES IN THE STAHL #1 PART OF THE THERESA FORMATION?

As part of Flagler's (1966) study of 38 deep test wells in New York State, he defined the upper contact of the Theresa as the position where the quartz grain content increases dramatically downhole from a low of approximately 1-2% in the overlying Little Falls Dolomite to a high on the order of 80-90% in the underlying Theresa Formation.

In the Little Falls Dolomite Flagler (1966) found that an arenaceous unit 21 feet (6.3 m) thick occurs 122 feet (37 m) above the Theresa in the Wilson well (the closest well to the Stahl #1 that Flagler, 1966, examined). It is conceivable that this unit could be misidentified as the Theresa (especially if the well bottomed in this unit rather than the true Theresa). The Little Falls Dolomite arenaceous unit consists primarily of dolomitic siltstone and arenaceous dolostone; minor amounts of shale, fine grained sandstone and limestone also occur. The lack of orthoquartzites and non-calcareous sandstones, and the thinness of the unit, aid in discriminating this unit from the "true" Theresa. This arenaceous unit was probably not encountered in the Stahl #1 well because most of the Little Falls Dolomite is missing as a result of the overlying Knox unconformity (only the lower 28 feet [8.5 m] of the Little Falls remain).

At the closest deep well west of the Stahl #1 (the Ellis well) that Flagler (1966) studied, the depth of the Theresa upper contact is -4296 feet (-1340 m) (bsl); to the east, across the Clarendon-Linden Fault System, the depth of the Theresa upper contact in the Wilson well is -4842 feet (-1476 m) (bsl). The top of the sandstones in the Stahl #1 is at -4347 feet (-1325) (bsl). This depth is consistent with the depth of the upper contact of the Theresa in the nearby wells, if the general ENE strike of the structural contours, the Clarendon-Linden Fault System, and the structural high where the Stahl well was drilled, are taken into account. Thus, the sandstones encountered in the basal section of the Stahl #1 are most likely the upper units of the Theresa.

The descriptions of deep tests that are relatively close to the Stahl #1 well (Flagler, 1966; summarized in Appendix 1 of this report) show that in the region of the Stahl #1 well, the upper Theresa is a thick sandstone (orthoquartzite) with a few thin interbeds of dolostone and shale. The middle section is variable but can be generalized to include interbedded sandstones, orthoquartzites and dolostones, with rare shales. The lower section is interbedded sandstone and dolostone, but has a high percentage of sandstone. This three-part division of sandstone overlying dolostone and sandstone in turn overlying sandstone, on the order of 700 feet (213 m) thick in vicinity of the Stahl #1 well, is similar to the three part sequence within the Gatesburg Formation in Pennsylvania wherein the Upper Sandy Member overlies the Middle Dolomite Member which in turn overlies the Lower Sandy Member. Riley et al. (1993) correlated the Upper Sandy Member with the Rose Run in Ohio. It is possible, therefore, that the upper sandy zone in the Theresa Formation correlates with the Rose Run Formation in Ohio. Such a correlation is consistent with the observed thicknesses of the Rose Run in Ohio (on the order of

100 feet [33 m], Riley et al., 1993) and the upper sandstones of the Theresa (on the order of 40 to 175 feet [12 to 53 m] thick). This proposed correlation, that the upper Theresa correlates with the Rose Run in Ohio, is pursued further in the well log correlations in the cross sections discussed below.

REGIONAL WELL LOG CORRELATIONS: THERESA CORRELATION WITH ROSE RUN

The Matusik #1 (API Permit # 31-121-22520) is located about 10,000 feet (3,048 m) southeast of the Stahl #1 well. The Matusik was also drilled as a Theresa test. Because the Matusik was drilled about 80 feet (24. 4 m) deeper into the Theresa than the Stahl #1, the Matusik was used for correlation in regional cross-sections discussed below. Figure 6 shows the correlations between the Matusik #1 and the Stahl #1.

Figure 1 is a regional well spot base map of selected wells drilled to the Trenton and deeper; selected lines of section used for this report are shown on the figure. Where possible, sample descriptions and bulk density logs were used to aid in correlation; however, the correlations were generally based on gamma-ray character. Figure 7 is a partial log from the Pennzoil Enterprise Transit #1 (API Permit # 31-009-09235) located in the Town of Allegany, Cattaraugus County, New York. This log was used as a type log for correlations.

Correlation of units above the Knox unconformity were straightforward, but the correlations were less certain for units below the Knox unconformity because few logs were available from wells drilled more than about 100 feet (33 m) beneath the Knox unconformity, and because only gamma-ray logs were available for many wells. Notwithstanding these difficulties, the distinctive gamma-ray signature of the Theresa sandstones and dolomites is generally evident. Cross-section AA' (Figure 8) demonstrates the truncation of progressively older Cambrian units at the Knox unconformity.

Several north-south cross sections (not shown) were used to select wells for the regional east-west cross-section (B-B') (Figure 9a). Wells that penetrated the Theresa top at or near the Knox unconformity (as in the Stahl #1) were included in cross-section B-B'. The western end of cross-section B-B' ties to the easternmost well in Riley et al's (1993) southwest-northeast cross-section X-X' (Figures 9b and 9c), and supports the proposed correlation of the Theresa with the Upper Sandy Member of the Gatesburg and the Rose Run.

PETROGRAPHY AND POROSITY OF ROSE RUN AND CORRELATIVE SANDSTONES

1) PREVIOUS PETROGRAPHIC STUDIES OF SANDSTONES IN OHIO, PENNSYLVANIA, AND NEW YORK

The following petrography of Rose Run sandstones and correlative sandstones in Pennsylvania is excerpted primarily from Riley et al. (1993). The cored Rose Run "sandstones" are primarily quartz arenites, subarkoses, arkoses and dolostones. In Ohio the constituent grains vary from subrounded to rounded, very fine to medium sand sized, poorly to moderately sorted. Bimodal size distributions are common. In northwestern Pennsylvania the sandstones are fine to medium sand sized, and moderately to well sorted.

Monocrystalline quartz and K-feldspar are the primary framework grains. In Ohio, quartz abundance ranges from 59% to 99%, and feldspar ranges from 1% to 35% (Figure 10). In contrast, in NW Pennsylvania, the quartz abundance ranges from 87% to 100%, and feldspar ranges from 0% to 13%. The abundance of feldspar in the Ohio samples is thought to indicate that the Waverly Arch (or other structural elements) may have been a positive relief area that functioned as a relatively nearby source for feldspar. Indeed, the abundance of framework constituent grains plot on the ternary sandstone provenance diagrams (Dickinson et al., 1983) in the "transitional continental" field--transitional between basement uplift and cratonic sediment sources (Riley et al., 1983).

In Ohio the cement observed in thin sections from cores of the Rose Run include (in descending order of abundance): 1) dolomite (11%), 2) quartz overgrowths (4%-5%), 3) clays (1%-4%), and 4) feldspar overgrowths (1%) (Riley et al, 1993). Most of the dolomite cement is comprised of anhedral crystals; subhedral crystals are less abundant. The dolomite cement postdates all the other cements. A third of the thin sections examined do not display dolomite cement; in these samples the original porosity was reduced by mechanical compaction, illite, quartz and feldspar overgrowths and pressure solution. Such reduction resulted in porosity < 3% for quartz arenites and 8-14% in subarkoses except for subarkose from NW Pennsylvania, which have 3% porosity. Clay minerals include illite, illite-smectite, chlorite and glauconite. In many of the more porous zones in the Rose Run, the clays have been partially leached. Quartz and feldspar overgrowths occur in all cores studied by Riley et al. (1993). Quartz overgrowths are commonly recognized by dust rims outlining the detrital grain or by their crystal faces. Some of the original grain outlines display a very rounded appearance (Figure 10), indicating that these grains were probably in an eolian environment sometime before final deposition. Feldspar cement is evidenced by euhedral overgrowths on detrital feldspar grains or by euhedral crystals filling pore space (Riley et al., 1993).

In New York, thin section petrography of the Theresa is described from outcrop samples (Selleck, 1984); Theresa thin sections held by the New York State Geological Survey from wells studied by Flagler (1966) are listed, but not described in his Appendix II. None of the thin sections in Flagler (1966) are from any of the wells that are close to the Stahl #1; rather most are from the Olin well in southernmost Steuben County. In thin sections from outcrops in the St Lawrence Lowlands, Selleck (1984) found that the most abundant framework grain in the sandstones/orthoquartzites is well rounded, non-undulose, inclusion-rich, sand-size quartz. Feldspar accounted for < 5% of the framework grains. Near Precambrian paleo-cuestas, the quartz grains have a wider range of characteristics, including angular, polycrystalline and undulose extinction grains. Selleck (1984) suggests that the well-rounded grains have an eolian history. Phosphatic material, including bioclasts, pellets, and laminated clasts, are relatively abundant. These observations suggest that parts of the Theresa had low deposition rates (Selleck, 1984) which is consistent with local unconformities in an estuarine/intertidal to shoreface environment inferred from the phosphatic material.

In the finer-grained Theresa siliciclastics, silt-size quartz grains are angular and have a non-undulose extinction. Detrital subrounded to angular feldspar is common in these sediments, up to 50%, whereas in the orthoquartzites/sandstones, the percentage is <5%. Clastic clay grains are absent from the Theresa. In the carbonates, pervasive recrystallization, including dolomitization, has apparently destroyed almost any trace of primary carbonate allochems.

Diagenetic characteristics include overgrowths on both the quartz and feldspar grains; the quartz overgrowths are in optical continuity with the detrital grain. These quartz and feldspar overgrowths predate sparry calcite cement. Dolomite textures and crystals also predate the sparry calcite cement. Selleck (1984) speculated that some of the dolomite might be original from crystallization in the sahbka, but suggested that the coarse crystals are diagenetic. In

Theresa III, Selleck (1984) found hoppers now filled with calcite, dolomite, pyrite and quartz; he suggested the former voids were sites of evaporite minerals.

2) PREVIOUS STUDIES OF POROSITY OF SANDSTONES IN OHIO

The intergranular volume of the Rose Run in Ohio averages 28.3% of the total volume, whereas cement averages 19.4% (Riley et al., 1993). The cement ranges from about 8% to 36% of the total volume, and accounts for up to ~90% of the destruction of original intergranular volume. The average porosity of the Rose Run, as determined from thin section point counts, is 7.5% (Riley et al., 1993). The Rose Run exhibits five pore textures, including: 1) intergranular pores (48% of total porosity, Figure 10), 2) moldic pores (19% of total), 3) oversized pores (12% of total) 4) intraconstituent pores (9% of total), and 5) fractures (2% of total). Oversized pores result from a combination of processes including 1) dissolution of grains, 2) dissolution of cement, and 3) dissolution of replacement dolomite (Riley et al., 1993). Moldic porosity results from dissolution of feldspar and lithic grains, and can be recognized by the shape of the mold. In the Rose Run, intraconstituent porosity results from the dissolution of feldspar grain interiors. Fracture porosity, characterized by partings and rock/mineral separations, is sparse in the Rose Run except in cores from wells in regions of cross-strike structural discontinuities (CSD's).

3) PETROGRAPHY AND POROSITY OF THE BASAL SANDSTONE IN THE STAHL #1 WELL AND COMPARISON TO THE ROSE RUN AND THERESA FORMATIONS

The sandstones in question were penetrated at the base of the Stahl #1 well, drilled by Belden and Blake in Wyoming County. The sandstones were encountered between 5961 feet (1817 m) and 6021 feet (1836 m) depth (-4347 feet and -4398 feet bsl [-1325 m and -1341m bsl]), except for a dolostone unit between 5974 feet (1821 m) and 5986 feet (1825 m) depth (-4360 feet and -4372 feet bsl [-1329 m and -1333 m bsl]) (Figure 11). The petrography of side wall cores was available from an Omni Laboratories report, from which the following summary was taken. The Omni Laboratories petrography was also used for the comparison between the Stahl #1 petrography and the Rose Run.

The average grain size in the Stahl #1 basal sandstones varies from very fine sand (0.08mm) to medium sand (0.49 mm), with medium sand size typical. These grain sizes are also typical of the Rose Run in Ohio (Riley et al., 1993) and the upper beds of Theresa encountered in the Veith well, Wyoming County, New York (Flagler, 1966).

The sorting in the Stahl #1 basal sandstones varies from poorly sorted to moderately well sorted, with moderately sorted typical. The sidewall cores near the base of the well at 6000.5 feet, 6003 feet, and 6005 feet (1829 m, 1830 m, and 1831 m) depth display the best sorting, from moderately well sorted to well sorted. The sidewall core from 6007 feet (1831 m) depth shows a bimodal distribution of quartz sand grains. The Rose Run in Ohio exhibits similar sorting. Some sandstones in the Stahl #1 basal sandstones appear massive (Figure 12), as do those in Pennsylvania.

Grain rounding in the Stahl #1 basal sandstones varies from subrounded to very well rounded, with well rounded typical. The original shape and roundness can be easily discerned by the dust rims that mark the original grain outline before quartz overgrowth occurred (Figures 12 & 13). The well rounded nature of the quartz grains indicates that they were in an eolian environment at some time during their history. Quartz grains that were well rounded when deposited (before quartz overgrowths) are prevalent in the sand units below 6000 feet (1829 m) depth, as well as in the side wall cores taken from depths of 5990, 5970, 5969, and 5968 feet (1826 m, 1820 m, 1820 m, and 1819 m). Other sidewall cores have a mixture of quartz grains that were originally both rounded and angular (before overgrowths), such as those at 5995, 5994, 5982, 5978, 5975, 5966, and 5963 feet (1827 m, 1824 m, 1822 m, 1822 m, 1820m, and 1818 m) depth. Sidewall cores with primarily angular quartz grains dispersed in a dolomite occur at depths such as 5948 feet (1813 m) and 5957 (1816 m) feet. As is typical for many sandstones, the better sorted units generally display better rounded and more spherical grains. The rounded quartz grains are from sandstones that are relatively massive (especially below 6000 feet [1829 m]), as determined from the thin sections and the Formation Micro Imager® (FMI) log, and are relatively thickly bedded, as determined from the FMI® log. Units with dolomite (e.g., at depths 5982 feet, 5980 feet, 5978 feet, 5975 feet, 5970 feet, 5966 feet, 5957 feet; 1824 m, 1823 m, 1822 m, 1820 m, 1819 m, 1816 m) typically display more angular and more poorly sorted quartz grains. The sidewall cores with both angular and rounded quartz grains are generally from relatively thinly-bedded units, based on the FMI® log.

The well rounded grains, coupled with a wide variation in grain rounding, are also typical of the Theresa in New York, both in outcrop and in well cuttings. This range in rounding is also similar to that of quartz grains in the Rose Run as well, but the typical degree of rounding is higher in the Stahl #1 well than in the Rose Run.

The framework grains in the Stahl #1 basal sandstones are generally monocrystalline quartz (25-70%), polycrystalline quartz (2%-7%), and K-feldspar (0%-7%). The samples analyzed are primarily quartz arenites, but finer grained units are more feldspathic, with samples falling into arkose and subarkose fields. These compositions are also typical of the Rose Run in Ohio and the Theresa in New York.

Cements include dolomite, quartz, clay, pyrite locally, and calcite. Dolomite typically occurs as coarse rhombs that fill the pores (Figures 14,15, and 16). Non-dolomitic sandstones exhibit extensive quartz overgrowths (as much as 31% volume in thin section, Figures 12 and 13). Clay mineralogy is primarily illite (1% to 16%). Authigenic illite occurs as both a pore-lining and less commonly as a pore filling. This illite commonly has two habits:1) a hair-like fabric, or 2) webby masses. These forms project into the open pores and pore throats. These cements are similar to those observed in the Rose Run in Ohio and Theresa in New York.

The porosity in the Stahl #1 basal sandstones, as observed in thin sections varies from 1% to 10%, with intergranular porosity the dominant type. Sandstones with higher porosity (e.g., at 5969 feet, 5971 feet, 5994 feet, and 5997 feet to 6009 feet [1820 m, 1827 m, 1828 m, and 1828 m to 1832 m] depth) have intergranular porosity of 3+% and have 0% to 2% additional secondary porosity. The secondary porosity occurs most commonly as large-grain moldic pores (i.e. complete dissolution of grains), as well as smaller intragranular porosity resulting from partial dissolution of feldspar and lithic grains (Figures 12, 16, and 17). The sandstones with quartz overgrowths generally display more primary porosity than those units cemented by dolomite (compare Figure 12 to Figure 13). Secondly, as would be expected, the sandstones with better sorting (moderately well sorted) exhibit a higher total porosity (compare Figure 12 to Figure 13). This porosity, as determined from thin sections, agrees in type with that observed in the Rose Run thin sections from Ohio.

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DEPOSITIONAL ENVIRONMENT OF THE ROSE RUN AND CORRELATIVE FORMATIONS

1) PREVIOUS STUDIES OF SANDSTONES AND INTERBEDDED DOLOSTONES IN OHIO, PENNSYLVANIA AND NEW YORK

The depositional environment described herein for the Rose Run in Ohio and correlatives in Pennsylvania is based primarily upon the work of Riley et al. (1993). The Rose Run was deposited on a broad continental shelf (Figure 5). Cyclic sea level changes resulted in sequences of fine grained quartz sand and lime mud interbedded with carbonates (e.g., Friedman, 1994).

The interbedded carbonates of the Rose Run correlative in central Pennsylvania (Upper Sandy Member of the Gatesburg) display ooids, flat and mounded algal laminae, and herringbone bedforms in outcrop (e.g., Riley, et al., 1993). In the St. Lawrence Lowlands of New York State, outcrops of the Theresa Formation include interbedded sandy dolostones with rare mudcracks and complete bioturbation, fine laminae of a probable algal mat origin in the middle and upper Theresa (Theresa II and Theresa III, respectively), and evaporite hoppers in Theresa III (Selleck, 1984). Vuggy dolostones also occur in Theresa III (Selleck, 1984).

Deep well tests in New York show that the characteristics of the Theresa dolostones, and the relative amount of dolostone, vary widely across the state (Flagler, 1966). The dolostones vary in color (light to dark), in texture (fine to coarsely crystalline), and in sand content (Flagler, 1966). Oolitic textures are common. In one sample from a well in southern Steuben County (Olin #1), large halite crystals were observed (Flagler, 1966).

Collectively, these elements found in the carbonates are characteristic of the intertidal portion of a carbonate ramp environment, such as the West Florida Shelf; these elements are also some of the components that are characteristic of a shore to nearshore sahbka depositional environment (e.g., Friedman, 1994), such as that in the Abu Dhabi region of the Arabian Gulf. A sahbka environment is a coastal environment with a low clastic input and high net evaporation, which together result in primarily carbonate and evaporite deposition (Figure 18). The carbonate deposition consists of oolites, oolitic pellet skeletal sands, pellet muds, and algal mats (Figure 19). Higher net evaporation can result in higher salinity waters (hypersaline) in evaporating basins, which in turn results in evaporite sequences and in more continuous algal mats (since the gastropods that normally trim the algae cannot survive in hypersaline waters). Thus, a spectrum of rock types can occur that is controlled by the salinity: the sahbka (evaporites, continuous algal mats, oolites, etc) in hypersaline environments grading to shallow-water carbonate environments (with, for example, reefal deposits, skeletal sands, oolites) and no evaporites in lower salinity waters. Additionally, quartz sand may be found in isolated dune fields (Figure 18). Karstification, associated with local unconformities and relative sea level falls on the broad, gently sloping carbonate ramp, may explain the vuggy dolostones in the Theresa III.

Consistent with the arid hypothesis, the paleoclimatic conditions hypothesized for the Appalachian Basin in Rose Run time most likely were very arid. The Appalachian Basin lay close to the equator and on the west margin of Laurentia (present coordinates), where a typical "West Coast Desert Climate" probably existed, similar to Baja, California, based on paleomagnetic data and proposed paleocirculation patterns (e.g., Wilde, 1991).

The sandstones interbedded with the carbonates have a number of proposed origins. In Ohio, the sands were thought to cover wide areas as coalesced storm-generated deposition systems (e.g., Johnson, 1978). In northwestern Pennsylvania, cored sandstones that comprise multiple fining upward sequences with erosional bases and unidirectional crossbeds were interpreted to be fluvial in origin, perhaps deposited in streams entering the nearby oceanic tract (e.g., Riley et al., 1993). Other Rose Run correlative sandstones cored in northwestern Pennsylvania consist of coarsening upward, otherwise massive quartz arenites. Shinn (1980) suggested that these sandstones represent eolian deposition. In central Pennsylvania, generally massive quartz arenites exhibit rare herringbone patterns and other crossbeds, leading Smith (1969) to suggest that these deposits represent eolian to intertidal environments.

In northern New York State where the Theresa outcrops, calcareous sandstones and siltstones are the predominant lithology in the section; only in the upper Theresa are dolostones typical. In Theresa I (the basal Theresa) calcareous siltstones with low angle cross-laminations; flat, planar laminations; low relief megaripples, and Planolites trace fossils are typical; bipolar cross laminae and "fossil death assemblages" are rare. Selleck (1984) suggested that storms and/or flood tides in a generally quiet intrashelf "lagoon" could account for these features. For Theresa II, quartz sandstones with a sharp basal contact and with rip-up clasts of underlying sandy dolostones implied to Selleck (1984) sharp fluctuations of relative sea level in a tidal flat setting (as evidenced by the carbonate characteristics such as algal laminae). However, tempestites (storm deposits) alone in a tidally influenced environment could account for these same observations. Observed bipolar current directions are consistent with the tidal influence hypothesis. For Theresa III, Selleck (1984) proposed that coarse grained sandstone bodies with a channel form may have originated as tidal channels in tidal mud flats and that laminated calcareous siltstones also were deposited in tidal mud flats. Locally, conglomerates and pebble-bearing calcareous sandstones occur in regions adjacent to Precambrian cuestas that were overlapped by the Theresa (Selleck, 1984).

In deep well tests in New York State, Flagler (1966) found highly variable amounts of interbedded sandstones and shales. The sandstones are fine to coarse grained, have angular to rounded and frosted grains; some sandstones are orthoquartzites, and a few of these contain ooliths. The shales are black and dark gray. These characteristics, combined with the petrography discussed in the preceding sections, are consistent with a sahbka depositional environment. More specifically, the rounded and frosted grains indicate these grains were in an eolian depositional environment sometime in their past; without additional information, such as bedforms, it is difficult to ascertain from Flagler's (1966) description of cuttings whether the final depositional site was in fact eolian. In any case, an eolian environment is consistent with a sahbka. The orthoquartzites with ooliths suggest a shoreface depositional site in a sahbka (see Figure 19). The shales could be either offshore or lagoonal.

2) DEPOSITIONAL ENVIRONMENT OF THE BASAL SANDSTONES IN THE STAHL #1 AND COMPARISON TO THE DEPOSITIONAL ENVIRONMENTS OF THE ROSE RUN AND CORRELATIVES

Some of the characteristics of the quartz arenites at the base of the Stahl #1 well are consistent with an eolian depositional environment, or a nearby eolian source. These characteristics include quartz grains that are generally well-rounded and well sorted, and bedding that is relatively massive. Such characteristics typify the section below 6000 feet (1829 m) depth, as evidenced by both the thin sections and the FMI® log (e.g., Figure 12; note that the core in Figure 12, listed in the Omni report at 5997 feet (1828 m) depth, is probably from 6000.5 feet (1829 m) depth, based on the FMI® log). A second zone between 5966 feet (1819 m) and about 5969 feet (1820 m) also displays generally rounded quartz grains and relatively thick bedding.

Although these petrographic features are consistent with an eolian final depositional site, evidence from the FMI® log introduces a complication to this scenario.

The FMI® log indicates only low-angled bedding, less than 15° and typically less than 10°, in all the sandy units, no matter what the degree of grain rounding or sorting. The only steeply dipping bedding (25°-27°) observed in the Theresa on the FMI® log occurs at 5994 feet (1827 m) depth. Probable steeply east-dipping fractures associated only with these highly dipping units suggest that the feature may be structural, not depositional. The general lack of high dips, which are traditionally regarded to be characteristic of dunes, might suggest that a dune was not the final depositional site for any of the sands. However, certain types of dunes (e.g., blowout dunes), or dunes with only moderate sorting do exhibit lower dips on the slipface (foreset beds), especially at the base; the dips can vary from essentially 0° to 35°, with one mode at 5° to 10° and a second mode at 15° to 20°. Thus, the dips observed in the Stahl #1, in the 5°-15° range, are similar to those of some types of dunes; the low dips in the Stahl #1 are thus not necessarily an exclusionary criterion for an eolian depositional site.

The dolomitic units, that are interbedded with the sandstone units on a cm scale, and the dispersed quartz grains in sandy dolomites are not consistent with an extensive dune field. Thus, only the deepest drilled sandstones (below 6000 feet [1829 m]) may represent an eolian depositional site. The remainder of the sandy units with a component of rounded quartz grains probably only had an eolian *source* for the rounded grains, but had shore/intertidal/lagoonal depositional sites. These sites were a part of a sahbka; some units may have been an interdunal facies, especially those units immediately above the 6000 foot (1829) sand.

Other evidence supports the suggestion that the majority of the sands penetrated by the Stahl #1, those above 6000 feet (1829 m) depth, were deposited in a shore/intertidal/lagoonal environment. Babasik (Schlumberger interpreter, pers commun. 1998) inferred a small tidal channel between 5965 and 5975 feet (1818 m and 1822 m) depth from the FMI® log. Furthermore, possible load casts at 5999.5 feet (1829 m) depth, and possible fluid escape structures/soft sediment deformation at 5992 feet (1827 m) depth can also be inferred from the FMI® log. These features are not consistent with a dune, but with a lagoonal or shore/nearshore environment.

The shallow dips observed on the FMI® log are not very discriminating for environments in the shoreface/nearshore/lagoonal realm, since a number of depositional sites in these environments can display shallow dipping sands in the limited extent sampled both vertically and horizontally by the single Stahl #1 well. These other environments include (but are not limited to) the inner planar, outer planar, and inner rough nearshore and shoreface environments, washover fans, tidal channels and tidal deltas.

The less well-sorted arenites could also have a number of shoreface to nearshore depositional sites, including intertidal. Although oolites were indicated in the overlying dolostones on the mud log (oolites would be consistent with beach site in a sahbka or carbonate ramp environment, Figure 7), reinspection of the well cuttings near the base of the overlying carbonates did not indicate ooliths.

In summary, the basal sandstones (below 6000 feet [1829 m] depth) may have had an eolian depositional site, but most of the overlying Theresa units had an intertidal to nearshore sahbka depositional environment. The source of the rounded quartz grains in these units was eolian.

These proposed depositional environments for the sandstones encountered at the base of the Stahl #1 well appear similar to that proposed for the Rose Run (and correlative) sandstones in Ohio, Pennsylvania and New York.

CONCLUSIONS

The Theresa sandstone encountered in the Belden & Blake Stahl #1 is a potentially important gas-producing reservoir in New York. Regional cross-sections demonstrate a good stratigraphic correlation between the Theresa Formation in western New York and the Rose Run Formation in Ohio. The lithologic characteristics of the basal sandstones in the Stahl #1 well are consistent with those of the Rose Run in Ohio and the Upper Sandy Member of the Gatesburg in Pennsylvania. The depositional environment of the basal sandstones in the Stahl #1 well are also similar to those proposed for the Rose Run and Upper Sandy Member. This study therefore supports previous research that proposed the correlation between the Theresa and Rose Run formations. Additionally, log and core data from the Stahl #1 indicate the presence of reservoir quality sandstone in the Theresa.

ACKNOWLEDGMENTS

We wish to thank Mr. David T. Bajek and Mr. E. Scott Billingsley, both at Belden and Blake, Mr. Douglas K. Walch, the U.S. Energy Project Manager, for helping expedite this project, and for enlightened discussions.

APPENDIX 1

SUMMARY OF THERESA RESULTS IN DEEP TEST WELLS
CLOSE TO THE STAHL #1 WELL (FLAGLER , 1966)

Wells closest to the Stahl #1 that penetrated the Theresa include the Wilson in southwestern Wyoming County, the Veith in southeastern Wyoming County, the Ellis in northwestern Cattaraugus County, the Niehaus in northern Chautauqua County and the Cook #2 in northern Allegany County (Figure 1; Flagler, 1966). The S. Shadle well in east central Chautauqua County, and the Fee #2 in northernmost Erie County are farther from the Stahl #1 (Flagler, 1966). The descriptions below are excerpted from the Flagler (1966) report.

The closest well, the Wilson, encountered the top of the Theresa Formation at -4,842 feet (below sea level, bsl).The Theresa is 702 feet thick here; the upper 140 feet consist of sandstone with two thin interbeds of shale, and the remainder is interbedded sandstone and dolostone. The grain size was not reported. Flagler (1966) marked the basal contact by a dolostone, but the transitional nature of the contact led others to place the contact 59 feet higher in the section. Flager's (1966) pick of the contact is based on a sharp decrease in dolomite content (from 80% to 10%), whereas the basal contact proposed by others (that was higher in the section) was placed where the dolomite content dropped from 98% to 80%. The various placements of the contact illustrate the difficulty in picking contacts in gradational boundaries.

In the Veith well, the Theresa is 730 feet thick and the top of the Theresa is at -4,842 feet (bsl). The uppermost bed is 40 feet thick and consists of medium-grained quartz sandstone with minor amounts of dolomite and black shale. Underlying this sandstone is 25 feet of black, non-calcareous shale. Below the black shale lies 175 feet of primarily fine to medium grained sandstone, with minor interbeds of variegated shale, limestone and dolostone. Below this level, interbedded sandstone and dolostone Theresa lithologies occur.

The Cook #2 well bottomed in the Theresa; the upper contact of the Theresa is located at -5552 feet (below sea level). The 113 feet of Theresa section sampled by the well is primarily orthoquartzite with minor black shale, and correlates with the uppermost unit in the Wilson and the Veith wells.

The Niehaus #2 well bottomed in the Theresa, where the top of the Theresa was placed at -3891 feet (bsl). The unit consists of 16 feet of interbedded fine to medium grained orthoquartzite, dolomite and variegated shale. Rounded and frosted quartz grains are common near the top.

The Ellis #1 encountered 653 feet of Theresa; the upper contact was located at -4296 feet (bsl). The Theresa in this well can be divided into three units. The upper unit, 176 feet thick, is comprised of orthoquartzite interbedded with dolostone and shale. The middle unit, 262 feet thick, is primarily dolostone. The lower unit, 215 feet thick, consists of fine to coarse grained sandstone and orthoquartzite interbedded with dolostone. The upper 149 feet of the lower unit is primarily sandstone, although dolostone accounts for about 1/3 of the total lower unit thickness

The S. Shadle well encountered the top of the Theresa at -4613 feet (bsl) and bottomed in the Theresa after penetrating 51 feet of section. The Theresa was defined on the presence of silt size quartz cuttings, but the primary constituent is dolostone for the upper 35 feet. Below that level, the estimated quartz content varied from 75% to 90%; the latter number implies

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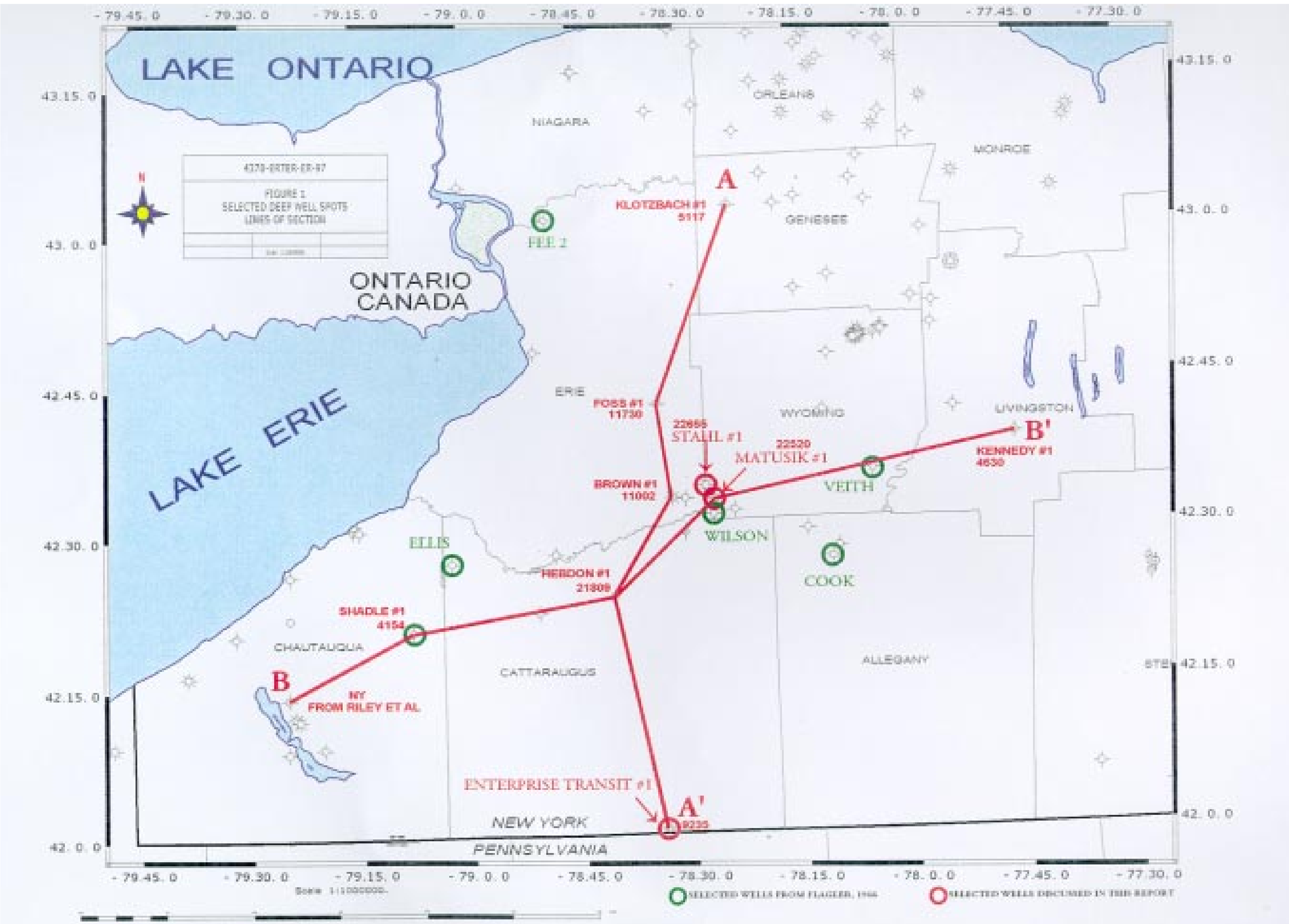
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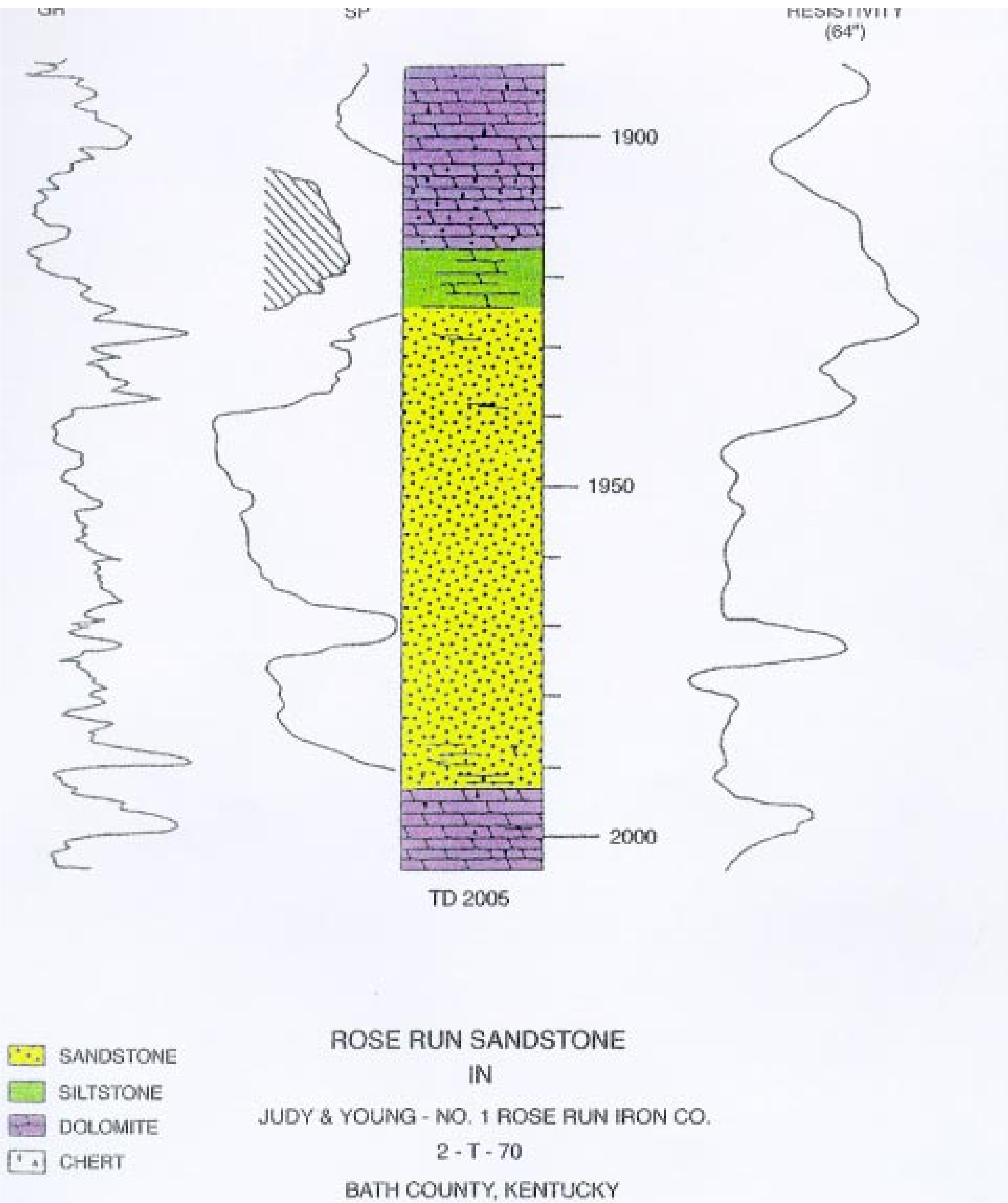
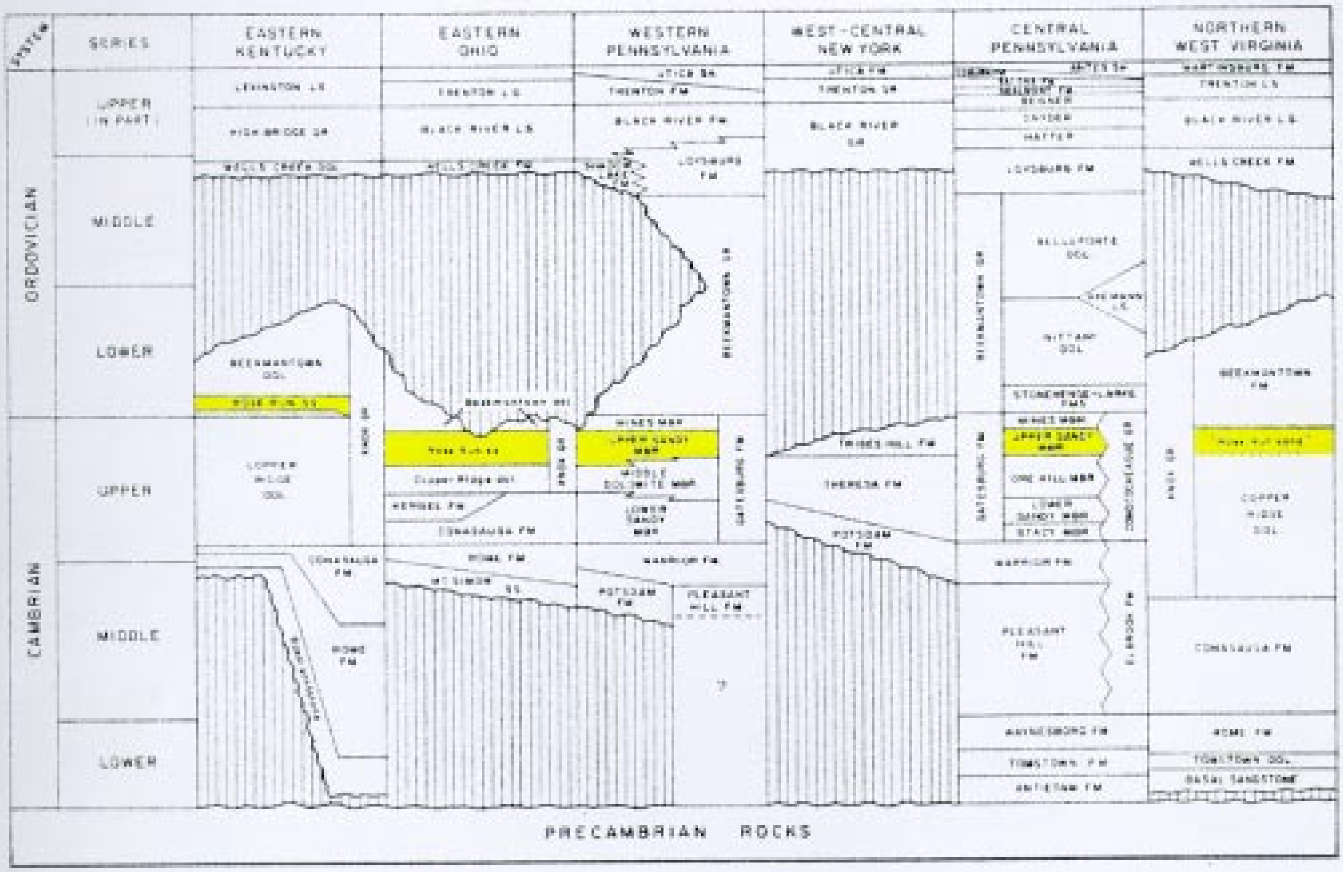
FIGURE 1
SELECTED DEEP WELL SPOTS
LINES OF SECTION
LAKE ONTARIO
LAKE ERIE
ONTARIO
CANADA
NIAGARA
ORLEANS
MONROE
GENESEE
ERIE
WYOMING
LIVINGSTON
CHAUTAUQUA
CATTARAUGUS
ALLEGANY
NEW YORK
PENNSYLVANIA
A
A'
B
B'
KLOTZBACH #1
5117
FOSS #1
11730
BROWN #1
11002
22656
STAHL #1
22520
MATUSIK #1
KENNEDY #1
4630
HEBDON #1
21809
SHADLE #1
4154
NY
FROM RILEY ET AL
ENTERPRISE TRANSIT #1
FEE 2
ELLIS
WILSON
VEITH
COOK
SELECTED WELLS FROM FLAGLER, 1966
SELECTED WELLS DISCUSSED IN THIS REPORT



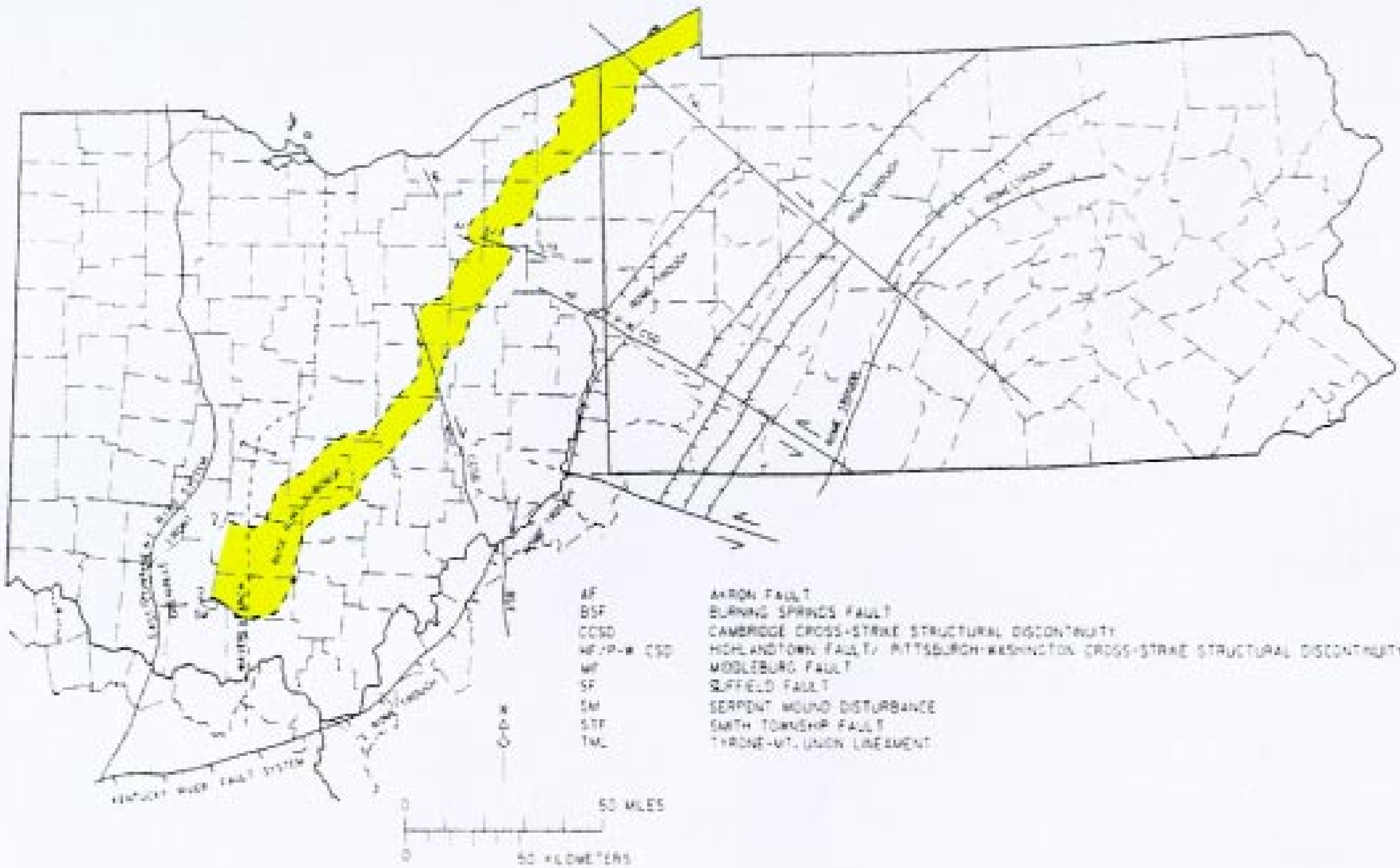
Type section of the Rose Run sandstone in the Judy and Young #1 Rose Run Iron Co. well in Bath County, Kentucky (modified from McGuire and Howell, 1963, fig. 2-15). GR-gamma ray log; SP-spontaneous potential log. (After Riley et al., 1993)

Figure 2



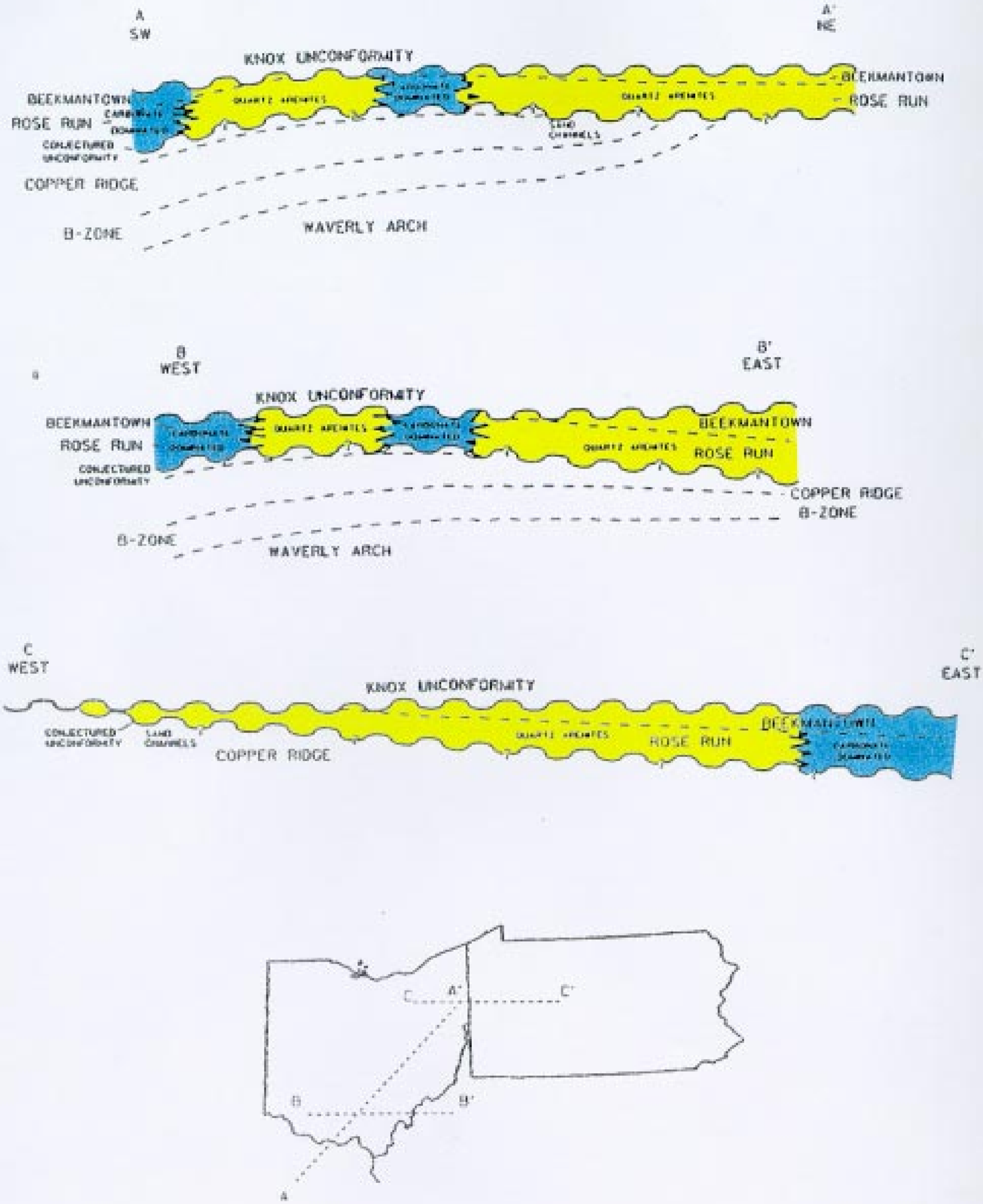
Generalized correlation diagram for Cambrian and Ordovician rocks in Ohio, Pennsylvania, and adjacent states. (From Riley et al., 1993)

Figure 3



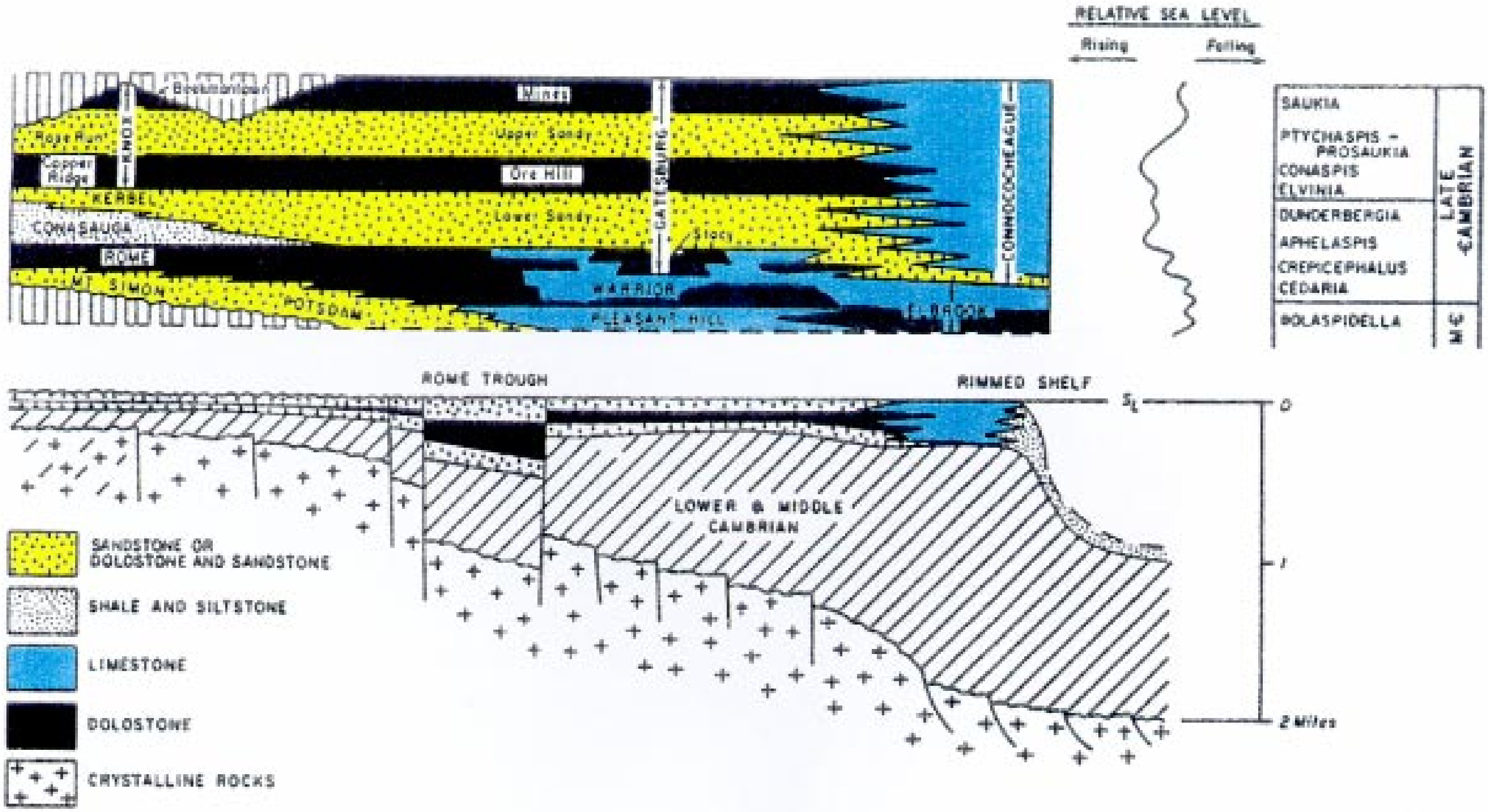
Map of the study area showing major tectonic features that affected late Cambrian deposition and subsequent structural development in Ohio and Pennsylvania. (From Riley et al., 1993)

Figure 4a



Generalized cross sections of the Appalachian basin. (After Riley et al., 1993)

Figure 4b



Upper Cambrian depositional and stratigraphic relationships (modified from Read, 1989. Top - Generalized chronostratigraphic relationships of the Upper Cambrian rocks of Ohio and Pennsylvania. Names on the right are trilobite index genera. Bottom - Generalized cross section of the Upper Cambrian continental shelf of eastern North America illustrating the concept of the rimmed shelf with platform morphology. (After Riley et al., 1993)

Figure 5

N **STRATIGRAPHIC CROSS-SECTION: ACTUAL** S

Datum = KNOX UNC. Domain = Depth

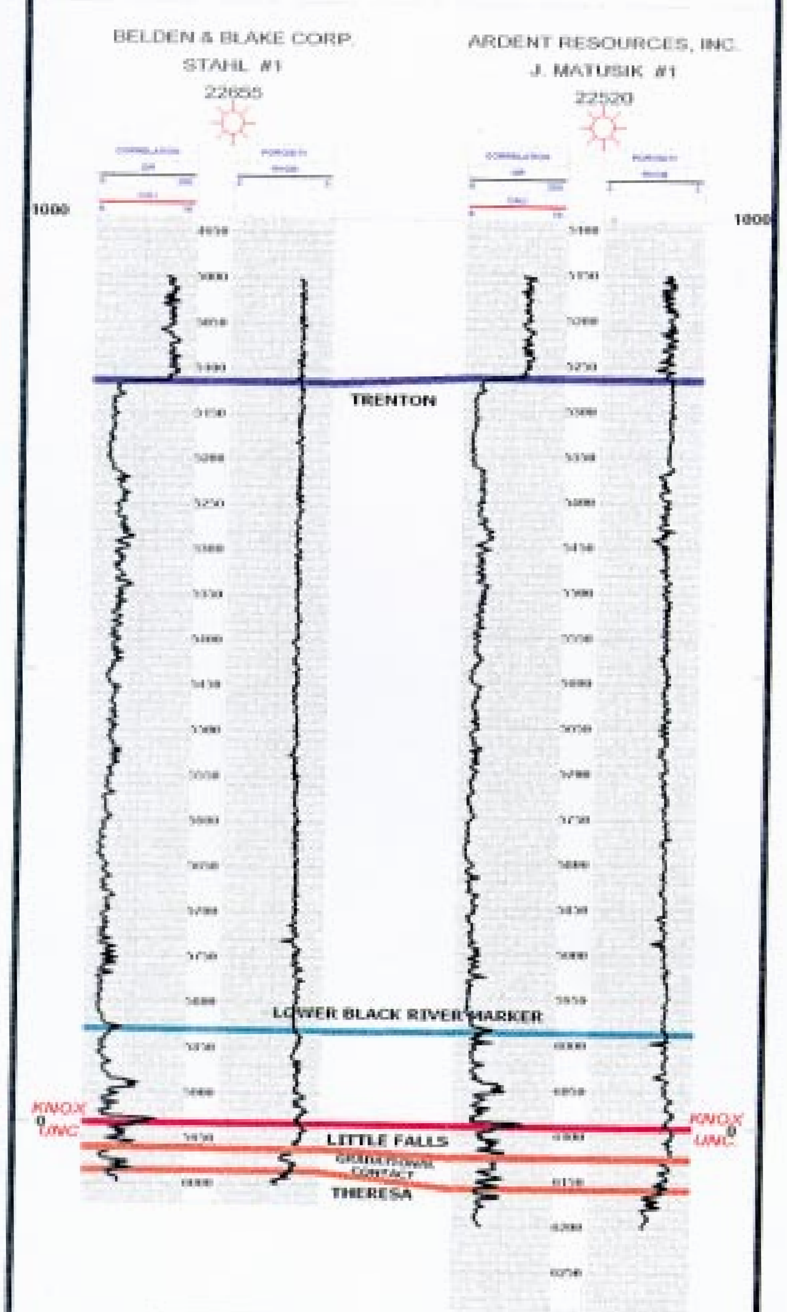


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FIGURE 6
STAHL-MATUSIK CORRELATIONS

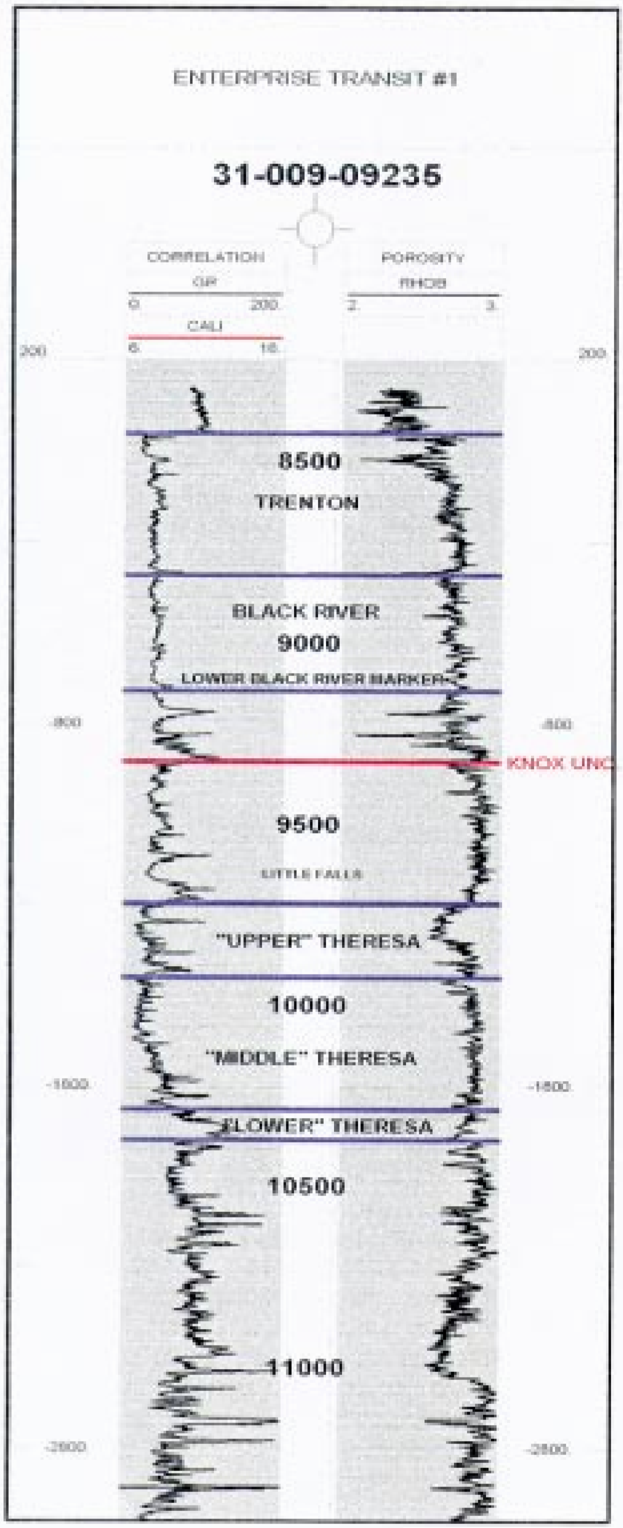

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FIGURE 7
ENTERPRISE TRANSIT #1

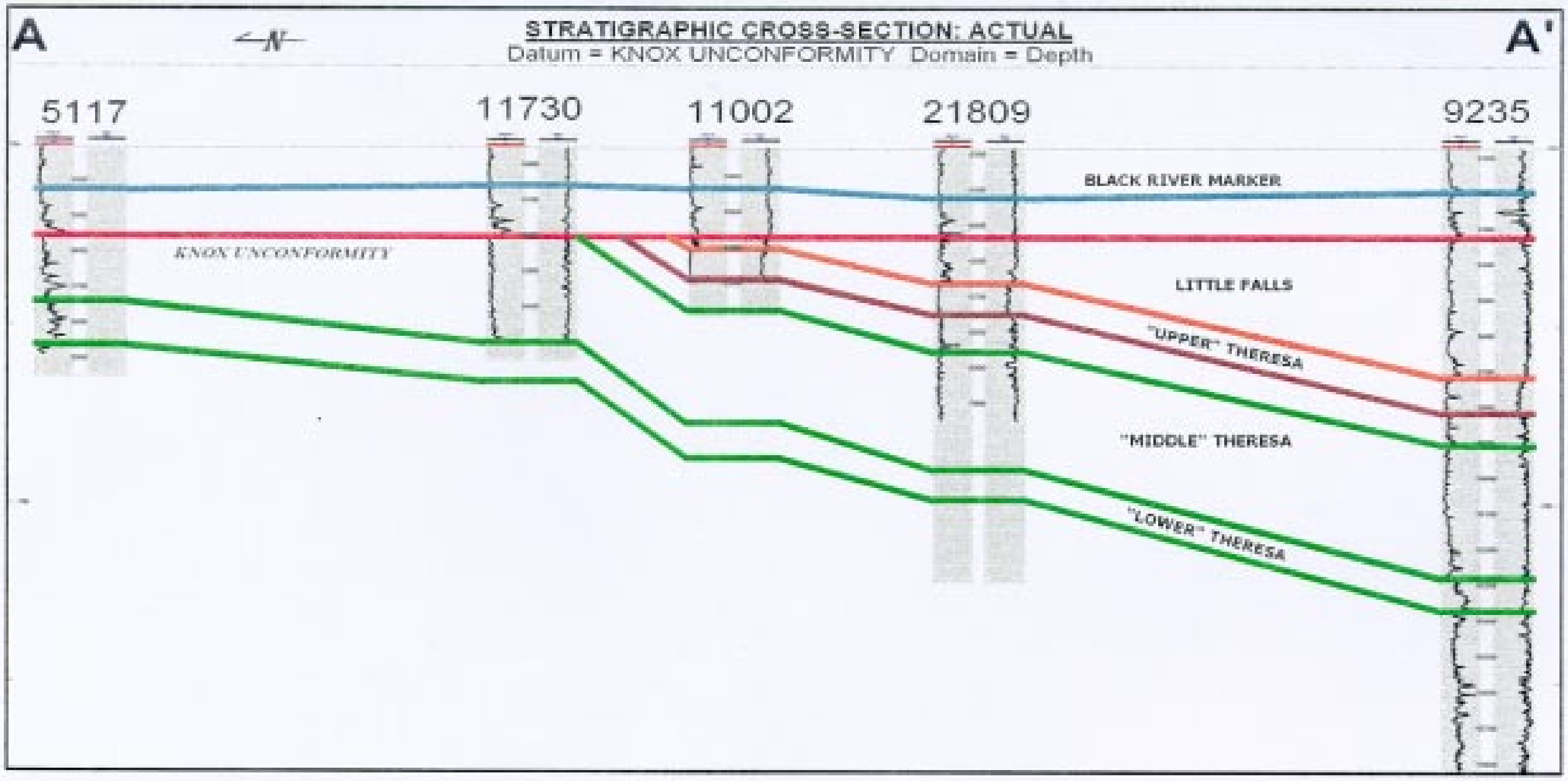

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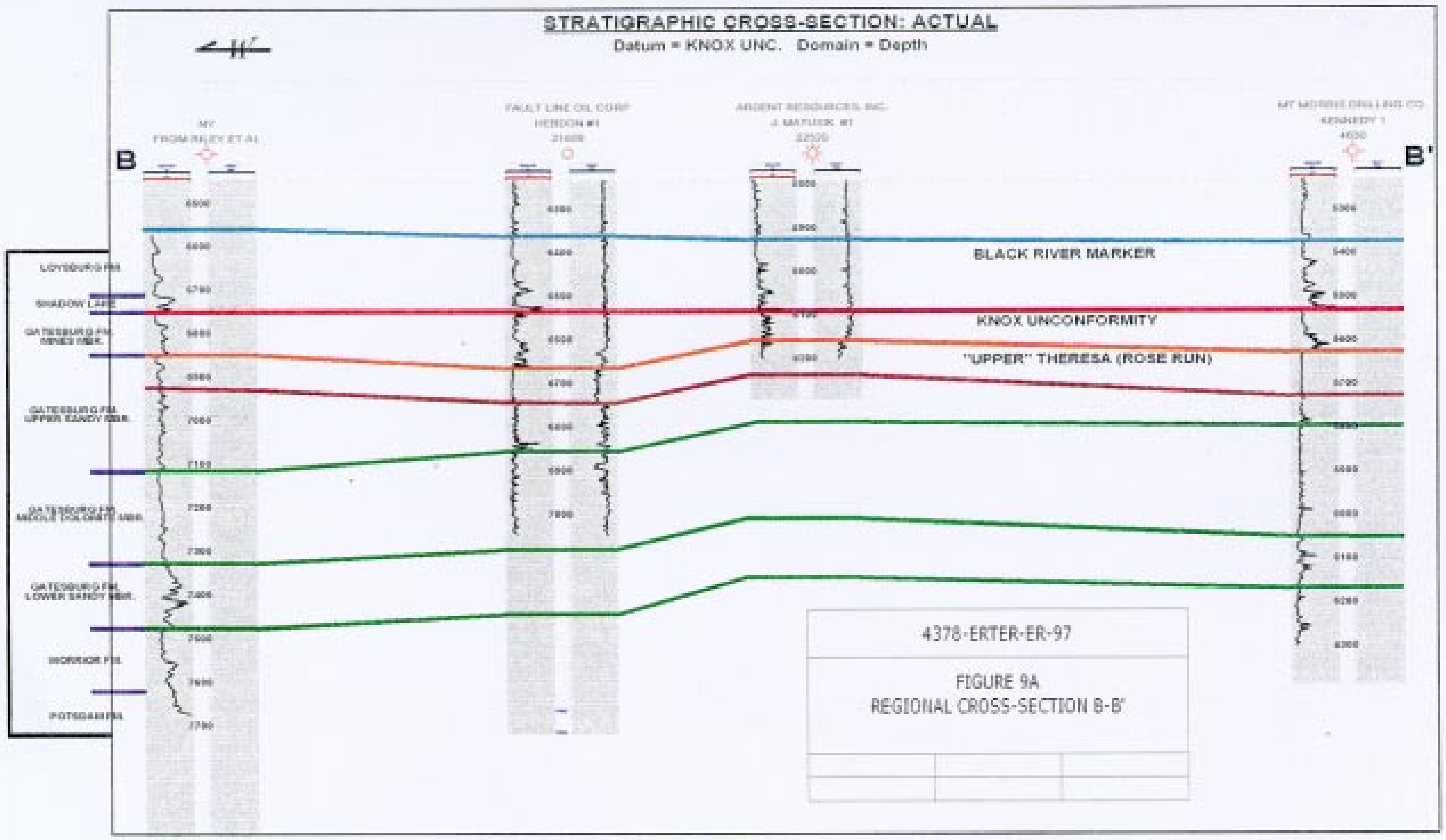
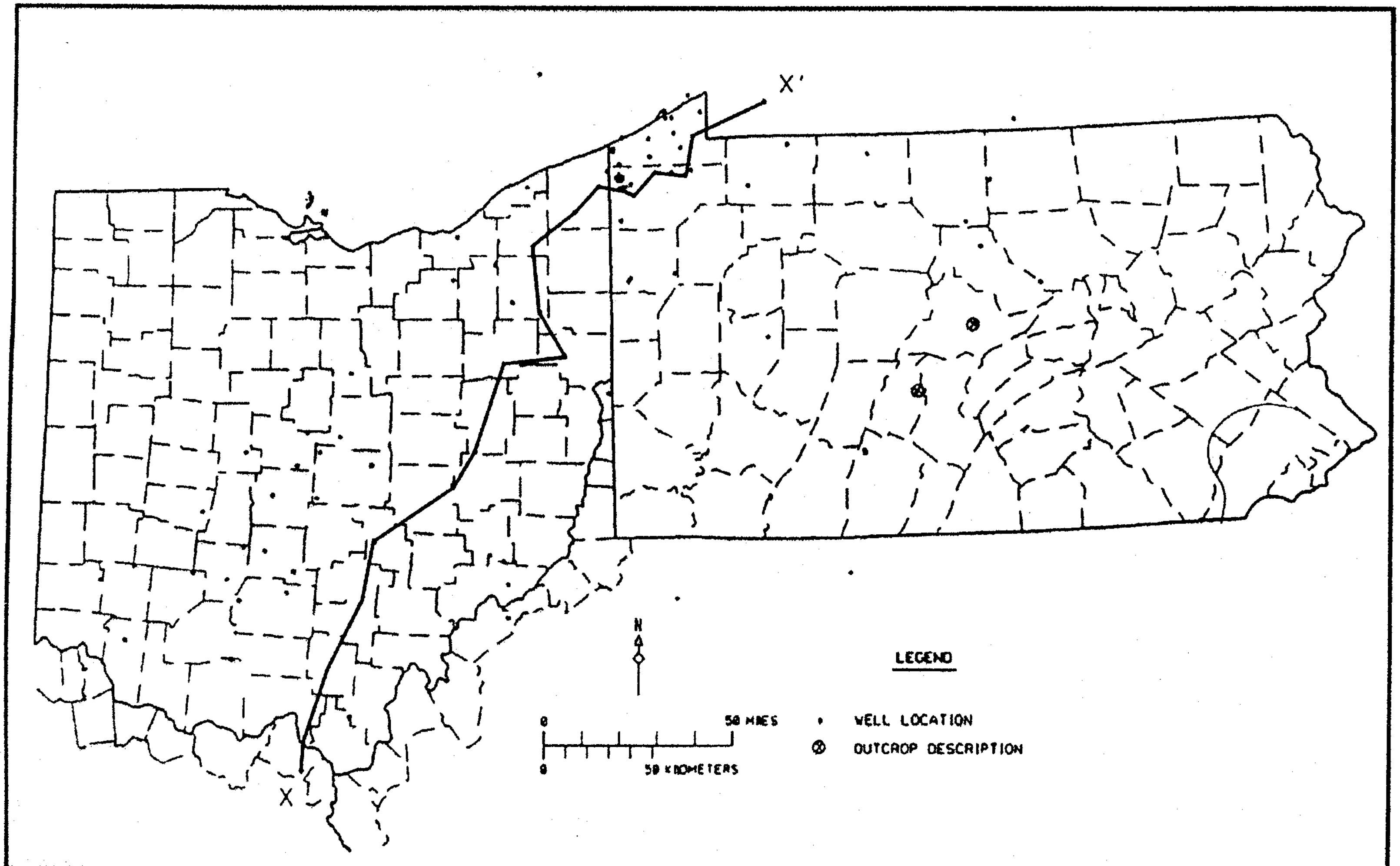
FIGURE 8
REGIONAL CROSS-SECTION A-A'

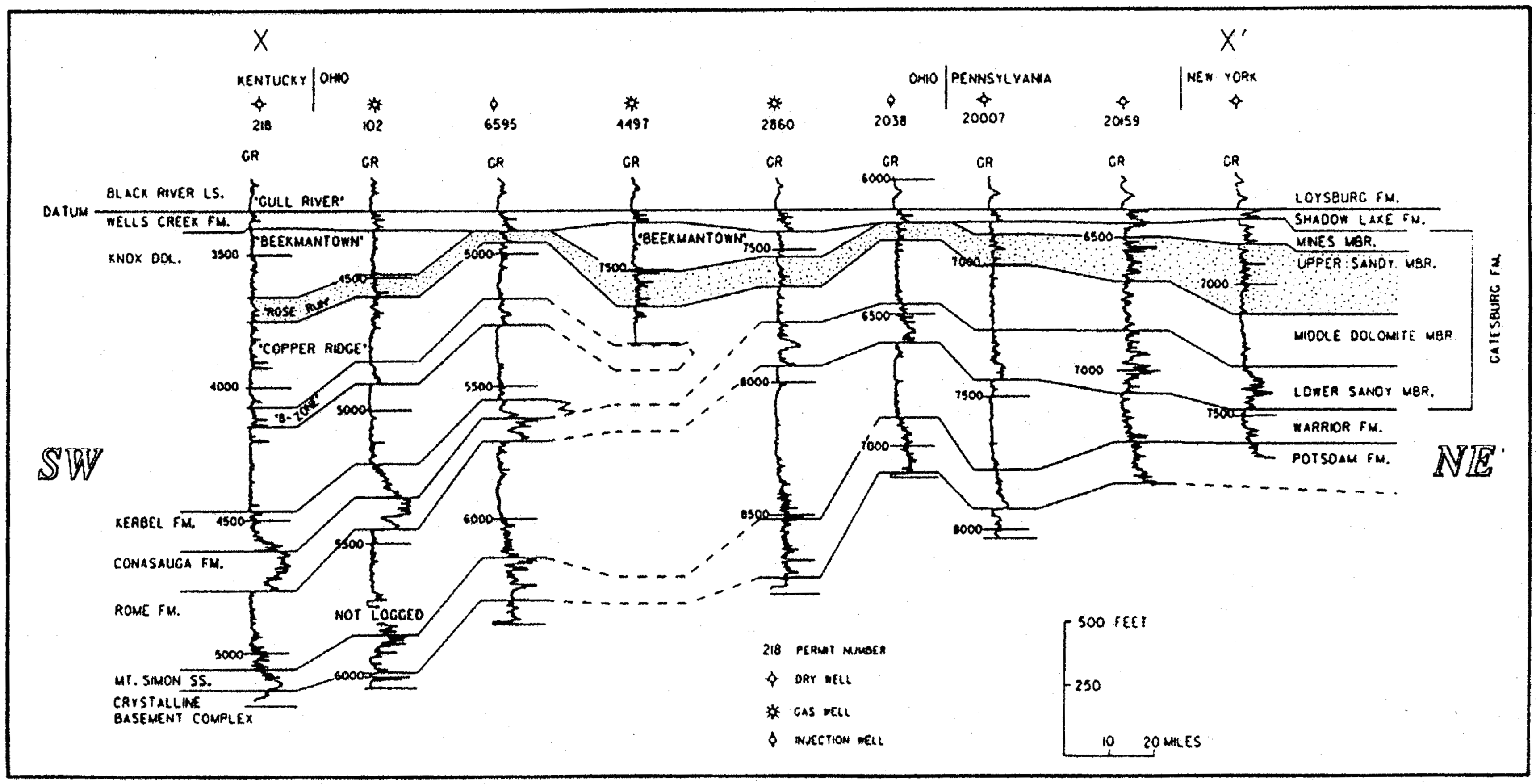


Correlations from Riley et al., 1993



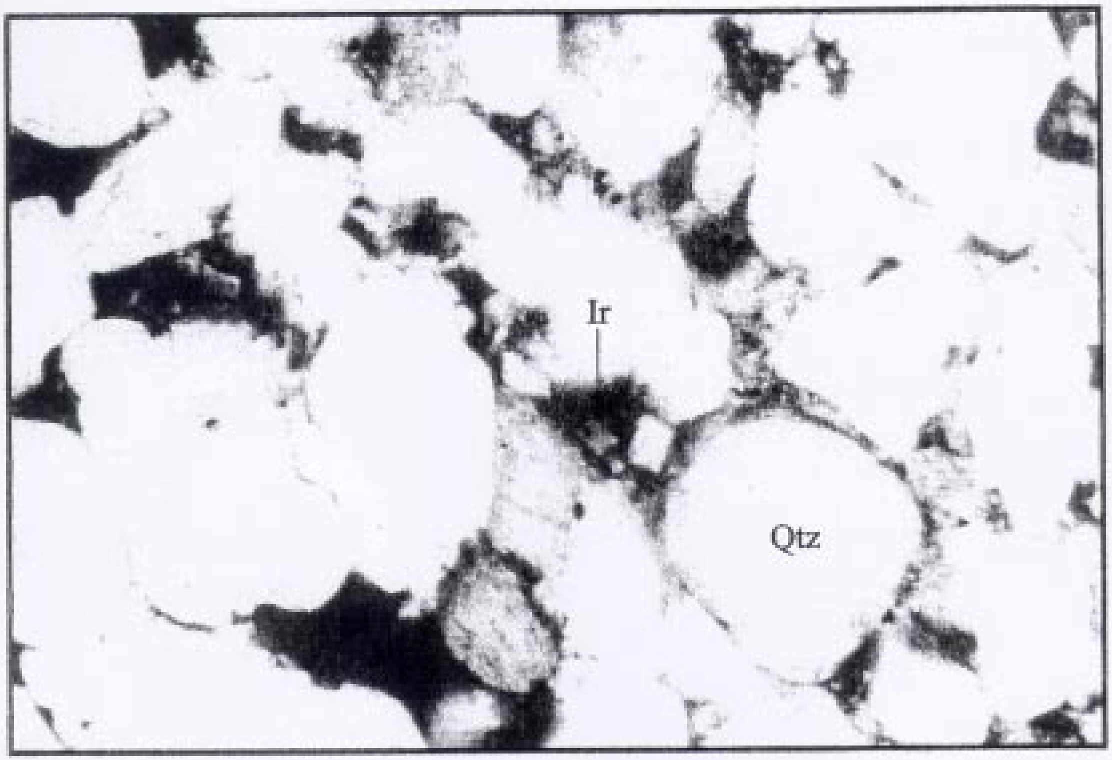
Location of regional cross sections constructed for this study. Cross section X-X' is shown in figure 9c. (after Riley et al, 1993)

Figure 9b



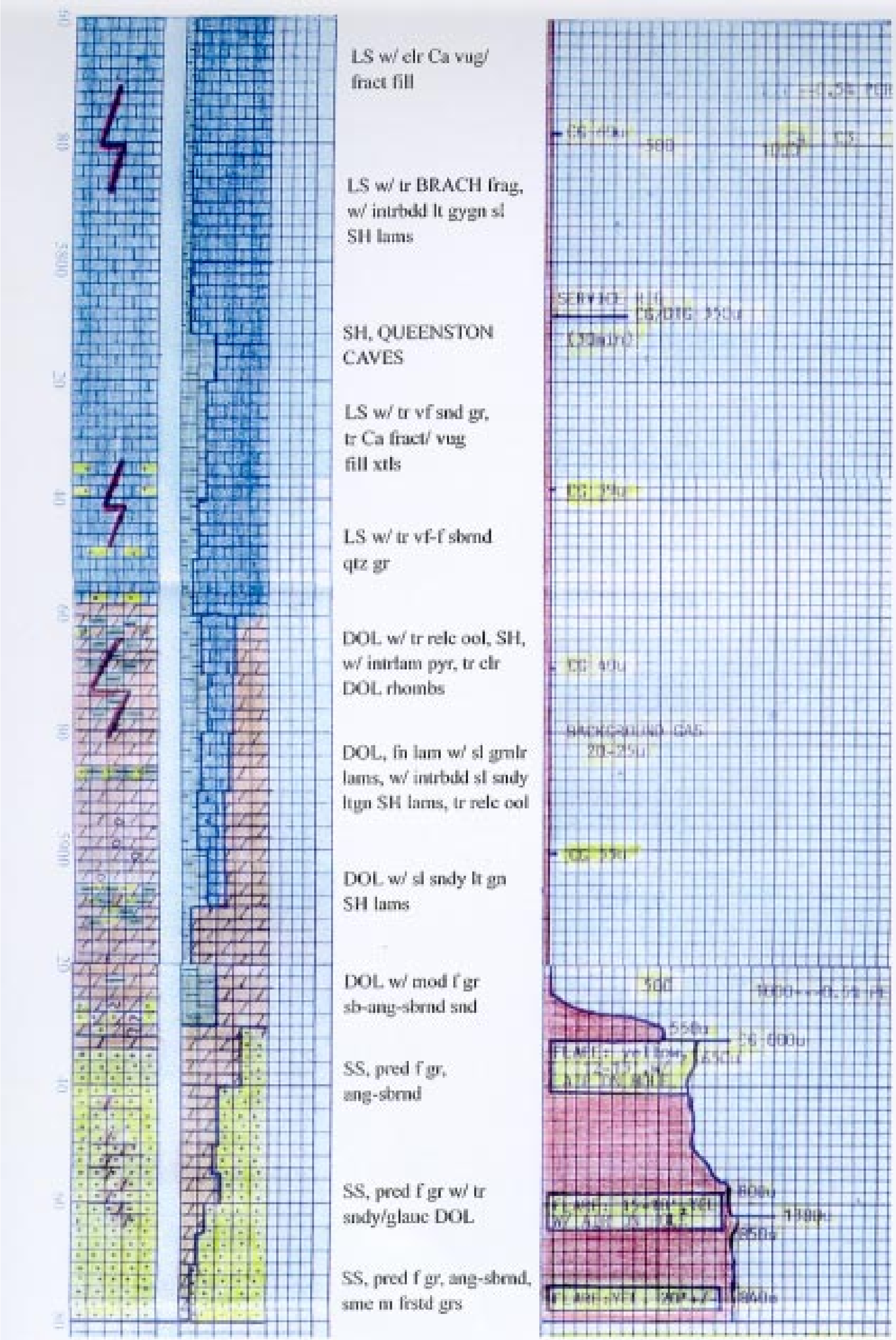
Regional cross-section X-X', using selected wells from line-of-section in Figure 9b. (After Riley et al., 1993)

Figure 9c



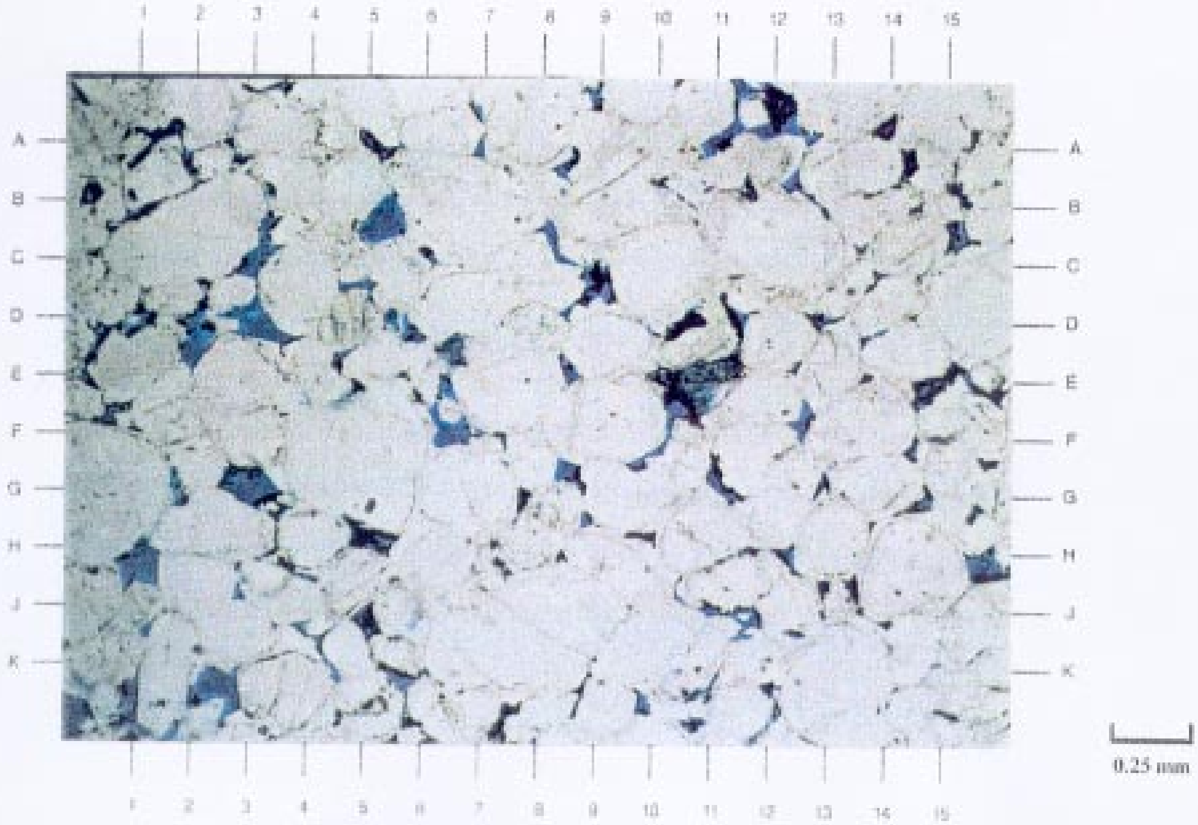
Photomicrograph of enlarged intergranular porosity (Ir) in Rose Run sandstone samples from Ohio. Note the rounded quartz grain in lower quadrant. (From Riley et al., 1993)

Figure 10



From a mud log of the Stahl No. 1 well by Stratagraph, NE., INC)

Figure 11

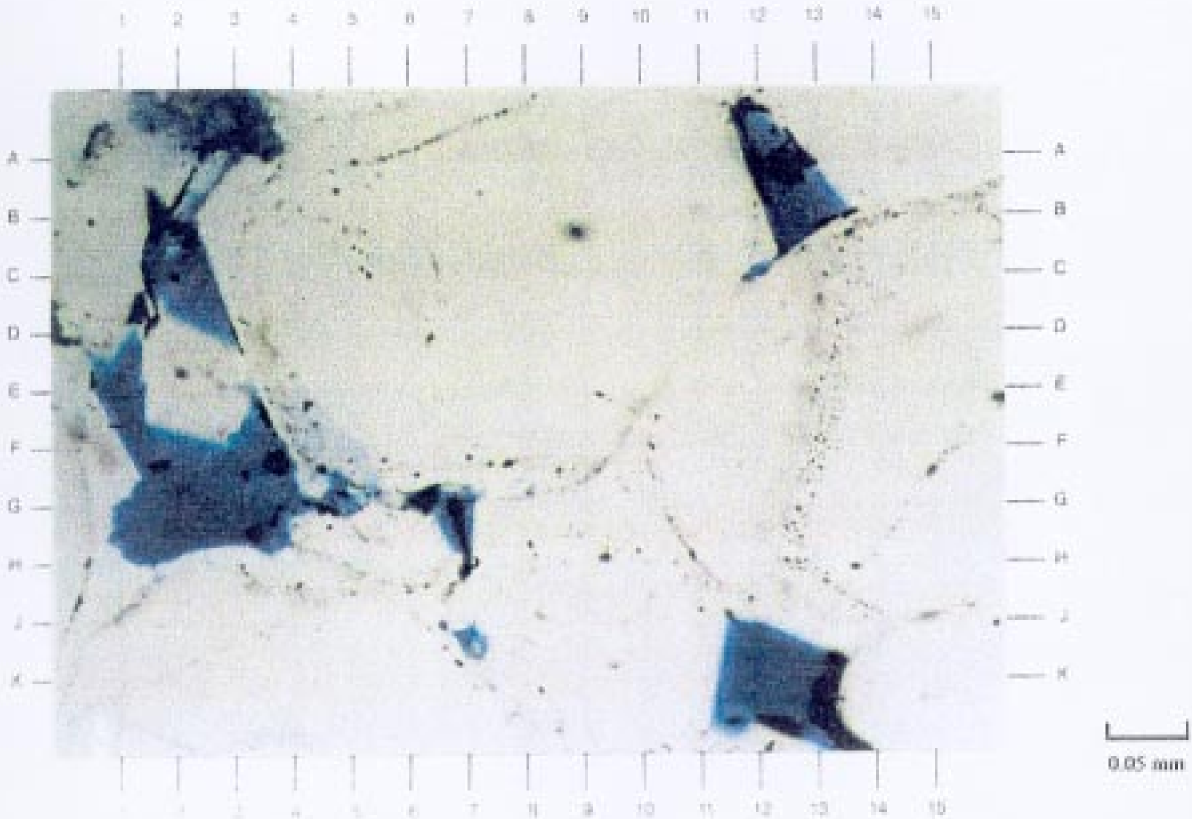


STAHL NO. 1 well, 5997 feet.

Variably distributed porosity is exhibited in the general overview above. This quartzarenite has a massive fabric and is well cemented by quartz overgrowths. Effective visible porosity includes both secondary grain-moldic pores (G3,B-C5) and primary intergranular pores (F12.5,H12,K5.5). (From a report by Omni Laboratories, 1996)

Magnification: 40X

Figure 12

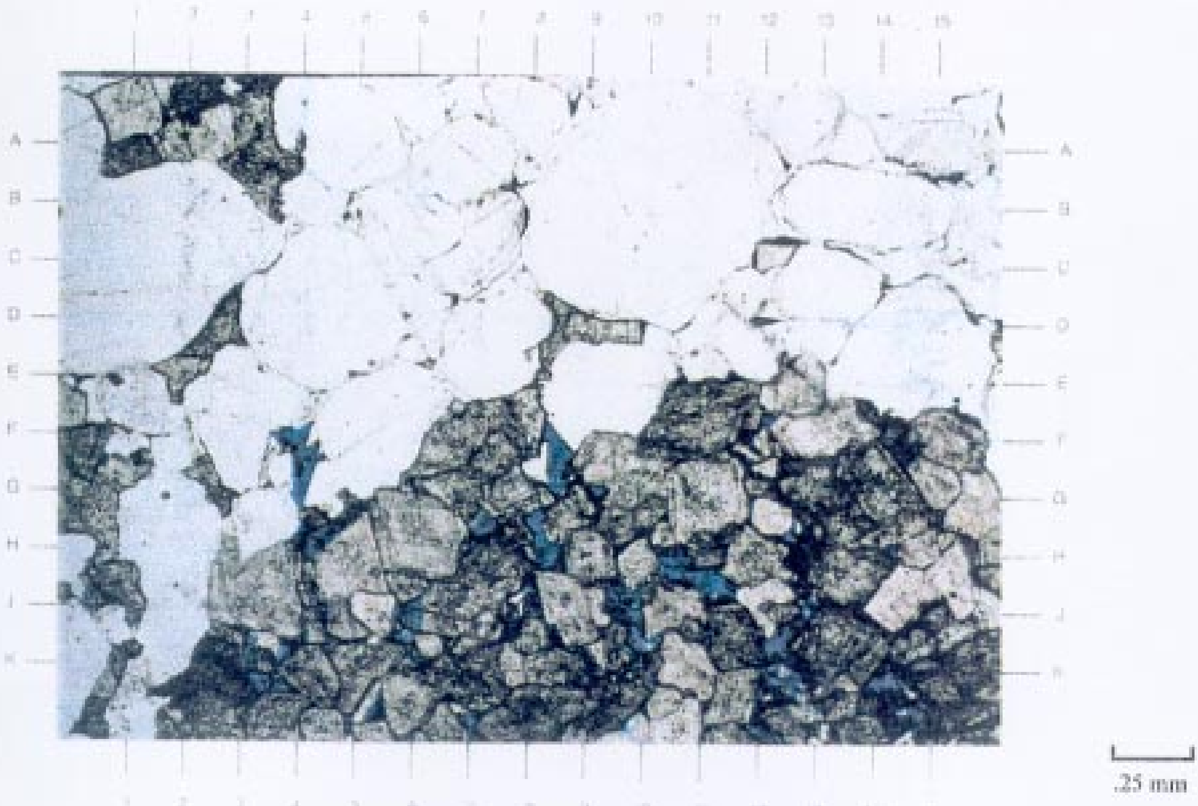


STAHL No. 1 well, 5997 feet

A high magnification view of the area near E8 in Figure 10 is shown in the photomicrograph above. All of the framework grains in this field of view are composed of monocrystalline quartz (D7, E14,K4). Secondary quartz overgrowths partially (B3,B12) to completely (G10) occlude primary intergranular pore space. Note the relatively clay-free nature of these pores (B12.5,K12). (From a report by Omni Laboratories, 1996)

Magnification: 200X

Figure 13

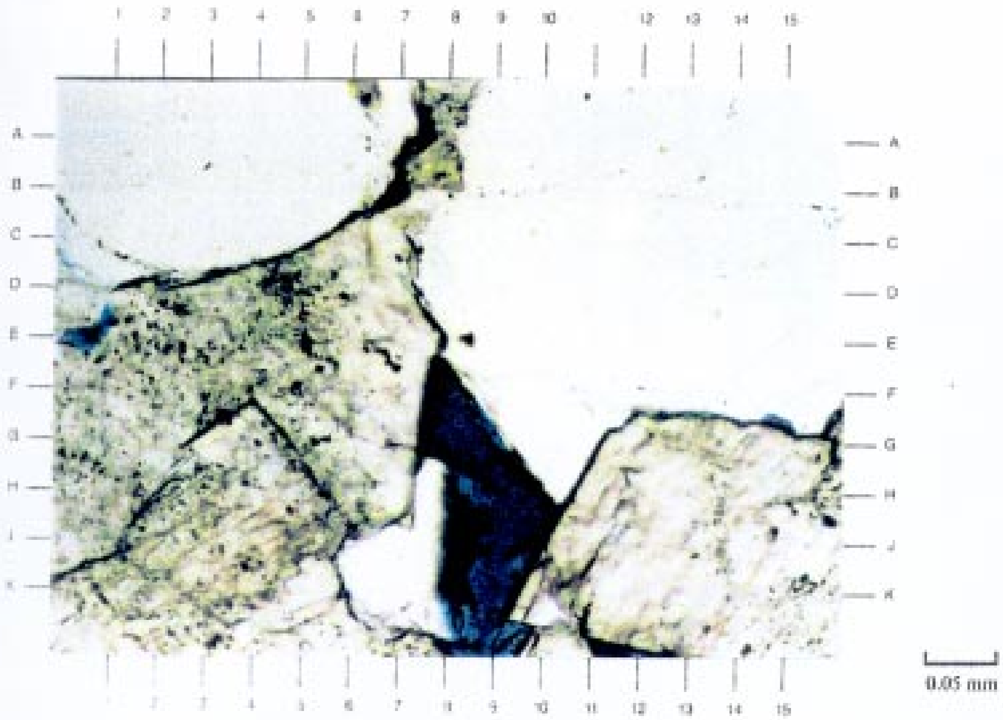


STAHL No. 1 well, 5970 feet

The low magnification photomicrograph illustrates the relatively large oval-shaped dolomitic regions (J3-J15,F11-K11) which exist in this quartzarenite. The more quartz-rich sand portions of this sample (upper half of photo) are relatively tight, whereas the dolomitic regions contain visible effective porosity. (From a report by Omni Laboratories, 1996)

Magnification: 40X

Figure 14

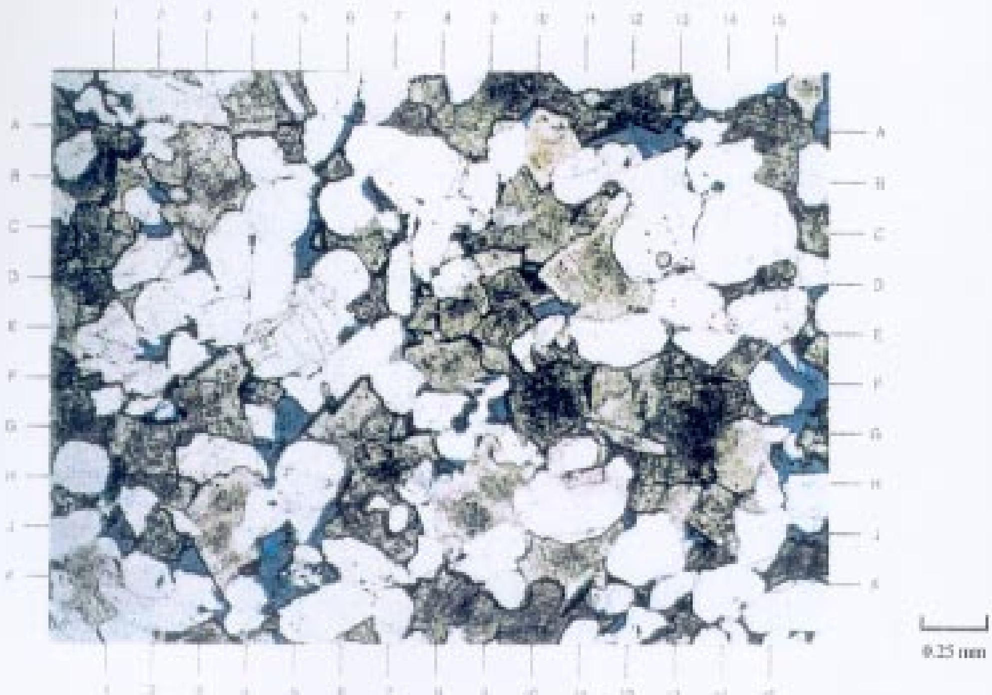


STAHL No. 1 well, 5997 feet

This is a high magnification view of the area near E8 in Figure 12. Rhombic crystals of secondary dolomite infill intergranular pore space (D6) and also replace portions of selective sand grains (G12). Secondary quartz overgrowths (C-D0.5) are discerned from their quartz host grains (D3) by thin dust rims (C0.5). (From a report by Omni Laboratories, 1996)

Magnification: 200X

Figure 15

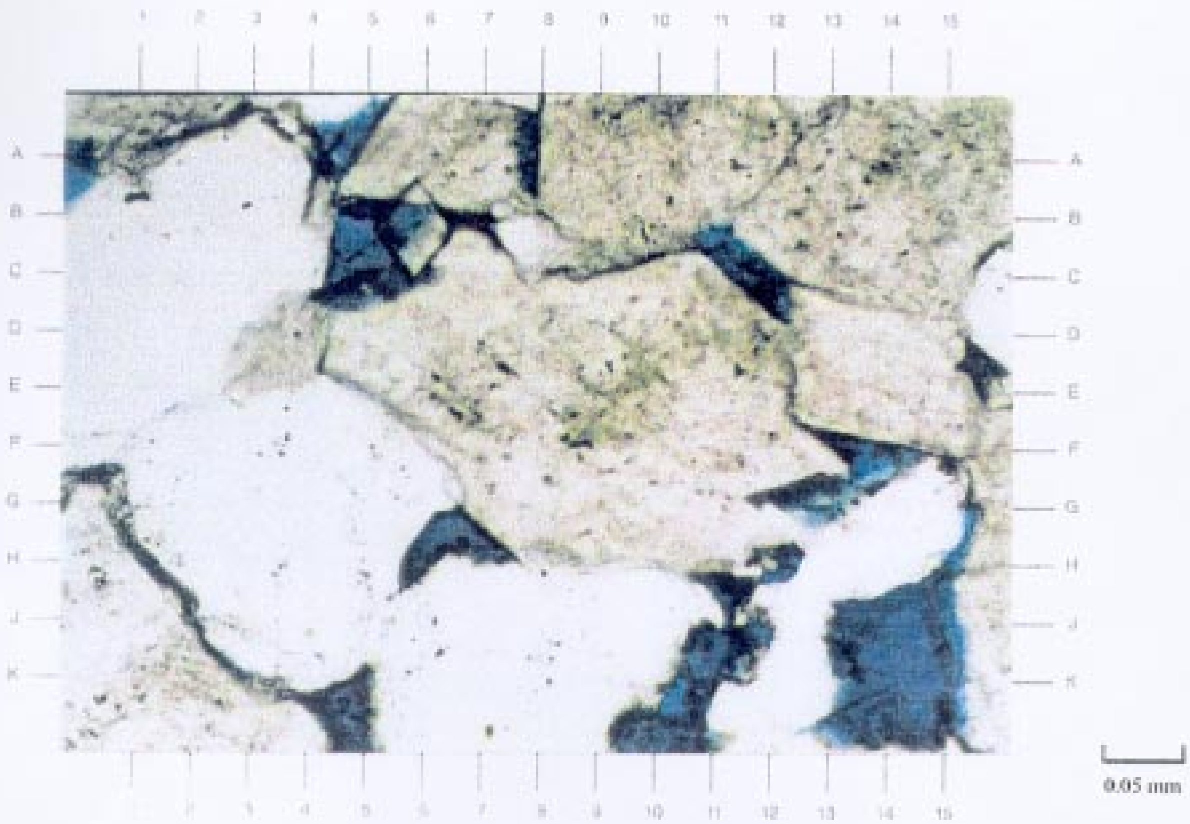


STAHL No. 1 well, 5971 feet

The general overview of this photograph shows a moderately sorted, medium-grained sandstone with relatively good reservoir quality. While dolomite cementation is pervasive (D3,D11,G13), both secondary pores (J-K4.5) and primary pores (C2,E-F2) remain. These pores, however, are unevenly distributed throughout this sample. (From a report by Omni Laboratories, 1996)

Magnification: 40X

Figure 16

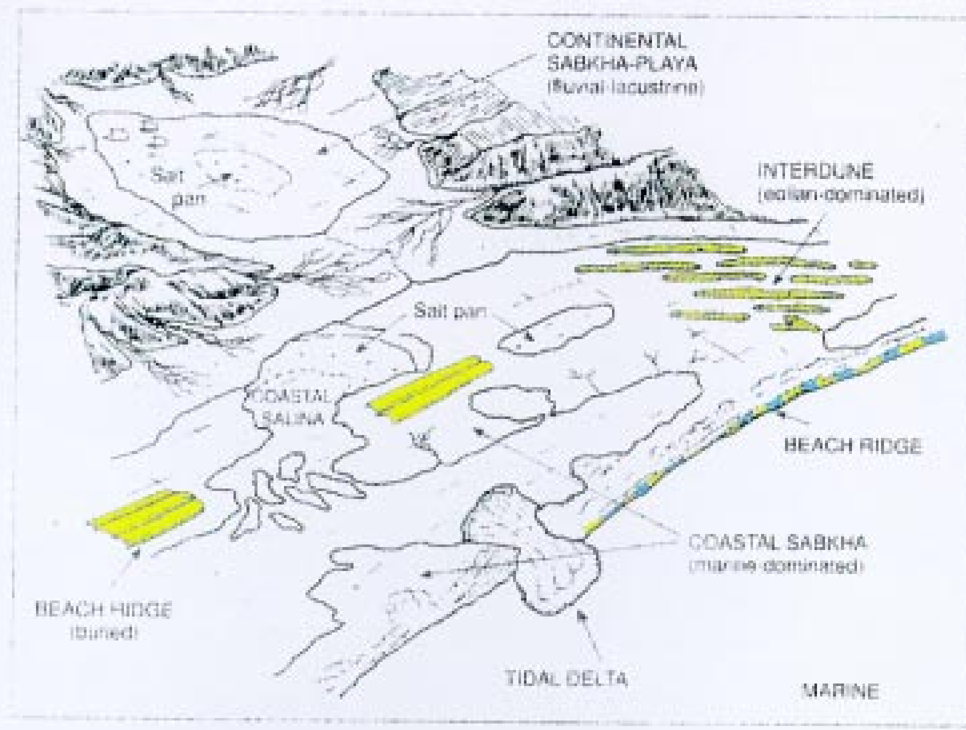


STAHL No. 1 well 5971 feet

A high magnification view of the area near F8 in Figure 14 is shown in this photomicrograph. Both intergranular pores (G-H6.5,A4.5) and secondary grain-moldic pores (J-K14) are partially interconnected in this sandstone. Many of these pores are partially lined by a thin dark substance (below C5,H6) which may be organic in nature. (From a report by Omni Laboratories, 1996)

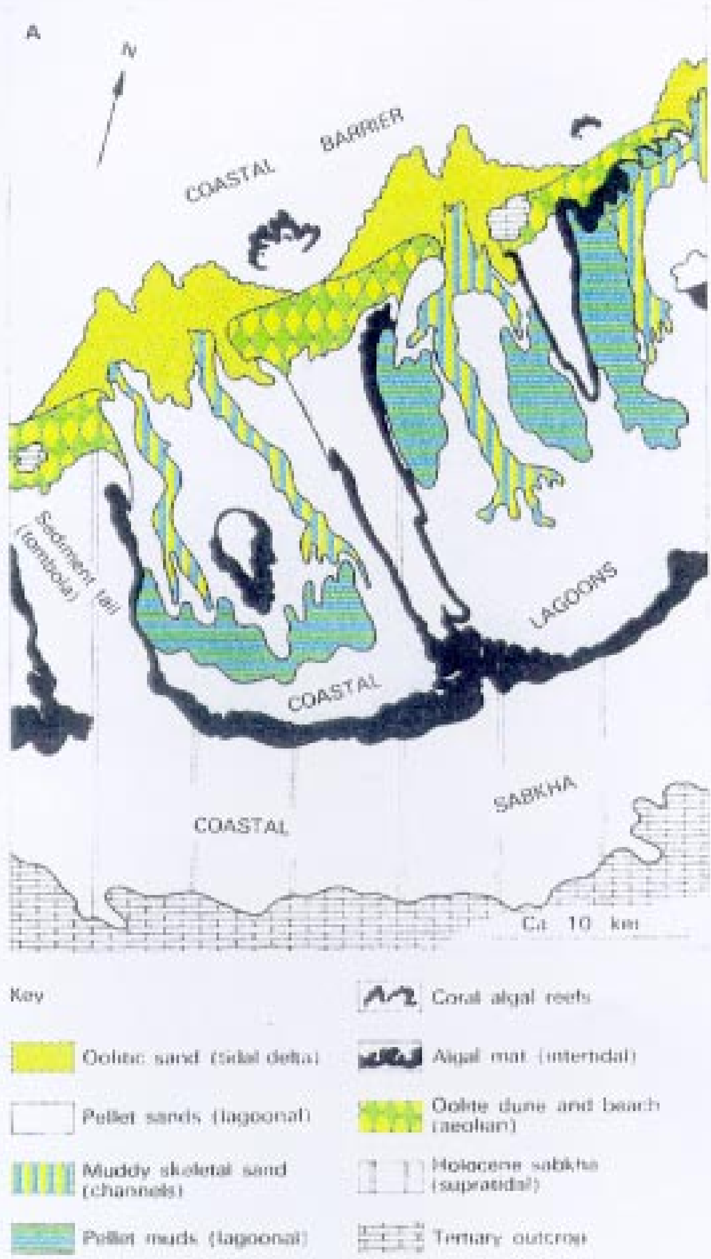
Magnification: 200X

Figure 17



Sabka depositional environment (After Kendall, A.C., 1984)

Figure 18



Schematic sketch map of the Abu Dhabi region, showing distribution of main sedimentary facies (after Purser and Evans, 1973).

Figure 19