BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 45, NO. 11 (NOVEMBER, 1961), PP. 1870-1883, 6 FIGS., 1 TABLE

COMPOSITIONAL LOGGING OF AIR-DRILLED WELLS[1]

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ABSTRACT

The mineralogical compositions of representative samples of air-drilled cuttings taken at 10-foot intervals from two wells in the Punxsutawney-Driftwood gas field of central Pennsylvania have been determined by routine methods of X-ray analysis. Distinct mineralogical zones were found to correspond closely with formations and formational contacts. Although the wells are 18 miles apart, correlations can be made. Compositional logs of air-drilled holes are easily obtained and can be used for interpreting subsurface geology in the same fashion as conventional electric logs. In addition, the presence, absence, and relative abundance of minerals yield information on the geological history of the area.

INTRODUCTION

Mineralogical composition has been used widely by geologists in gaining a better understanding of problems involving sedimentation, facies, environment, zonation, and geologic history including metamorphism. Some workers have stressed heavy minerals, others, clay minerals; whereas, in fact, the entire mineral assemblage may be useful. Most mineralogical studies have been conducted using microscopic methods which are tedious and time consuming. X-ray techniques developed in the last decade or so are supplementary to the microscope and have made it possible to determine the clay minerals. Furthermore, any crystalline constituent in a rock can be identified and the approximate amount determined from X-ray data.

Gude (1950) in a study of the Upper Cretaceous Laramie Formation of Colorado used mineralogical composition determined by X-ray analysis to define lower, middle, and upper intervals in this formation and to establish the contact with the underlying Fox Hills Formation. Similar studies by Weaver (1958) have aided in unravelling the geologic history of the Ardmore basin. Although X-ray methods of studying rock samples clearly add one component to the multivariate system of geologic interpretation, it has not been fully exploited for many reasons, such as time of sample preparation, interpretation of data, and cost of analysis. In some, but not all, situations, the geological information determined from X-ray analyses can be gained by other less sophisticated methods, for example, binocular examination.

Air drilling poses a new problem in obtaining subsurface geological information. The cuttings are, in general, fine-grained and not readily amenable to examination by binocular methods. Megafossils and even microfossils are usually destroyed in the drilling operation. Conventional electric logs can not be run unless the hole is filled with mud or fluid negating some of the advantages of air drilling. Induction and radiation logs are possible and are becoming more widely used.

This study was conducted to determine the feasibility of locating formational contacts and intraformational zones based on changes in mineral assemblages. If this information could be determined fairly accurately using strictly routine X-ray methods of analysis, it would seem that compositional logs for air-drilled wells could be constructed and utilized in much the same manner as conventional electric logs for subsurface geological studies.

LOCATION

The sites of the two air-drilled wells selected for this study are shown on the index map (Fig. 1). Both of these wells were drilled by the New York State Natural Gas Corporation and are located in the Punxsutawney-Driftwood gas field of central Pennsylvania. The A. J. Palumbo well No. 9 is situated in Huston Township, Clearfield County on the northwestern flank of the Chestnut Ridge anticline in Section C of the Penfield Quadrangle. The R. Kriner well is about 17.5 miles southwest of the Palumbo well and is located in Bra

[1] Manuscript received, February 28, 1961. Publication authorized by the executive vice-president of the Gulf Research and Development Company.

[2] Gulf Research and Development Company. The writers express their gratitude to the geological personnel of New York State Natural Gas Corporation, especially R. N. Metzler and John McFadden for the collection of samples used in this study and for supplying information concerning the air-drilling procedure. The writers also thank C. Heathcote of New York State Natural Gas Corporation for critically reviewing the manuscript. Special thanks are extended to Betty H. Smock and Scott Crawshaw of Gulf Research and Development Company, who prepared the samples for X-ray analysis.

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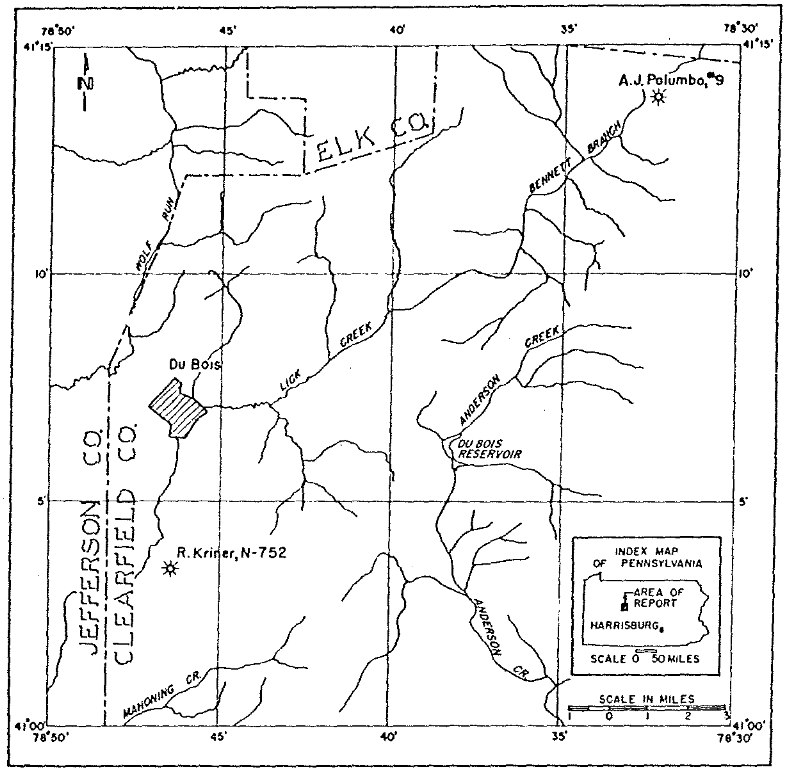

FIG. 1.—Map showing locations of R. Kriner well N-752, and A. J. Palumbo well No. 9 in vicinity of DuBois, Pennsylvania.

Township, Clearfield County, on the northwestern flank of the Chestnut Ridge anticline in Section I of the Dubois Quadrangle. These wells are along the strike of the folds in the Allegheny Plateau.

GENERAL GEOLOGY

Rocks cropping out in the Chestnut Ridge and Sabinsville anticlinal area of the Allegheny Plateau are predominantly Pennsylvanian in age, although Mississippian rocks crop out in places along stream channels which dissect the folds. These southwesterly plunging anticlines and the intervening Caledonia syncline have flank dips of 3°–10° and amplitudes of 1,000–1,500 feet. Reverse faulting is common in the area. Displacements averaging 50–100 feet are common but many faults exhibit displacements ranging from 500 to 1,000 feet.

Gas production in the Punxsutawney-Driftwood field is obtained from the Onondaga and Oriskany Group of Middle and Lower Devonian Age which overlies the Salina Formation of Silurian Age. The Middle and Lower Devonian interval, usually less than 1,000 feet in thickness, is interbedded marine shale and limestone with sandstone at base. The Chemung Series of Upper Devonian Age overlies the Tully Limestone and consists of a sequence of gray shales with thin streaks of siltstone and sandstone. Although thinner in this area than in east-central Pennsylvania, the Chemung and associated groups have a thickness of about 4,800 feet. The uppermost 350–500 feet of Devonian rocks are a series of reddish shales with interbedded red and gray sandstones. These rocks represent the western edge of the Catskill delta and are called the Catskill Formation.

Mississippian rocks which have several thousand feet of thickness in eastern Pennsylvania are not well developed in this part of the Allegheny Plateau. The Pocono Group overlying the Devonian Catskill is composed of sands and shales, being more shaly in the lower part. The overlying Mauch Chunk Formation is composed of reddish shale and gray sandstone. Following deposition of this sequence, central Pennsylvania was uplifted so that part of it was removed by erosion (Ashley, 1926). However, in this study area the Mauch Chunk Formation has a thickness of 200–300 feet.

The basal Pennsylvanian Pottsville Group, primarily a siltstone-sandstone sequence with interbedded coals, unconformably overlies the Mississippian rocks, and is overlain by the Allegheny Group. The Allegheny Group, like the Pottsville Group, consists of interbedded sandstone and siltstone zones with scattered carbonaceous shale beds and coals. The Pennsylvanian rocks in this area have been adequately described by Ashley (1926, 1940) and Carter and others in the Guidebook for Field Trips, Pittsburgh Geological Society Meeting (1959).

Sample Collection

Since the cuttings from an air-drilled operation arrive at the surface in the form of "dust," a device had to be constructed which could split a representative sample of the dust from the exit flow-line as well as exclude any cavings. This problem was adequately solved by R. N. Metzler of the New York State Natural Gas Corporation. The rock dust was fractionated by means of a metal baffle enclosed within the main exit flow-line which diverted approximately one-fourth of the dust into an off-shoot line. A metal box containing various mesh-size, tilted, sieving screens in the off-shoot line was used to separate most of the cavings from the dust. It was believed that a satisfactory test for compositional logging could be conducted if a composite sample was collected of each 10-foot interval penetrated. To lessen the probability of cavings in the sample for analysis, only the very fine-grained portion was collected. In this geological setting, cavings can usually be differentiated from air-drilled cuttings based solely on size.

Experimental Procedure

A representative portion of each 10-foot composite sample to be analyzed was ground until the entire sample had a grain size maxima of approximately 0.04 mm. A mixture of this rock powder and distilled water was used to prepare a sample on a glass slide for X-ray analysis. No dispersing agent was used to bring out the clay minerals as a strictly routine method of analysis was being sought. The rock powder mixtures on the glass slides were X-rayed and the diffraction patterns interpreted. Monomineralic samples of the rock-forming minerals were examined and the average intensities of certain strong diffraction peaks were operationally defined as representative of the maximum number of intensity units for that specific mineral. The intensities of the same diffraction peaks of those minerals occurring in the air-drilled samples were compared with the intensities of the reference samples. It should be emphasized at this point that by using X-ray diffraction, all of the crystalline constituents of a rock can be identified. Furthermore, it is impossible to differentiate cementing agents from grains by X-ray analysis. In this study any rock yielding greater than 10 intensity units of carbonate minerals was called a carbonate rock, whereas, those rocks yielding less than 10 intensity units of carbonate minerals were arbitrarily interpreted as detrital rocks containing carbonate cement since it is known that the rocks in this stratigraphic sequence are well cemented. However, it should be remembered that small amounts of carbonate minerals could be partly attributed to fossil fragments and(or) fracture fillings. The approximate amount of each mineral species in each sample was calculated from diffraction peak intensities and the data entered on IBM cards for processing in the IBM equipment. The results were printed out in the form of a mineral compositional log showing the mineralogy of each 10-foot composite sample in order proceeding down the borehole. This method was used so that similar mineral assemblages could be easily and quickly delineated by visual inspection into correlatable zones. By comparing the stratigraphic interval represented by these zones with the formational "tops" picked in the test wells by personnel of New York State Natural Gas Corporation, it was observed that the mineralogical zone boundaries were either on or very near the formational contacts. By using the mineral assemblages, it became apparent that the A. J. Palumbo well No. 9 could be correlated with the R. Kriner N-752 well.

Interpretation of Mineralogical Data

Inspection of the "compositional log" (Fig. produced by the IBM equipment suggested immediately the possibility of differentiating sandstones, siltstones, and shales on the basis of relative abundances of quartz as determined peak intensities. The intensities of certain diffraction peaks of quartz were plotted against depth in the form of a horizontal bar graph (Fig.

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FIG. 2.—Compositional log produced by IBM.

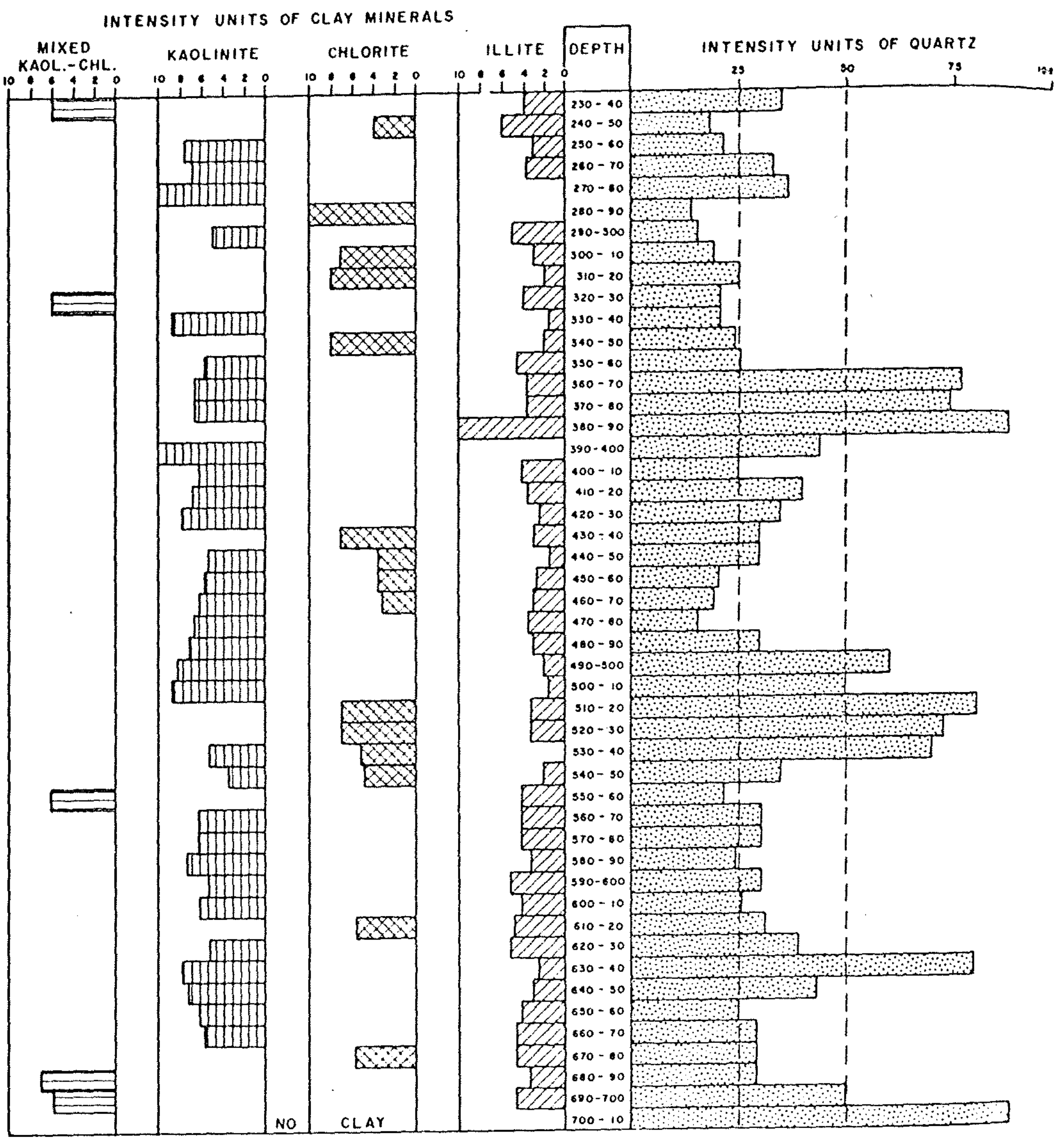
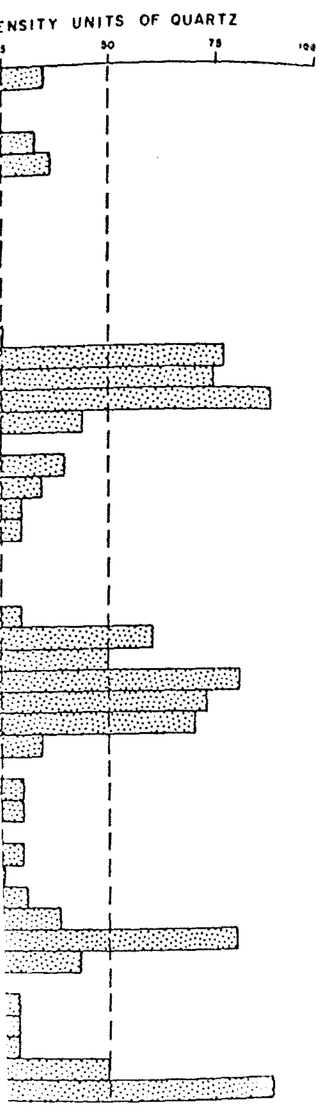


Fig. 3.—Diffraction data for Pottsville formation in Kriner well N-752.

the Pottsville Group of rocks in the Kriner well. Shale was arbitrarily defined by those samples yielding peak intensities for quartz of 25 units or less; siltstones, 25–50 units; and sandstones, more than 50 units. From the variations in the intensities of the diffraction peaks for quartz it is clear that the abundance of quartz can be used to delineate sandstone, siltstone, and shale.

Thus, a definite cyclical pattern of sedimentation is apparent in the Pottsville Group in the vicinity of the Kriner well. From the mineralogical assemblage it is possible to determine the transitional or non-transitional nature of the upper and lower boundaries of the sandstones and their association with the adjacent lithologic types. A plot of the intensities of certain diffraction peaks for the clay minerals in each sample against depth (Fig. 3) was made to determine whether or not specific clay minerals were associated with specific lithologic types. By assuming 10 units intensity as representative of the total clay fraction, it was found that specific clay minerals were not confined to one lithologic type. It is emphasized that the units of intensity in the plots shown



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The clay minerals of the penetrated sequence in each well are illite, chlorite, and kaolinite. Although the geologic significance of the clay mineral assemblage found in a single sample is obscure, systematic variations in occurrence and relative abundances of clays through rock sequences are commonly indicative of geologic history. In the geologic situation being considered, a plot of the ratios of diffraction peak intensities for illite to kaolinite, plus chlorite versus depth, for the Allegheny Formation in the two wells (Fig. 4), suggests that significant variations in the ratios exist intraformationally and may be associated with the depositional environment and sedimentary pattern of the Allegheny Formation. In view of the clay mineral relations, this interpretation seems valid but it must be realized that variations in clay mineralogy may be due to source, weathering conditions, environment of deposition, diagenesis, or some combination of these factors. In a vertical sequence where systematic variations in mineralogy occur, differing sedimentary environments should be suspected.

Murray (1953) studied a suite of Pennsylvanian shale samples from Indiana and Illinois which had been genetically interpreted as marine, brackish, and non-marine. He found that the ratio of illite to kaolinite-chlorite increased progressively from non-marine through brackish to marine environments. His findings substantiate the recent sediment study of Dietz (1941), who found that illite is the predominant clay mineral most distant from shore, whereas, kaolinite was found nearshore. Other recent sediment studies by Grim and Johns (1953) and Powers (1953) show that the clay minerals, whether kaolinite or montmorillonite, react similarly when contacted with marine water. These authors found that chlorite and illite begin to form from clays introduced into a saline environment; kaolinite and montmorillonite occurred only in those sediments nearshore, whereas, chlorite was identified in the brackish-water zone near the river mouth. Further, they reported that illite was found to be the predominant clay mineral most distant from the shore and proposed that it was formed under open marine conditions where the sedimentation rate is slow and time permits extensive reaction with clay material before burial to form illite. These studies of sedimentary environments suggest the following generalities: (1) kaolinite occurs most abundantly in rivers and areas nearshore, (2) chlorite tends to form very soon after coming into contact with sea water and as a result is more abundant in a nearshore marine environment, and (3) although illite probably begins to form upon contact with sea water, it apparently forms at a slower rate and would be predominant in areas where the rate of sedimentation is low usually some distance from shore.

These observations based on both recent sediments and ancient rocks, suggest that an increase in illite to kaolinite-chlorite ratios indicates a change to more open marine conditions. However, caution must be exercised in applying this theory as clay minerals in coarse-grained sediment may vary extensively from those deposited as a result of diagenesis promoted by fluid movement after burial. Fine-grained sediments which become relatively impervious after burial, compaction, and cementation do not tend to be modified in this manner as shown by Milne and Earley (1958), Grim (1953), and Powers (1953).

If the clay minerals are attributed to depositional environments, it follows that the relative abundance of these minerals may be indicative of transgressive-regressive shoreline conditions. In combinations they may also suggest direction of an ancient shoreline. Application of these generalities to the data plotted in Figure 4 suggests that the Allegheny Formation of the two wells is a product of fluctuating shoreline conditions.

Since the majority of sedimentary rocks consists of sandstone, siltstone, shale, limestone, or combinations of these, Figure 5 was constructed to show how mineralogy was used to define these different lithologic types. By plotting the diffraction intensity units of calcite in each sample it is easy to delineate calcite-cemented rocks from limestones as previously defined. The diffraction intensities for calcite and quartz for each sample from within the lower part of the Chemung and associated series to the bottom of the Kriner well are plotted in Figure 5. The intensity units for quartz are used to define sandstones, siltstones, and shales within this interval following the same method as described previously for Figure 3.

Following this mineralogical classification of the samples, the plotted part of the Chemung and associated series consists predominantly of calcareous siltstones with one shaly unit and three limestone zones. As all of the samples from the two wells are 10-foot composites, the abundances represent the mean mineralogy for that

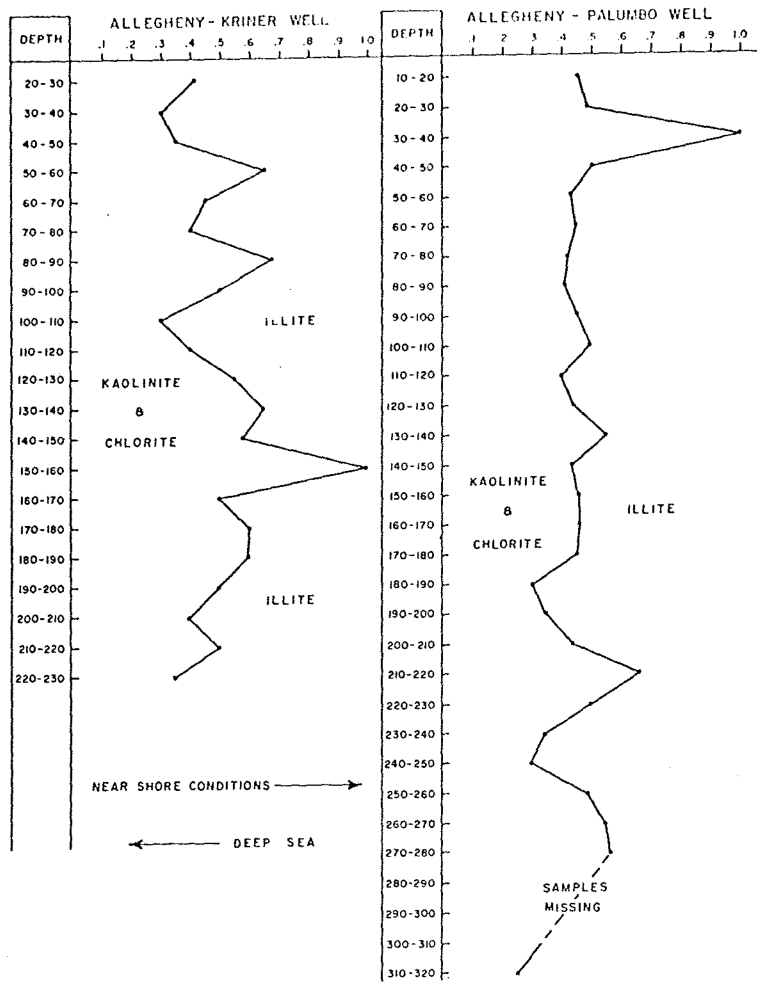


Fig. 4.—Diffraction intensity plots of kaolinite plus chlorite to total clay as function of depth where total clay includes kaolinite, chlorite, and illite.

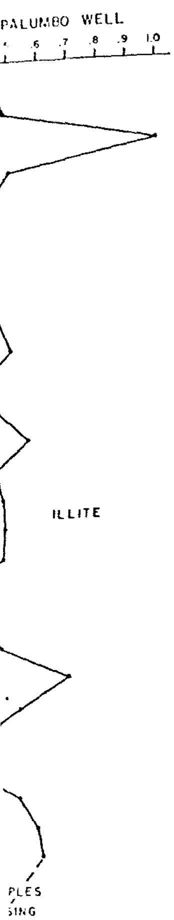
specific 10 feet of rock. It would be incorrect to state that a limestone bed 10 feet in thickness occurs at 6,520 feet in the Kriner well but rather that this zone contains rocks which have a large amount of calcite. The Tully Formation consists predominantly of limestone with two calcareous siltstone zones, whereas the Hamilton Formation consists of calcareous siltstone with three calcareous zones. The Marcellus Formation is composed of calcareous siltstone with one minor calcareous zone. The Onondaga Formation consists of calcareous siltstone-shale, except the basal 20 feet, which contain abundant silica and represent the Onondaga Chert. The Oriskany Formation is represented by a very quartzose sandstone unit which has calcite cement in its lowermost 10-foot composite sample.

Formational Composition

A brief stratigraphic description of the various formations penetrated and their compositional constituents follows. The boreholes are represented as lithologic logs in Figure 6.

Allegheny Formation

Both wells were spudded in this Middle Pennsylvanian formation which forms the surface of most of the Punxsutawney-Driftwood gas field. This sequence consists of yellow sandstones, gray siltstones and shales, and a small amount of coal and carbonaceous material. Based on mineralogy, two well developed sandstone units were penetrated in the Kriner well but none was detected in the Palumbo well. The upper (stratigraphically) sandstone is very clean (65–95% quartz



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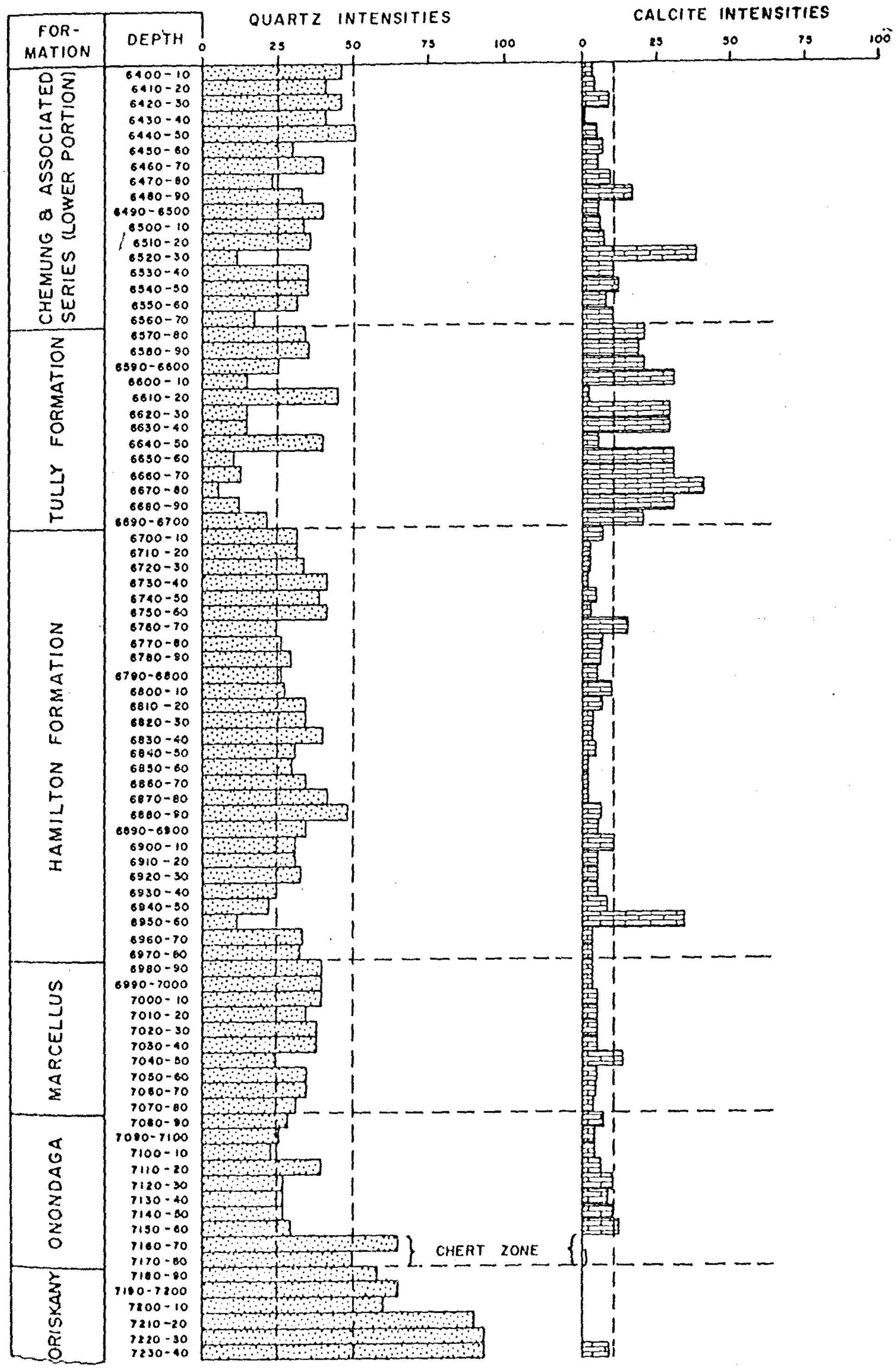


FIG. 5. Quartz and calcite abundance based on X-ray diffraction intensities in lower part of Kriner well N-752.

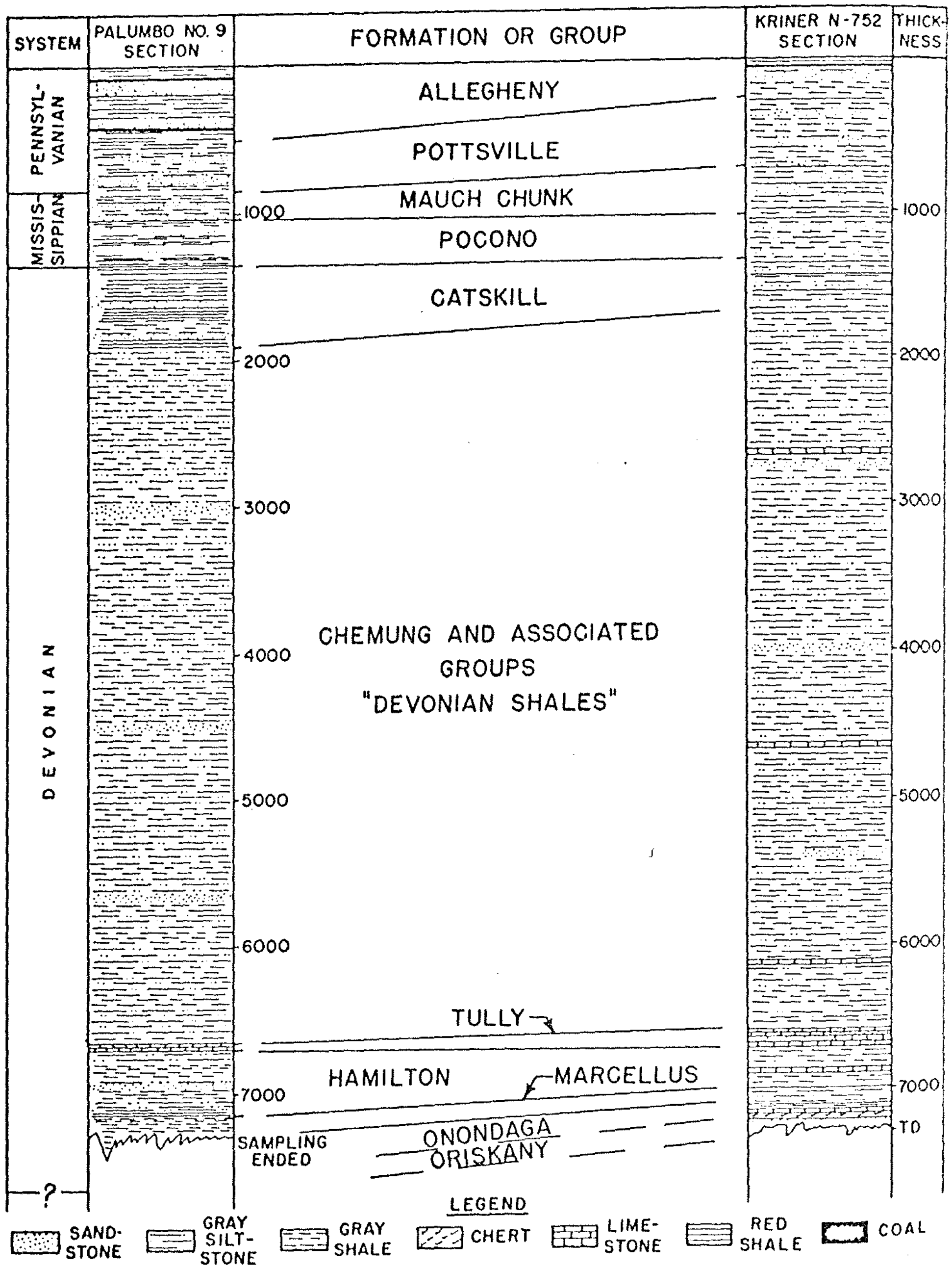
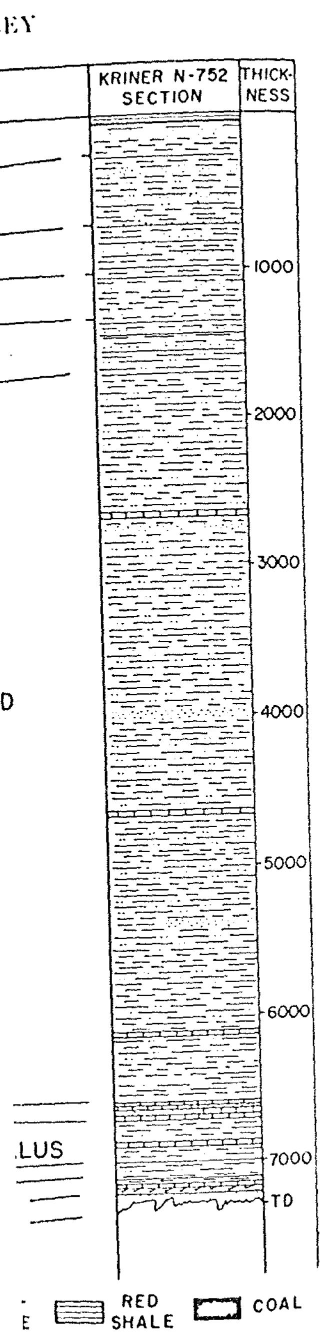


FIG. 6.—Generalized geologic columns prepared from X-ray analyses of air-drilled well samples.

and is non-calcite-cemented; whereas, the lower sandstone has calcite cement near its upper surface and contains varying amounts of interstitial clay. These sandstones also contain small amounts of plagioclase and potash feldspar. The shales and siltstones in both wells are calcareous, being cemented with 5–35 per cent calcite. The clay minerals in the upper sandstone (Kriner well) are predominantly kaolinite with subordinate illite, whereas those in the lower sandstone are illite and mixed chlorite-kaolinite in almost equal proportions. The clay minerals in the shales and siltstones of the Allegheny Group are predominantly illite, with subordinate quantities



s of air-drilled well samples.

kaolinite, chlorite, and mixed kaolinite-chlorite. Most of the shaly zones in the Allegheny Group also contain varying amounts of apparently non-crystalline material which may be amorphous silica. One unique difference between the two wells is that a very distinct 10-foot limestone zone was found in the Kriner well in the Allegheny but no limestone was detected in the same zone in the Palumbo well.

Depositionally, this part of the Allegheny probably represents fluctuating marine, brackish and non-marine environments. The marine part is evidenced by the occurrence of alternating coarse and fine to very fine detrital material containing chlorite and illite clay minerals. One pulse of carbonate sedimentation in the area of the Kriner well supports this view of marine conditions. Coaly beds indicate the existence of non-marine phases operative during deposition of this rock sequence.

POTTSVILLE GROUP

The Pottsville Group is represented in both of the wells by an interval of rocks consisting of alternating siderite-rich, tan-gray, to gray sandstone and shale-siltstone zones. Siderite occurs throughout this zone in the form of concretionary pellets, nodules, and prominent layers. The siderite content appears to be highest in the siltstone zones and lowest in the sandstone zones. This zone is unique in both wells in that this is the only penetrated group which has an ubiquitous siderite distribution. Five prominent sandstone units were encountered in the Kriner well, whereas only two were observed in the Palumbo well. However, there are numerous less prominent sandstone units in the Pottsville interval in the Palumbo well. All of the well developed sandstones in both wells, excepting the uppermost one in the Kriner well are similar mineralogically in that they contain only sporadic occurrences of calcite cement and their dominant interstitial clay is illite with subordinate amounts of kaolinite and chlorite. The shales and siltstones occurring between the sandstones in both wells show varying amounts of calcite cement, magnesian calcite cement, and traces of dolomite cement. In addition, there appears to be an increase in calcite cement upward regardless of lithology in the Pottsville Group of the Kriner well. Plagioclase and potash feldspar occur in small quantities throughout the entire Pottsville interval in both wells with the exception of the well developed sandstone zones. It, therefore, appears that during those times of coarse clastic (sand) deposition the amount of detrital feldspar was at a minimum. The clay mineralogy of the shales and siltstones of the Pottsville is dominantly illite with subordinate amounts of kaolinite and mixed kaolinite-chlorite. One exception to the homogeneous clay mineralogy of the Pottsville is the occurrence of chlorite in this interval of the Palumbo well, but not the Kriner well.

A cyclical form of marine to non-marine sedimentation in the Pottsville sequence is suggested by fluctuating occurrences of illite, kaolinite, and mixed kaolinite-chlorite clay minerals. The siderite concentration in the Pottsville group may be attributed to diagenetic processes operating within a reducing environment; thus, iron-rich salts were reduced by organic compounds to form siderite. Wood fragments and coaly material were observed associated with siderite in the fine-grained shales and siltstones.

MAUCH CHUNK FORMATION

The Mauch Chunk Formation was observed in both wells and lithologically consists of light gray sandstones interbedded with pink, purplish, and light gray shales and siltstones. No well defined sandstone units were observed in the Mauch Chunk interval in the Palumbo well, but three sandstones were detected in the Kriner well. These sandstones contain sporadic occurrences of calcite cement, small amounts of plagioclase, potash feldspar, and varying quantities of interstitial illite and chlorite. Small amounts of siderite occur throughout the Mauch Chunk and appear to be concentrated mainly in the shale and siltstone intervals. Material which is apparently non-crystalline occurs, usually associated with the siderite zones, throughout the formation with no regard for lithologic boundaries. The clay fraction of the shales and siltstones is homogeneous throughout the formation in both wells, consisting predominantly of illite and chlorite. A portion of the fine-grained zones shows primarily calcite and magnesian calcite cement and minor dolomite cement. All of the shales and siltstones contain small amounts of plagioclase and potash feldspar.

The mineralogy of the Mauch Chunk seems to support the findings of Swartz (1955) that these rocks represent subaerial deposits of a low delta plain, formed under conditions of marked seasonal rainfall. The reddish color of this sequence of rocks, undoubtedly due to the oxidized state of iron, is in agreement with Swartz's interpretation of subaerial deposition of the sediments.

POCONO FORMATION

The Pocono Formation consists lithologically of thin (less than 20 feet) gray sandstones with intervening dark gray shales and siltstone zones. Calcite cement occurs throughout the entire interval but is more abundant in the upper third of the formation. An impure limestone zone was encountered within this interval in the Palumbo well. The lower two-thirds of the Pocono rocks contain about equal amounts of sporadically distributed calcite and dolomite cement. Plagioclase and potash feldspar occur in small quantities in all of the samples, regardless of lithology. Material, apparently non-crystalline, occurs sporadically scattered, throughout this interval but appears to be mainly associated with the sandstones and sandy zones. Siderite occurs scattered throughout this formation and does not appear to show any preference for specific lithologic types. The clay mineralogy of the Pocono Formation is very uniform, the sandstones containing the same types of clay minerals as the siltstones and shales. The fine-grained fraction consists of illite and chlorite in approximately equal proportions with traces of kaolinite and mixed chlorite-kaolinite.

Based on the abundant plant fragments and coaly material in the Pocono rocks, it seems that these sediments were probably deposited upon a low delta-like surface which was acquiring its sediments from streams. The clay minerals found in these rocks also suggest subsequent burial of a subaerial fluvial plain.

CATSKILL FORMATION

The Catskill Formation, as observed in the two wells, lithologically consists of an upper red shale with alternating red and light gray to green sandstones, siltstones, and shales. Most of this sequence of rocks consists of shale and has a very striking red color.

The sandstones are located mainly near the middle of the formation and contain a significant amount of dolomite and calcite cement. Dolomite predominates in the Kriner well, whereas calcite cement is much more abundant in the Catskill sandstones of the Palumbo well. Thin sandstone units are much more apparent and abundant in the Kriner well than in the Palumbo well. Plagioclase feldspar was found in small amoun in all of the samples, whereas potash feld occurs sporadically. Material which is apparen non-crystalline occurs in varying amou through the formation but tends to be m closely associated with the sandstones than w the fine-grained rocks. The clay minerals com posing the matrix of the sandstones are the sa as those in the shales and siltstones: prima illite, subordinate chlorite, and traces of mix chlorite-kaolinite. Small amounts of kaolin were also found sporadically distributed throu out the Catskill rocks in the Palumbo well. C cerning the relative abundances of clay mine in the Kriner well it is interesting to note t the upper half of the Catskill contains a grea amount of chlorite than does the lower h whereas the chlorite content of the same interv in the Palumbo well is relatively constant.

The mineralogy, clays and non-clays, of t Catskill Formation appears to be characteris both in distribution and occurrence of a vast l delta.

CHEMUNG AND ASSOCIATED GROUPS

Those rocks representing the Senecan a Chatauquan Series of Upper Devonian time a considered together since they form a homo neous lithologic zone. The interval is comm referred to by drillers as the "Devonian shal and appears to occupy approximately the sa stratigraphic interval as the Ohio shale of Ohio Valley. Lithologically this zone cons primarily of light gray shales, secondarily light gray siltstones, and minor occurrence thin, light gray, fine-grained sandstones. A thin argillaceous, dark gray, hard limestone z were also observed, mainly in the Kriner Small amounts of plagioclase feldspar were tected throughout the sequence. Potash feld and small amounts of siderite occur sporadic Calcite cement is dominant throughout the tion, but small amounts of dolomite, calcit mite, and magnesian calcite cements are present. The majority of the samples conta calcite and (or) dolomite cement in va amounts with a gradual increase in calcite ward from about the middle of the sequence t top of the underlying Tully Limestone. O the most striking features observed conc the lower part of this sequence is the thin stone zones which are approximately 10 fe thickness and vary from 65 to 90 per cent calcite. The calcic dolomite and magnesian calcite zones of cementation in this interval appear to represent definite units, but their significance is not known because of the lack of stratigraphic data for the rocks comprising the interval between the Catskill and Tully formations. The clay mineralogy of this rock assemblage is homogeneous, consisting of illite and chlorite in approximately equal proportions with small amounts of kaolinite and mixed kaolinite-chlorite occurring in thin well defined zones.

Based on the mineralogy of these samples, it is apparent that marine conditions were prevalent during this time, with fine-grained detritus the dominant sediment. The thin limestone zones suggest short periods during which clastic sedimentation was very low.

TULLY LIMESTONE FORMATION

The Tully limestone formation, lithologically, is composed of dark blue to black, dense, marine limestone. However, two separate minor sandstone units were observed in this zone in the Kriner well. Texturally, the Tully Formation is arenaceous, argillaceous, very fine-grained limestone with minor amounts of dolomite. Traces of plagioclase were found scattered through the formation. The clay mineralogy of the Tully formation consists of illite and chlorite, with the chlorite slightly more abundant.

Based on lithologic characteristics, distribution of minerals, texture, and color of these rocks, it is likely that the Tully Limestone was deposited under conditions essential for a restricted marine environment. However, the lithic change and increase in thickness, from 40 feet in the area of the Palumbo well to 130 feet at the Kriner location, suggest that conditions were variable in this basin. The two thin sandstone zones in the Tully limestone of the Kriner well apparently represent influxes of clastic material, with only a very small amount of calcite accumulated during their deposition.

HAMILTON FORMATION

The Hamilton Formation consists of calcareous black to gray shales, siltstones, and some thin sandstones and limestones. Most of the rocks in this interval contain calcite cement in varying amounts, up to 30 per cent; however, a thick unit in the Kriner well is void of calcite but contains dolomite cement. Small amounts of plagioclase feldspar are uniformly distributed through the formation and sporadic occurrences of potash feldspar were also observed. Varying quantities of apparently non-crystalline material occur in these rocks and appear to be concentrated mainly in the lower half of the formation. The limestones are dense, black, arenaceous, and non-transitional with the surrounding rocks. The clay minerals in the rocks are predominantly illite and chlorite with minor occurrences of kaolinite and mixed kaolinite-chlorite in the Palumbo well.

Because of the presence of the thin marine limestones, black calcareous shales, siltstones, and sandstones, it seems that the Hamilton rocks represent marine conditions during which time the influx of clastic material varied from appreciable to negligible. The clay mineral assemblage is also suggestive of marine conditions.

MARCELLUS FORMATION

The Marcellus Formation was penetrated in both wells; however, sampling was discontinued within this unit at the Palumbo well. Therefore, the base of the Marcellus is not known in that location. Lithologically the Marcellus rocks consist of very calcareous, black shale and siltstone, with the shale relatively more abundant. All of these rock samples contain calcite and dolomite cement in varying amounts as well as small quantities of plagioclase feldspar. Traces of potash feldspar were observed in a few of the samples. Amorphous material was not observed in any of the Marcellus samples. This lack of occurrence is interesting since the overlying rocks of the Hamilton are similar but contain an abundance of amorphous material. The clay minerals in these rocks are illite and chlorite in about equal proportions.

Based on the preponderance of black, fine- to very fine-grained clastic material in these rocks and the clay mineral assemblage, it seems that marine conditions existed throughout this time. The same type of sedimentation existent in Marcellus time appears to have extended into Hamilton time.

ONONDAGA FORMATION

The Onondaga Formation in the Kriner well consists of an upper, very clacareous shale and limestone zone and a lower siliceous zone, rep-

TABLE I

Formation	*Diagnostic Minerals Used in Correlating "Zones"*	*Lithologic Character of Formations Based on Total Mineralogy*
Allegheny	Consistent siderite zone begins at base High chlorite content	Alternating sandstones, siltstones, and shales with minor coaly beds. Thin limestone zone in Kriner well
Pottsville	Consistent siderite zone Abundant mixed kaolinite-chlorite	Alternating sandstone, siltstone, and shale
Mauch Chunk	Siderite both above and below this unit Kaolinite scarce below this zone	Sandstones, pink shales, and siltstones
Pocono	Siderite zone Mixed kaolinite-chlorite reappears	Sandstones with intervening shales and siltstones Small amount coaly material
Catskill	Red color dominant No kaolinite Zone of mixed kaolinite-chlorite Siderite zone ends at top of unit	Red shale and siltstone, few sandstones
Chemung and Associated Series	Thin kaolinite zones Thin limestone zones Potash feldspar decreases below	Gray shales, siltstones, and scattered sandstones Few thin limestone beds
Tully	Lithologic change to limestone Dolomite-free zone Kaolinite absent Mixed-kaolinite-chlorite absent	Black limestone with thin sandy stringers in Kriner well
Hamilton	Lithologic change to shale Thin dolomite-cemented zones Thin limestone zones	Shales and siltstones with minor sandstone and limestones
Marcellus	Kaolinite absent Decrease of potash feldspar Mixed-kaolinite-chlorite absent	Shales and siltstones
Onondaga	Limestone zones Chert zone	Upper calcareous shaly zone, lower chert zone
Oriskany	Lithologic change to pure quartz sandstone Decrease in clay abundance Decrease in cementation	Sandstone

resentative of the Onondaga chert. The calcareous part of this formation is gray-blue to black and comprises about three-fourths of the formation. The cherty part is very hard, black, dense, and comprises mainly the basal fourth of the formation.

In order that visual examination of the Onondaga chert could be conducted, outcrop samples were collected and thin sections prepared. Analysis of these thin sections revealed that the chert was originally a black, marine, silty shale which was silicified sometime following deposition. X-ray examination of the silty shale revealed that it was composed of illite and chlorite. According to J. McFadden (verbal communication) of New York State Natural Gas Corporation, there is a thin bentonite called the "Tioga metabentonite" overlying the Onondaga formation in the Punxsutawney-Driftwood area which may have been the source of silica for the development of chert. However, this bentonite zone was not detected in this study.

ORISKANY FORMATION

The Oriskany Sandstone formation was the objective "pay" for each of the two study wells in the Punxsutawney-Driftwood gas field. The Oriskany is an excellent example of a "clean" orthoquartzite, which in this locality is partly cemented by small amounts of dolomite. The only calcite cement observed was in the lowermost sample which is not basal Oriskany but somewhere within the sandstone body. No feldspar was observed in the Oriskany Formation and only small amounts of clay, illite and chlorite, were found in two of the samples.

The monomineralic character of the Oriskany sandstone and the near absence of fine-grained material suggest that these rocks probably represent the detritus obtained from the reworking and winnowing of previous sandstones. According to Pettijohn (1957), orthoquartzites such as the Oriskany are the product of relatively quiescent tectonic conditions operative during peneplanation or near peneplanation. Our findings suggest that these conditions prevailed during Oriskany sedimentation, in agreement with those of Pettijohn.

Correlation

As the test wells are located about 18 miles apart, precise correlation based on mineral zonation seemed unlikely. A partial listing of the criteria used by the writers for defining formational tops and also in establishing correlatable mineral assemblages is shown in Table I under "Diagnostic Minerals." It is realized that some of the apparent thickening and thinning of various mineralogical zones may not correspond with formally named formation boundaries as it is possible that specific mineral-forming and depositional environments may have crossed biostratigraphic boundaries. Therefore, the zones delineated by mineralogical data should be called "mineralogical zonations" rather than formations. The term formation was used, however, as a convenience to the writers in coordinating this study with other geological investigations.

Conclusions

It was found that the mineralogical zonations based on X-ray analysis of the samples from the N. J. Palumbo well No. 9 closely correspond with those for the R. Kriner N-752 well. Therefore, X-ray analyses of samples from air-drilled wells may be effectively utilized in constructing a "log" of the well so that formational contacts may be located. It was also observed that the mineralogical zonations for these wells closely corresponded with those formational contacts determined using other criteria. It is believed that construction of a compositional log is less time-consuming and gives considerably more precise geological information than the conventional lithologic strip log. It is also apparent that by using X-ray mineralogy much more information can be obtained about the lithologic sequence than by binocular examination. Furthermore, compositional logs serve as an aid in interpreting environments of deposition. One of the most important conclusions which can be drawn from this study is that clay minerals, easily identifiable by X-ray, can be used as an aid in interpreting genesis, source areas, and geological history of the rocks. Thus, the entire mineralogical composition of cuttings can be used to gain subsurface geological information.

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