FACIES DISTRIBUTION IN URANIUM HOST ROCKS OF THE SOUTHERN POWDER RIVER BASIN, WYOMING

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ABSTRACT

Data from more than 1,000 electric and gamma-ray logs of holes drilled to explore the uranium-bearing host rocks in the southern part of the Powder River Basin, Wyoming, were used to generate facies maps for five successive 93-m (300-ft) zones, two below and three above the top of the School House coal. Sandstone to mudstone ratios in each zone were contoured to differentiate areas underlain by a sandy facies (ratios >1.0), an intermediate facies (ratios 0.5 to 1.0) and a muddy facies (ratios <0.5). The locations of subsurface radioactivity anomalies within each zone are also shown on each map. These log data were also used to generate four cross-sections showing the correlation of various lithologic units and the position of the radioactivity anomalies.

The facies maps indicate that northerly trending paleostreams drained a granitic source area south of the Powder River Basin and supplied the detritus in the host rock units which are the Eocene Wasatch Formation and, possibly, the uppermost part of the Paleocene Fort Union Formation. The facies maps record a fluctuation, with time, in the volume of sand that was being deposited. The maps also indicate changes in depositional environments, braided streams predominant at some times and meandering streams at other times. Some changes in the direction of sediment transport are also indicated.

Radioactivity anomalies occur in all three facies, with 48 percent in the sandy facies, 34 percent in the intermediate facies, and 18 percent in the muddy facies. No consistent relationship between sites of ore deposits and facies distribution is indicated on the facies maps; some groups of anomalies occur in one facies and are distributed parallel to the facies boundaries,

and other groups are distributed normal to the boundaries and occur in each of the three facies.

The relationship that must exist between facies changes and uranium deposition might be documented by a computer-assisted manipulation of the log data using added parameters such as the number of alternations of mudstone and sandstone beds and the mean thickness of sandstone units.

INTRODUCTION

The study area is located in the southern part of the Powder River Basin in northeastern Wyoming (fig. 1, Plate 1). The Wasatch and upper part of the Fort Union Formations are the principal host rocks for uranium deposits and consist of interbedded mudstone, siltstone, carbonaceous shale, coal, and sandstone. The proportions of the various rock types in each formation vary both in horizontal and vertical directions. Generally, both formations contain the highest percentage of sandstone at the southwestern edge of the basin and in a zone extending northward parallel to the northwesterly trending axis of the basin.

Roll-type uranium deposits occur in the sandstone beds of both formations at various stratigraphic levels throughout much of the southern part of the basin. A subsurface study was initiated in 1972 to ascertain the influence of facies distribution on the emplacement of uranium deposits. Electric and gamma-ray logs obtained from many of the companies exploring the region were utilized for the study, the logs having been collected throughout the period 1972 to 1979. All the logs were recorded originally at a scale of one in. equal to 10 ft so as to provide more details of lithology than is available on logs of oil tests which are generally recorded at a scale of one in. equal to 100 ft. Of a total of 1,050 logs obtained, about one half are of holes drilled to depths of from 305 m to slightly more than 610 m (1,000 to 2,000 ft), and the rest are of holes drilled to depths of less than 305 m (1,000 ft). About 100 logs are of holes drilled to depths of less than 123 m (400 ft) which, although of little use for the facies study, provided data on the location of radioactivity anomalies. Because data on alteration of sandstone are generally unavailable, the exact position and extent of roll fronts are not well enough known to be included in the study.

Sandstone beds were identified by a characteristic configuration of self-potential and resistivity traces on each log; the other rock types present, except coal, could not be identified with confidence. A ratio comparing the total thickness of individual sandstone beds to the total thickness of all the other lithic types combined was calculated for successive 93-m (300 ft) intervals above the top and below the base of the School House coal. Although rocks other than mudstone are included in the lithic types being compared to sandstone, these other rocks are all called mudstone for the sake of brevity. The ratios of sandstone to mudstone were plotted to generate five facies maps, one for each 93-m (300-ft) interval from 186-m (600 ft) below to 275-m (900 ft) above the datum coal bed (plate 1). Gamma-ray anomalies within each 93-m (300-ft) interval are indicated on the appropriate facies map.

Log data were also used to construct four cross sections depicting the correlation of sandstone and coal beds. One cross-section is oriented parallel to the axis of the basin; three others are approximately normal to it (plate 2). The positions of gamma-ray anomalies are also indicated on the cross sections.

The coal bed used as a datum is generally known as the School House coal but personnel of some exploration companies call it the Pacific Power coal (Plate 2, A-A′). It has a maximum thickness of about 8 m (25 ft) in the area of this study and locally splits into two beds. From its eroded outcrop on the southwest side of the basin, it thins eastward to a pinchout along a northerly trending line near the east side of T. 36 N., R. 74 W. It thins to the north and can be traced as far as the north edge of T. 40 N., R. 75 W. Northward from there, as shown on section A-A′ (plate 2) near its north end, the stratigraphic position of the School House coal is occupied by a coal bed that generally ranges in thickness from 15 to 30 m (50 to 100 ft) and locally is 49 m (160 ft) thick. The top of this coal bed is the datum for the 93-m (300-ft) intervals above it in the northern part of the area studied. The few holes drilled to 93 m (300 ft) below this thick coal do not permit the generation of facies maps for the strata below the coal in the northern part of the area.

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Previous Studies

Previous studies dealing with facies of the Wasatch or Fort Union Formations in the Powder River Basin include that of Davidson (1953) who was the first to report the progressive change of facies from south to north in the Wasatch Formation and to relate uranium deposition to facies type. Sharp and others (1964) and Sharp and Gibbons (1964) expanded the study of Davidson and mapped the limits of various facies. Davis (1969) discussed the occurrence of roll-fronts in proximity to sudden decreases in grain size. McKeel and Crew (1972) published variously oriented cross-sections depicting the correlation and variation in thickness of mudstone, sandstone and coal beds. Langen and Kidwell (1974) mentioned facies changes in a report on the Highland uranium deposit. Denson and Horn (1975) published data on the heavy mineral assemblages in the Fort Union and Wasatch Formations. Seeland (1976) presented data on the distribution of grain sizes and shapes as well as data on crossbed orientations in the Wasatch Formation which were used to develop a paleostream map. Dahl and Hagmaier (1976) noted that the largest uranium deposits in the area occur at the distal margins of sandstone beds where they grade laterally into finer strata. Raines and others (1978) demonstrated that, because of a relationship of vegetation density to the type of local substrate, the facies distribution at the surface can be detected using computer-enhanced Landsat images. Galloway (1978) delimited mixed-load and suspended-load channel facies as well as floodplain and backswamp-lacustrine facies and discussed the relationship of uranium deposits to facies.

GEOLOGIC SETTING

The Fort Union Formation of Paleocene age and the Wasatch Formation of Eocene age comprise the rocks exposed at the surface throughout the area studied. Both formations consist of interbedded mudstone, siltstone, sandstone, carbonaceous shale, and coal. In some areas of the basin the contact between the Wasatch and Fort Union Formations is a recognizable disconformity or a surface of erosion (Sharp and Gibbons, 1964, p. D10). Over much of the basin, however, no definite contact is evident, and detailed heavy-mineral or palynological studies are needed to differentiate the units.

In pre-Oligocene time these units were broadly folded to form the asymmetrical structure of the Powder River Basin. Subsequent to the folding, erosion removed part of the Wasatch and, at the margins of the basin, some of the Fort Union. The tuffaceous White River Formation was then deposited on the erosion surface in Oligocene time and over it the tuffaceous Arikaree Formation was deposited in Miocene time. Erosion in post-Miocene time removed all the post-Eocene rocks except a thin remnant of White River Formation that forms the cap on the Pumpkin Buttes (fig. 1). During this cycle of erosion more than 305 m (1,000 ft) of Wasatch as well as some Fort Union strata were also removed.

Devitrification of volcanic ash in the Arikaree and White River Formations released uranium which was carried to the pre-Oligocene erosion surface and introduced into the Fort Union and Wasatch Formations by downward-percolating water. Ground water derived from the granitic terrane that supplied the detritus in the host rocks, or the detritus itself, may have been sources for some of the uranium in these strata.

During deposition of the host rocks, some of what is now bituminous coal was in the form of peat accumulations. It seems reasonable to expect, therefore, that some of the uranium in the water draining the granitic source area would have been adsorbed by the peat. Szalay (1958) demostrated the ability of peat to adsorb uranium from dilute solutions. The complete absence of uranium in virtually all the coal beds of the Powder River Basin indicates that there was no early influx of uranium in solution or in detrital minerals. The granite that was the source of the host rocks was, therefore, probably not anomalously uraniferous.

After the host rocks were exposed by post-Miocene erosion, oxygenated surface waters entered the permeable units of the host rocks. Uranium was mobilized and carried downward to where reducing conditions caused redeposition of the uranium along roll-fronts between oxidized and unoxidized sandstone. The paths taken by the uranium-bearing oxygenated water and the loci of uranium deposition were necessarily influenced by the distribution of facies in the host rock. It is reasonable to expect, therefore, that the distribution of uranium deposits should be related to the facies distribution.

DISTRIBUTION OF FACIES AND RADIOACTIVITY

Figure 2 (plate 1) shows the distribution of facies in zone A, which is 93 to 186 m (300 to 600 ft) below the School House coal. A conspicuous northerly trend of paleostream courses is evident. Sandstone-mudstone ratios in the sandy facies (ratios >1.0) range from 1.0 to 19.0, and reflect the presence of very thick sandstone units in some places. The character of the boundaries between the various facies, inasmuch as they are not particularly sinuous, suggests that mainly braided rather than meandering streams deposited the detritus in this zone. Zone A corresponds roughly to the X sandstone package of Galloway (1978, fig. 7) and the sandy facies in this zone corresponds to his mixed-load channel facies. Although some of the radioactivity anomalies represent isolated occurrences, many of those in T. 36 N., R. 71, 73, and 74 W. represent ore deposits being mined at the present time or in the recent past. The ore deposits occur in all three facies, but most are in the sandy facies (at least as defined for the zones selected). Holes 11 and 21 of section B-B′ (plate 2) illustrate the contrast between uranium deposits in a single thick sandstone unit and in a number of thin sandstone beds.

Some controversy exists as to whether zone A represents the upper part of the Fort Union Formation or the lower part of the Wasatch Formation. Because the rocks in the Highland Mine about 61 m (200 ft) below the School House coal (hole 11, section B-B′, plate 2) contain palynomorphs of Paleocene age, Dahl and Hagmaier (1976, p. 245) considered them to be part of the Fort Union Formation. N.M. Denson (written commun., 1979), however, found that sandstone samples from the lowermost workings of the Bill Smith Mine (hole 21, section B-B′, plate 2), as well as some from the Highland Mine, contain a distinct heavy-mineral assemblage that is characteristic of the Wasatch Formation and unlike that in the Fort Union Formation below zone A. It would seem, therefore, that either the uppermost part of the Fort Union Formation locally contains Wasatch-type arkosic sandstone or, the lowermost part of the Wasatch Formation was deposited in Paleocene time. The inferred granitic source of Wasatch-type sandstone was, thus, probably exposed in latest Paleocene time and the northerly trend of paleostreams that was to persist into Eocene time was already established (Sharp and Gibbons, 1964, and Seeland, 1976).

Figure 3 (plate 1) shows the distribution of facies in zone B, which includes strata from 0 to 93 m (0 to 300 ft) below the datum. This zone corresponds roughly to the middle of the X sand package of Galloway (1978, fig. 7) and either includes portions of both the Fort Union and lowermost Wasatch Formations or is entirely within the Wasatch Formation depending on whether the contact is chosen on the basis of heavy mineral content or on Paleocene palynomorph distribution. As in zone A, a conspicuous northerly trend of paleostream courses is evident. A source to the south is seen to persist but several tributary streams entering the area from the west also contributed sediments.

Ratios in the sandy facies range from 1.0 to 4.0, indicating that the coarsest parts of this facies here, in addition to occupying a smaller area, contain less sandstone overall and fewer thick multistoried sandstone units than do the coarsest parts of zone A (where ratios are as high as 19.0). The intermediate facies (ratios 0.5-1.0) occupies a much broader area and the boundaries between facies are considerably more sinuous than in zone A. This may reflect a change in the character of streams from predominantly braided in zone A to predominantly meandering in zone B.

Although some radioactivity anomalies occur in the sandy facies, most are near the boundaries between the muddy and intermediate facies. This indicates that, whereas uranium deposits may occur in the muddy facies where ratios are slightly less than 0.5, few, if any, occur where the ratios are as low as 0.1. Thin beds of sandstone extending from the sandy facies into these zones apparently constitute an environment for uranium deposition that is more favorable than the central part of the sandy facies. The Bear Creek mine (hole 21, section C-C′, plate 2) is an example of a uranium deposit near the boundary of the fine facies.

Figure 4 (plate 1) shows the distribution of facies in zone C, which includes strata from 0 to 93 m (0 to 300 ft) above the datum. This zone is entirely within the Wasatch Formation and near its base. The pattern resembles that of zone B but has less area made up of the sandy facies. Ratios in the sandy facies range from 1.0 to 3.3 and indicate that, as in zone B, the coarsest parts contain less sandstone overall and fewer thick multistoried sandstone units than do the coarsest part of zone A. The presence of the School House coal at the base and the widespread Badger coal bed about 52 m (170 ft) above the datum coal indicate that swampy conditions and low stream gradients existed at the time of deposition. The large area occupied by muddy and intermediate facies and the sinuous boundaries between facies also suggest deposition by low-gradient meandering streams.

Most of the radioactivity anomalies occur in the sandy and intermediate facies but their distribution seems unrelated to the trend of the boundaries between facies as was the case in zone B.

Figure 5 (plate 1) shows the distribution of facies in zone D, which includes strata from 93 to 186 m (300 to 600 ft) above the datum. This zone is in the lower one-third of the Wasatch Formation, its upper boundary being about 510 m (1700 ft) below the pre-Oligocene erosion surface that marks the top of the formation. As in each of the zones below, a conspicuous northerly trend is evident. Ratios in the sandy facies range from 1.0 to 11.0 to reflect the presence of thicker or more numerous sandstone beds than occur in the sandy facies of zones B and C below. The increase in volume of the sandy facies over that in zone C indicates renewed uplift in the source area. Paleostreams appear to have entered the area from the southwest and somewhat north of where they entered in the lower three zones. Because stratigraphically equivalent beds were eroded from the area to the south it is not certain whether the sandy facies shown on figure 5 (plate 1) was coextensive with a sandy facies further south. It may be that streams draining the original source area skirted the west side of the area and entered at a point farther north than they had previously.

Although a few radioactivity anomalies occur in the muddy and intermediate facies, most are in the sandy facies. Most of those in the sandy facies are near the boundaries with the intermediate facies. The distribution of anomalies in this zone resembles that in zone A and is unlike that in zones B and C.

Figure 6 (plate 1) shows the distribution of facies in zone E, which includes strata from 186 to 275 m (600 to 900 ft) above the datum. This zone is in the lower half of the Wasatch Formation, its upper boundary being about 430 m (1400 ft) below the pre-Oligocene erosion surface that marks the top of the formation. As in each of the zones below, a conspicuous northerly trend is evident. Ratios in the sandy facies range from 1.0 to 19.0 and reflect the presence of a greater proportion of sandstone in the sandy facies of all but zone A. The relatively large volume of sandy facies compared to that in zones B and C indicate a continuation of the renewed uplift of the source area that began during deposition of strata in zone D. The flood of arkosic material, probably carried by mainly braided streams, resulted in the accumulation of thick multistoried sandstone units. Because stratigraphically equivalent rocks have been eroded from the area to the south, it is not certain how far south the sandy facies extended.

Radioactivity anomalies occur in all three of the facies delimited with most occurring in the sandy facies. Most of those in the sandy facies are near the boundaries with the intermediate facies.

SUMMARY

The distribution of facies shown on figures 2-6 (plate 1), particularly that of the sandy facies (ratios >1.0), supports the results of previous studies that northerly flowing paleostreams, draining a granitic source area to the south, deposited the Wasatch and uppermost part of the Fort Union Formations. Some time after the deposition of zone C (fig. 4, plate 1), renewed uplift of the source area occurred and some detritus, apparently derived from the west, was contributed to the Wasatch Formation. The coarse material entering the area from the west may indicate a contribution from a new source area farther north than the one originally supplying sediments to the uppermost Fort Union, or it may, more likely, indicate that stream courses shifted westward, skirted the southern part of the area, and entered at points farther north than they had previously. Oxidation fronts moving through the coarse sediments supplied by variously oriented streams probably account, to some extent, for the diverse orientation of roll fronts so common to the region.

No consistent relationship between sites of uranium deposition and facies distribution is indicated on the facies maps; radioactivity anomalies occur in all three facies, with 48 percent in the sandy facies, 34 percent in the intermediate facies, and 18 percent in the muddy facies. Zones A and E, which contain the greatest proportion of sandstone, each contain almost twice as many anomalies as either zones B and C, in which the proportion of sandstone is smallest. In some places, groups of anomalies occur in one facies and are distributed parallel to the facies boundaries. In other places, groups of anomalies are distributed normal to the boundaries and occur in each of the three facies.

The locations of three large mines with respect to various facies illustrate this diverse relationship. Deposits at the Bill Smith Mine (fig. 1, plate 1) are well within the sandy facies of zone A and occur at several levels in a single sandstone unit as much as 93 m (300 ft) thick. Deposits at the Bear Creek Mine occur in the muddy facies of zone B and are distributed parallel to the boundary with the intermediate facies. Deposits at the Highland Mine, and extensions of it, occur in all three facies and are distributed perpendicular to the facies boundaries.

The presence of many anomalies well within the sandy facies seems to contradict the observations reported by Davis (1969) and by Dahl and Hagmaier (1976), who found that roll fronts in general, and the larger uranium deposits, typically occur near grain-size changes in the distal portions of thin sandstone beds. It may be that the facies changes associated with ore deposition are too subtle or of such limited stratigraphic extent as to be lost in the 93 m (300 ft) intervals individually analyzed. It may be, however, that subtle facies changes only within the host sandstone units themselves are the controls for roll-front emplacement and ore deposition, and that the number or thickness of interbedded mudstone strata are of little importance even on a regional scale.

The data on which this report is based have been entered into a computer. Various computer-assisted permutations of the data using added parameters such as the number of alternations of mudstone and sandstone beds and mean thickness of sandstone units may reveal a consistent pattern that accords with reported observations. Further manipulation of these data may demonstrate, however, that the relationship that must exist between facies distribution and uranium deposition cannot be documented by using only data that can be abstracted from electric logs.

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