Repo copy

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Paleotectonic, Biostratigraphic, and Economic Significance of Osagean to Early Meramecian Starved Basin in Utah

A talk presented at the Annual Meeting of the Geological Society of America, November 9, 1976, and updated for presentation to the Rocky Mountain Association of Geologists, Denver, Colorado, February 11, 1977

By

Charles A. Sandberg and Raymond C. Gutschick

Open-File Report 77-121

1977

This report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards and nomenclature.

PALEOTECTONIC, BIOSTRATIGRAPHIC, AND ECONOMIC SIGNIFICANCE OF OSAGEAN TO EARLY MERAMECIAN STARVED BASIN IN UTAH

By

Charles A. Sandberg and Raymond C. Gutschick

A thin, 10- to 20-m-thick, phosphatic shale unit has received only scant attention, possibly because of its thinness and poor exposures, in many reports on Mississippian stratigraphy and phosphate occurrences in Utah written during the past half-century. (See Gutschick, 1976, p. 10-11, for a tabulation of reported occurrences.) Because of conflicting age assignments resulting from studies of diverse fossil groups, most workers have been uncertain whether all the phosphate occurrences represented one or several levels within the thick Mississippian sequence. Now, my coauthor and I have become firmly convinced from detailed stratigraphic and conodont sequences at several localities, shown graphically by Gutschick (1976), that the Mississippian phosphatic unit represents a single genetic unit that was deposited slowly in a starved basin during most of Osagean and part of early Meramecian time (Sandberg and Gutschick, 1976). These new data have helped provide the basis for a major revision of Mississippian stratigraphy in northeastern Utah and eastern Idaho (Sando and others, 1976). Terrigenous sediments from the craton on the east were largely prevented from entering the starved basin by the presence of a "stratigraphic reef" that was proposed and described by Rose (1976). Independently of Rose's interpretation of the seaward relief of the carbonate-platform margin, we concluded from our sedimentologic and biostratigraphic study of the starved-basin sediments that they were deposited at depths of about 300 m in marine waters of a foreland basin. We are being supported in our work by W. J. Sando, who has begun a study of the related coral faunas. On the basis of our investigations we believe that the phosphatic unit has a paleotectonic, biostratigraphic, and economic significance far out of proportion to its miniscule thickness.

PALEOTECTONIC SIGNIFICANCE

FIGURE 1

On figure 1, dots locate the 34 localities where the phosphatic shale unit has been recognized to date. For reference, the position of the carbonate-platform margin with a steep western seaward face, as delineated by Rose (1976), is shown. Larger dots mark the phosphate localities for an east-west cross section from basin center to back-reef carbonate platform and for a north-south cross section along the platform margin-starved basin interface. These two cross sections--from Buckhorn to Ophir to Rock Canyon, and from Ophir Canyon southward to Mammoth Peak, North Gilson Mountains, and Dog Valley Peak--are shown in figures 3 and 4. Please note the three localities in far western Utah. From south to north, these are the Needle Range, Burbank Hills, and Confusion Range. To date, at the first two localities we have found only covered slopes at the inferred position of the phosphatic zone; but in the Confusion Range, we have found phosphatic shale interbedded with phosphorite at the base of the flysch sequence, in addition to phosphorite nodules scattered through the burrowed siltstone flysch.

FIGURE 2

The dotted pattern on figure 2 shows the extent of the starved basin, as we have documented it to date. Actually, it may extend even farther west--into the Gold Hill area, which is the HIGH, along the Nevada-Utah State line--and farther southwest--into the Pahranagat Range of Nevada, located just above the "N" of "PILOT BASIN." The location of this largely Osagean starved basin is contrasted on this figure with the locations of slightly older Early Mississippian and Late Devonian paleotectonic features. Note that the Late Devonian Lower Pilot basin lay mostly west of the largely Osagean basin. A northern erosional remnant of the Lower Pilot basin was laterally offset by the late Mesozoic Wells strike-slip fault. Farther west, beyond the Roberts Mountains thrust, is the location of the

Antler Orogenic Highlands, which produced the Mississippian flysch sediments that intertongue with and overwhelm the youngest (early Meramecian) phosphatic sediments along the Utah-Nevada State line. Please note that the starved basin slightly overlaps the axis of the older Late Devonian (Frasnian) miogeosynclinal basin that had been filled mainly by shallow subtidal and intertidal carbonate sediments. And finally, note that the largely Osagean basin onlaps two latest Famennian to early Kinderhookian ancestral highs--the smaller Stansbury uplift to the north and the larger ancestral Sevier geanticline to the south. This ancestral feature, which occupies the same area as the Mesozoic feature of the same name, is recognized to have been active in Late Devonian to earliest Mississippian time, because it separates totally different facies of very late Devonian rocks on the west and east, whereas older Devonian, Silurian, and Ordovician rocks are lithologically unchanged across it. Furthermore, a fossiliferous intertidal nodular limestone at the base of the Joana Limestone onlapped the west side of the uplift as it was reduced below sea level in Early Mississippian time. Thus we see a drastic change in depth in sedimentation as well as an eastward migration of basin axes between Late Devonian and Osagean time, when the ancestral Sevier geanticline became part of the floor of the basal Deseret starved phosphatic basin.

BIOSTRATIGRAPHIC SIGNIFICANCE

FIGURE 3

We will now examine some of the important biostratigraphic implications of the Osagean to early Meramecian starved basin. Figure 3 shows the east-west cross section, as indicated in the index map of Utah at the upper left. Beds and concretions of limestone are shown by a vertical-lined pattern; phosphatic shale, by thin horizontal dashes; sandstone, by a random pattern of small dots; and siltstone, by a regular pattern of large dots. Bedded or nodular phosphorite is shown by small circles. Black chert is shown by heavy black lines and blobs and is emphasized by triangles to the right of the column. The phosphatic member rests with a sharp conformable contact on the Gardison Limestone to the east and on the Joana Limestone to the west. This contact is a virtual time plane. The underlying limestones and basal beds of the phosphatic member contain a Pseudopolygnathus multistriatus Fauna, which indicates an early Osagean age. Time lines, with T's inserted, are drawn at the base of two higher conodont faunas. The Doliognathus Fauna indicates a middle Osagean age, and the first appearance of the Taphrognathus Fauna indicates a late Osagean age. Please note that the time lines cross the top of the phosphatic member and converge downward to the west. This convergence indicates that intervals of Osagean time are represented by progressively thinner stratigraphic thicknesses westward, but that the duration of phosphate deposition there was longer and extended into the early Meramecian. Also, the thick limestone bed in the lower part of the Deseret Limestone at Rock Canyon must intertongue westward into the phosphatic shale and be represented by one or more thin limestones at Ophir Canyon and by only a thin zone of limestone concretions at Buckhorn Canyon. To put this westward thinning in quantitative terms, let us examine the Doliognathus time line in relation to the datum. At Rock Canyon, Doliognathus first appears 30 m above the datum; at Ophir Canyon, 13 m; and at Buckhorn Canyon, only 3.5 m. Also note that, at Buckhorn Canyon, the flysch-derived, more rapidly deposited burrowed siltstones of the Woodman Formation intertongue with the phosphatic shale, causing an expansion of the upper part of the phosphatic interval.

FIGURE 4

The cross section in figure 4 extends north-south along the interface between the starved basin and platform margin, as indicated in the index map. It repeats the Ophir Canyon type section of the Deseret Limestone and employs the same lithologic symbols as the preceding slide, with the addition of straight diagonal lines, which represent dolomite near the top of the Gardison Limestone, and curved diagonal lines, which represent cross-bedded calcarenite in the phosphatic shale member at Dog Valley Peak. Note the similarity of the phosphatic shale member in the northern three sections--Ophir Canyon, Mammoth Peak, and North Gilson Mountains. These sections lie close to the crest of the carbonate platform margin, where the phosphatic member was buried beneath prograding platform carbonate rocks. The southernmost section--Dog Valley Peak--lies at the toe of the westernmost margin. It differs from the other sections by having less phosphatic shale and by containing cross-bedded, very coarsely fossil-fragmental limestone or calcarenite, which we interpret as reef debris, intercalated with deep-water cherty micritic limestones. Other thinner debris flows in this section contain mixtures of phosphorite pellets and fossil fragments. Dog Valley Peak, more than any other section, displays the mixed lithologies that might be expected at the interface between carbonate-platform and starved-basin sediments. In the southern three sections, the siltstone overlying the phosphatic member is lithologically similar to the siltstone member of the Little Flat Formation, which also overlies the phosphatic member farther north at Old Laketown Canyon, in northern Utah.

FIGURE 5

Figure 5 lists and illustrates some of the criteria that influenced our interpretation of a deep-water, euxinic, fondothemic origin for the starved-basin facies. We do not believe that upwelling, at least upwelling by oceanic currents, was important in the production and preservation of phosphorite in the starved basin. Remember that the Antler Orogenic Highlands far to the west in Nevada were emergent and separated the foreland, part-flysch and part-starved, basin from the open ocean that may have been as far west as present-day California.

Most of the starved-basin sediments are characterized by even planar bedding, except for the few debris-flow interbeds. The phosphorite and associated phosphatic shale are dark brown to black and organic rich. The chert is black and is both spiculitic and radiolarian; it resembles the deep-water chert that is called lydite in Germany. Some of the chert replaces and retains the structure of pelletal phosphorite. The limestone beds and lenses are dark gray and micritic and contain black nodular chert. The limestone concretions contain phosphorite pellets and abundant pelagic microfossils. The siltstone and mudstone contain *Zoophycos* markings and locally some burrows, but evidence of extensive bioturbation like that in the intertonguing siltstone flysch on the west is lacking.

Perhaps the strongest evidence for a deep-water origin of the sediments is their fossil content, as well as the absence of the shelly fauna—large colonial and horn corals, bryozoans, and spiriferid and productid brachiopods—that characterizes time-equivalent strata of the adjacent carbonate platform. The most abundant fossils of the starved-basin sediments are monaxon, tetraxon, and hexaxon sponge spicules and sphaerellarian and hagiastrid spumellarian radiolarians, although conodonts are found in almost every processed limestone sample. Radiolarians are so abundant that silicified patches of some concretions form radiolarites. Some benthonic agglutinate Foraminifera have been found, but calcareous forms are restricted mainly to debris flows. The only indigenous corals are extremely small and may be comparable to present-day forms that live below the photic zone. Crushed goniatites occur on bedding surfaces and uncompressed specimens are locally abundant in some concretions. The only common brachiopod is *Leiorhynchoidea*, which may occur as molds on bedding surfaces and in some concretions. In summation, most of the fossils are pelagic and are either siliceous or phosphatic. The few benthic corals and brachiopods that do occur suggest that the absence of other calcareous shelly fossils is due to water depth and not to toxicity or post-mortem

Railroad Valley, and the southern Egan Range to the southern Schell Creek Range. The third area, which we regard as having unusually high potential, encompasses the area of the western three starved-basin localities in the Needle Range, Burbank Hills, and Confusion Range (fig. 1).

How does this concept of "hot spots" and "cold spots" fit into current theories of plate tectonics? If the "hot spots" or mineralized districts of the Great Basin are related to mantle plumes, we think it is quite possible that convection currents within the mantle could also have produced "cold spots" that would cause abnormally low geothermal gradients in the overlying continental crust. Thus, if the "hot spots" or mineralized areas were produced by the slow movement of the North American continent over mantle plumes, it is logical to assume that the same movement might have produced elongate "cold spots." Thus any area that previously passed over or is now resting on one of these "cold spots" would have been refrigerated and had the thermal maturation retarded, so that even today Paleozoic source rocks could remain at or near optimum temperatures for generation and expulsion of petroleum and natural gas.

Now, what about the maturation of hydrocarbons in the central and eastern parts of the starved-basin area? At most localities shown on figure 1, such as Ophir Canyon in the Oquirrh Mountains, Rock Canyon in the Wasatch Mountains, and Mammoth Peak in the East Tintic Mountains, conodont samples were collected from well-known stratigraphic sections, which unfortunately lie in proximity to mineralized or contact-metamorphosed areas. Hence, most of the studied conodonts from these areas have CAI values of at least 5, which indicate severe thermal overcooking. However, at other localities, such as Buckhorn Canyon, North Gilson Mountains, and several sections in the northern Wasatch Mountains and Bear River Range, which are at least 2 km from mineralized areas, the CAI values average about 3. A CAI value of 3 in the Appalachian region indicates temperatures permissive of natural gas production (Epstein and others, 1977). We believe that this value applies to most of the eastern Great Basin in Utah, except for the mineralized areas, and so most of this region could be expected to produce natural gas.

Most important to petroleum exploration, however, are the two "cold spots" that have been found to date. These "cold spots" have CAI values of 1 1/2, which indicate an optimum temperature for petroleum generation—especially in Paleozoic rocks, because of the long time during which they were subjected to geothermal heating. Both "cold spots" are on or near the seaward face of the carbonate platform margin as shown here. One of the evaluated localities is Dog Valley Peak in the southern Pavant Range. The other is Old Laketown Canyon, which is the northernmost Utah locality shown on figure 1. On the basis of conodont collections from these and nearby localities, both the southern Pavant Range and the area around Bear Lake in northern Utah offer the best prospects for successful petroleum exploration of the Cordilleran hingeline in Utah.

But what about probable reservoir rocks? Many of the eastern localities of the starved basin lie beneath the prograded carbonate platform or at the toe of dipping beds of the platform margin. This location makes the phosphatic shale member a probable source of hydrocarbons for updip and vertical migration into adjacent and overlying Osagean and Upper Mississippian rocks of the carbonate platform margin along the Cordilleran hingeline in Utah. These rocks are generally fossil-fragmental and encrinitic limestones, which would provide excellent reservoirs because of their high porosity and permeability. These reservoir characteristics may be enhanced in areas of secondary dolomitization such as in the Brazer Dolomite of the Crawford Mountains (fig. 1).

dissolution. We believe that a water depth of about 300 m is mandated by the fossil content and the sedimentational model.

ECONOMIC SIGNIFICANCE

So far, we have discussed the paleotectonic and biostratigraphic implications of the Osagean to early Meramecian starved basin (fig. 1). Now, what about the economic significance? The importance of the phosphatic content is obvious and has been discussed by previous workers, but our study of the paleotectonics and sedimentation may suggest areas where phosphorite accumulated in beds of commercial thickness. More important than the phosphatic content, however, is the organic-carbon content of both the thin phosphorites and thicker phosphatic shales. Preliminary analyses suggest that the phosphorites may average about 1 percent organic carbon, whereas the phosphatic shales may run more than 3 percent. Thus the phosphatic shale member may be an important petroleum source rock.

To evaluate the petroleum potential of these source rocks, we must consider the thermal maturation of their contained and expelled hydrocarbons. In previous talks and reports (Sandberg, 1975; Sandberg and Poole, 1975), I have emphasized that although the regional thermal gradient is generally high in the eastern Great Basin, this region was not pervasively overcooked. Using the geothermometer provided by conodont color alteration index (or, simply, CAI) values and the supporting, but scant, available information on bottom-hole temperatures, it is possible to discern "cold spots" (Sandberg, 1975, p. 5), where the thermal maturation of hydrocarbons has remained at an optimum for the generation and expulsion of petroleum and natural gas. Three such "cold spots," two of which are in Nevada, to the left of the map area of figure 1, were previously discussed. One of these is in the Piñon Range, south of Carlin. The other, which now appears to be elongated in an easterly direction, extends from the southern Pancake Range eastward through the new (Dec. 1976) Trap Spring oil field, One final consideration for exploration of the Mississippian is the availability of a seal above possible Mississippian reservoir rocks. A seal may possibly be provided by the Manning Canyon or Doughnut Shales or other similar shales high in the Mississippian sequence. Where these shales have been removed by Pennsylvanian erosion, the oil expelled from the phosphatic shale member may have migrated upward into upper Paleozoic or Mesozoic formations.

For the reasons just discussed, we consider the economic significance and paleotectonic setting of the phosphatic shale member of the Deseret Limestone to be analogous to those of the phosphatic shales in the Permian Phosphoria Formation to the north in Idaho and Wyoming.

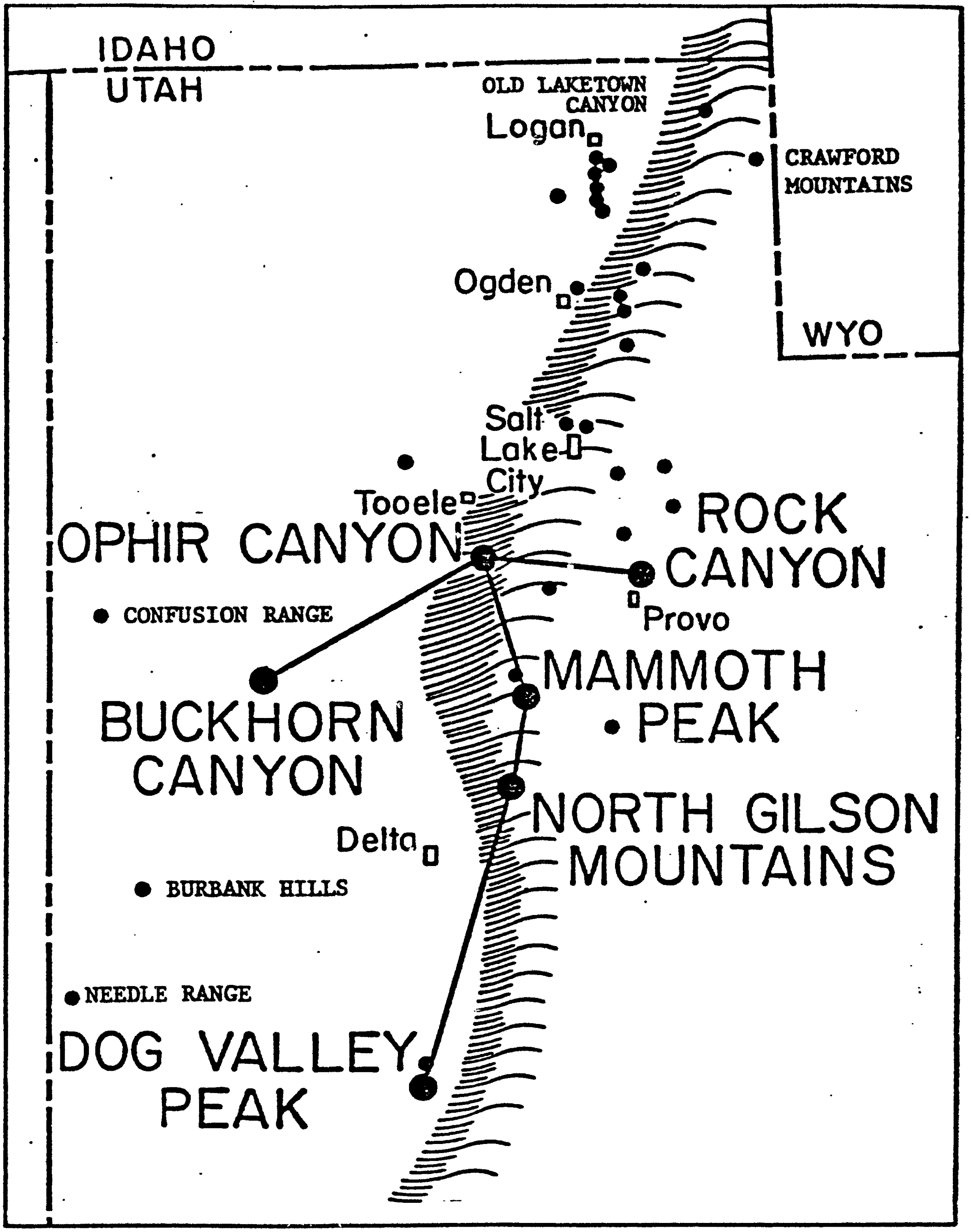

FIGURE 1.—Index map of northwestern Utah showing position of phosphate localities, cross sections, and the Mississippian (Osagean to Meramecian) carbonate-platform margin.

REFERENCES CITED

Epstein, A. G., Epstein, J. B., and Harris, L. D., 1977, Conodont color alteration--an index to organic metamorphism: U.S. Geol. Survey Prof. Paper 995, 27 p.

Gutschick, R. C., 1976, Preliminary reconnaissance study of Lower and lower Upper Mississippian strata across northwestern Utah: U.S. Geol. Survey Open-File Rept. 76-200, 40 p., 14 figs.

Rose, P. R., 1976, Mississippian carbonate shelf margins, Western United States: U.S. Geol. Survey Jour. Research, v. 4, no. 4, p. 449-466.

Sandberg, C. A., 1975, Petroleum geology of Paleozoic rocks of Cordilleran miogeosyncline; Talk for U.S.G.S. Petroleum Research and Resources Seminar, Dec. 12, 1974: U.S. Geol. Survey Open-File Rept. 75-96, 13 p., 6 figs.

Sandberg, C. A., and Gutschick, R. C., 1976, Paleotectonic, biostratigraphic, and economic significance of Osagean starved basin in Utah: Geol. Soc. America Abs. with Programs, v. 8, no. 6, p. 1083, 1085.

Sandberg, C. A., and Poole, F. G., 1975, Petroleum source beds in Pilot Shale of eastern Great Basin--Talk for Oil and Gas Session I, Rocky Mtn. Sec. Meeting, American Association of Petroleum Geologists, Albuquerque, N. Mex., June 2, 1975: U.S. Geol. Survey Open-File Rept. 75-371, 13 p., 4 figs.

Sando, W. J., Dutro, J. T., Jr., Sandberg, C. A., and Mamet, B. L., 1976, Revision of Mississippian stratigraphy, eastern Idaho and northeastern Utah: U.S. Geol. Survey Jour. Research, v. 4, no. 4, p. 467-479.

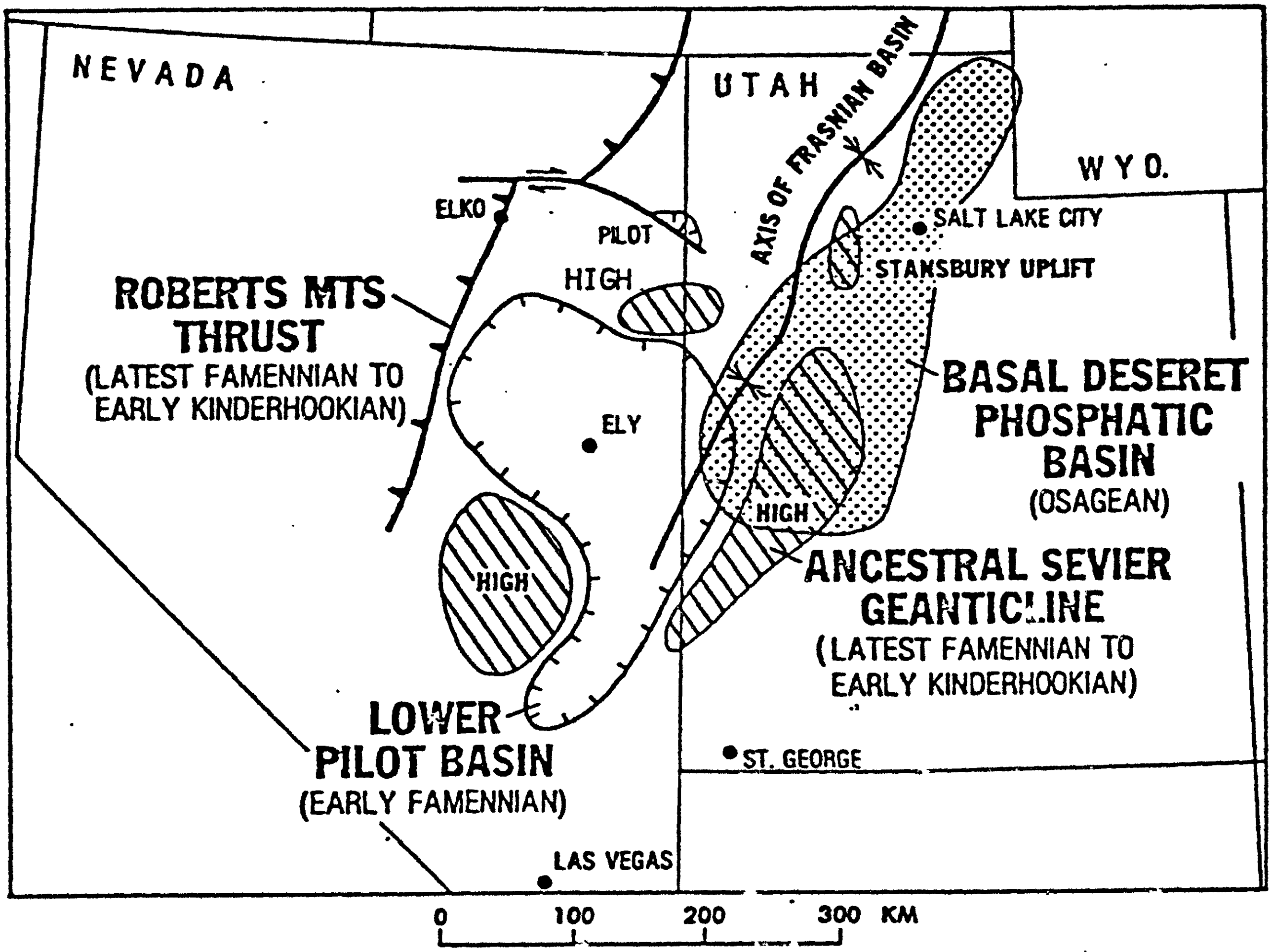

FIGURE 2.--Location of basal Deseret starved phosphatic basin and slightly older (Frasnian to early Kinderhookian) paleotectonic features.

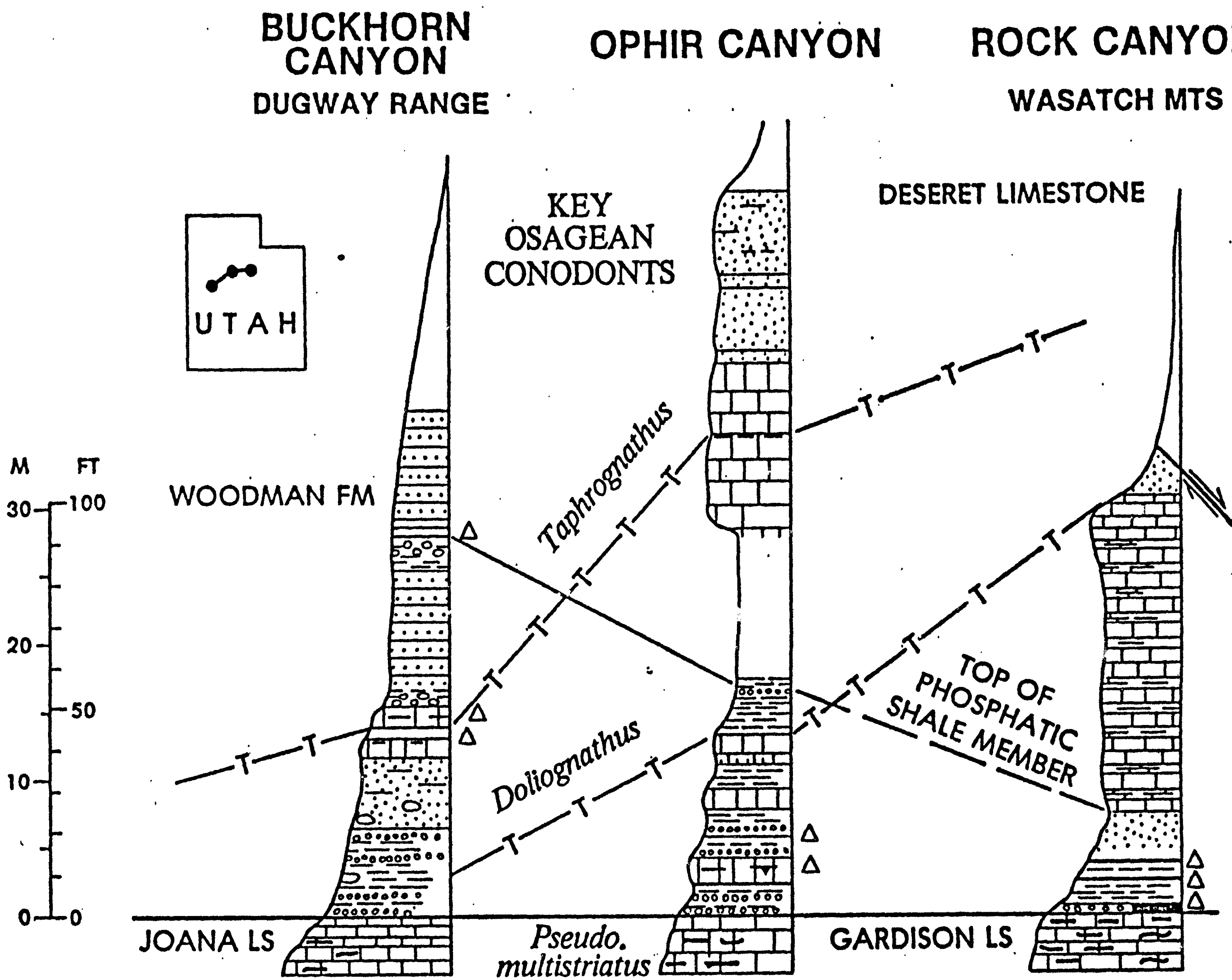

FIGURE 3.--Cross section from central part of starved basin to carbonate platform.

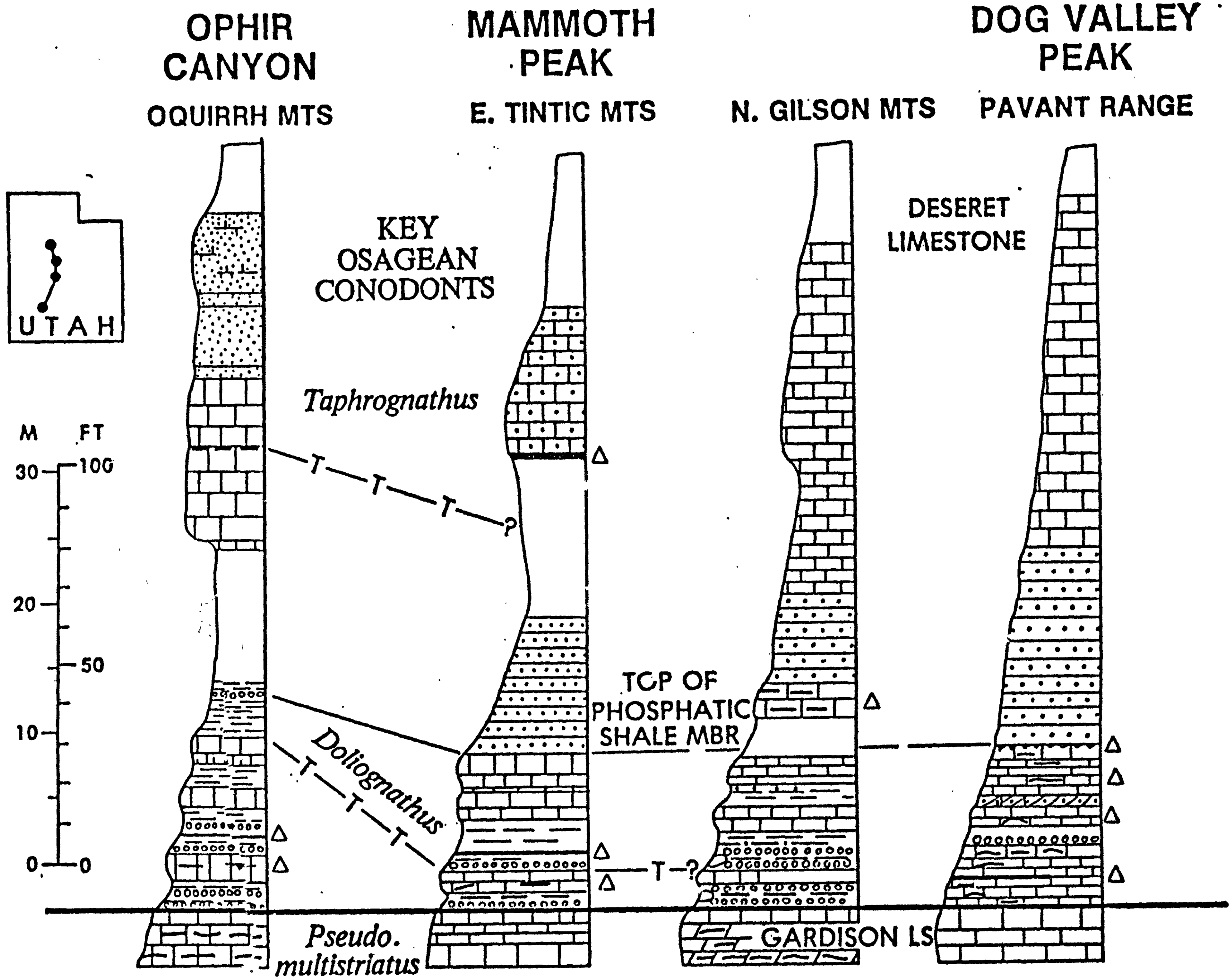

FIGURE 4.--Cross section along starved basin-platform margin interface.

DEEP-WATER STARVED-BASIN FACIES

(Euxinic, Fondothemic)

PHOSPHORITE dark brown, peloidal, even planar bedding

SHALE dark brown to black, organic, phosphatic, peloid phosphorite

CHERT black, even-bedded, laminate, spiculitic, peloid phosphorite

LIMESTONE dark gray, micritic, black nodular chert

CONCRETIONS large and small, ovoid, phosphatic, fossils

FOSSILS radiolarians, sponge spicules, *Zoophycos*, foraminifera, goniatites, small corals, conodonts

SILTSTONES, MUDSTONES

SLOW SEDIMENTATION RATES

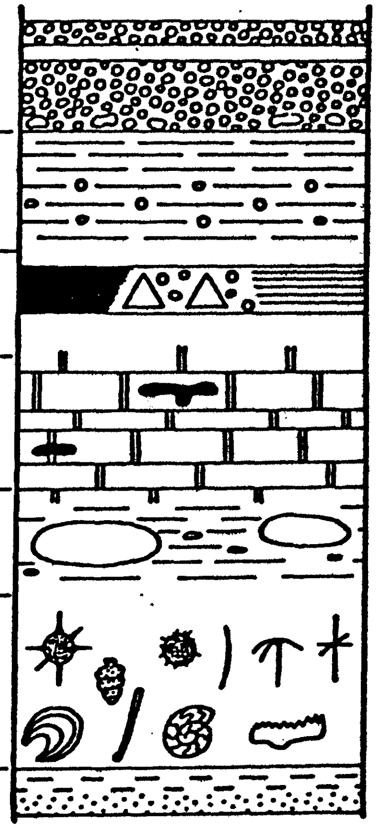

FIGURE 5.--Criteria for deep-water origin of starved-basin facies.