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AUTHOR(S): Charles A. Sandberg and Forrest G. Poole

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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

By

Charles A. Sandberg and Forrest G. Poole

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

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

By

Charles A. Sandberg and Forrest G. Poole

This afternoon, I will discuss the petroleum source beds of the Pilot Shale in western Utah and eastern Nevada. This study is one of 3 Great Basin source-rock investigations (Maughan, 1975; Poole, Sable, and Sandberg, 1975; Sandberg and Poole, 1975), in which the U.S. Geological Survey has been engaged for the past 2 years. The following 2 talks on this afternoon's program will discuss the results of other phases of our preliminary source-rock investigations. The 3 studies were part of a pilot program to determine the feasibility of further investigations of petroleum potential of the eastern Great Basin. Our preliminary results have been promising and have encouraged us to embark on a new 3-year project to investigate the petroleum geology of the middle and upper Paleozoic rocks of the eastern Great Basin. Through this new study, we hope to provide a complete stratigraphic, tectonic, and petroleum source-rock analysis of the Devonian, Mississippian, Pennsylvanian, and Permian rocks of this virtually untested area. The sites and tectonic settings of source-rock deposition will be determined, paths of possible oil migration into the adjacent Rocky Mountain Province will be traced, and possible stratigraphic and structural traps that may have retained oil in the eastern Great Basin will be delineated. We are well aware of the myth of excessive thermal gradient in the eastern Great Basin and hope that our preliminary results will help dispel this myth. We believe that determination of TIMING is the key to a successful exploration program in this area--timing of expulsion and migration, timing of overcooking and thermal degradation, and timing of fracturing of petroleum generation systems and reservoirs by Basin-and-Range faulting.

SLIDE 1

As shown diagrammatically by this first slide, the Pilot Shale is a complex of 3 rock bodies with different ages, histories, and areas of distribution. The upper Pilot is entirely Kinderhookian, has at least 2 separate narrowly limited areas of distribution, and few organic-rich shales in a sequence of relatively deep water limestone, chert, and siltstone. The middle Pilot, which was depositionally continuous with the Leatham Formation of northeastern Utah, is very late Devonian in age. It comprises a basal coarse sandstone, medial organic-rich but thin shales, and overlying tan siltstones. The middle Pilot has little likelihood of being an important source-rock interval, but its porous basal sandstone could provide a good reservoir. The middle Pilot overlies a major unconformity that reflects retarded subsidence and uplift on parts of the shelf in association with early movements of the Antler orogeny farther west. The lower Pilot was deposited in a rapidly subsiding basin on a miogeoclinal carbonate shelf in middle to late Late Devonian time. It is divisible into 2 parts--a basal part that is equivalent to the upper part of the Devils Gate and Guilmette Limestones and an upper part that is equivalent to the shallow-water West Range Limestone. A time plane--established from detailed conodont zonation at the base of the Lower _Palmatolepis crepida_ Zone and shown as a dashed line on this slide--passes through the lower Pilot and into the surrounding shelf carbonates. The upper part of the lower Pilot, which is entirely early Famennian or late Late Devonian in age, contains carbonaceous mudstone and limestone beds of sufficient thickness, areal distribution, and organic richness to merit consideration as source beds for petroleum generation. These beds, which are shown by shading on this slide, will be discussed in detail during the remainder of my talk.

SLIDE 2 (Kodachrome, not included herewith)

The next 2 slides illustrate the characteristic mode of outcrop of the Pilot Shale on the slopes of limestone-capped cuestas and buttes in western Utah and eastern Nevada. This Kodachrome shows the sequence in the Burbank Hills, Utah. On the skyline is the cliff-forming Joana Limestone. The underlying ledges and slope are the upper Pilot. The double ledge in the middle of the picture is formed by rusty-weathering sandstone of the middle Pilot above and by unconformably underlying silicified siltstone at the top of the lower Pilot below. The lower slope and weak ledges extending to the bottom of the slide are the lower Pilot, which in this area is relatively thin because of intertonguing with the West Range Limestone.

SLIDE 3 (Kodachrome, not included herewith)

This next Kodachrome illustrates the sequence at Little Mile-and-a-Half Canyon in the Confusion Range, western Utah. Again, at the top, is the cliff-forming massive Joana Limestone underlain by ledges and slopes of the yellow-weathering thin-bedded upper Pilot. The reddish-brown smear on the right of the gully in the center of the slide is organic-rich shale of the middle Pilot. On the ridge to the left of the gully, the bare lower slope extending to the bottom of the slide is the brownish-weathering sequence of organic-rich shales and interbedded limestones in the upper part of the lower Pilot. I will analyze these possible source beds in a few minutes, but first let us examine an isopach map.

SLIDE 4

This slide shows an isopach map, drawn at 100-metre intervals, of the lower Pilot. The peripherally intertonguing shelf limestones are named: Devils Gate on the west, Guilmette on the east, West Range on the southeast and southwest, and Crystal Pass at the extreme south.

The unusual shape of the Pilot basin would appear to reflect a large oroclinal flexure. However, the influence of Antler-related uplifts on the continental shelf may be a more likely explanation. For example, on the southwest is an uplift wherein Joana unconformably overlies West Range and the intervening Pilot is eroded. The indentation on the northeast, containing the word Guilmette, is part of a westward-trending ancestral arch that extends from the craton on the east and passes through the Gold Hill mining district near the Utah-Nevada line. Note that the lower Pilot has a maximum thickness in excess of 300 metres near the basin center. The area of favorable source beds, shown by shading, occupies the thickest part of the depositional basin. Note the position of Little Mile-and-a-Half Canyon, located by the X, in western Utah. A line of section passing through this X locates the cross section that will be shown on the next slide.

SLIDE 5 (same as SLIDE 1)

On this cross section, note at the top, the position of the Nevada-Utah State line and to its right, the X that locates Little Mile-and-a-Half Canyon. This slide shows diagrammatically how fine clastics of the lower Pilot intertongue with turbidites, debris-flow deposits, and shallow-water limestones such as the Calvinaria Limestone at the bottom center, and thus grade peripherally into limestones of the West Range, Devils Gate, and Guilmette. The Joana truncates the lower Pilot to the west and in turn is truncated by the Chainman Shale, so that Chainman rests directly on lower Pilot at Devils Gate, west of Eureka, Nevada. Shown by shading are the possible source beds in the upper part of the lower Pilot lying between a conodont-dated turbidite below and leaner siltstones and mudstones above. The next slide will show a columnar section at the position of the X.

SLIDE 6

This slide shows at the left, a columnar section from the top of the Guilmette to the base of the Joana Limestone at Little Mile-and-a-Half Canyon, Utah. Carbonaceous mudstones and siltstones are differentiated by heavier lines from noncarbonaceous mudstones and siltstones. At the right, the percentage of organic carbon is shown graphically by a curve resembling a neutron log curve. Please note that most of the measured section has values from 0.2 to 1.7 percent organic carbon. The upper Pilot generally contains less than 0.3 percent organic carbon; the thin shale at the base of the middle Pilot contains about 1.2 percent organic carbon; and the basal part of the lower Pilot contains less than 1 percent organic carbon, except for a single thin bed. These three intervals can be dismissed as possible source beds and will not be discussed further. Instead, let us consider the upper part of the lower Pilot, and in particular the interval designated anticipatively as source beds in the right margin. The interbedded deep-water limestones are relatively thin and had to be exaggerated to show in the columnar section. Actually, they make up less than 5 percent of the total source-bed interval. Consequently, by a dashed line, I have indicated what the gross curve would be, if these limestone beds were discounted. What we see from the curve then, is a rather homogeneous unit of organic-rich calcareous carbonaceous mudstone with values ranging from 1.5 to 3.2 percent organic carbon and an average content of 2.2 percent. The thin interbedded limestones average only 0.5 percent organic carbon, but they have high yields of soluble hydrocarbons, as you will see in the next slide, which provides a detailed section of the interval here labelled source beds.

SLIDE 7

On this final slide, you see at the left, an enlargement of the 93-metre-thick source-bed interval with thick turbidite or debris-flow limestones at the base and top of the column. Most of the limestone interbeds are deep-water micrites; some occur as lenses; others as zones of concretions. The second column shows the same organic-carbon curve as on the previous slide. The third and perhaps most important column shows the soluble hydrocarbons in hundreds of parts per million. Please note that, exclusive of the limestones, the curve indicates minimum values of slightly more than 100 ppm and a maximum value of nearly 900 ppm near the base of the source-bed interval Also note that the second highest value--about 550 ppm--occurs above the source-bed interval in a bed containing only 0.8 percent organic carbon. I believe that there is some significance to the fact that the highest soluble hydrocarbon values occur adjacent to thick limestones at the top and bottom of the column in rocks that do not show high organic carbon values. This is merely a speculation, but could these associations of high soluble hydrocarbon and low organic carbon indicate that hydrocarbons were expelled upward and downward from the main body of source beds until they encountered thick, rather impervious limestones? Another significant feature of this third column is the higher soluble hydrocarbon content of the thin micrites--220 to 370 ppm--as shown by the sharp deflections of the curve to the right in direct alignment with the leftward deflections in the second column. Obviously, the interbedded limestones yield much more soluble hydrocarbons per unit of organic carbon than do the mudstones. The fourth column shows a curve giving the percentage of carbonate. The sharp deflections reflect limestone interbeds and parallel the deflections in the hydrocarbon curve. Moreover, there is a general parallelism of the third and fourth curves, which shows that the yield of soluble hydrocarbons is directly proportional to the carbonate content of the mudstones. Another speculation--is it possible that some types of limestone make better source beds than shales or mudstones?

The fifth column shows maturation values based on 5 samples for which visual kerogen analyses were performed. The X's show the plots of individual samples, whereas the dashed line enclosing them shows the range of values to be from 1+ to 2/2+. Such values indicate nearly optimum conditions of maturation. This indication is supported by conodont alteration-colors, which have index numbers of 1½ to 2, suggesting that the maximum temperature to which this source-bed interval was subjected was about 100^{o} Centigrade. This compares with temperatures only as high as 140^{o} Centrigrade, also determined from conodonts, for the westernmost outcrops of the same source-bed interval in eastern Nevada. Certainly, such a range of temperatures does not indicate overcooking by a high regional thermal gradient.

In summary, I believe I have demonstrated that probable source beds do exist in the lower part of the Pilot Shale. Their present-day leanness may be due partly to slight alteration or silicification that occurred after expulsion of petroleum and partly to more recent degradation by surficial weathering. Moreover, most of these rocks remain at or near optimum maturation and were not regionally overcooked, dispelling the myth of excessive thermal gradient in the eastern Great Basin. Future work on the Pilot Shale includes core-sampling the source beds well below the zone of surficial weathering and establishing parameters for documenting probable paths of eastward migration of expelled petroleum. I hope these results will justify my enthusiasm for expounding the attributes of the eastern Great Basin and that the Geological Survey and the petroleum industry will be able to collaborate in developing this new frontier basin. I will be happy to answer your questions in public or in private. Thank you for listening.

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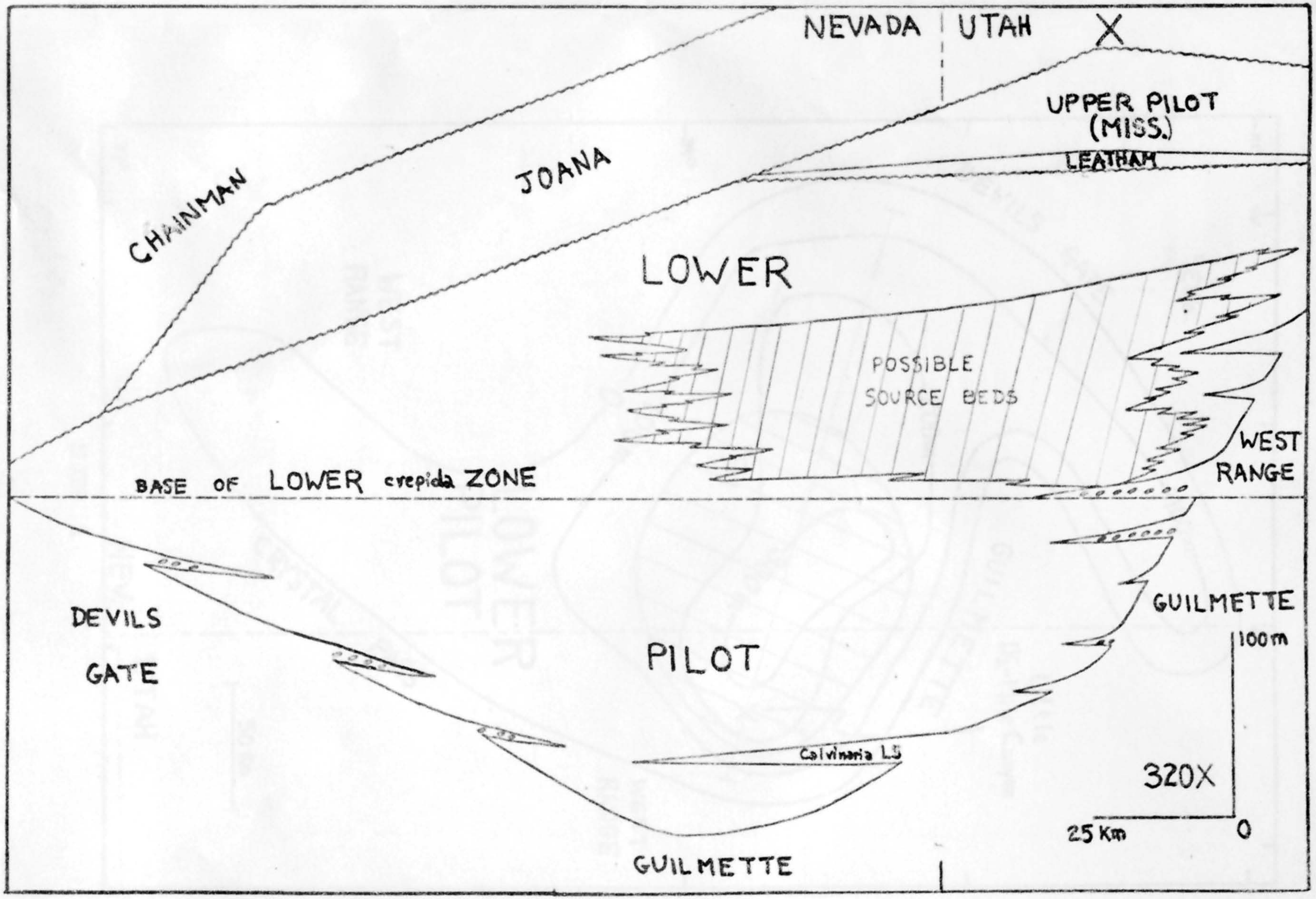
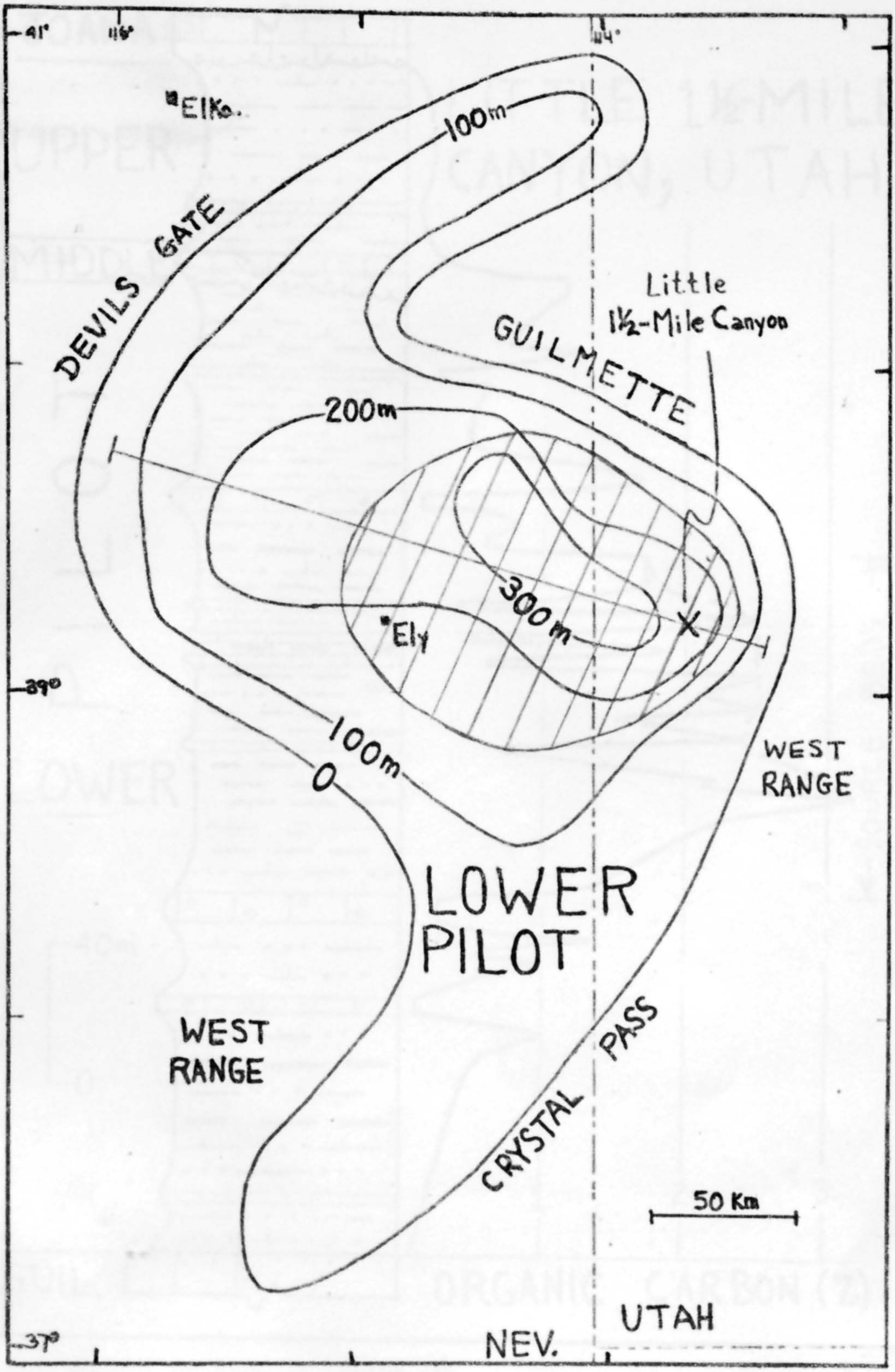


SLIDES 1 and 5



41°
116°
114°
Elko
100m
DEVILS GATE
GUILMETTE
Little
1½-Mile Canyon
200m
300m
Ely
39°
100m
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WEST
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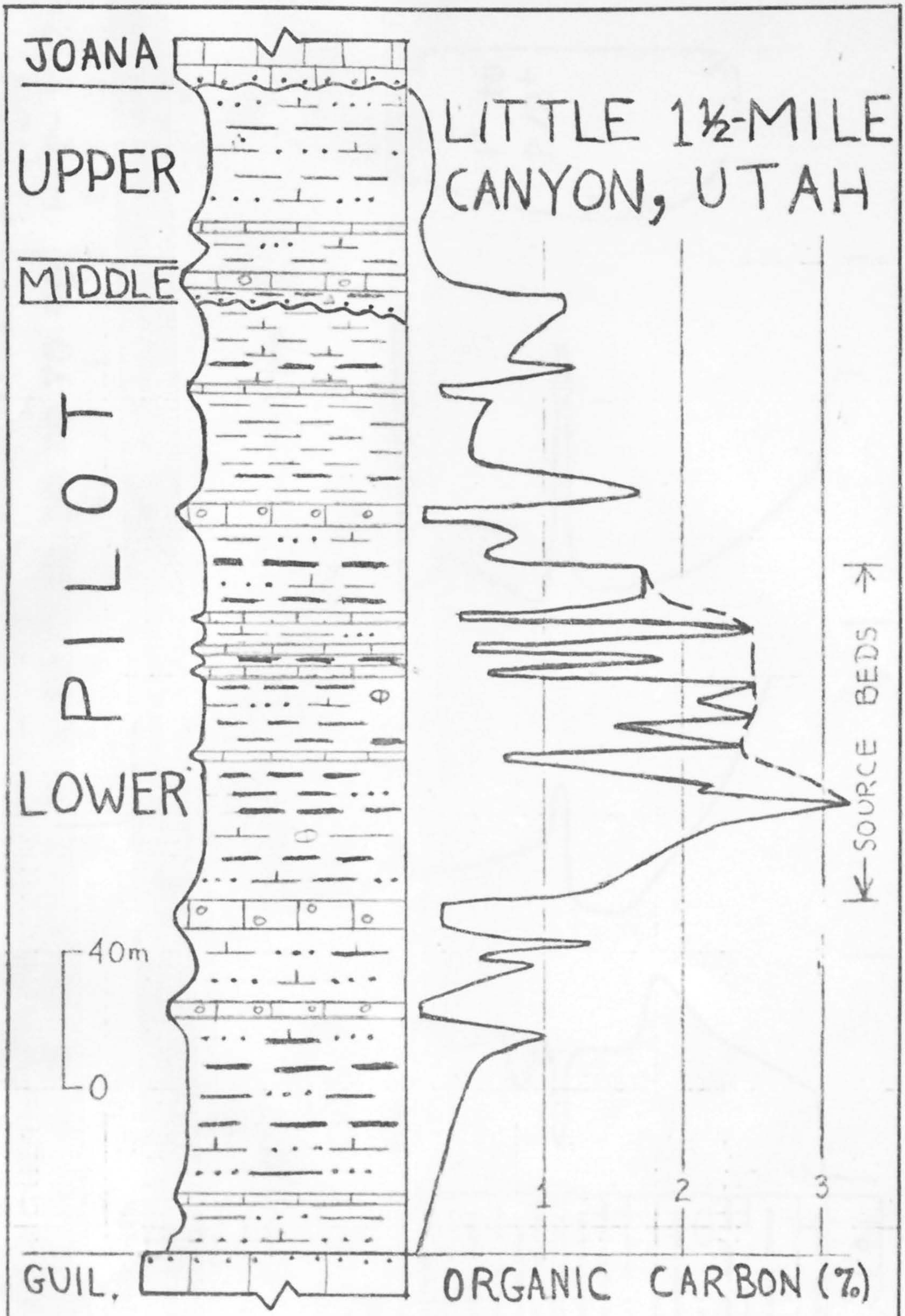
UTAH

SLIDE 4


JOANA
UPPER
MIDDLE
PILOT
LOWER
LITTLE 1½-MILE CANYON, UTAH
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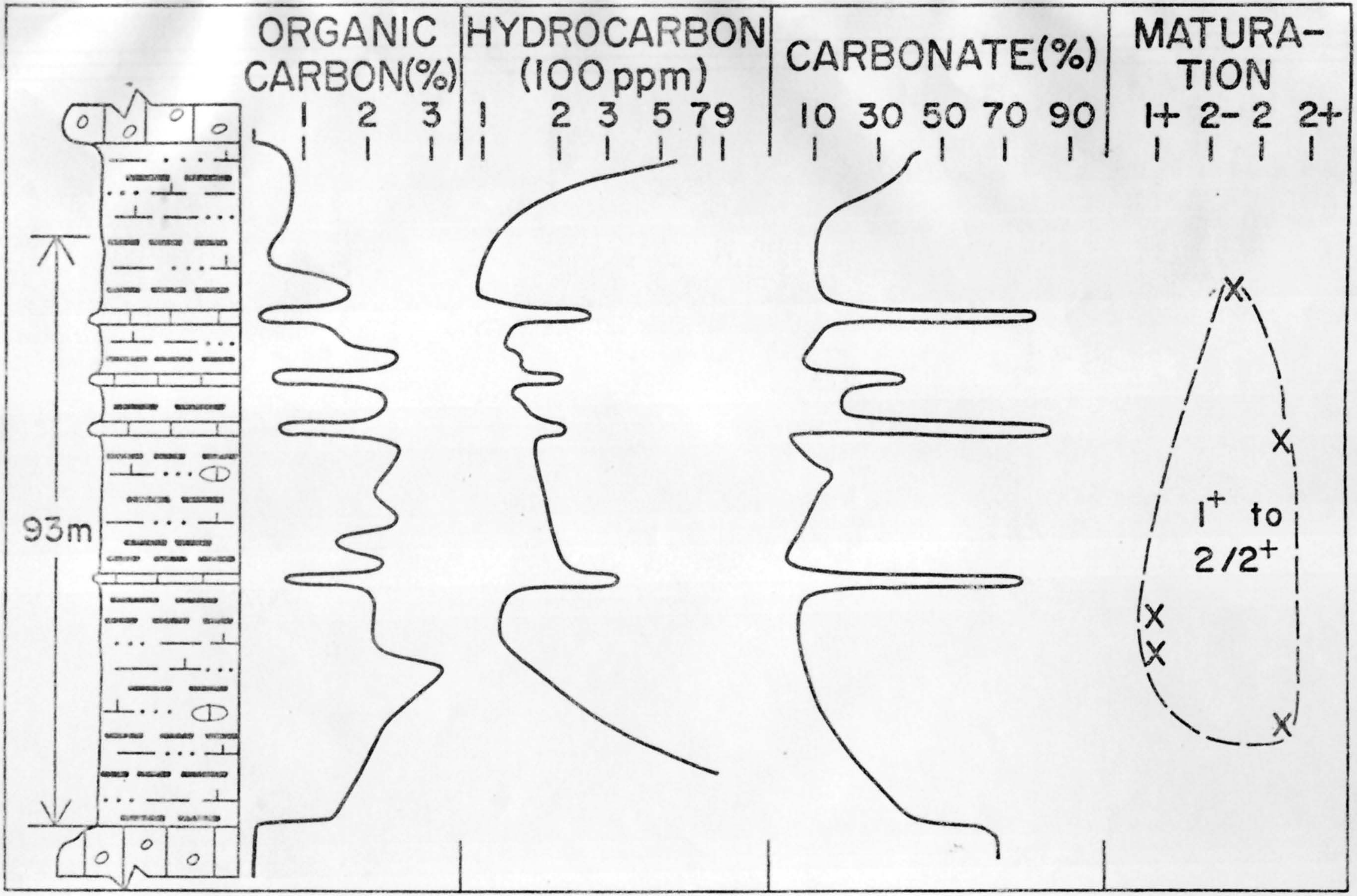
SOURCE BEDS
1
2
3
GUIL.
ORGANIC CARBON (%)

SLIDE 6


ORGANIC CARBON(%)
1 2 3
HYDROCARBON (100 ppm)
1 2 3 5 7 9
CARBONATE(%)
10 30 50 70 90
MATURATION
1+ 2- 2 2+
93m
1^+ to $2/2^+$

SLIDE 7

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