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PROGRESS REPORT ON THE POTASH DEPOSITS OF THE KHORAT PLATEAU, THAILAND

By

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X-ray fluorescence spectrometer analyses by H. L. Groves,

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INTRODUCTION

During the period September 20 to October 21, 1980, the author visited Thailand on a temporary assignment as part of the U.S. Geological Survey's (USGS) program to assist the Thailand Department of Mineral Resources (DMR) in assessing the progress of the Khorat Plateau potash project. The program was sponsored by the Agency for International Development (USAID). A large volume of new drilling data on the potash resources obtained since the author's last visit in 1974 was studied at DMR headquarters in Bangkok, in office space graciously provided by the Economic Geology Division. Laboratory studies and report writing were performed upon returning to Denver, Colorado.

While in Bangkok and during a field trip to the Khorat Plateau, invaluable assistance was rendered by DMR geologists and engineers Thawat Japakasetr, Prakorn Suwanich, and Phitaks Ratanajavuraks. Several discussions with Dr. Anant Suwanapal, Senior Mining Engineer, concerning problems of developing the potash deposits were most informative and stimulating. Thorough and constructive technical reviews by J. R. Dyni and J. K. Pitman (USGS) greatly improved the quality of the report.

Potash, in the form of carnallite ($KCl.MgCl_2.6H_2O$), was discovered on the Khorat Plateau by the DMR in 1973 in a core hole located in the town of Udon Thani. Since the author's last visit in 1974, about 124 core holes have been completed, which indicate a very thick, nearly continuous deposit of carnallite that extends over a large area of the Plateau. This drilling also established that sylvite (KCl) deposits are present locally in the same stratigraphic interval (Japakasetr, 1980). Because sylvite is the most valuable ore of potash, it is important to determine the location, geometry, and size of these deposits. Exploration for sylvite will be successful only if the geologic controls governing its formation are understood. This report stresses the genesis of the sylvite deposits and the associated salt anticlines, and provides exploration guidelines to assist in the search for new deposits and the delineation of known deposits. Also discussed are the exploitation of carnallite, problems of salt solution and collapse, and some findings that may be important to the development of ground water and uranium exploration on the Khorat Plateau.

STRATIGRAPHY

The Khorat Plateau potash deposits are in the Maha Sarakham Formation of Cretaceous age. This formation was subdivided into a Lower Salt, Middle Salt, and Upper Salt by Hite and Japakasetr (1979, fig. 3); to date significant amounts of potash have been found only in the lower salt. For this report, the following stratigraphic terminology is used:

Maha Sarakham Formation

Upper Clastic

Upper Salt

Middle Clastic

Middle Salt

Lower Clastic

Lower Salt (potash bearing)

Basal Anhydrite

SALT ANTICLINES

During the early stages of potash exploration on the Khorat Plateau, the evaporite sequence was assumed to be essentially flat lying (Hite, 1974). Recently, however, drilling near the city of Khorat has outlined a salt anticline (Hite and Japakasetr, 1979). We now recognize that salt anticlines are common over much of the Plateau. Nearly half of the widely scattered core holes in both the Khorat and Sakon Nakhon Basins are probably located on salt anticlines. Locally, drilling density is sufficient to explain the origin of these structures, and how they affect the distribution and mineral facies of the potash deposits. Three such localities, Banmet Narong, Khon Kaen, and Non Sung (fig. 1) were studied in detail in this investigation.

Banmet Narong

An area along the western edge of the Khorat Basin, which includes the village of Banmet Narong in Chaiyaphum Province (fig. 1), was chosen by the Thailand Government as a potentially favorable site for the development of rock salt reserves to be used in soda ash manufacture. The DMR has conducted an extensive exploration program in this area, and at the time of the author's visit, about 50 core holes had been drilled in an area of about 26 km^2 (fig. 2).

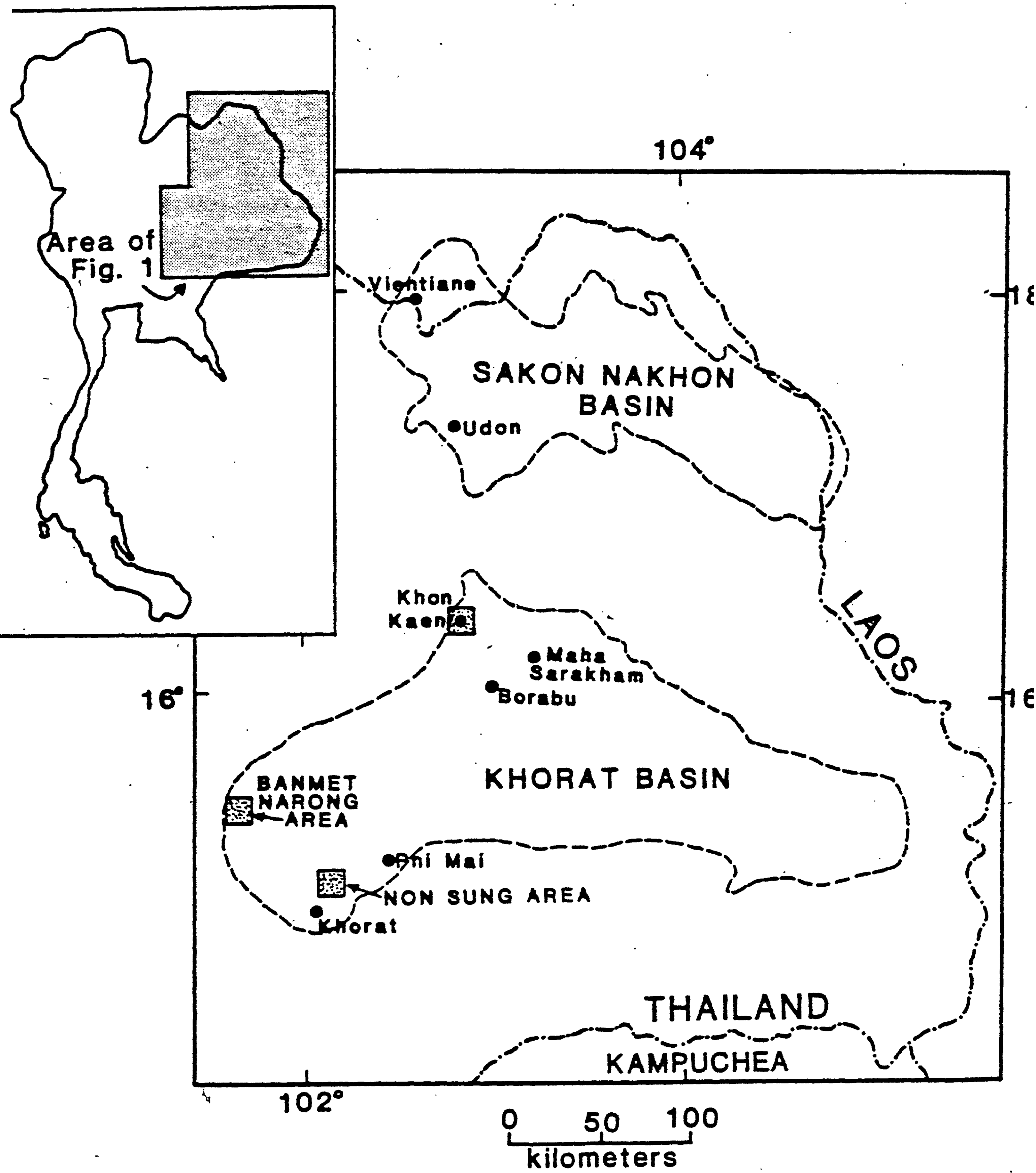

Figure 1. Index map of Khorat Plateau.

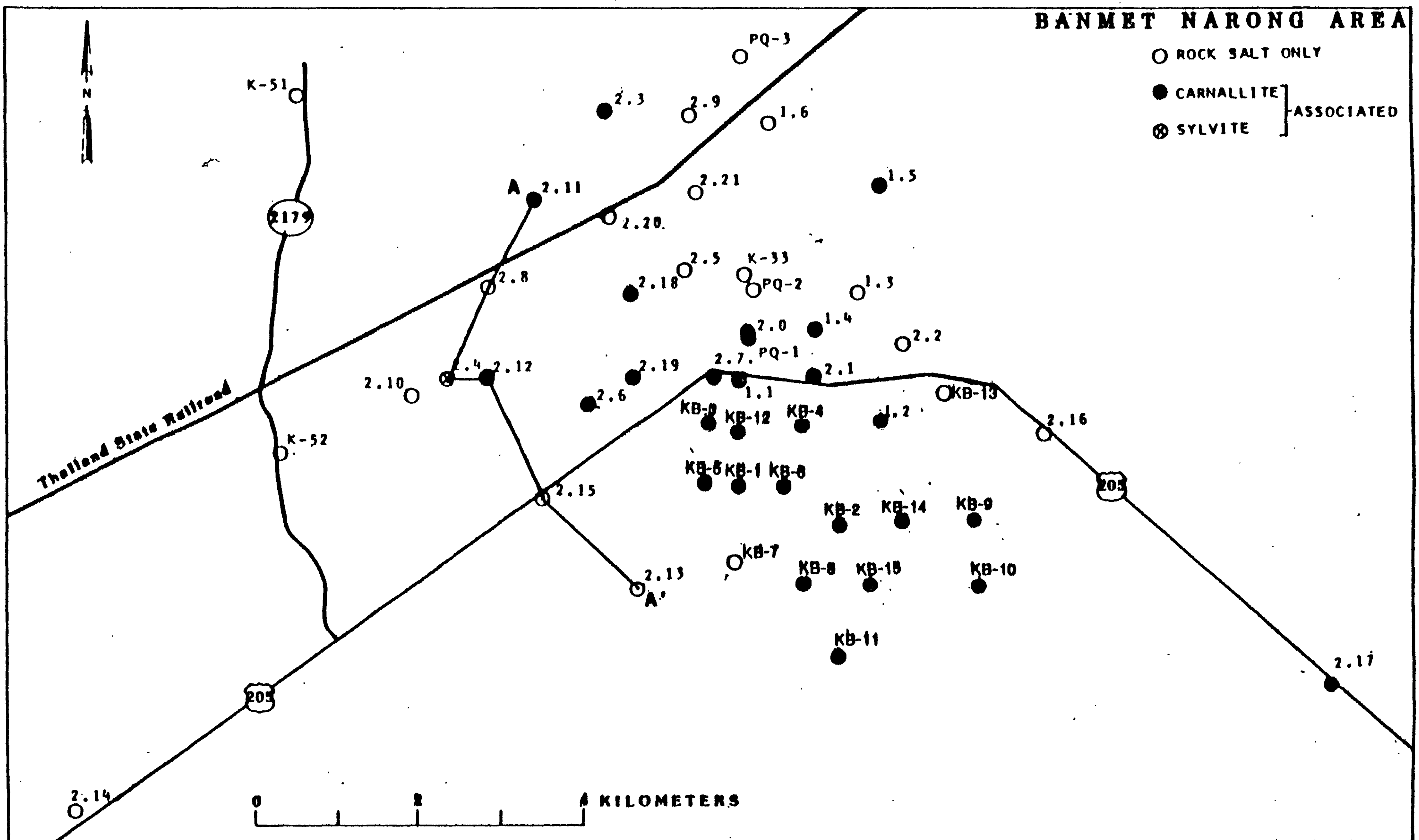

Figure 2. Index map of the Banmet Narong area. Line A-A' shows line of section for figure 5.

At the Banmet Narong locality, the structure on the base of the Lower Salt is quite different from that on the top of the Lower Salt. The regional dip on the base of the Lower Salt is 75 m per kilometer to the southeast into the Khorat Basin and is broken only by a slight nosing of structure contours (fig. 3). The structure on top of the Lower Salt is entirely different (fig. 4). At this stratigraphic horizon the rocks are strongly folded, amplitudes of some folds reaching 200 m or more. A prominent syncline can be traced from the southeast part of the area northwestward to about the area center where the fold axis curves toward the southwest. The Upper Salt is preserved only in this deep syncline. Three anticlinal axes have been outlined by drilling and these also show divergent trends. A north-south cross section (fig. 5) shows these folds and the complete structural discordancy between this folding and beds below the Lower Salt. There appears to be no genetic relationship between the anticlinal folds and pre-evaporite structure. Also shown is a conspicuous thinning of the Lower Salt in the syncline and corresponding thickening in the adjacent anticlines. The Lower Salt is thickest in core hole RS 2.16, where it is 295 m (fig. 6).

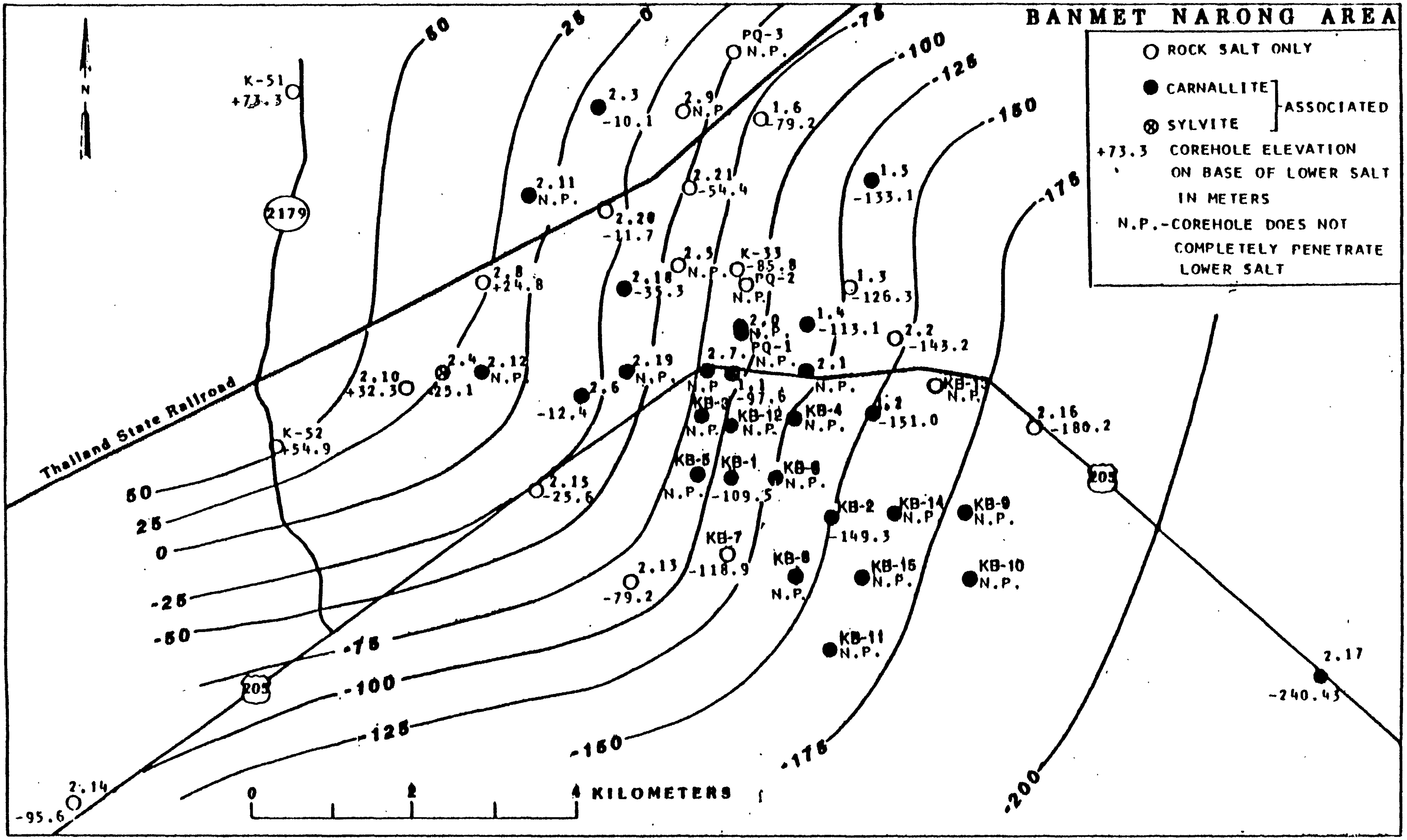

Figure 3. Structure-contour map showing structure on the base of the Lower Salt in the Banmet Narong area (contours in meters).

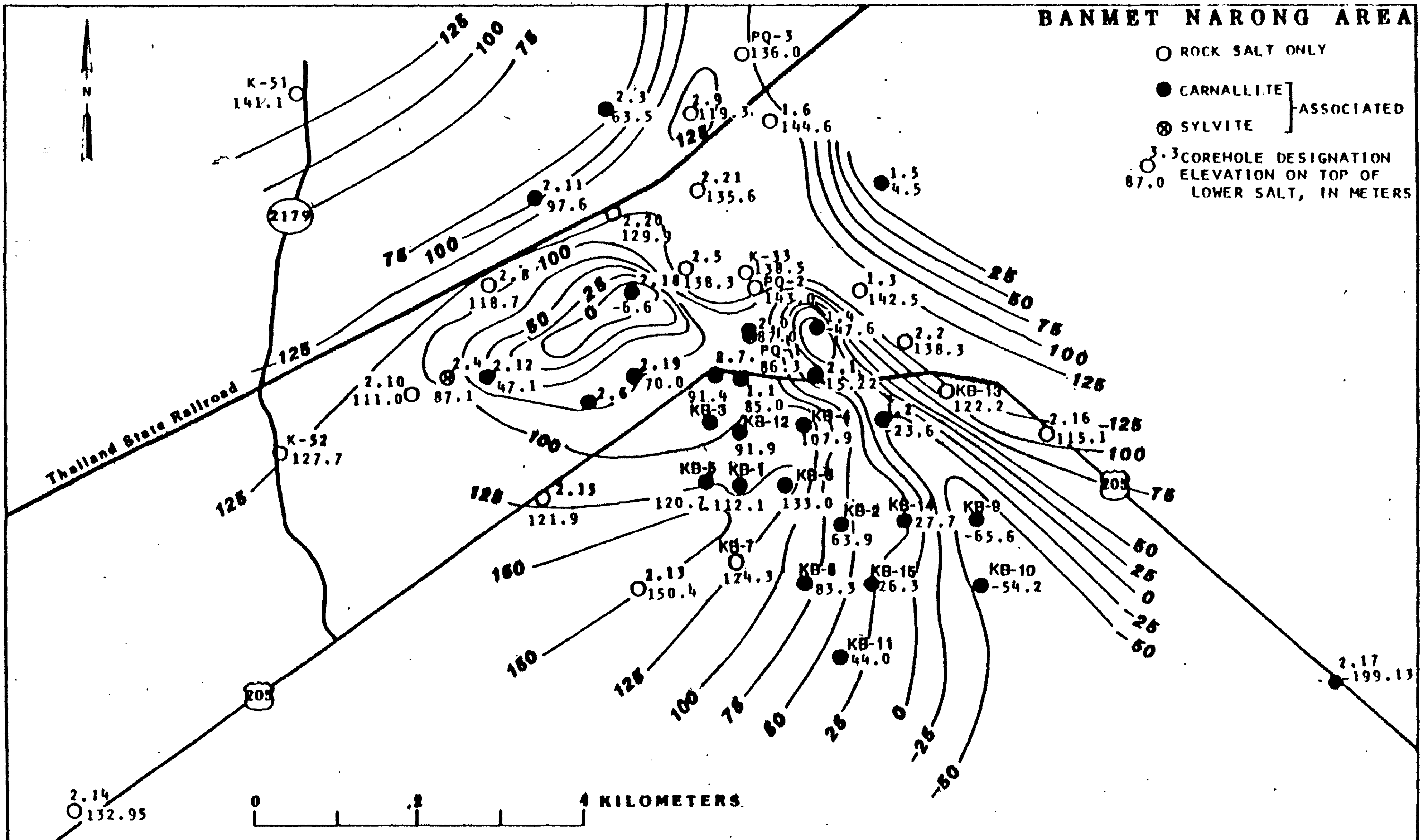

Figure 4. Structure-contour map showing structure on the top of the Lower Salt in the Banmet Narong area (contours in meters).

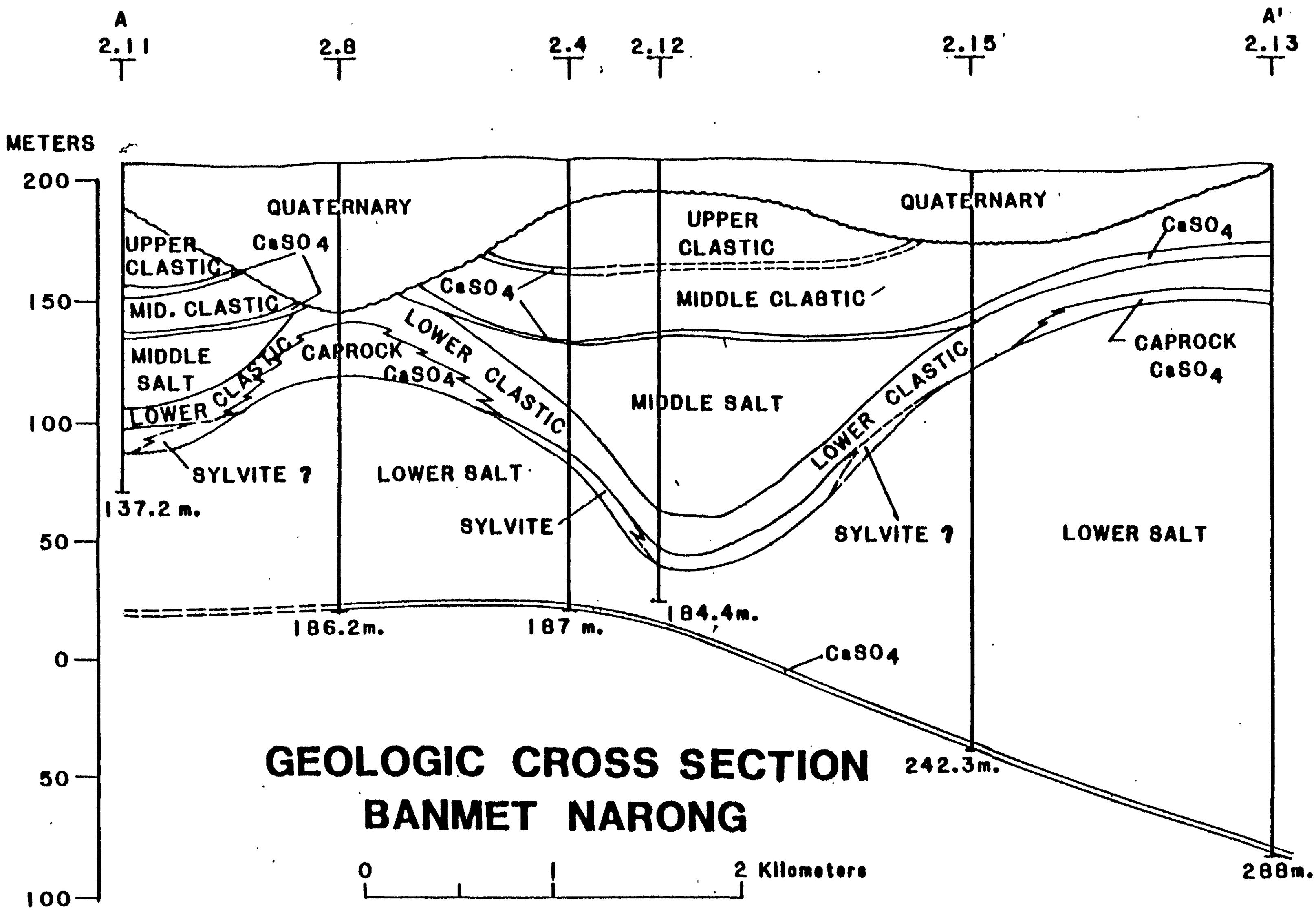

Figure 5. North-south geologic cross section through the Banmet Narong area.

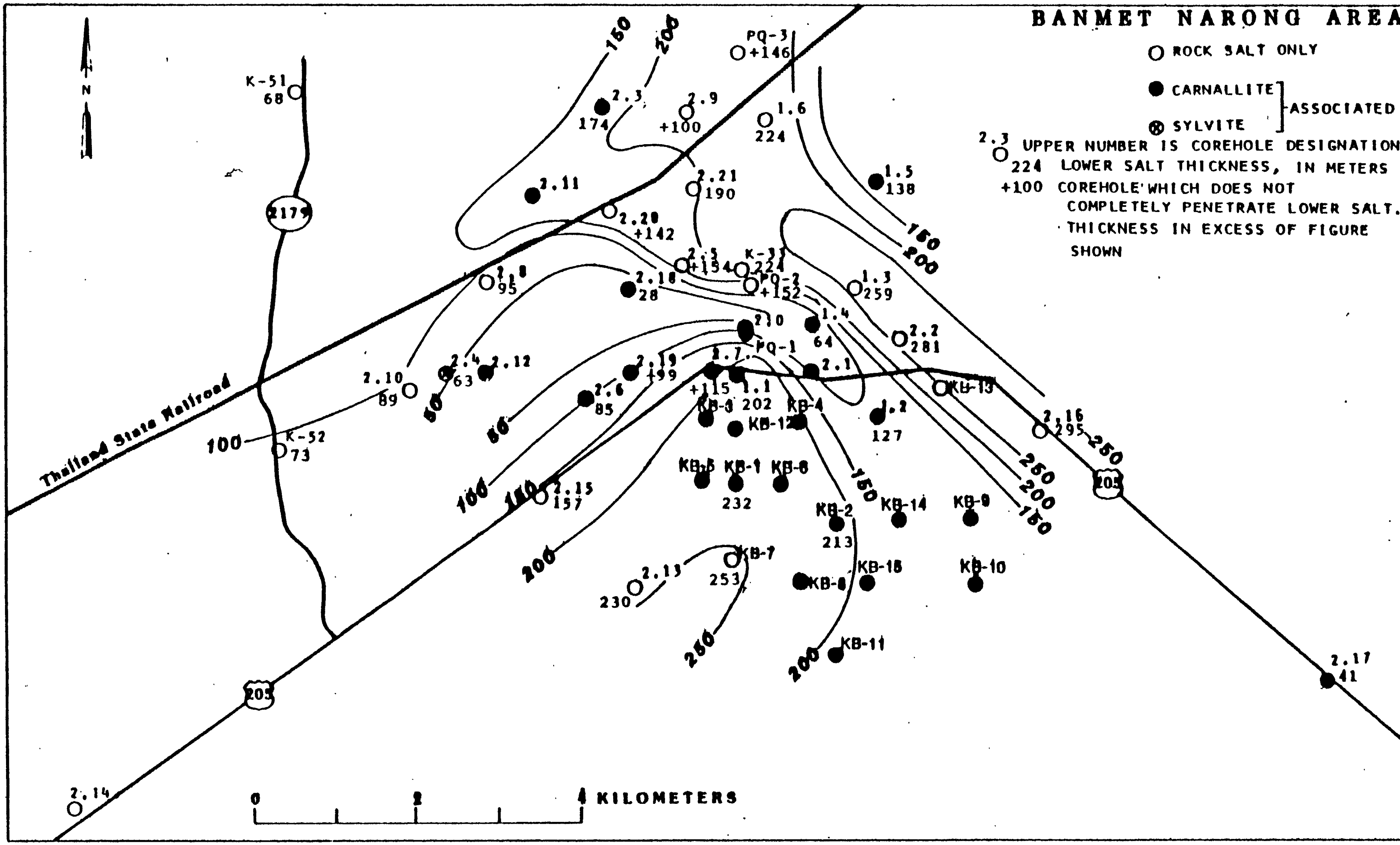

Figure 6. Isopach map of the Lower Salt in the Banmet Narong area (isopachs in meters),

Variation in thickness of stratigraphic units overlying the Lower Salt are related to the history of growth of the salt anticlines at Banmet Narong. An isopachous map of the Lower Clastic in that area is shown on figure 7. The values shown are penetration thicknesses and therefore, do not necessarily represent the true depositional thickness of the unit. It is possible that high dips in some of the core holes may give misleading thicknesses. Unfortunately, dips were not recorded in the available core descriptions by DMR geologists. In addition, post-Cretaceous erosion has thinned this unit in some core holes, principally RS 1.3, 2.5, 2.8, 2.9, and 2.20. A tabulation of thicknesses for the Lower Clastic at Banmet Narong (table 1) shows that variations in thickness do not appear to be related to local structure. Thinning is associated with synclines as well as anticlines. In core holes RS 1.1, 2.0, 2.7, and PQ 1, the Lower Clastic is very thin, but it is overlain by the Middle Salt. Here it can be assumed that thinning was not due to erosion. Anomalous thinning occurs in a small area around core holes RS 1.1, 2.0, 2.7, PQ 1, and KB 4 (fig. 7). Although this area coincides with a prominent syncline, it appears to be completely surrounded by more normal thicknesses. Because the Middle Salt is present in this area, the Lower Clastic has obviously been protected from post-depositional erosion. It, therefore, can be concluded that variations in thickness of the Lower Clastic in the Banmet Narong area are not the result of growth of the salt anticlines during time of deposition of this unit. Furthermore, there appears to be no relationship between thickness of the Lower Clastic and thickness of the underlying potash deposit (table 1). This point will be discussed later in detail.

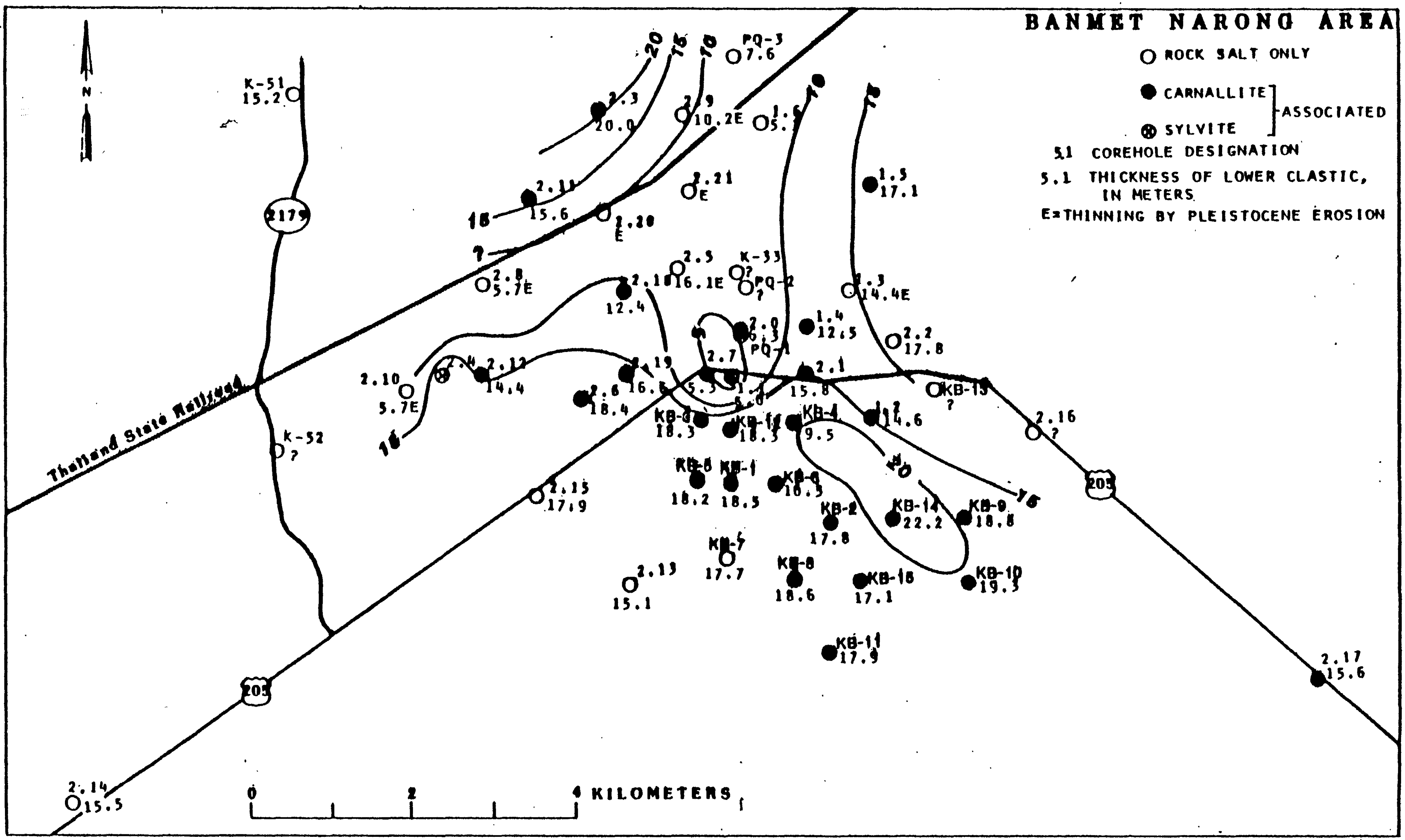

Figure 7. Isopach map of the Lower Clastic in the Banmet Narong area (isopachs in meters).

Table 1.--Thickness of the lower clastic, potash and caprock, and the type of structure at the corehole location in the Banmet Narong area. The letter E indicates the unit may be thinned by erosion. N.P. indicates the unit was not completely penetrated

		Thickness (meters)			
Core hole	Lower clastic	Carnallite	Sylvite	Caprock	Structure
RS 1.1	5.03	25.7	2.0	0	Syncline
RS 1.2	14.55	27.2	0	0	Syncline
RS 1.3	14.43 E	0	0	26.7	Anticline
RS 1.4	12.49	13.2	0	0	Syncline
RS 1.5	17.14	29.6	0	0	Syncline
RS 1.6	5.06	0	0	6.6	Anticline
RS 2.0	6.32	39.5	.91	0	Syncline
RS 2.1	15.81	7.6 N.P.	0	0	Syncline
RS 2.2	17.80	0	0	3.6	Anticline
RS 2.3	20.01	8.3	0	0	Syncline
RS 2.4	17.78	0	5.1	0	Intermediate
RS 2.5	16.10 E	0	0	5.4	Anticline
RS 2.6	18.37	9.4	0	0	Syncline
RS 2.7	5.28	32.9	0	0	Syncline
RS 2.8	5.67 E	0	0	22.1	Anticline
RS 2.9	10.21 E	0	0	28.8	Anticline
RS 2.10	5.69	0	0	13.1	Anticline
RS 2.11	15.59	9.4	0	0	Intermediate
RS 2.12	14.38	6	0	0	Syncline
RS 2.13	15.09	0	0	3.8	Anticline
RS 2.14	15.48	0	0	0.2	Unknown
RS 2.15	17.90	0	0	0	Anticline
RS 2.16	?	0	0	1.8	Anticline
RS 2.17	15.57	8.1	0	0	Unknown
RS 2.18	12.32	4.3	0	0	Syncline
RS 2.19	16.55	4.5	0	0	Syncline
RS 2.20	0. E	0	0	1.3	Anticline
RS 2.21	18.00 ?	0	0	10.7	Anticline
KB 1	18.47	38.8	0	0	Intermediate
KB 2	17.83	37.1	0	0	Intermediate
KB 3	18.30	33.6	0	0	Syncline
KB 4	19.50	36.3	0	0	Syncline
KB 5	18.19	36.7	0	0	Intermediate
KB 6	16.46	32.7	0	0	Anticline
KB 7	17.65	0	0	0. ?	Anticline
KB 8	18.57	36.0	0	0	Syncline
KB 9	18.79	22.0	0	0	Syncline
KB 10	19.33	27.2	0	0	Syncline
KB 11	17.94	40.0	0	0	Syncline
KB 12	18.27	39.2	0	0	Syncline
KB 13	?	0	0	0. ?	Anticline
KB 14	22.24	41.6	0	0	Syncline
KB 15	17.14	39.6	0	0	Syncline
PQ 1	7.04	39.2	1.0	0	Syncline
PQ 2	28.35 ?	0	0	17.1	Anticline
PQ 3	7.57	0	0	11.6	Anticline
K 33	?	0	0	15.9	Anticline
K 51	15.16	0	0	0	Unknown
K 52	18.59 ?	0	0	19.5	Anticline

At the time of this study, 49 core holes had been drilled at Banmet Narong. In 19 of the holes, only the Lower Salt was present and in all but 3 of these a gypsum caprock was present on the top of the Lower Salt (table 1). The caprock thickness ranges from 28.8 to 0.2 m. The areal distribution of caprock is closely coincident with the crests of salt anticlines (fig. 8).

The high density of drilling at Banmet Narong allows the bedrock surface to be mapped in considerable detail. As a result some significant discoveries were made in regard to this surface. A contour map showing the topography of the bedrock surface (fig. 9) clearly indicates a deeply incised paleo channel trending southwest to northeast through the northwestern part of the area. The deepest part of the channel appears to be centered around core holes RS 2.20 and RS 2.8. This particular channel coincides closely with the axis of a salt anticline (fig. 4). Another bedrock channel is present along the south-central part of the Banmet Narong area. It trends north through core holes KB 8, KB 2, and KB 6, before curving west where it is centered near core holes KB 1, and RS 2.15. For most of its extent, this particular channel does not appear to coincide with the axis of a salt anticline. Another channel is probably present on the east-central part of the area. This channel trends southeast to northwest and passes through core holes RS 2.16, RS 2.2, and RS 1.3. Although there drilling is insufficient in this locality to completely define the channel boundaries, it appears to coincide with the axis of a salt anticline (fig. 4). The maximum amount of topographic relief created by channel incision in this area is about 66 m. This relief occurs in a horizontal distance of about 1 km between core holes RS 2.20 and RS 2.18. Locally the channels are cut down into salt deposits. In core hole RS 2.20, rock salt of the Lower Salt forms the bedrock surface (fig. 10), and in core holes KB 6 and KB 2, rock salt of the Middle Salt forms the bedrock surface (fig. 10).

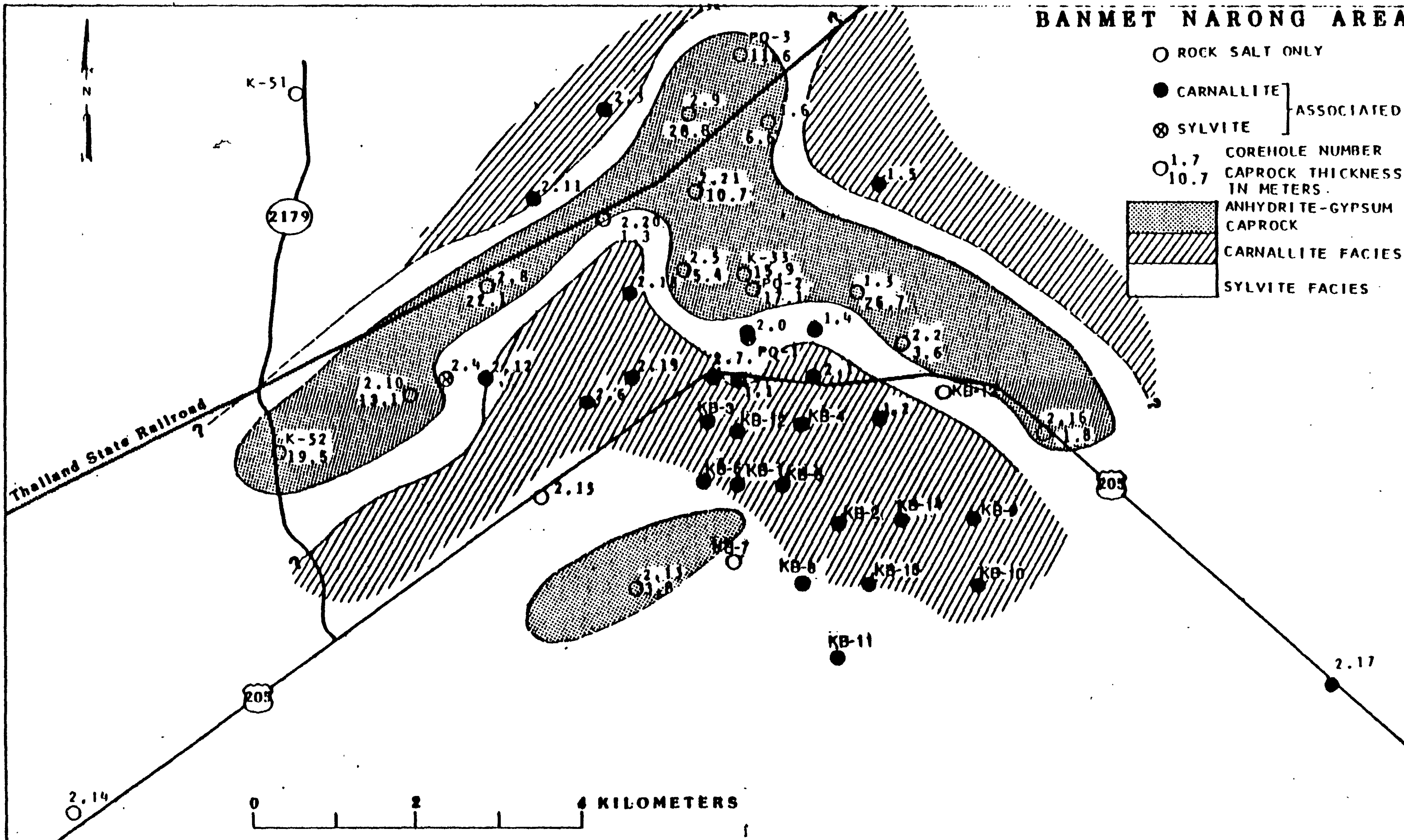

Figure 8. Map showing distribution of caprock, carnallite, and sylvite in the Lower Salt at Banmet Narong.

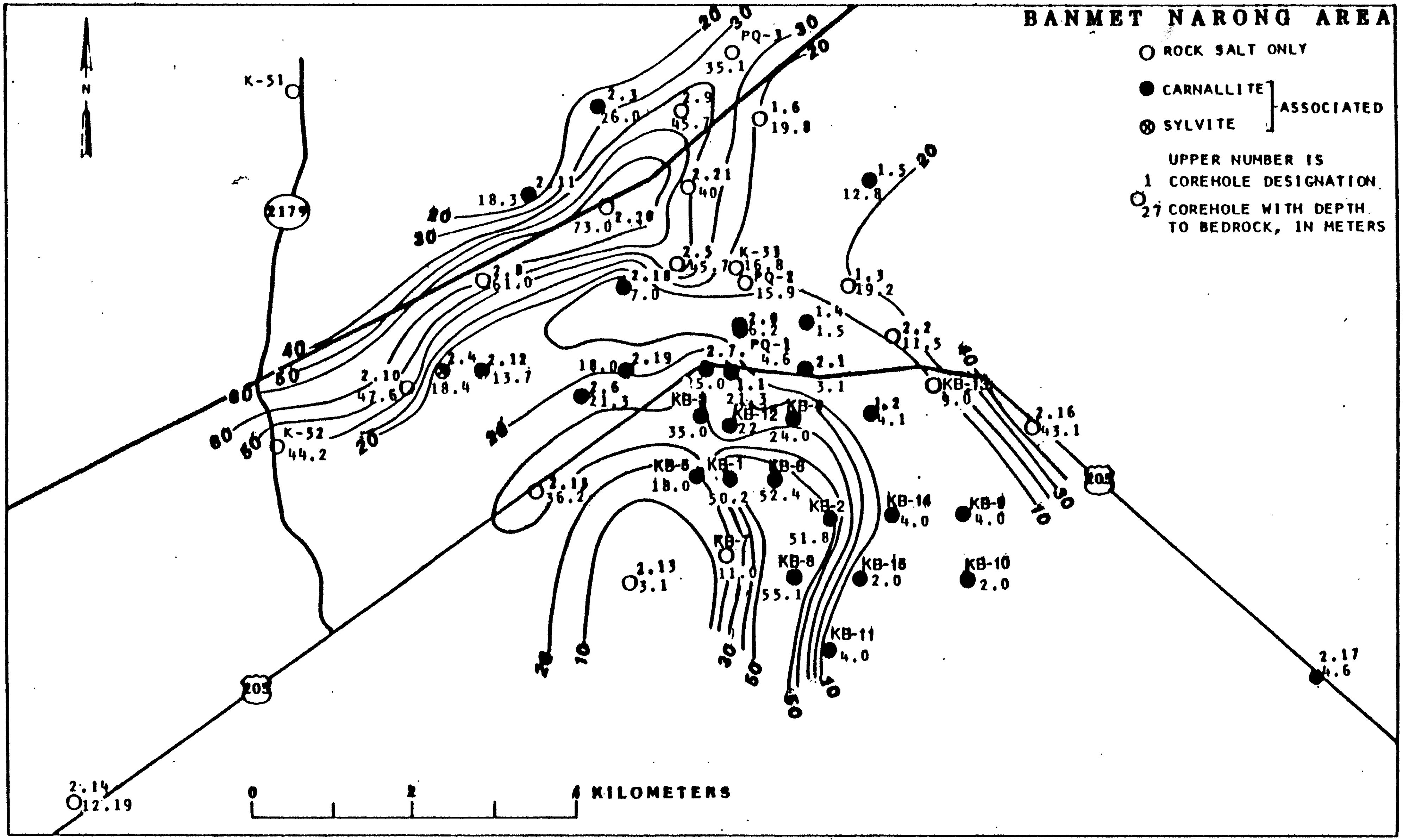

Figure 9. Topography of the bedrock surface at Banmet Narong (contours in meters).

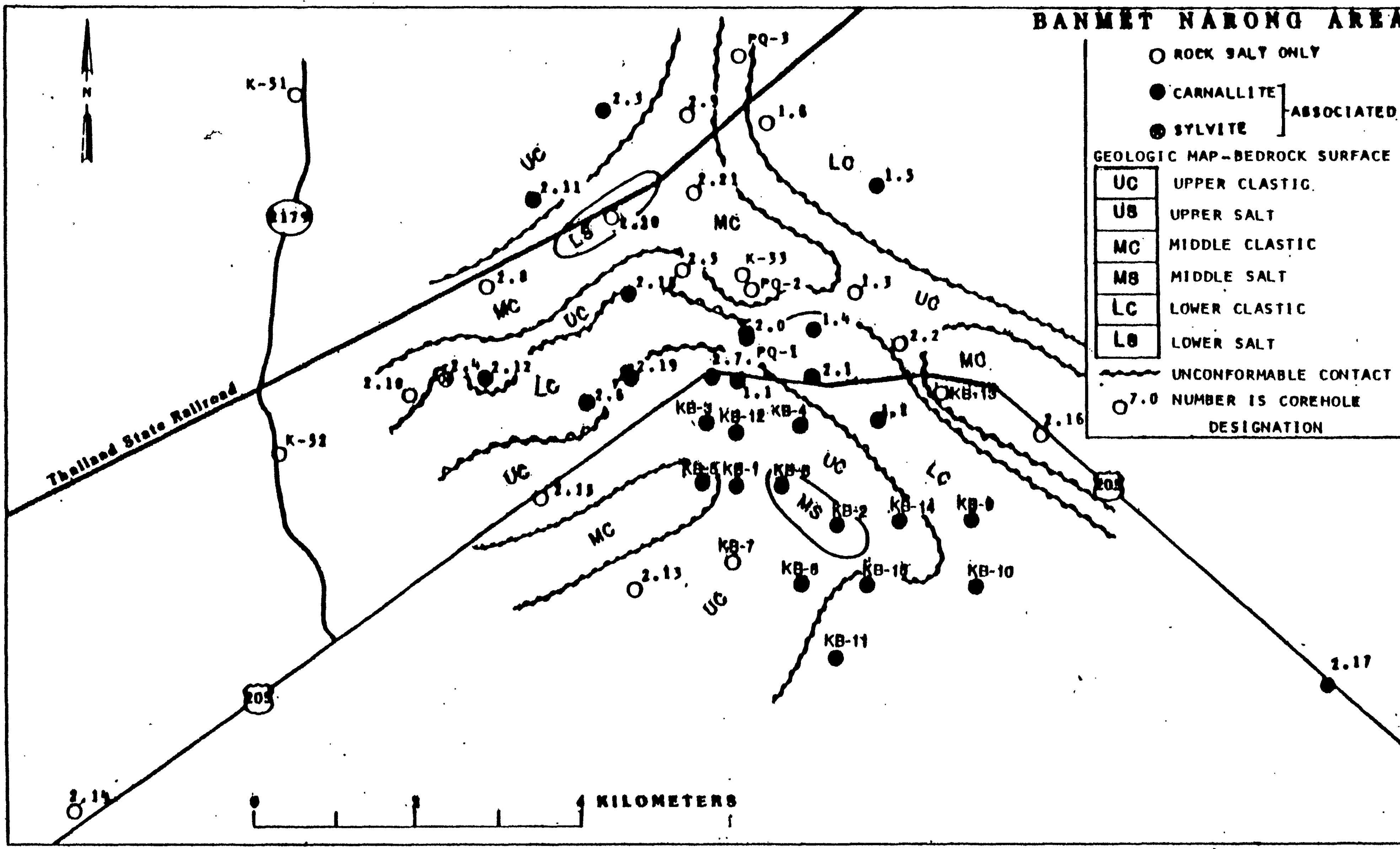

Figure 10. Geologic map of the bedrock surface at Banmet Narong. Unconformable contacts are shown between most clastic units because the intervening salt beds have been dissolved.

Khon Kaen

The Khon Kaen area is located in the vicinity of the city of Khon Kaen in the northeast corner of the Khorat Basin (fig. 1). At the time of this investigation, 12 core holes had been drilled in an area of about 12 km^2. A sylvite deposit was discovered in core hole K47. In attempting to delineate the boundaries of the deposit, enough drilling was done to reveal many of the relationships described at Banmet Narong.

The Lower Salt is the only halite bed intersected in core holes in this area. However, in core hole KK1, a thin (.17 m) layer of halite underlying 2.42 m of anhydrite might be a remnant of the Middle Salt. This is also true for KK2, where 2.0 m of anhydrite underlain by 0.55 m halite and 6.05 m of halitic clay were found just above the Lower Clastic. In core hole K57, all of the units in the Maha Sarakam Formation are probably present except the Upper and Middle Salt, which have been dissolved. These salt beds are now represented by residual layers of anhydrite and gypsum. In this area, the Lower Salt contains a thin (0.30 to 0.94 m) anhydrite bed about 85 to 150 m above its base. The bed is quite persistent and is a very useful stratigraphic marker.

The base of the Lower Salt in the Khon Kaen area appears to bear little relation to the structure at its top (fig. 11). However, as only four of the core holes in this area penetrated the base of the Lower Salt, the structural configuration of this stratigraphic horizon is not well defined. The four core holes and elevation of the base of the Lower Salt are listed below:

Core hole	Elevation Base Lower Salt (Sea level datum)
K47	125 m
K50	131 m
KK3	127 m
KK4	101 m

The only significant difference in elevation in these four holes is in KK4. It is very likely that the 26 m of structural relief between KK4 and KK3 is the result of faulting. However, this faulting does not seem to effect younger stratigraphic horizons.

Structure on top of the Lower Salt includes two parallel northeast-trending anticlines, separated by a closed syncline (fig. 11). The period of the folding is about 2 km. Assuming that the base of the Lower Salt is relatively flat, considerable thickening of salt has occurred in the anticlines, just as in the salt anticlines at Banmet Narong.

In most of the core holes at Khon Kaen, the stratigraphy above the top of the Lower Salt cannot be established. For that reason, it was not possible to ascertain relationships between growth of the anticlines and thickness variations in units such as the Lower Clastic.

An anhydrite caprock is present at the top of the Lower Salt at Khon Kaen (fig. 12). The thicknesses developed here are considerably less (maximum of 2.89 m in KK5) than at Banmet Narong.

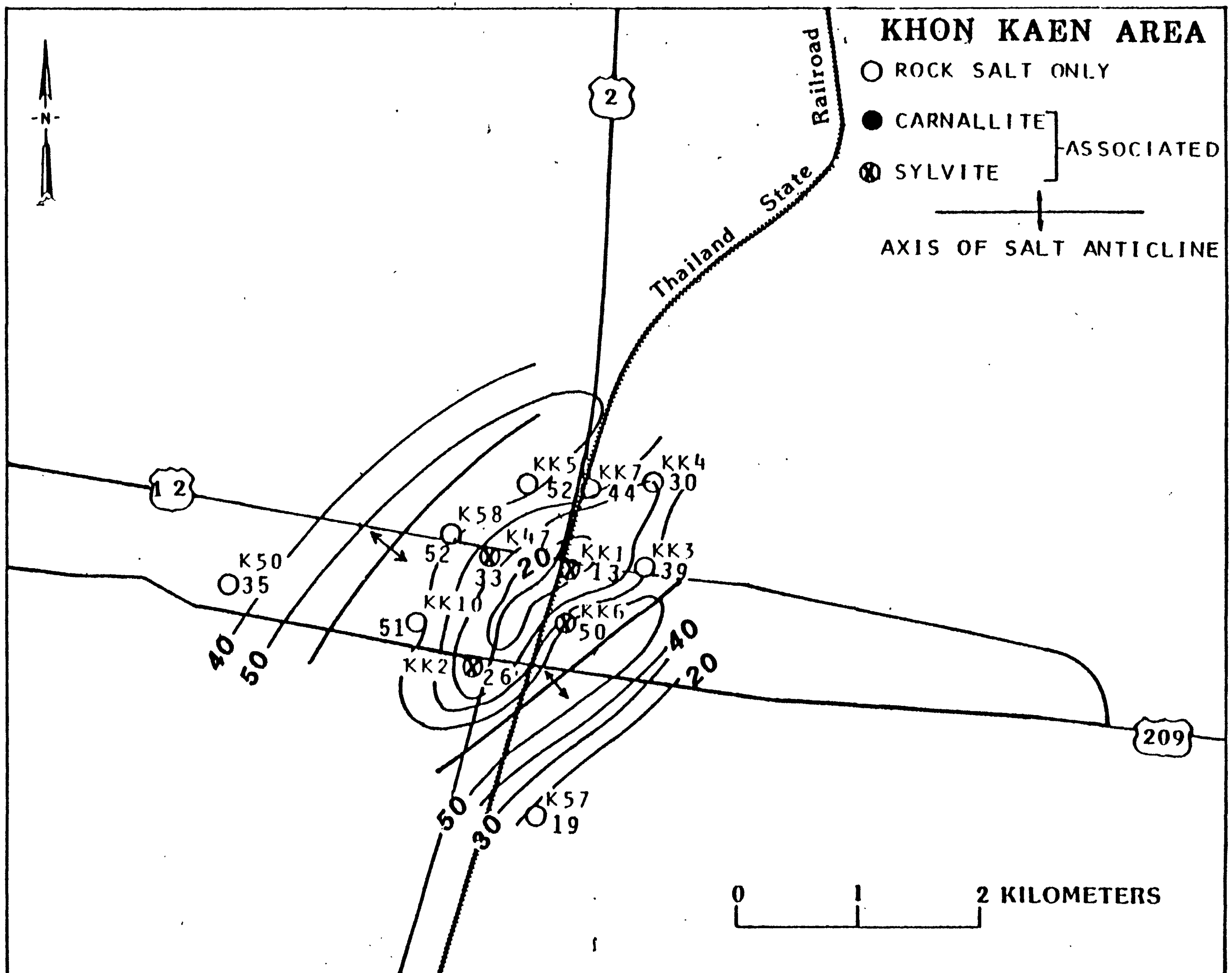

Figure 11. Structure-contour map showing structure on top of the Lower Salt at Khon Kaen (contours in meters).

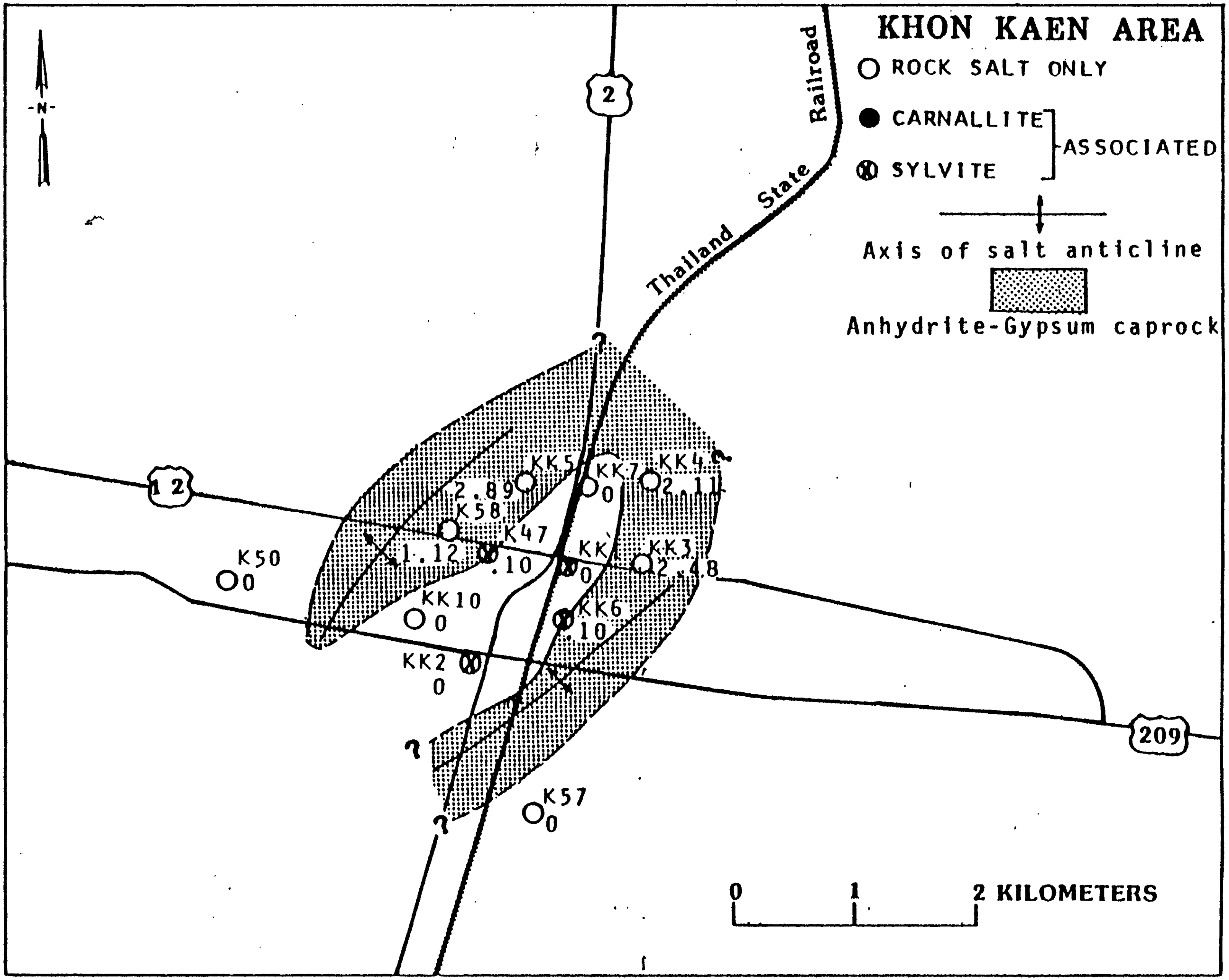

Figure 12. Map showing distribution of caprock at Khon Kaen.

The bedrock surface at Khon Khaen cannot be mapped in great detail because of insufficient core hole control; however, the presence of at least one deep-erosion channel was established (fig. 13). This channel appears to trend northeast to southwest and has at least 96 m of topographic relief. The deepest part of the channel appears to coincide with the axis of one of the salt anticlines. It is possible that another channel may be present between core holes KK6 and K57, which would coincide with the southern anticlinal axis that passes between these two locations (fig. 11). However, additional drilling will be necessary to prove the existence of such a channel.

Non Sung

The Non Sung area is located in the Khorat Basin about 16 km northeast of the city of Khorat (fig. 1). Exploration here involved seven core holes located within an area of about 9 km^2.

Only three core holes in the Non Sung area were deep enough to reach the base of the Lower Salt. These holes and the elevation of the base of the Lower Salt are:

Core hole	Elevation on base of Lower Salt (Sea level datum)
K19	-35 m
RS 3.2	-49 m
RS 3.4	-49 m

These holes suggest that structure on the base of the Lower Salt is of a lesser scale than structure on top of the unit. The difference in structural elevation (14 m) between RS 3.2 and K19 probably represents a gentle regional northern dip into the Khorat Basin.

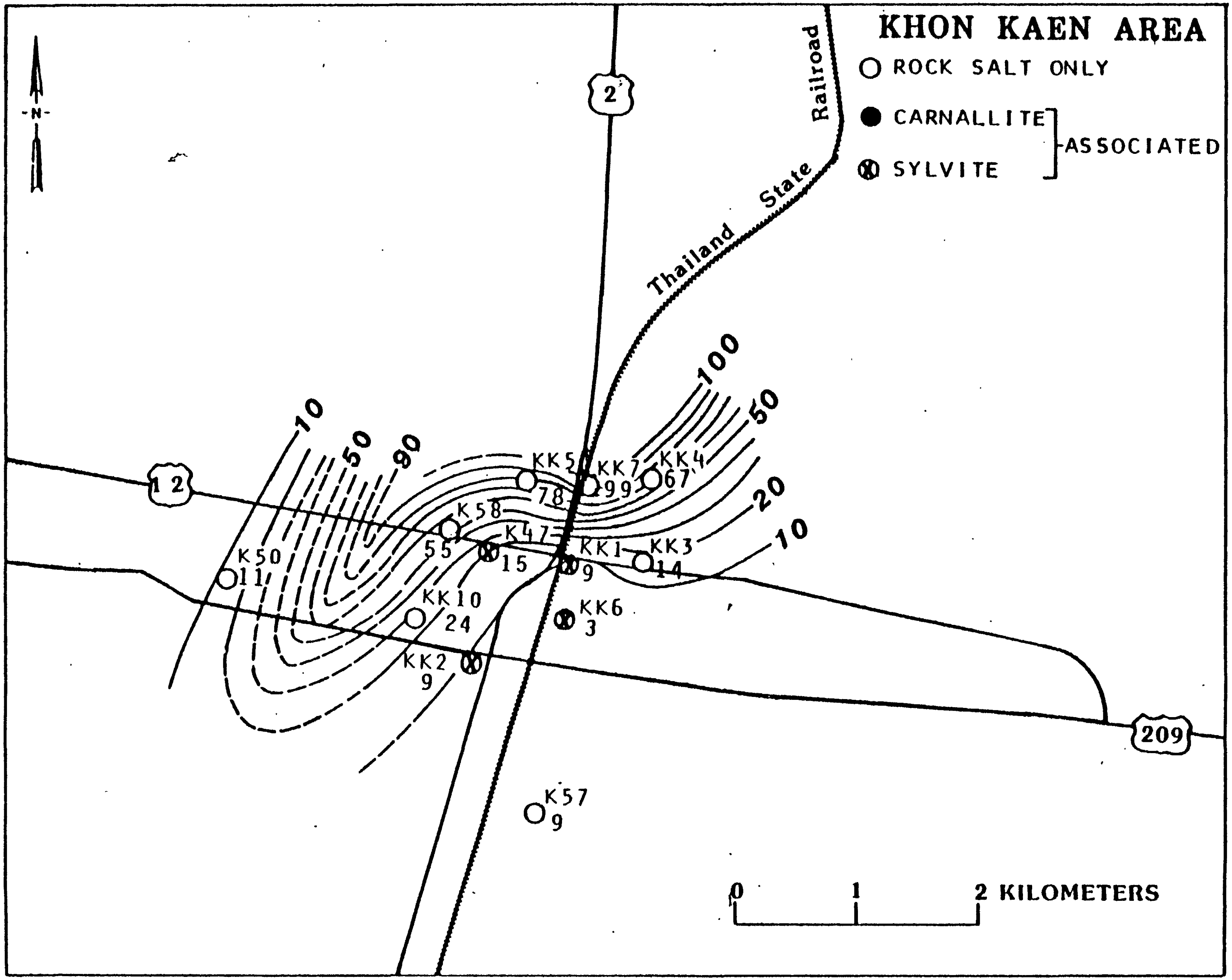

Figure 13. Topography of bedrock surface at Khon Kaen. Contours(in meters) are dashed where configuration is not well defined.

The upper surface of the Lower Salt appears to be folded into two northeast trending anticlines in this area (fig. 14). Drilling is insufficient to define the crest of the southernmost of these two folds. The minimum period of folding is about 2 km.

The Lower Salt is at least 96 m thick (the base was not reached by drilling) in the northernmost anticline at Non Sung. In the southernmost anticline, it is 116 m thick in K19 and at least 125 m thick in RS 3.1. In the intervening syncline, the Lower Salt thins to about 77 m in RS 3.2.

At Non Sung, an anhydrite caprock is present at the top of the Lower Salt over each of the salt anticlines, reaching a maximum thickness of 10 m in core hole RS 3.1 (fig. 15).

A contour map (fig. 16) of the bedrock surface at Non Sung shows dissection of a similar nature and scale as at Banmet Narong and Khon Kaen. The map suggests the presence of two northeast- to southwest-oriented channels with paleo-topographic relief of at least 60 m. The base of these channels apparently coincides with the axes of the two salt anticlines (fig. 14).

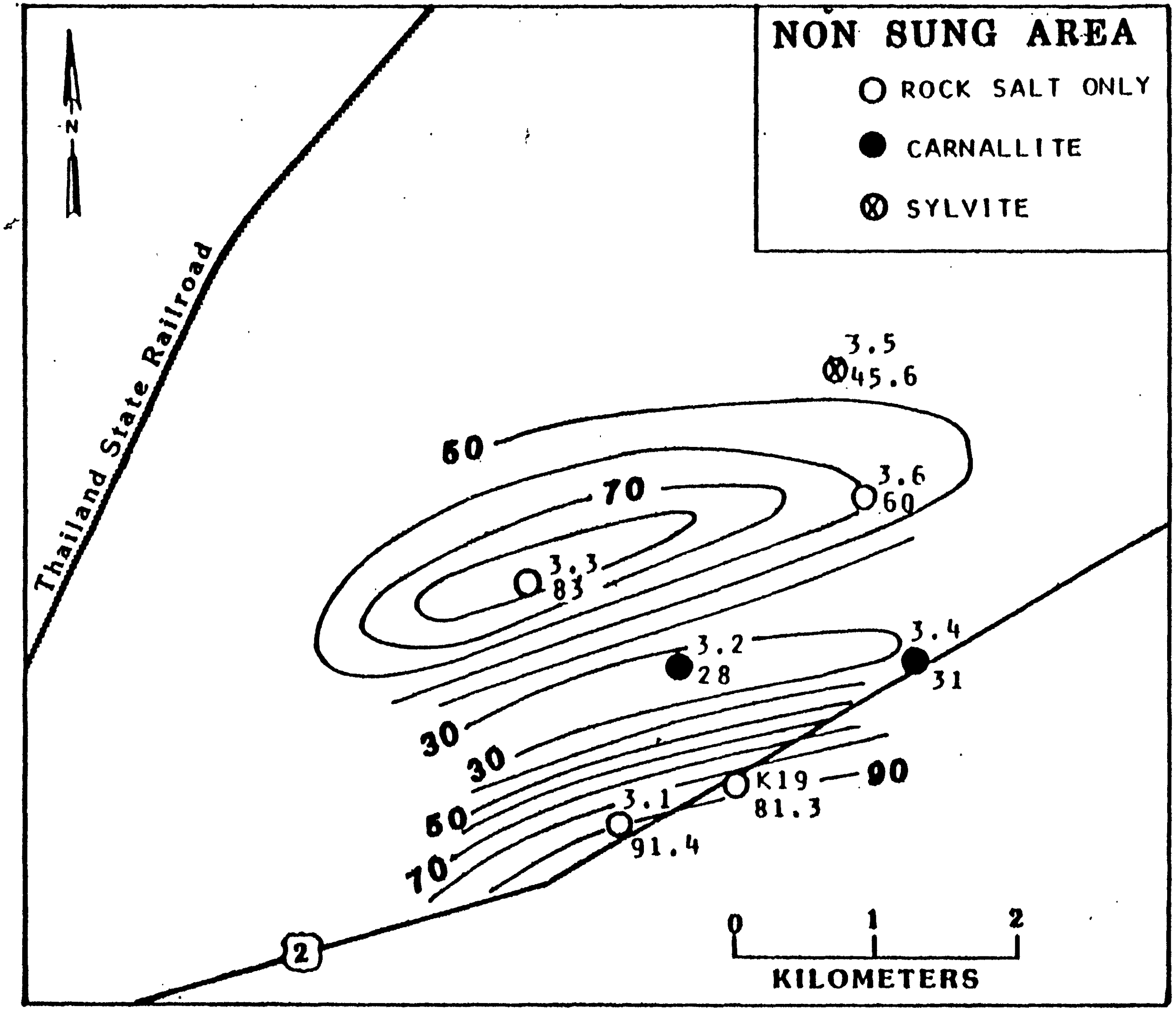

Figure 14. Structure-contour map showing structure on top of the Lower Salt at Non Sung (contours in meters).

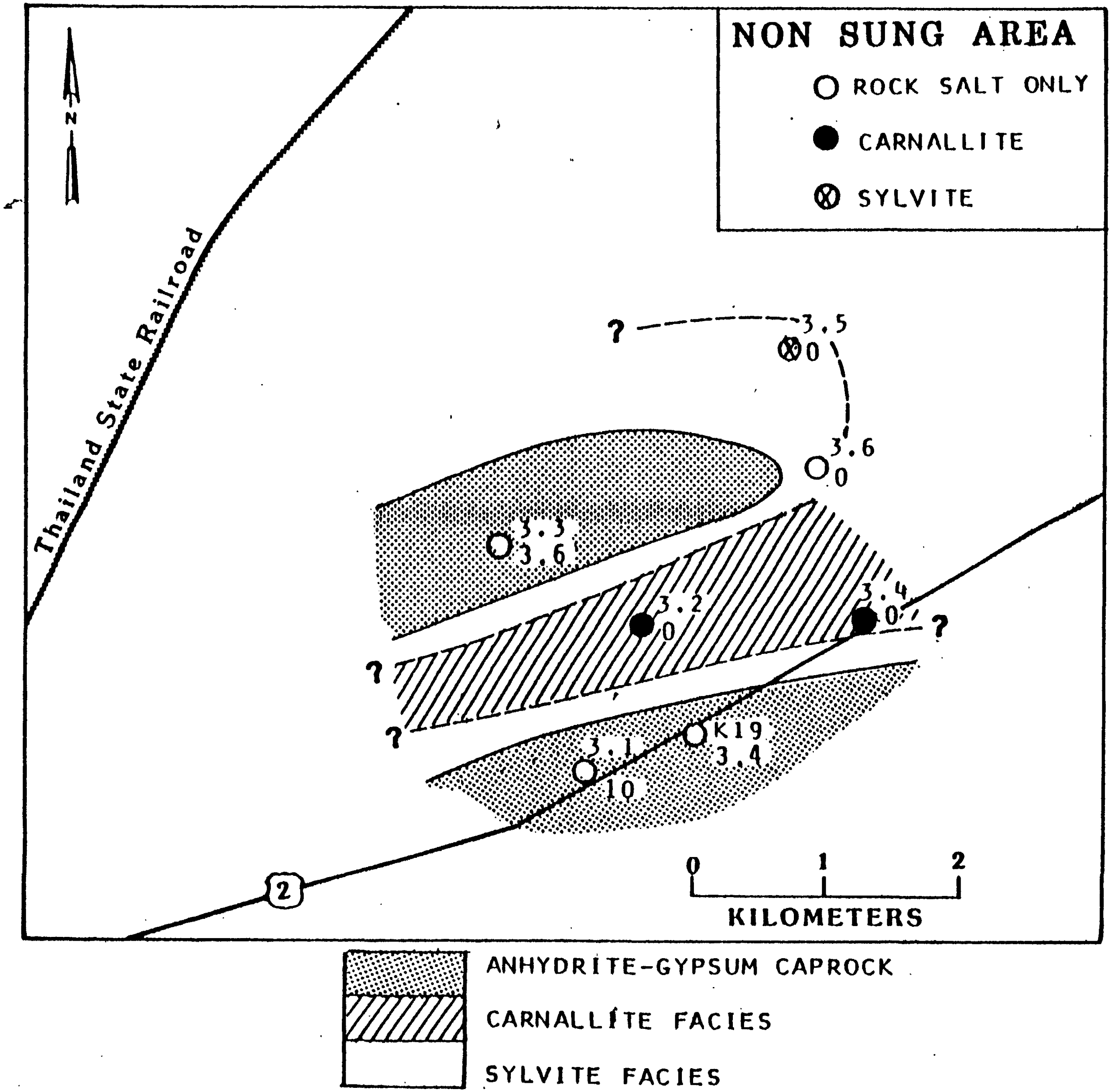

Figure 15. Map showing distribution of caprock, carnallite, and sylvite at Non Sung.

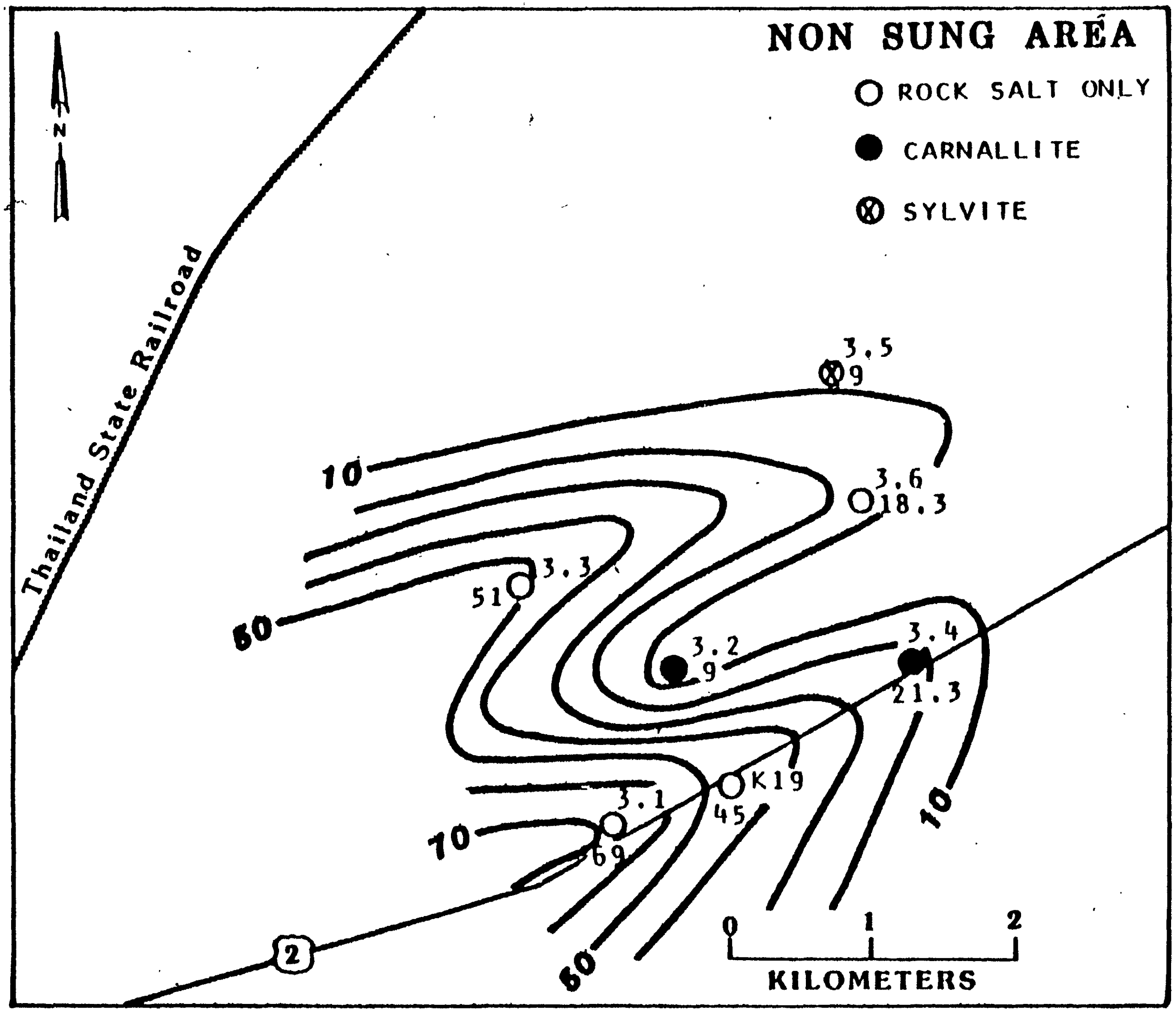

Figure 16. Topography of bedrock surface at Non Sung.

ORIGIN OF THE SALT ANTICLINES

An evaluation of the data obtained from about 120 core holes in the Khorat and Sakon Nakhon Basins shows the presence of a large number of salt anticlines. These structures were formed by flowage of the thick Lower Salt. Because the base of the Lower Salt shows little evidence of deformation, and the salt layer occurs at very shallow depths, flowage does not seem to be related to either tectonic events or differential loading by sedimentation. The discovery that bedrock of the Khorat Plateau is deeply dissected by what is interpreted to be paleo-stream channels may be the key to understanding the origin of the salt anticlines. It can be shown in areas of high-drilling density that there is a high coincidence between the paleo channels and the axes of salt anticlines. Therefore, a logical mechanism to bring about salt flowage and the creation of salt anticlines would be unloading of sediments as a result of paleo-stream erosion of the channels. Locally the paleo channels appear to be more than 150 m deep (see core hole K54) and show stratigraphic penetration to the top of the Lower Salt. Conditions of salt flowage on the Khorat Plateau suggests that some of the rules of "halokinesis" need to be rewritten. The combined thickness of halite and potash in the Upper, Middle, and Lower Salt before flowage, may have been as much as 500 m in the deeper parts of the original basin. This generally would be considered an adequate thickness for incipient halokinesis if depth of burial was at least 1000 m, and if there was a differential in the confining pressure. On the Khorat Plateau, flowage and anticlinal growth may have begun with as little as 350 m of overburden on the salt-bearing sequence. The subsequent removal of 100-150 m of this overburden by down-cutting streams created local conditions of differential loading. Although the differential was small, it was apparently adequate to cause salt to flow

toward areas of lower confining pressure; i.e., the deep channels. Initial flowage was probably facilitated by the thick layer of highly mobile salts (carnallite and tachyhydrite) present at the top of the Lower Salt. Once flowage began, and the strata underlying the channels were upfolded, erosion would have been accelerated in the entrenched stream channels so that one process would have aided the other. It is possible that some anticlines could have become diapiric particularly where erosion was deep enough to expose the Lower Salt.

Most if not all the salt anticlines on the Khorat Plateau have a capping of anhydrite on the Lower Salt. This caprock was formed by the dissolution of halite rock which left behind a residue of relatively insoluble material consisting primarily of anhydrite. The insoluble content of salt beds probably averages about 2 weight percent, so that a caprock thickness of 28.9 m (see core hole RS 2.9, table 1) represents the dissolution of about 1979 m of halite rock.

Caprock may also be present over the Middle and Upper Salt. For example, the 4.57 m of anhydrite overlying the Upper Salt in core hole K3 is probably the result of dissolution of halite. In this case, the core hole is either located downdip on the flank of a salt anticline, or anticlinal growth and channel incision were arrested in an early stage of development.

There are several core holes which are probably located on salt anticlines, and yet there is no caprock present, or it is very thin. This might be explained by the fact that anhydrite or gypsum are only relatively insoluble in water. With enough time, these minerals can also be removed by dissolution. Thin or missing caprock may simply have been dissolved away.

In the Lower Salt, much of the water-insoluble material includes the mineral boracite [Mg,Fe,Mn)$_3$ClB$_7$O$_{13}$], which is associated with the potash deposit that occurs in the upper third of this bed. Caprock from a core hole in which the potash deposit was completely dissolved away would be expected to contain a high percentage of boracite; however, a sample of caprock from core hole RS 2.21, which was examined by X-ray diffraction, contained no boracite. This sample, taken about 3 m above the caprock contact with the Lower Salt, may have been a poor selection to examine for boracite. Caprock is an unusual sedimentary rock because it does not conform to the Law of Superposition. The youngest part of a caprock is at its base. The caprock in RS 2.21 is 10.7 m thick and probably only the upper 1 m of this material was formed from the dissolution of the boracite-bearing potash deposit. Therefore, it is not too surprising that the sample taken contained no detectable boracite.

Absolute dating of the inception of anticlinal growth would be dependent on establishing the time when the paleo-stream channels were eroded. The channels are cut down to about 50-100 m above present-day mean sea level. Apparently the eroding streams on the Khorat Plateau reached base level, and the diminished gradient caused gradual filling of the channels with alluvium. Today there is little or no surface evidence of these buried channels on the peneplane of the Khorat Plateau. The unconsolidated nature of the alluvial fills and the evidence that a single, and very young, erosional cycle caused channel development suggests a Pleistocene age for the channels and the consequent formation of the salt anticlines. Although some of the salt anticlines may still be growing, the growth is probably slow because the filling of channels with alluvium has to some extent equilibrated conditions of loading on the salt layers. The author knows of no evidence of displacement of a present-day stream drainage that might be the result of upward movement on a salt anticline. However, more detailed work would be required to really answer this question.

Although additional drilling will undoubtedly reveal more details and possibly some exceptions, the most significant findings regarding the salt anticlines of the Khorat Plateau can be summarized as follows:

(1) There are probably hundreds of salt anticlines on the Khorat Plateau some of which may be diapiric.

(2) Most if not all of the anticlines formed as the result of unloading the salt horizons by stream channel incision of the overlying bedrock.

(3) The anticlines are very young. A Pleistocene age is favored.

(4) Halokinesis occurred at unusually shallow depths.

(5) Core holes, which penetrate a sequence where the Upper and Middle Salt are missing and a thick Lower Salt with or without a caprock containing no potash, are probably located on a salt anticline.

(6) Anhydrite or gypsum deposits on top of the Lower Salt are probably caprock that resulted from dissolution of halite rather than part of a normal depositional sequence.

SYLVITE DEPOSITS

The first sylvite deposit on the Khorat Plateau was discovered in 1974, in core hole L1 located on the outskirts of Vientiane, Laos, in the Sakon Nakhon Basin. The deposit is truly remarkable, considering that it is almost 34 m thick, has select intervals that average over 30 percent K_2O, and is at a depth of about 100 m (Hite and Japakasetr, 1979). In terms of thickness, grade, and depth, no other deposits in the world are as attractive as the Vientiane occurrence. At the time of discovery, only two core holes had been drilled on the Thailand side of the Sakon Nakhon Basin (K1 and K2), and both intersected a thick carnallite deposit. At the time of the sylvite discovery, little was known about its genesis; however, because only three holes had been drilled, and they were some distance apart (about 70 km between K1 and L1), it was assumed that the odds for finding other occurrences of sylvite on the Thailand side of the basin were very favorable. Subsequent drilling, however, showed that sylvite deposits were not common. Of the 63 K series core holes (table 2), 30 holes intersected a carnallite deposit in the Lower Salt, 25 intersected no potash, 5 were not deep enough to reach the Lower Salt, and only 13 holes intersected sylvite. Thus it becomes apparent that although random drilling on the Khorat Plateau will probably result in more intercepts of sylvite, such a program would be prohibitedly expensive and might still fail to outline an economic sylvite deposit. If the distribution of sylvite deposits follows a predictable pattern and if the geologic factors governing deposition of sylvite are understood, then the search can be narrowed and even development drilling made more cost effective.

Table 2.--Thicknesses of salt units and potash beds in series K potash coreholes

[The letters N.P. indicate the hole was not deep enough to either reach or completely penetrate the unit.]

Core hole	Thickness in meters						
	Upper Salt	Middle Salt	Lower Salt	Caprock	Carnallite	Sylvite	Tachyhydrite
K1	0	0	244.9	.08	37.4	0	0
K2	64.8	69.4	N.P.	0	30.8	trace	major
K3	11.2	106.0	N.P.	.15	41.5	0	major
K4	0	0	71.4	0	0	0	0
K5	66.8	104.0	N.P.	0	49.9	3.2 and 2.3	major
K6	0	108.6	N.P.	0	76.8	0	major
K7	0	55.2	63.2	0	0	0	0
K8	0	0	67.5	0	26.9	0	major
K9	0	0	72.4	0	0	0	0
K10	0	4.6?	181.3	0	44.0	2.3	trace
K11	0	0	309.8	0	22.4	12.7	0
K12	0	0	55.8	0	trace	0	0
K13	0	0	111.7	0	0	0	0
K14	0	0	74.4?	.91?	21.0	0	minor
K15	0.	?	278.0	0	0	0	0
K16	0	0	173.4	6.1	0	0	0
K17	0	96.5	88.3	0	27.7	.6	major
K18	0	23.5	67.5	.31	1.2	1.52	0
K19	0	0	116.4	3.28	0	0	0
K20	0	0	177.6	2.99	0	0	0
K21	0	105.6	41.5	.12	10.7	0	major
K22	0	38.3	168.3	0	61.4	0	major
K23	0	0	229.8+	5.49	0	0	0
K24	0	90.2	90.3	0	14.1	0	major
K25	0	89.9	91.0	0	30.3	0	major
K26	0	0	223.4	7.01	0	0	0
K27	0	0	92.5	0	trace	0	0
K28	0	0	72.6	1.01	0	0	0
K29	0	0	138.5	3.0	0	0	0
K30	0	11.1	242.3	0	94.8	0	major
K31	0	0	297.7	5.58	0	0	0
K32		Total depth	120.4	did not reach salt			
K33	0	0	224.2	15.85	0	0	0
K34	0	7.6	135.1	0	.8	1.34	0
K35		Total depth	213.4	did not reach salt			
K36	11.2	94.5	N.P.	0	29.3	0	major
K37	0	0	338.5	1.98	0	0	0
K38		Total depth	213.4	did not reach salt			
K39		Total depth	299.7	did not reach salt			
K40	2.7	111.0	166.3+	1.10	72.2	1.42	0
K41	13.9	114.9	N.P.	.15	2.8+	0	N.P.
K42	0	96.8	315.6	.96	51.7	0	major
K43	0	90.8	174.4	0	22.3	0	major
K44	0	16.8	144.1	0	67.6	4.15 and 2.31	major
K45	0	0	76.9	.61	0	0	0
K46	0	74.8	90.6	0	42.2	0	major
K47	0	0	158.0	.10	7.5	11.12	0
K48	0	112.4	368.0+	0	79.0	19.6	major
K49	0	0	203.0	.30	2.72	10.7	0
K50	0	0	165.3	0	0	0	0
K51	0	0	67.7	0	0	0	0
K52	0	0	72.8	19.5	0	0	0
K53	0	79.5	210.3	0	40.8	0	major
K54	0	0	111.4	7.3	0	0	0
K55	0	112.4	436.3	0	82.3	0	0
K56	9.3	89.0	111.9	.07	40.4	3.04	major
K57	0	0	N.P.	0	0	0	0
K58	0	0	N.P.	1.12	0	0	0
K59	0	129.9	150.3	0	25.1	3.21	major
K60	0	0	N.P.	0	50.6	3.03	major
K61	0	0	2.4	0?	0	0	0
K62	25.3	57.0	N.P.	N.P.	N.P.	N.P.	N.P.
K63	0	0	54.5	2.33	0	0	0

Genesis

It was recognized in the early stages of exploration that the thick carnallite deposit at the top of the Lower Salt was probably a primary deposit, and that locally this layer had been leached by undersaturated solutions which removed $MgCl_2$ but left KCl behind (Hite and Japakasetr, 1979). Supporting geochemical evidence includes the low-bromine content (450 ppm) and the high rubidium content (35 ppm) of the sylvite. Furthermore, it was suggested that the sylvite facies would be peripheral to barren "salt horses" (intervals in the potash deposit now represented by barren halite rock) in the carnallite deposit. Since that time, additional drilling has provided data which supports the original hypothesis, but shows that it needs to be expanded. Originally it was not known when or how undersaturated solutions got into the carnallite deposit. Recent drilling data now show that most if not all of the "salt horses" are associated with the crestal portion of salt anticlines. The early recognition of "salt horses" was based on profiles showing the vertical distribution of bromine through the Lower Salt (Hite and Japakasetr, 1979). In many core holes, these profiles were essentially vertical, i.e., the bromine values started low and remained low (see figs. 17-21). Bromine profiles with these characteristics occurred where no potash was present in the Lower Salt. These profiles contrast with more normal distribution of bromine, represented by figures 22-31. It was assumed that the vertical bromine profiles resulted from aqueous recrystallization of halite that was formerly associated with the potash deposit in the Lower Salt. The aqueous recrystallization of halite always lowers its bromine content. At localities where undersaturated solutions have totally removed the original carnallite deposit they would also bring about much recrystallization of the primary halite. This secondary halite would have a

low-bromine content (see fig. 18). Using the new drilling data, vertical profiles in many core holes are now interpreted to be the result of halite flowage in salt anticlines. Plastic flow of halite results in solid recrystallization without attendant loss of bromine. However, it is possible that flowage brought halite of low-bromine content from the lower half of the Lower Salt up into the crest of some of the salt anticlines. In these cases, the original halite containing high concentration of bromine has been leached away and may be represented by caprock.

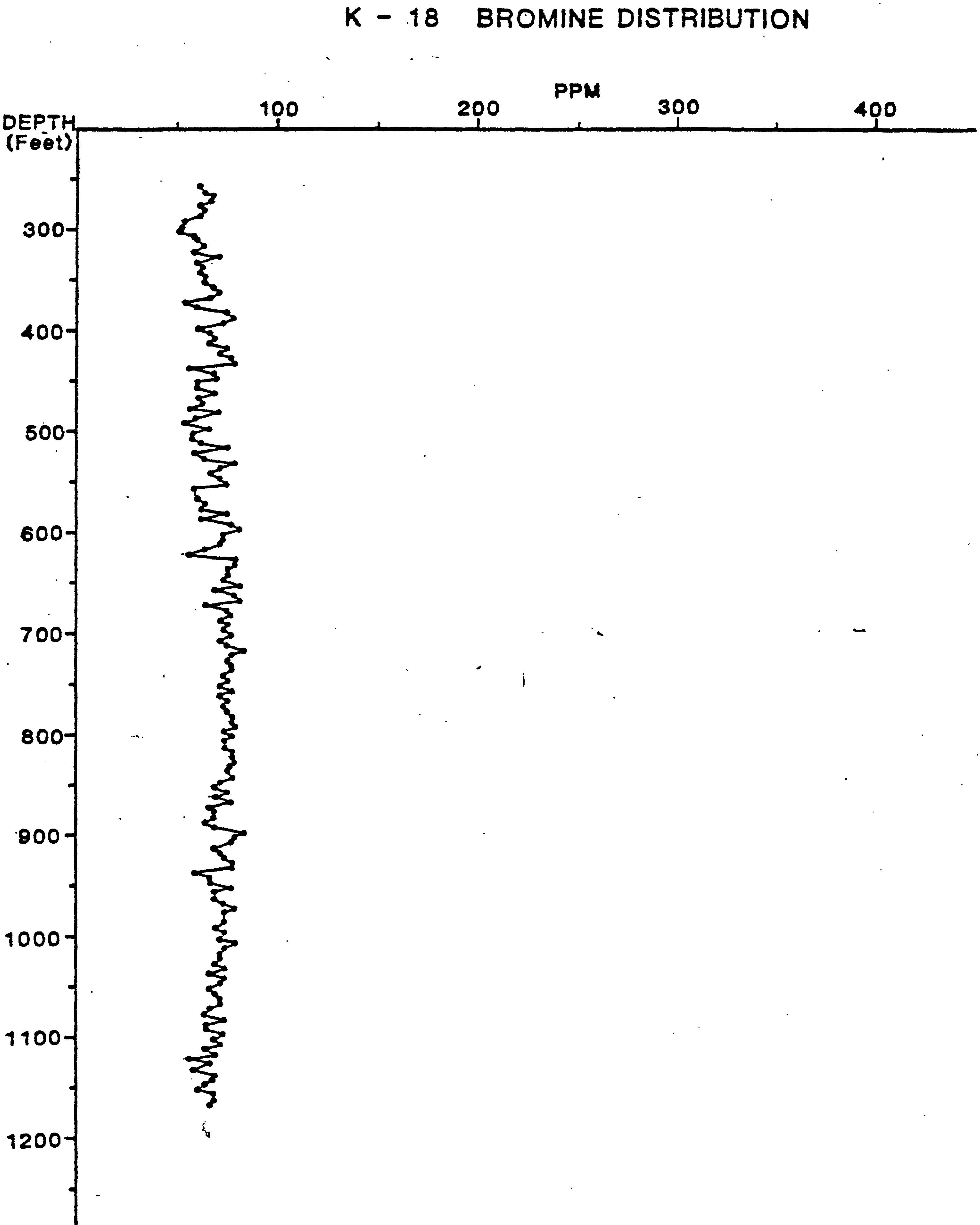

Figure 17. Bromine profile through the Lower Salt in core hole K18 (X-ray fluorescence spectrometer analyses by H. L. Groves, U.S. Geological Survey, Denver, Colorado).

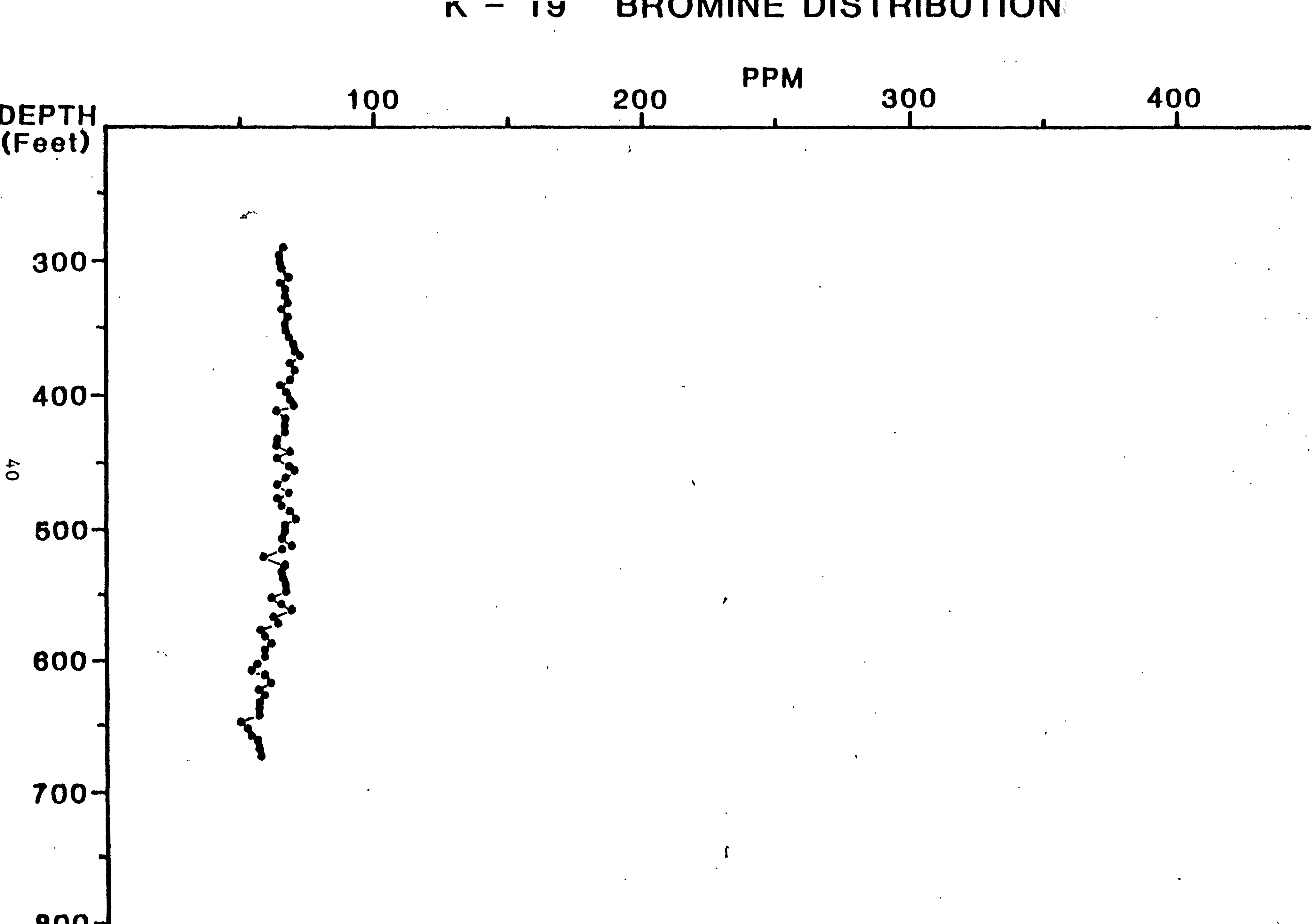

Figure 18. Bromine profile through the Lower Salt in core hole K19 (X-ray fluorescence spectrometer analyses by H. L. Groves, U.S. Geological Survey, Denver, Colorado)

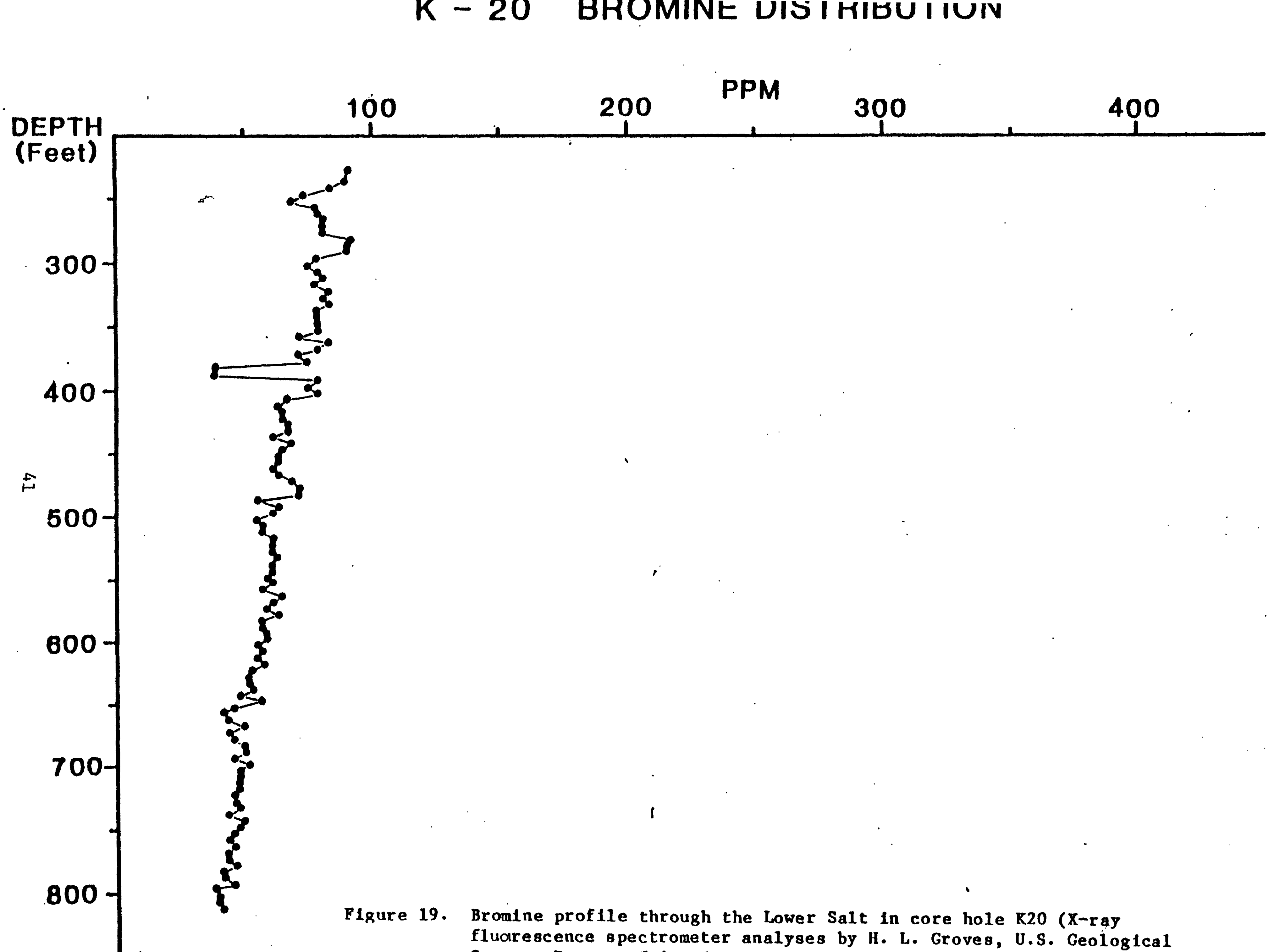

Figure 19. Bromine profile through the Lower Salt in core hole K20 (X-ray fluorescence spectrometer analyses by H. L. Groves, U.S. Geological Survey, Denver, Colorado),

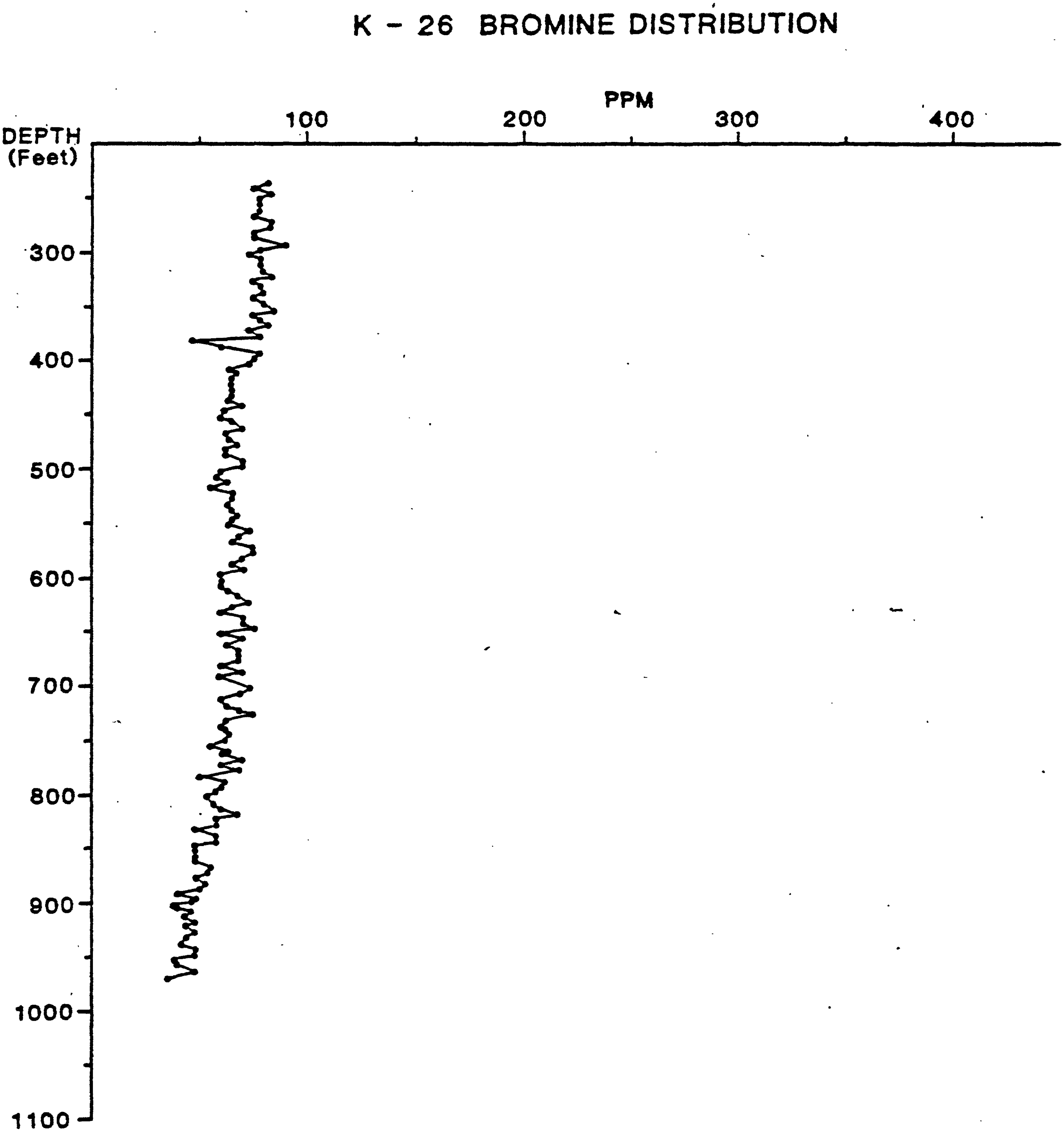

Figure 20. Bromine profile through the Lower Salt in core hole K26 (X-ray fluorescence spectrometer analyses by H. L. Groves, U.S.Geological Survey, Denver, Colorado).

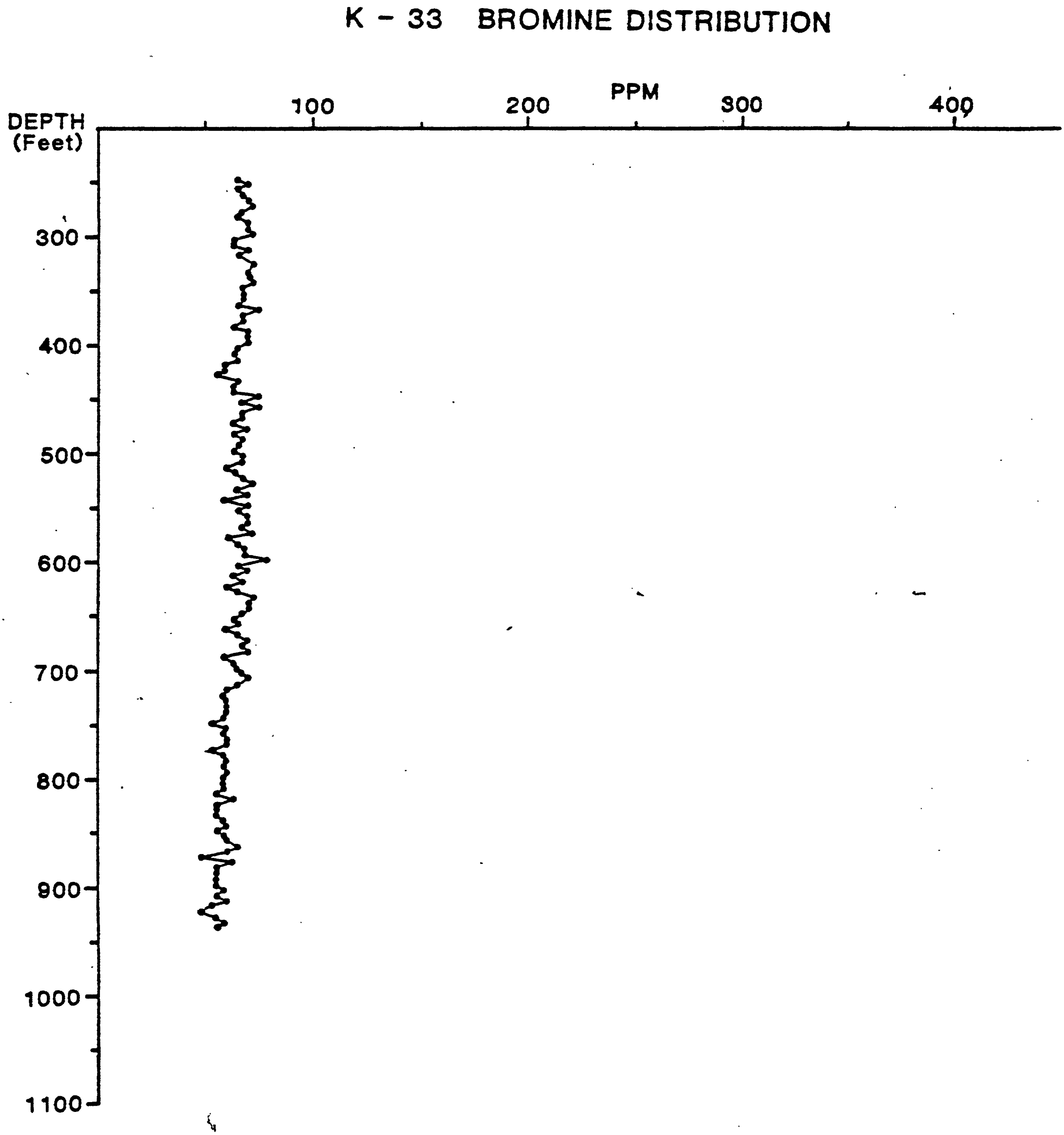

Figure 21. Bromine profile through the Lower Salt in core hole K33 (X-ray fluorescence spectrometer analyses by H. L. Groves, U.S. Geological Survey, Denver, Colorado),

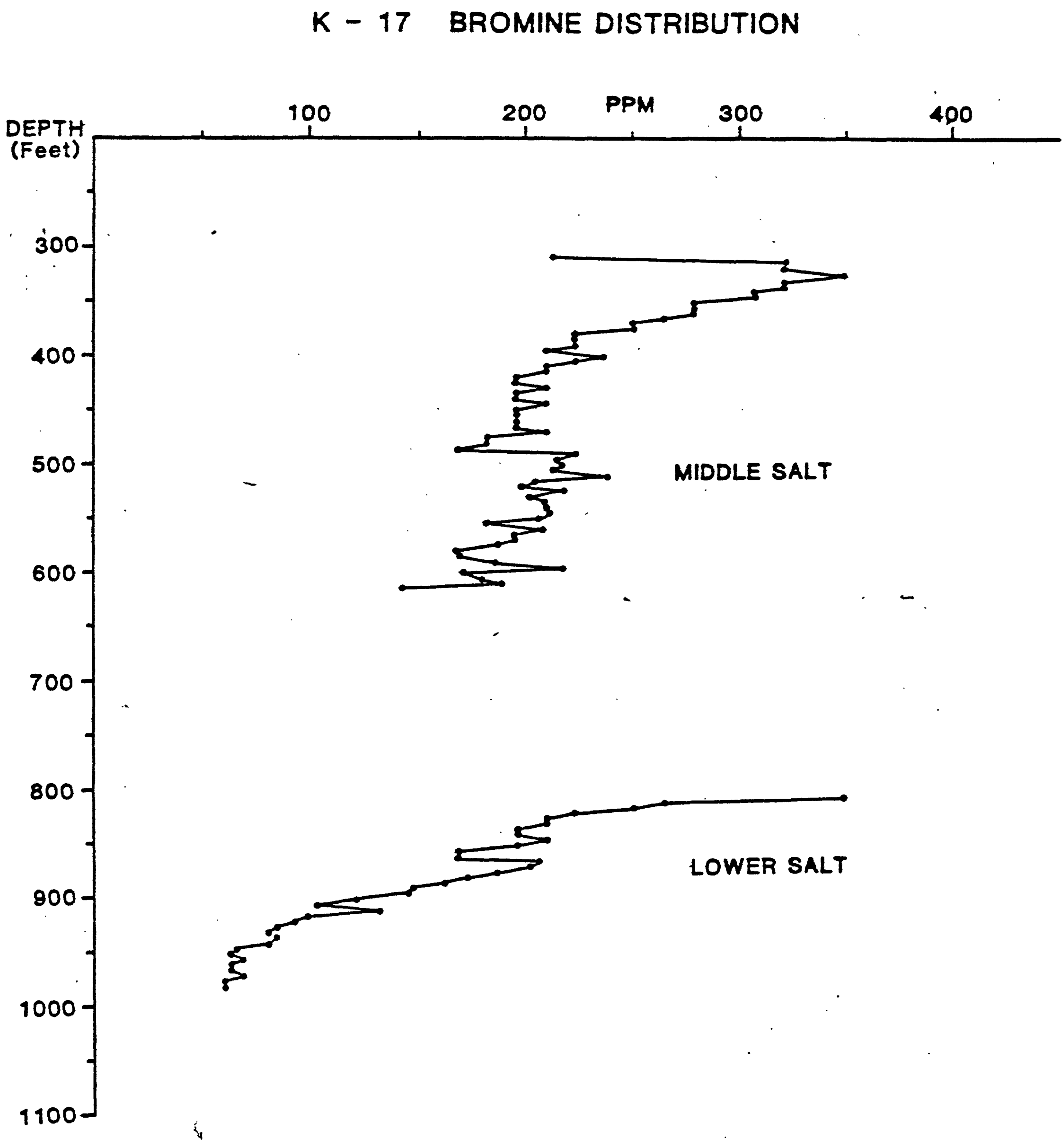

Figure 22. Bromine profile through the Lower Salt in core hole K17 (X-ray fluorescence spectrometer analyses by H. L. Groves, U.S. Geological Survey, Denver, Colorado).

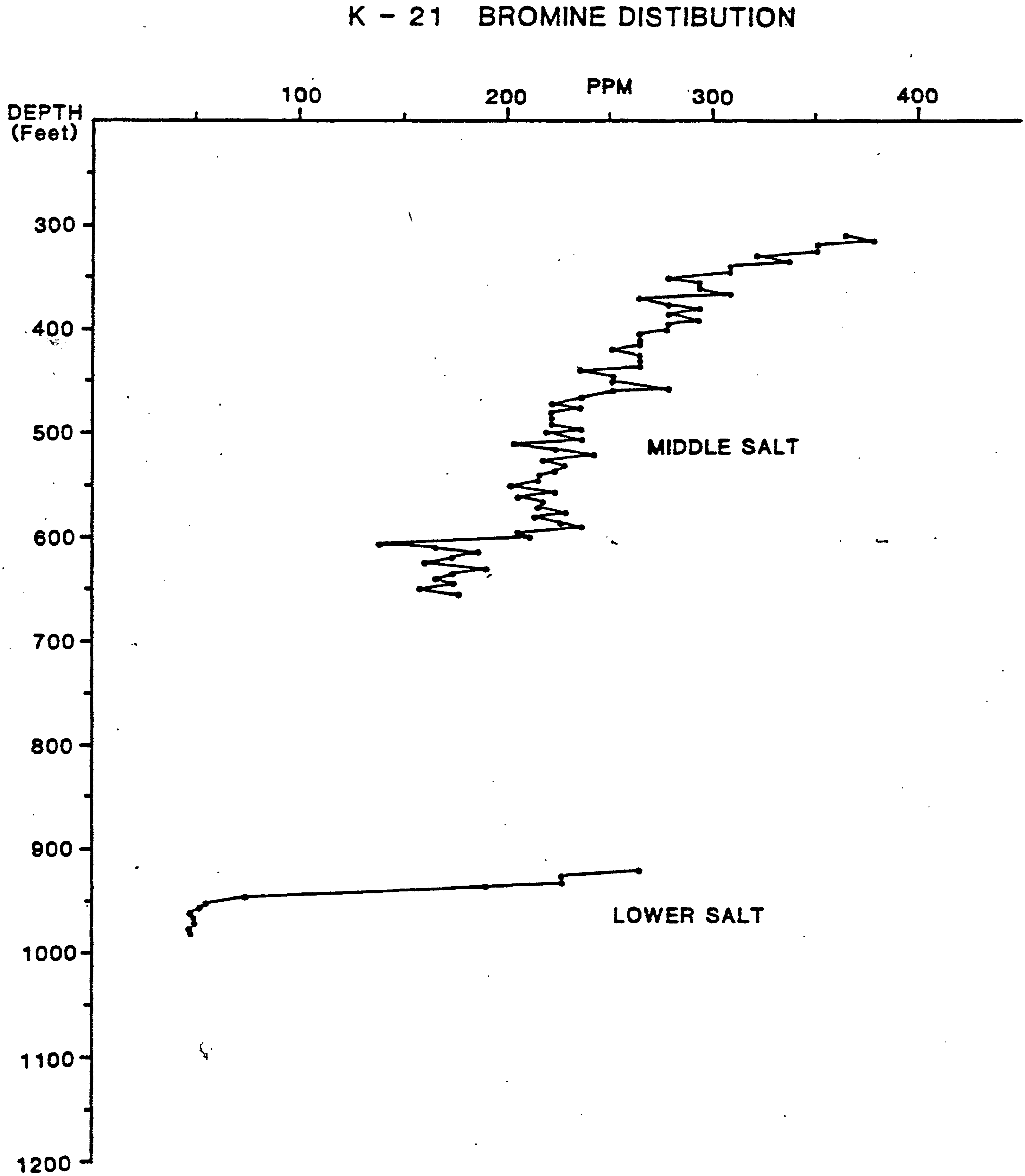

Figure 23. Bromine profile through the Lower Salt in core hole K21 (X-ray fluorescence spectrometer analyses by H. L. Groves, U.S. Geological Survey, Denver, Colorado).

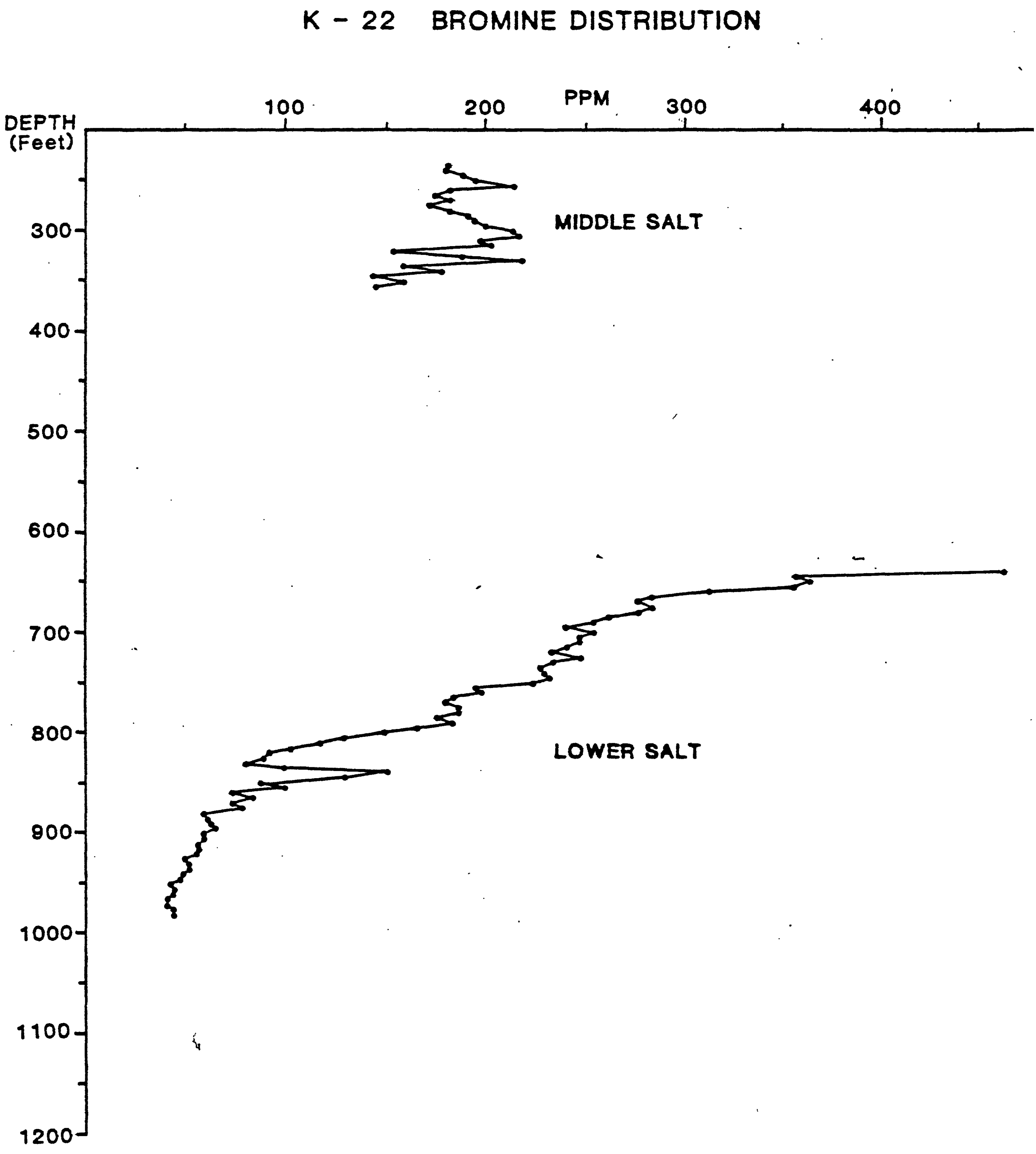

Figure 24. Bromine profile through the Lower Salt in core hole K22 (X-ray fluorescence spectrometer analyses by H. L. Groves, U.S. Geological Survey, Denver, Colorado),

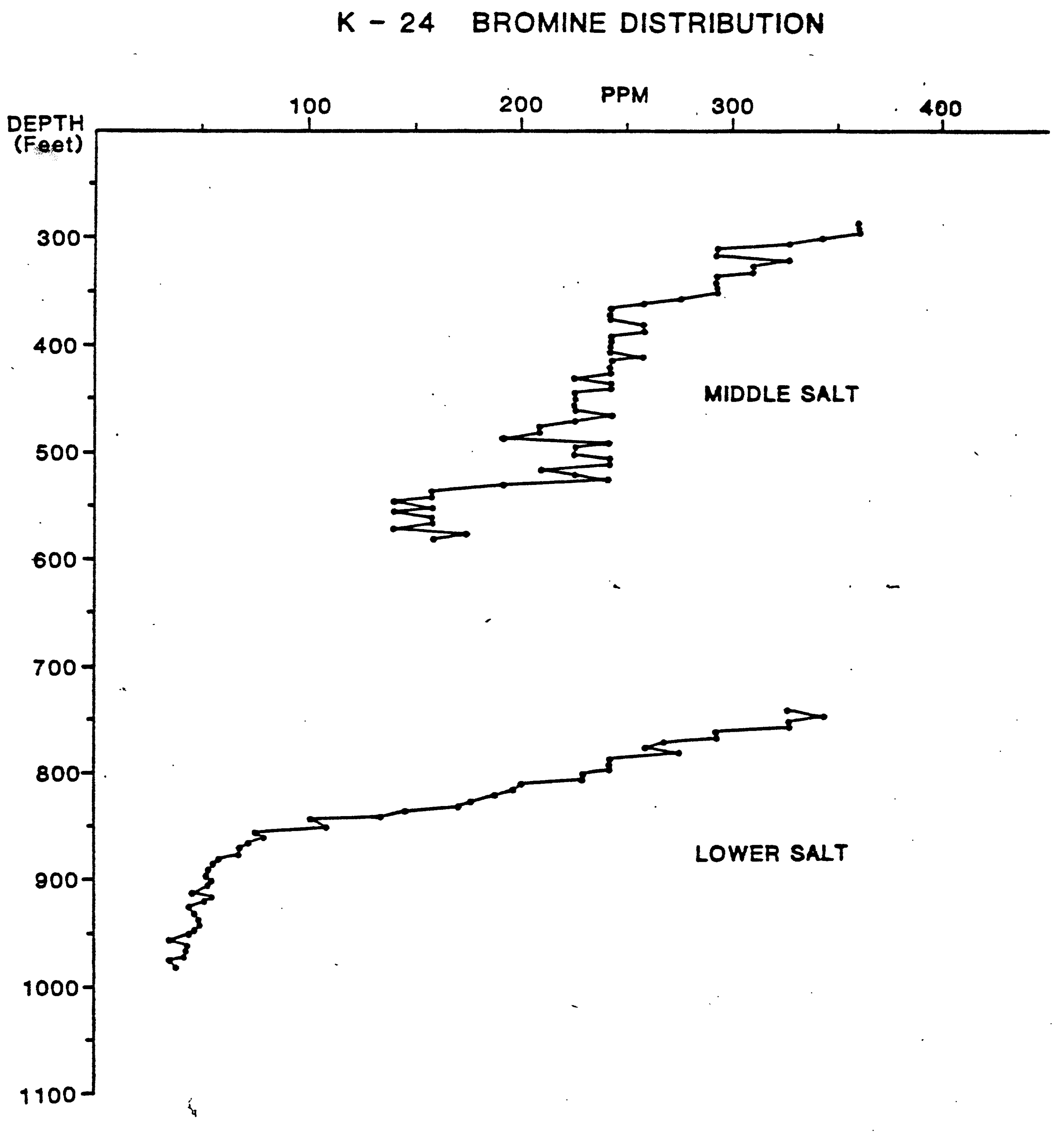

Figure 25. Bromine profile through the Lower Salt in core hole K24 (X-ray fluorescence spectrometer analyses by H. L. Groves, U.S. Geological Survey, Denver, Colorado).

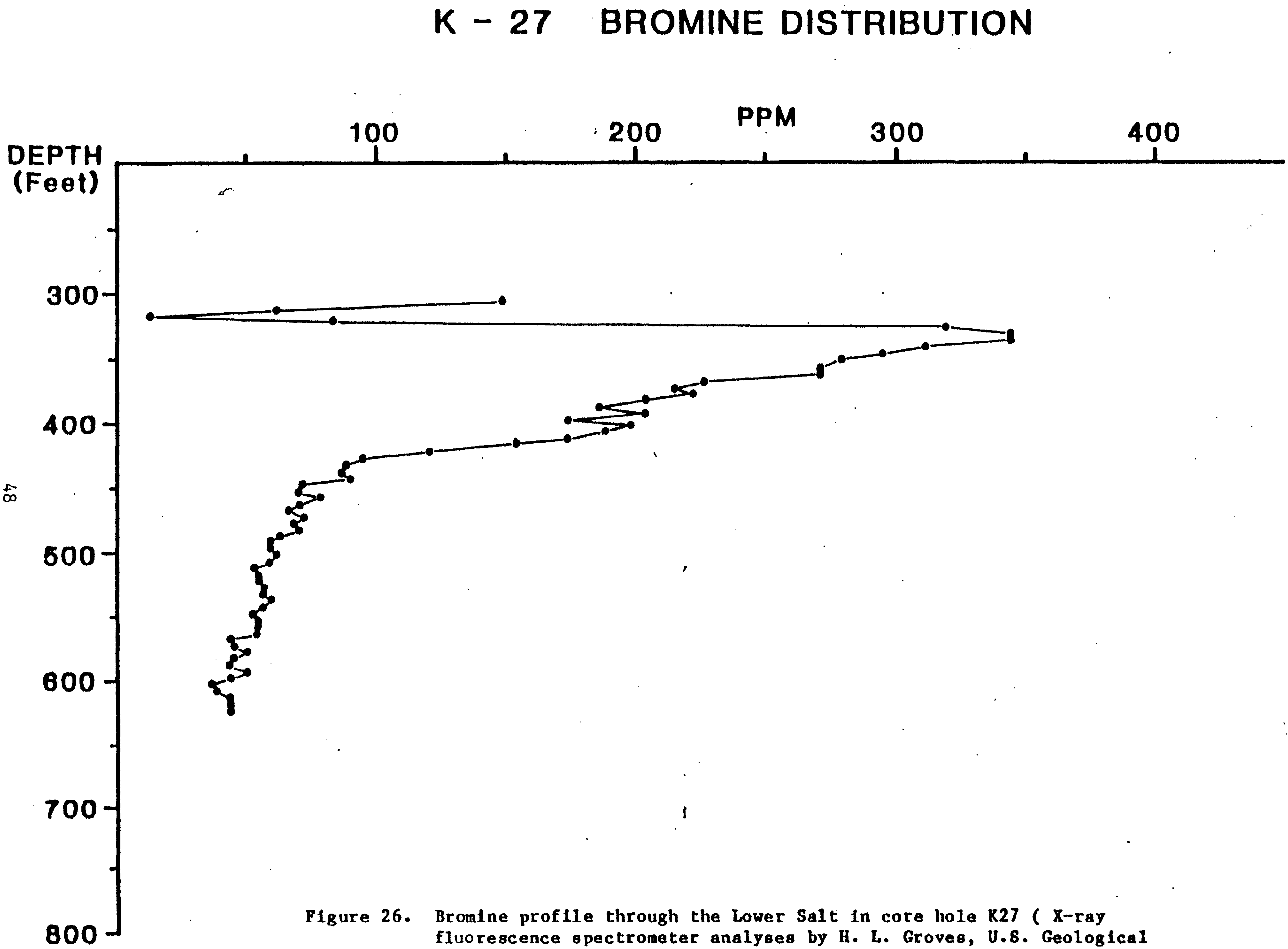

Figure 26. Bromine profile through the Lower Salt in core hole K27 (X-ray fluorescence spectrometer analyses by H. L. Groves, U.S. Geological Survey, Denver, Colorado).

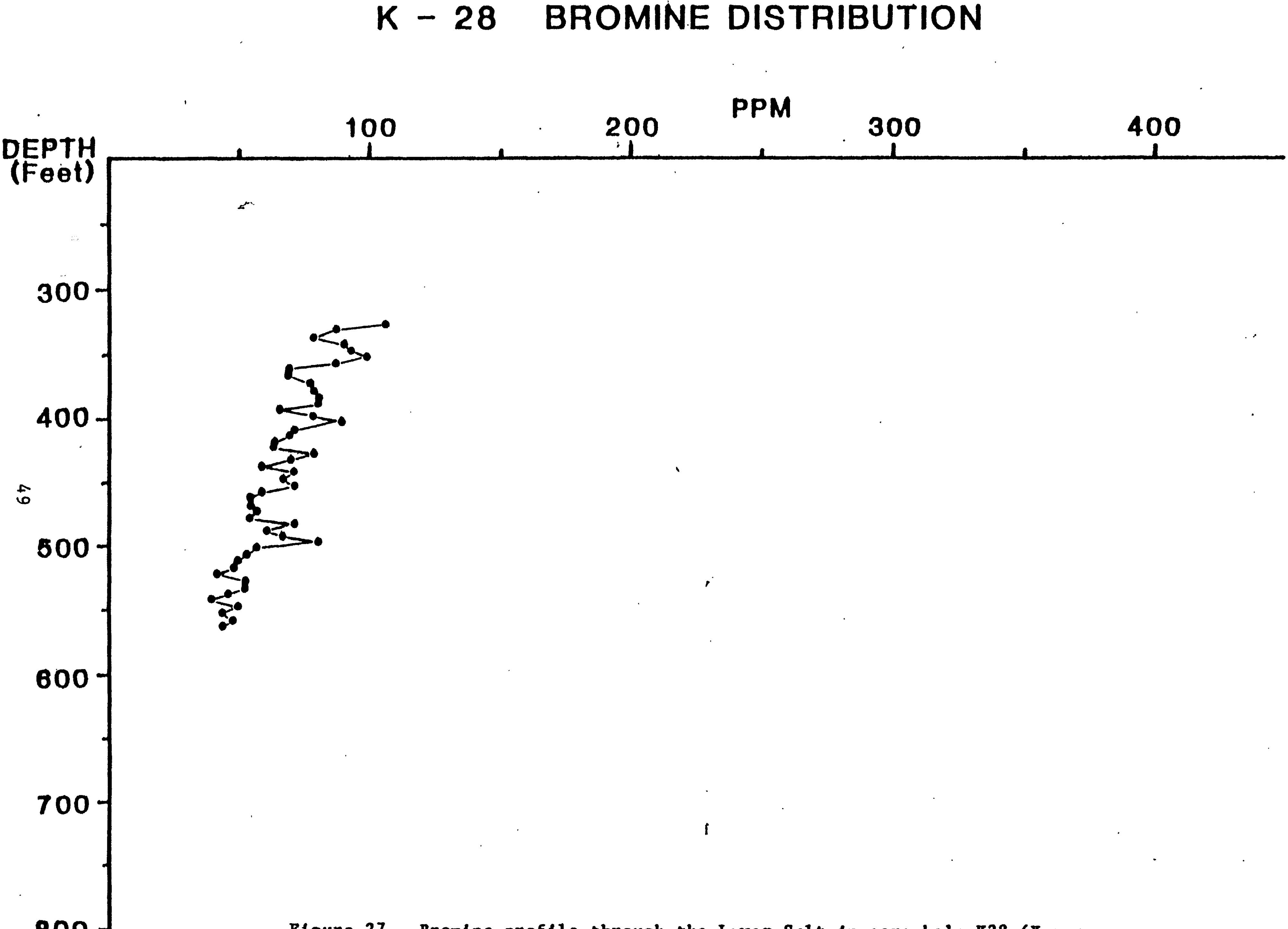

Figure 27. Bromine profile through the Lower Salt in core hole K28 (X-ray fluorescence spectrometer analyses by H. L. Groves, U.S. Geological Survey, Denver, Colorado).

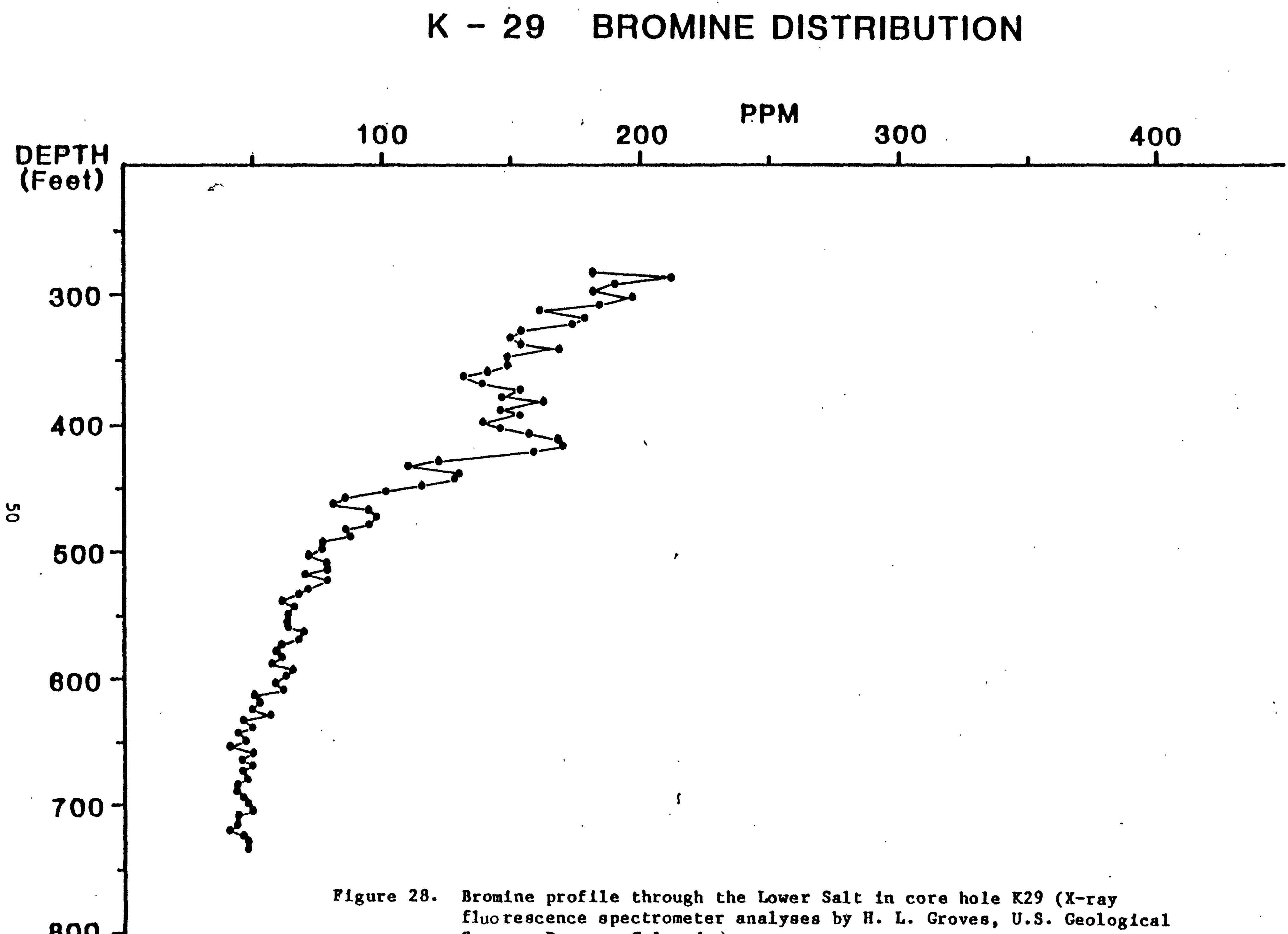

Figure 28. Bromine profile through the Lower Salt in core hole K29 (X-ray fluorescence spectrometer analyses by H. L. Groves, U.S. Geological Survey, Denver, Colorado).

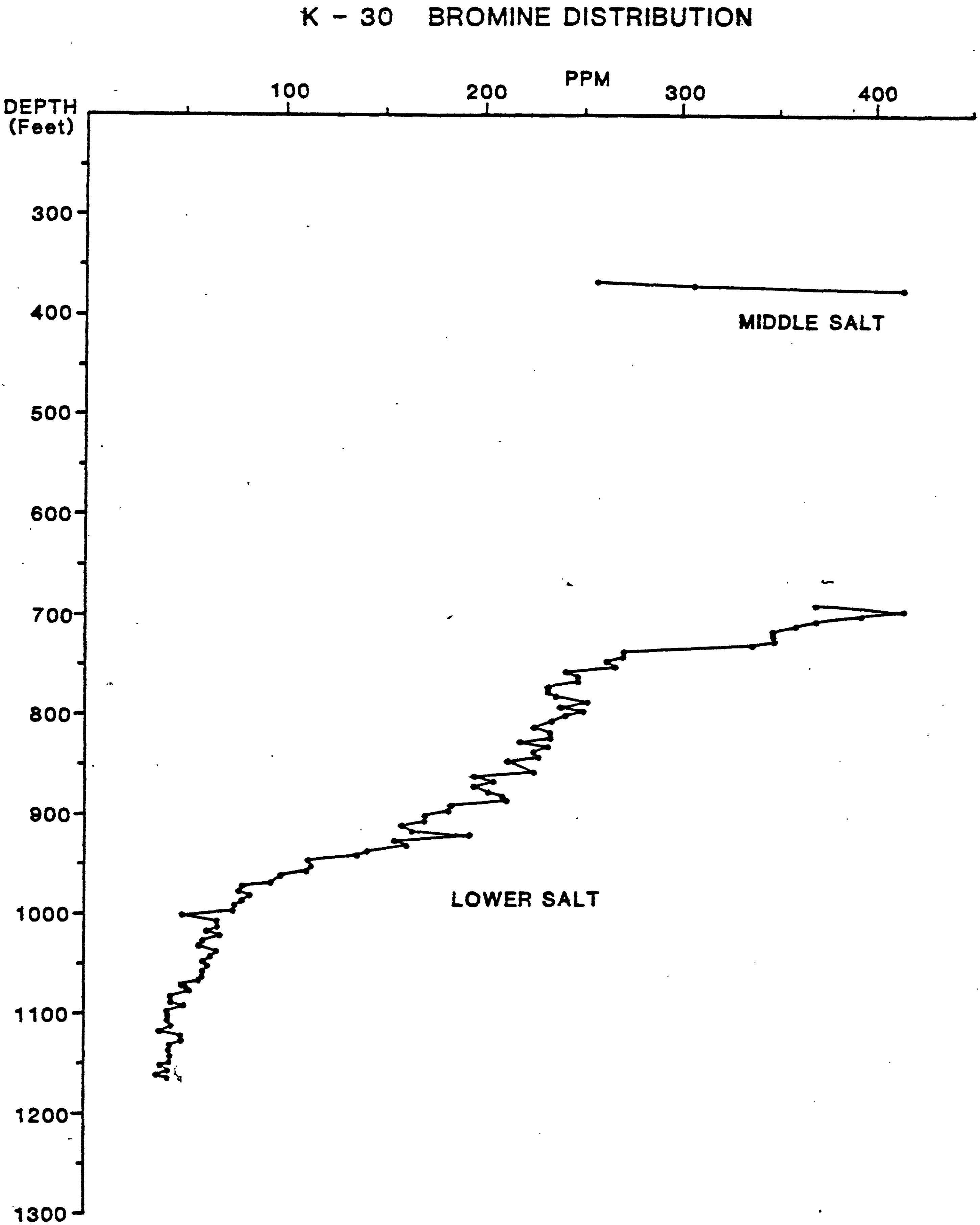

Figure 29. Bromine profile through the Lower Salt in core hole K30 (X-ray fluorescence spectrometer analyses by H. L. Groves, U.S. Geological Survey, Denver, Colorado),

K – 31 BROMINE DISTRIBUTION

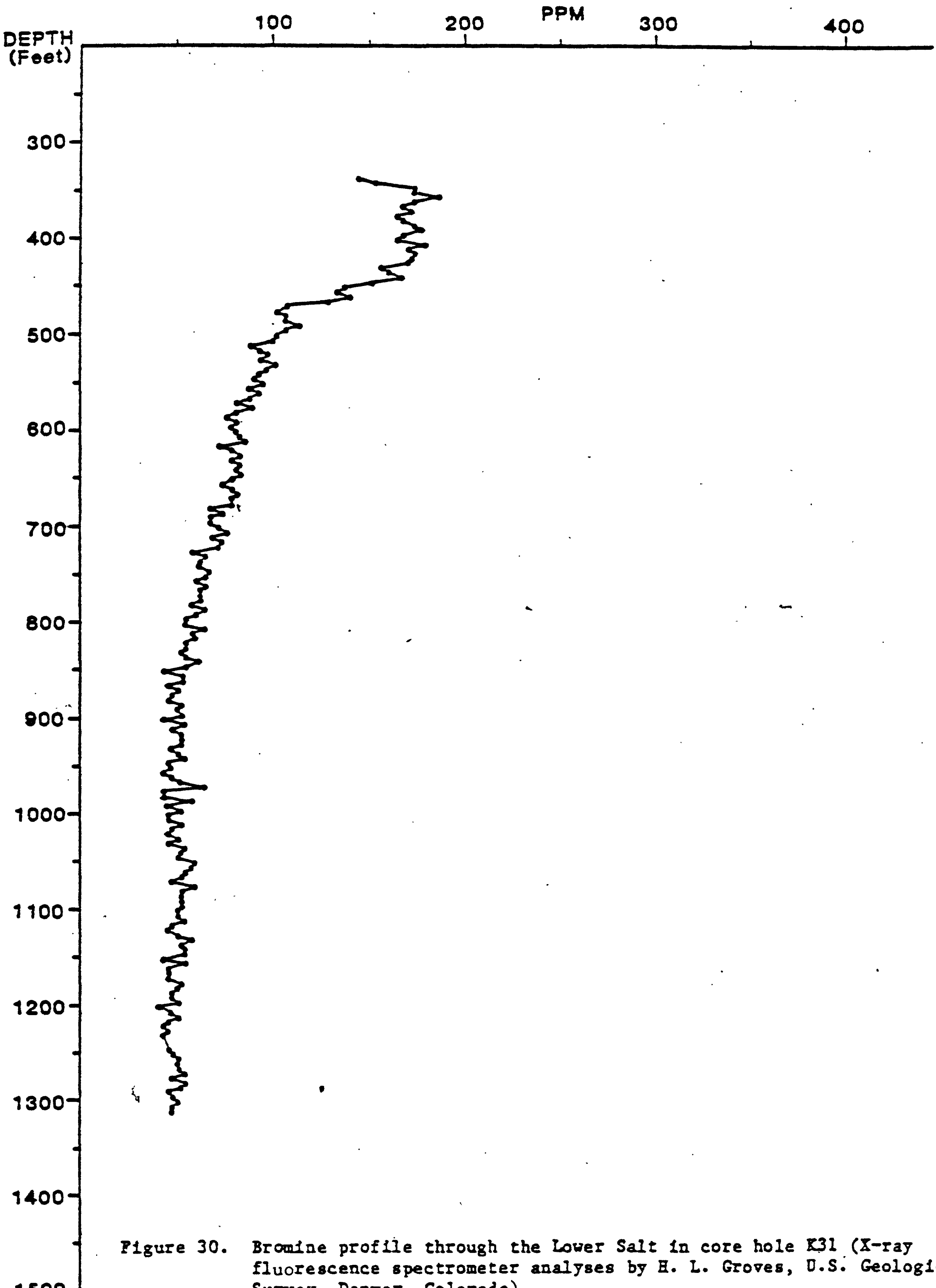

Figure 30. Bromine profile through the Lower Salt in core hole K31 (X-ray fluorescence spectrometer analyses by H. L. Groves, U.S. Geologica[l] Survey, Denver, Colorado).

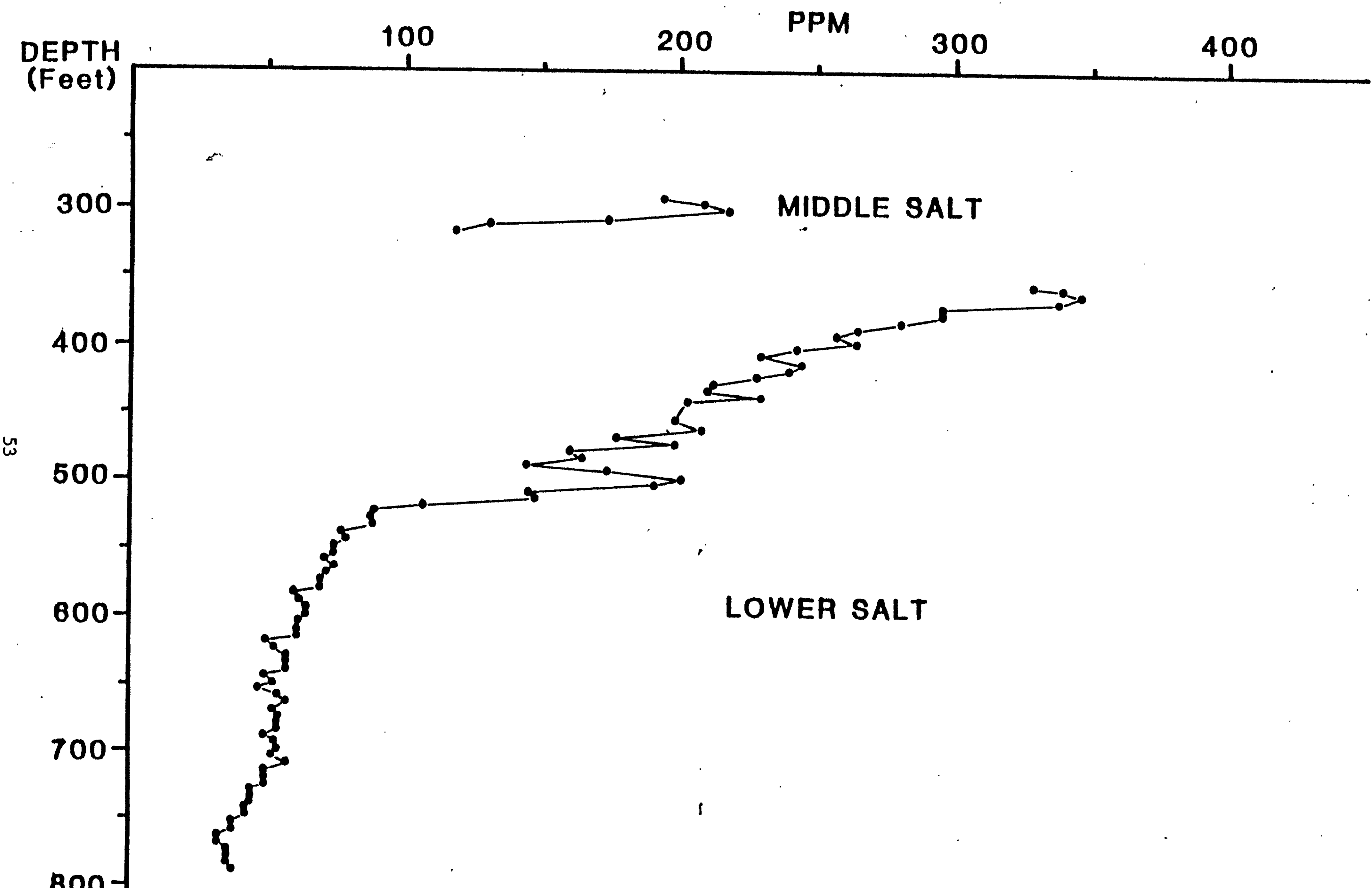

Figure 31. Bromine profile through the Lower Salt in core hole K34 (X-ray fluorescence spectrometer analyses by H. L. Groves, U.S. Geological Survey, Denver, Colorado).

There may be sufficient data to establish the time of formation of the Khorat sylvite deposits. Because these deposits result from the incongruent solution of the original carnallite, it would seem logical that the process might begin at the first return of lower-salinity conditions in the evaporite basin. Just before the deposition of the Lower Clastic, the salinities in the basin decreased, causing cessation of carnallite deposition and dissolution or decomposition of the upper part of the carnallite deposit. Some of the pigmented (trace amounts of hematite) and banded salt that commonly contains some sylvite (see KK12) may have been deposited by this process. Even greater freshening in the basin would have taken place during the deposition of the Lower Clastic, and this would be a likely time for the principal decomposition of the carnallite deposit. However, considerable data refute this possibility. For example, during incongruent solution of carnallite, there is about a 45 percent reduction in volume (see fig. 32). Thus there should be an increase in thickness of the Lower Clastic corresponding to the amount of decomposition of the underlying carnallite deposit if decomposition took place during or slightly before deposition. Data from core holes at Banmet Narong (table 1) show no change in thickness of the Lower Clastic where the underlying carnallite deposit is thin or absent. Similar relationships can be observed elsewhere. For example, in the area near the city of Yasothorn (fig. 1) core hole K18 penetrated 64 m of Lower Clastic. The underlying potash deposit consisted of 1.52 m of banded halite with traces of sylvite overlain by only 1.22 m of carnallite. Here, the Lower Clastic is 59 m thick in core hole K40, and the potash deposit consists of 1.42 m of sylvite and 72.16 m of carnallite. The similar thickness of the Lower Clastic in these two core holes, despite a radical difference in thickness of the underlying potash deposit, suggests a regional thickening of the Lower Clastic that is unrelated to decomposition and volume change in the potash.

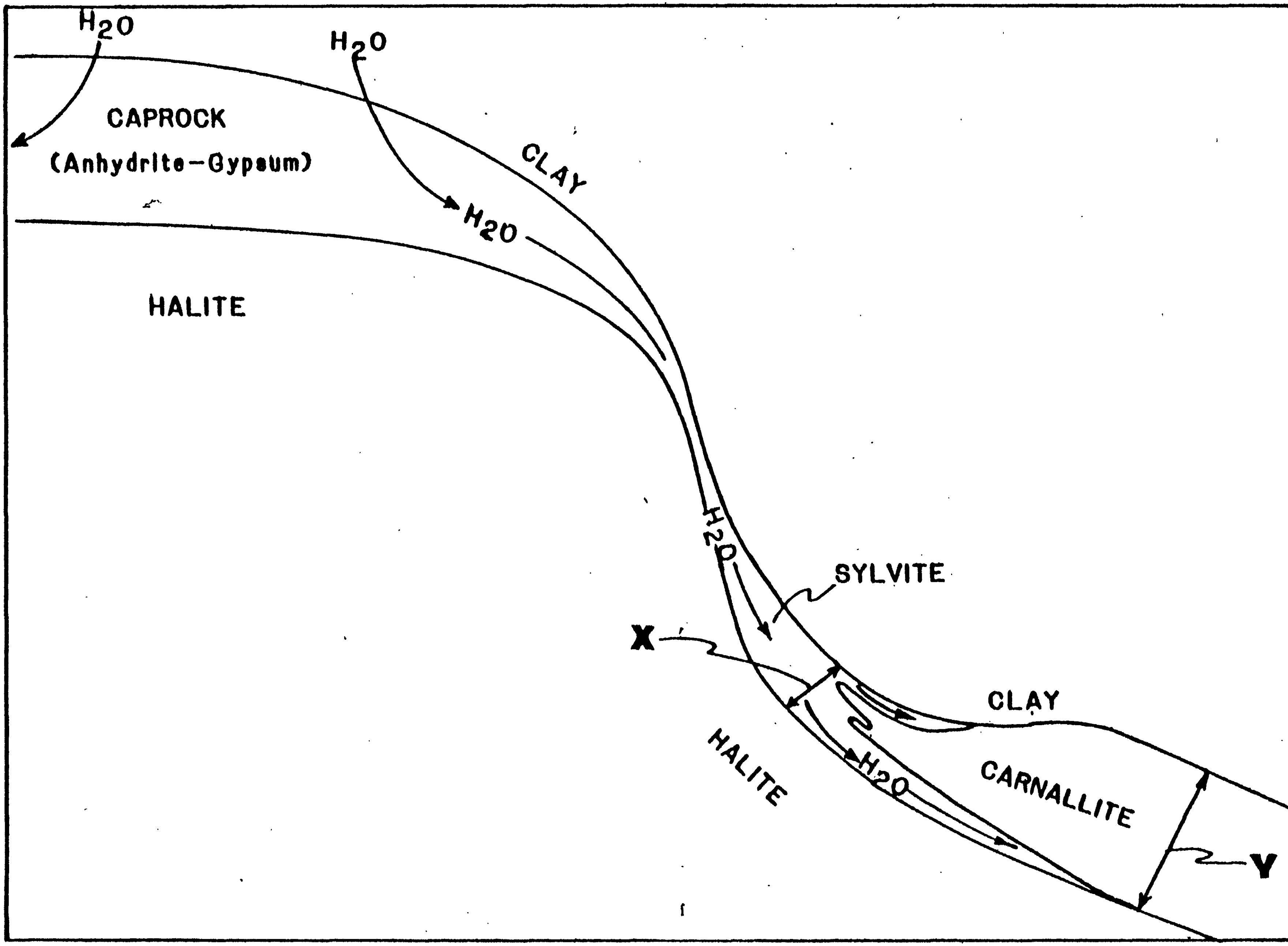

Figure 32. Hypothetical mechanism of sylvite formation showing alteration (incongruent solution) of original carnallite deposit. Volume change is represented by thickness X and Y.

These relationships suggest that the decomposition of carnallite and the formation of sylvite occurred sometime after deposition of the Lower Clastic. Further refinement of the time of sylvite formation by using younger stratigraphic units of the Maha Sarakham Formation is difficult. Thickness variations in the Middle and Upper Salt are probably the result of flowage and dissolution on the flanks of salt anticlines. Only thickness variations involving the Middle and Upper Clastics would be truly depositional in nature. Unfortunately, these units are commonly eroded over the anticlines, or their stratigraphic boundaries are difficult to determine where the intervening salt beds are missing. The best interpretation of the available data is that the sylvite deposits are post-Lower Clastic in age.

An important question regarding the genesis of the Khorat sylvite deposits is, how did undersaturated solutions gain access to the carnallite deposit? The deposition of the Lower Clastic effectively covered the carnallite deposit in the Lower Salt with a relatively impervious layer of clay. Thus in some way this layer would have to be breached. The salt anticlines appear to furnish the means to accomplish this breaching. Over the crests of some of these structures, erosion and dissolution removed aquicludes, such as the Upper and Middle Salt. Locally, erosion by paleo streams has cut channels down to the Lower Salt (fig. 10). Therefore, it follows that ingress of water to the carnallite deposit would be most likely along the crests of the salt anticlines. Once fresh water got into the highly soluble carnallite, it would move downdip along the flanks of the anticline (fig. 32). Initially in the crestal portion of the anticline, the water would totally remove carnallite. As the $MgCl_2$ content of the water increased, incongruent solution of carnallite would leave sylvite (KCl) behind. Over the crest of the anticline, many meters of halite from the Lower Salt might also be dissolved, leaving a residue of anhydrite to form a caprock. The initially porous caprock would have facilitated ingress of water. Water would tend to gravitate downward into the carnallite deposit until it reached the barren and less soluble NaCl at its base, and perhaps selectively move laterally through the deposit along layers of tachyhydrite ($CaCl_2 \cdot 2MgCl_2 \cdot 12H_2O$), which is even more soluble than carnallite. This might explain the presence of sylvite at the base of the carnallite deposit (K48, K5, KK12, RS 2.6, RS 2.12). In K5, and KK12, sylvite was found both above and below the carnallite deposit. The above hypothesis is supported by very sharp basal contacts of sylvite deposits that occur both above and below the carnallite deposit (KK12 and P135 are good examples).

Recent drilling in the Kong District (about 60 km north of Khorat) has provided data which strongly support the theory of origin proposed here. In core hole K80, a thick sylvite deposit (8.3 m) was found at a very shallow depth (104.9 m) at the top of the carnallite deposit in the Lower Salt. The sylvite deposit is overlain by very coarse grained halite that includes some crystals that are as much as 50 mm in diameter. Much of the halite has a brilliant sapphire-blue color. This halite is in very sharp contact with the underlying sylvite. The halite in this interval is extremely porous (estimated 40 percent), with intercrystalline voids that are as much as 15 mm in diameter. Many of these pores are connected, suggesting that at least locally the interval has a high fluid conductivity. For about 3 m above the contact, the core is badly broken because of the coarse texture and porosity. At the base of the sylvite deposit is a thin zone of coarse-grained very porous halite which is very similar to the upper zone. This halite appears to have crystal growth planes oriented across the primary bedding of the rock. The coarse-grained halite is separated from the underlying carnallite deposit by 0.3 m of fine-grained halite that contains a few scattered crystals of carnallite and is probably a primary layer. That part of the carnallite deposit immediately underlying this layer is very pure (80-90 percent carnallite).

The features seen in the K80 core constitute a remarkably well preserved record of the flow paths of solutions that entered the carnallite deposit and altered it to sylivte. Such flow paths (the coarse-grained porous halite intervals) are seldom seen in potash deposits becuase deep burial and consequent compaction destroy most porosity. In this case, the deposit is so shallow that the porosity has been preserved.

From the relationships observed in the K80 core, it seems likely that meteoric water gained access to the carnallite deposit and dissolved it's way downdip following rich layers of carnallite or tachyhydrite. Intervals consisting principally of halite, such as the one at the top of the carnallite deposit in K80, would be less soluble and probably acted as dissolution barriers. In the process of dissolving carnallite, the solutions left behind a recrystallized coarse-grained porous network of halite crystals, especially near the margins of the dissolution front, which continued to act as flow paths for the ingressing solutions. It is quite possible that the flow paths may still be active, and that the process of sylvite formation is taking place today. It will be very important for any mining operation on the Khorat Plateau to keep these relationships in mind because extraction of a sylvite deposit that is still connected to a ground-water flow system could be very hazardous. In drilling out any sylvite orebody, all core holes, showing any evidence of porosity, should be carefully tested for brine flows.

The origin of the Khorat sylvite deposits can be summarized as follows:

(1) The original potash deposit in the Lower Salt consisted of a thick and very widespread layer of carnallite containing a high percentage of tachyhydrite.

(2) An interval of halite and minor sylvite that shows color banding (orange to red) at the top of Lower Salt may be a primary deposit.

(3) Locally the carnallite deposit has been altered so that the $MgCl_2$ has been leached out leaving KCl behind. Blue halite is frequently associated with this alteration.

(4) The alteration of the carnallite deposit and the formation most of of the important sylvite deposits probably took place during the Pleistocene. Locally, however, the process may still be continuing.

(5) The sylvite deposits are localized along salt anticlines which were breached by paleo-stream channels that provided access for water which decomposed the original carnallite.

(6) Starting at the anticlinal crest and moving downdip, the expected facies consist of (a) barren halite overlain by a gypsum or anhydrite caprock, (b) sylvite which is usually associated with blue halite, and (c) carnallite associated with tachyhydrite.

(7) Where caprock is present all potash will probably be gone.

(8) If the Upper and/or Middle Salt is present, potash should be present unless the locality is outside the area of original deposition.

(9) Incongruent solution of carnallite can theoretically leave behind a layer of sylvite which will be 55 percent of the original carnallite volume. Considering the great thickness of the primary carnallite deposit (locally over 80 m), it is possible that sylvite deposits of unusual thickness can be found.

Exploration Guides for Sylvite Deposits

From what is now known about the genesis of the sylvite deposits, some guidelines can be established that will assist future exploration for these deposits, as well as delinating known deposits.

Most core holes, which penetrated barren halite but are located inside the areas of the Sakon Nakhon and Khorat basins where carnallite would normally be expected, are probably located on salt anticlines (table 2). Using the proposed model of sylvite deposition (fig. 32), it is suggested that sylvite can be found at these localities by moving downdip on the structure. Because the belt of sylvite may be narrow (1/2 km or less), the step-out drilling should probably be limited to 1/4 km spacing.

Salt anticlines can be located by first locating buried Pleistocene-stream channels which will probably be filled with water-saturated (locally high conductivities because of salt content) alluvium. Electrical or gravity geophysical techniques should work quite well in mapping channel locations. Recent work by J. C. Wynn, (written commun.) U.S. Geological Survey, in the Na Chuak locality has demonstrated that gravity methods work quite well for reconnaissance mapping of the paleo channels and the associated salt anticlines. Again when salt anticlines are located, exploration drilling should be programmed to follow the sylvite model (fig. 33).

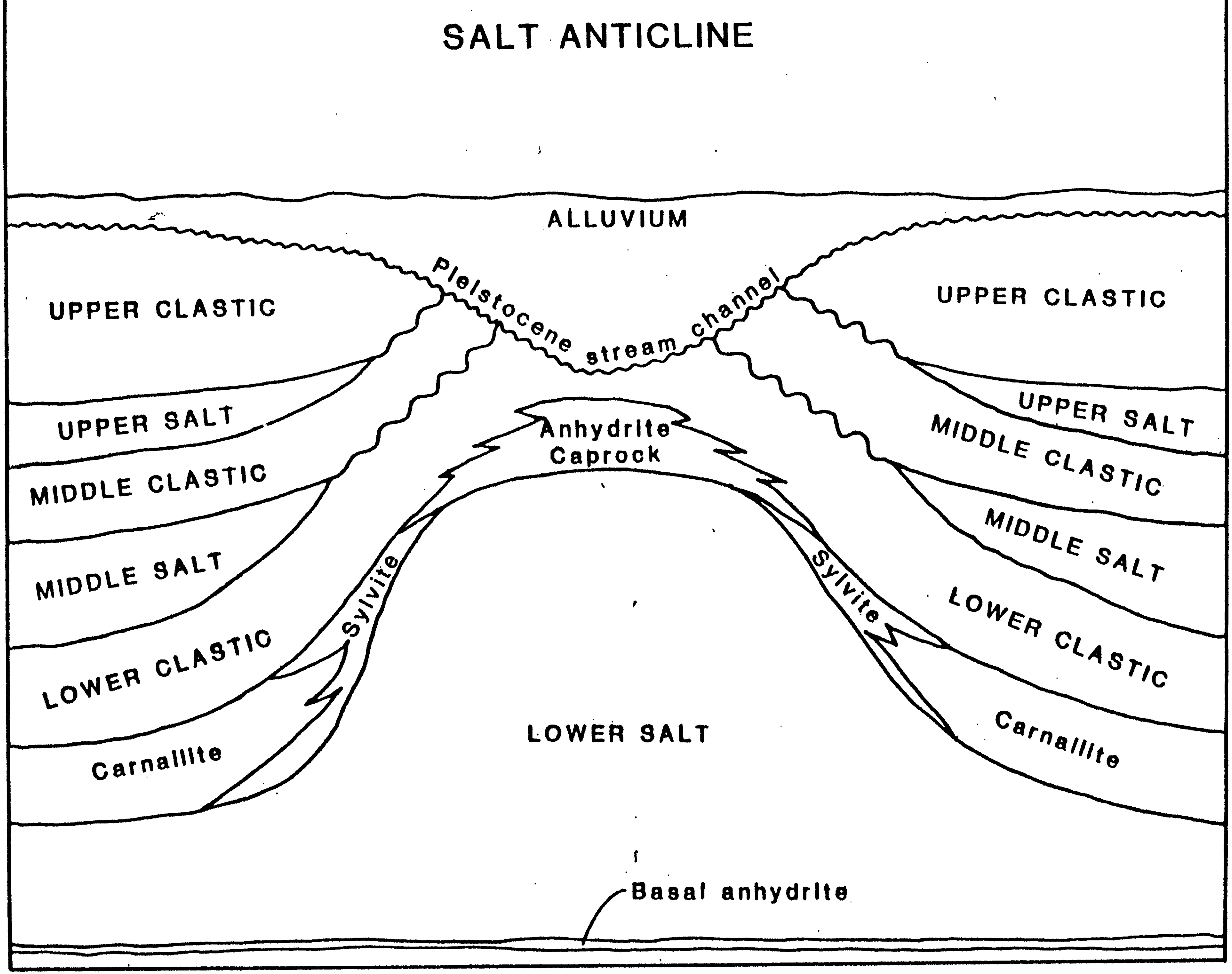

Figure 33. Idealized salt anticline-sylvite facies model for the Khorat Plateau.

In core holes where sylvite underlies the base of a carnallite deposit (K48), it is recommended that future drill hole locations be moved to slightly updip positions. For example, another hole located slightly updip from K48 may find an interval consisting entirely of sylvite. In holes such as KK12, where sylvite is found at both the base and top of the carnallite deposit, it is also recommended that another hole be drilled slightly updip from that location, with the expectation that the two sylvite deposits would coalesce, forming a thick intercept of sylvite.

In areas where drilling is sufficient to outline the distribution of caprock over a salt anticline, such as Banmet Narong (fig. 9), the most favorable ground for drilling would be along the edge of the caprock. In any core hole where the caprock is 1 m thick or more, the entire potash deposit has probably been dissolved, and sylvite could only be found be moving farther downdip.

EXPLOITATION OF CARNALLITE DEPOSITS

The Khorat Plateau is endowed with vast resources of carnallite. Carnallite is a less desirable ore of potash than sylvite because of its lower K_2O content (17 percent K_2O). In contrast sylvite, which forms the most important potash ore, contains 63 percent K_2O. Carnallite contains $MgCl_2$, which makes it very hygroscopic. In Thailand's humid climate, carnallite immediately begins to melt when exposed to the atmosphere. Large quantities of magnesium chloride would be produced as a result of carnallite processing, which would present a difficult disposal problem unless a market could be developed for this byproduct.

The association of tachyhydrite with carnallite will also create some problems if the carnallite deposits are exploited. This mineral is even more hygroscopic than carnallite. It is doubtful that any market could be developed for byproduct calcium chloride in this region. Therefore, the calcium chloride would have to be disposed of in a manner that would not adversely affect the environment. It may be possible to find areas where the carnallite deposit is free of tachyhydrite. Core holes K1, K10, K11, K40, and K55 penetrated carnallite that was completely free or contained only traces of tachyhydrite (table 2). A regional pattern of distribution for tachyhydrite is not apparent. The salt is found in both the Khorat and Sakon Nakhon Basins. At Banmet Narong, tachyhydrite is generally absent in the lower third of the carnallite deposit. At present, data are not sufficient to positively identify areas or stratigraphic intervals within the carnallite deposit that will be free of tachyhydrite.

At the time of the author's visit, there seemed to be considerable interest in shaft mining of carnallite, particularly at Banmet Narong. Because of the hygoscopic nature of the carnallite, it would probably be very difficult to mine by conventional shaft techniques unless the air going into the mine was refrigerated to lower the high natural humidity. The lack of low-cost power in the area would probably make large-volume air conditioning prohibitively expensive. One factor that would assist carnallite mining is that the geology of the deposits does make it possible to emplace all shafts and roadways in halite rock. For example, shafts can be located on salt anticlines where only halite in the Lower Salt is present. Inclines can then be driven across structure until they intersect the base of the carnallite deposit. All main roadways could be located below the carnallite.

Considering some of the potential problems in mining carnallite by conventional methods, it is recommended that more emphasis be placed on the potential of recovering these deposits by solution mining. The great thickness of the carnallite deposit and its shallow depth would facilitate this type of mining.

It may be possible that solar energy could be used as part of the energy needs to bring about crystallization of potassium chloride from brines derived from solution of carnallite. Currently sodium chloride is produced by solution mining at Phi Mai (fig. 1). The mine, which is located 45 km northeast of the city of Khorat, prepares a sodium chloride brine by injecting fresh water through a single well into a cavern dissolved in the Middle Salt. Each year a new cavern is mined. The brine is pumped to the surface to evaporation ponds which cover an area of about 400,000 m^2. Approximately 2 cm of salt is harvested monthly during a 4 month period of the dry season from November to May. Total yearly production of salt is about 40,000 tons. That it is possible to produce solar salt in this part of the world seems rather surprising. However, weather recording stations on the Khorat Plateau show that evaporation exceeds precipitation in many localities. For example, at Khon Kaen in 1966, pan evaporation (2169 mm) greatly exceeded precipitation (1000 mm) (Phoenix, unpubl. data, 1970). Climate would still impose some severe restrictions on producing KCl from brines derived from solution of carnallite and tachyhydrite. For example, even during the dry season the relative humidity remains quite high, and because brines containing large amounts of Ca^{2+} and Mg^{2+} are very hygroscopic it would be impossible to totally desiccate them in solar ponds. Nevertheless, solar evaporation might be used to augment energy from fossil fuels or hydropower which is in short supply in this region.

In summary, it is recommended that feasibility studies of carnallite exploitation should investigate the amenability of solution mining to this large resource. Considering the low cost of drilling shallow-brine wells into the carnallite deposit, much valuable experimental data could be obtained at reasonable cost. More thought should be given to developing carnallite resources where tachyhydrite is not present and where these resources are located favorably in terms of climate and transportation.

HOLOCENE DISSOLUTION OF SALT

Large volumes of halite and associated potash salts have been leached from the Maha Sarakham Formation at many different localities on the Khorat Plateau. Most salt dissolution probably took place during the Pleistocene, but some dissolution is currently taking place at several localities.

On October 8, 1980, the author visited an area near the village of Borabu, which is about 56 km south of the city of Khon Kaen (fig. 1). For many years, the people in this area produced salt from brines that were pumped from very shallow wells (2- to 3-m deep). Originally the salt was produced by boiling the brines to dryness. In recent years, some small concrete-lined ponds have been used to make solar salt.

Along the southern edge of the brining area, there is visible evidence of active salt dissolution. Several deep circular holes 20 to 50 m in diameter are present in the rice paddies at this point. One of these had formed very suddenly a few days before our visit. The collapse features appear to be aligned in a north to south direction. The entire area seems to be part of a large depression, part of which is filled with a natural lake, Nong Bo, that may also be related to solution and collapse. Core hole K70, drilled in the village of Borabu, apparently penetrated a thick alluvial fill. Unconsolidated silt, sand, and gravel were found in this hole to a depth of over 100 m. From about 107 to 300 m, the driller's log describes semiconsolidated sandstone. The depth to bedrock in this hole is at least 107 m and possibly 300 m. This suggests that a deep paleo channel is present in this area, and it probably cuts down into salt beds of the Maha Sarakham Formation. The Lower Salt is probably in contact with alluvium along the base of this paleo channel, and the Upper and Middle Salt may subcrop along channel walls. The relationships observed at Borabu suggest that the salt dissolution is a natural phenomena not related to the brining operations. New collapse depressions probably will continue to form along the trend of the postulated paleo channel.

In conclusion, it seems likely that most, if not all, salt dissolution on the Khorat Plateau is localized by the paleo channels cut into the Maha Sarakham Formation. The hydrology of the paleo channels is unknown, but it is possible that large supplies of ground water suitable for irrigation might be developed from their alluvial fills. Water wells in the channels would have to be carefully completed to avoid producing water from near the channel base, which in most cases would be characterized by high total dissolved solids. The quality of ground water in some channels may be too poor for irrigation use. Nevertheless, it is recommended that investigations of the paleo channels, as pertaining to the Economic Geology Division potash project, should also be coordinated with hydrologic studies by the Ground Water Division of DMR. Both Divisions would benefit by a cooperative effort.

PALEO-CHANNELS AND URANIUM OCCURRENCE

Paleo-stream channels incised into the Maha Sarakham Formation may also have localized uranium deposits of economic value. Several potash core holes (K27, K30, and K31) had radioactive anomalies in the alluvial fill of what are assumed to be channels. These anomalies were commonly at or near the bedrock contact. In some core holes, carbonized plant debris and pyrite have been noted near the base of the channel alluvium. If as suspected, ground water moving along the base of these channels has a high chloride content, the geochemical environment at the base of many of the channels may be strongly reducing. From what we have observed concerning the formation of gypsum-anhydrite caprock, there has been a large volume of ground water flowing through these channels. If the channels are Pleistocene in age, then any associated uranium deposits would be quite young. In deposits this young, the uranium is commonly not in equilibrium and the equivalent U_3O_8 as determined by gamma-ray logging is less than chemical U_3O_8. This should be taken into account in any exploration program.

In summary, the alluvial fills in the paleo-stream channels described in this report offer good potential for hosting uranium deposits of economic value. Some of the channels delineated by the potash drilling or by earlier exploration for ground water should be tested by some shallow reconnaissance drilling.

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