# Evaporite Deposits of the Khorat Plateau, Northeastern Thailand[1]

Robert J. Hite
*U.S. Geological Survey*
*Denver, Colorado 80225*

## ABSTRACT

*Thick beds of rock salt have been penetrated by numerous water wells in the Khorat Plateau of northeastern Thailand and central Laos. These deposits of Cretaceous age occur in the Maha Sarakam Formation of the Mesozoic Khorat Group. Beds of rock salt may also be present in the Sao Khua and Phu Khadung Formations in the Khorat Group and possibly in the Kanchanaburi Group of Paleozoic age.*

*The salt-bearing Maha Sarakam Formation extends over 21,000 square kilometers in the Sakon Nakhon basin in the northern half of the plateau. An additional 36,000 square kilometers occurs to the south in the Khorat basin. The maximum thickness of the halite facies is unknown, but may exceed 1,000 meters. Some individual salt beds are at least 150 meters thick and are at depths of less than 60 meters.*

*Studies of the distribution of trace bromine and potassium in halite cores from Chaiyaphum indicate that at least one salt bed is a favorable target for potash exploration.*

## INTRODUCTION

Thick beds of rock salt and associated gypsum and anhydrite have been penetrated at unusually shallow depths by numberous water wells in the Khorat Plateau of northeastern Thailand and central Laos (Fig. 1). Although the full extent and character of these evaporites is unknown, there is little doubt that they are among the world's larger deposits.

The Khorat Plateau is an area of about 170,000 square kilometers in northeastern Thailand. It is bordered on the north and east by the southerly flowing Mekong River. The western and southern boundaries of the plateau are formed by an escarpment of upturned Mesozoic strata. Most of the plateau is a flat-lying somewhat featureless plain which is covered by tropical savannah and locally dense forests. Rice-paddy agriculture is practiced where sufficient water supplies are available (Fig. 2).

A network of highways, several paved and others surfaced with crushed laterite, provide excellent access to much of the plateau. In addition, an excellent rail system connects the plateau with Bangkok (Fig. 1).

Annual rainfall on the plateau ranges from 110 to 390 centimeters; however, most of it falls during the southwest monsoon season from May to September. As a result, drought conditions prevail for several months creating severe hardships for the agricultural community. The massive Pa Mong dam on the Mekong River (Fig. 1), which is still in the planning stage, would help alleviate this problem by providing large amounts of irrigation water. In addition, this structure would also provide the area with a large supply of hydroelectric power.

## ACKNOWLEDGMENTS

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The author is indebted to a large number of people whose numerous courtesies and freely given assistance made this investigation possible. The Royal Thai Department of Mineral Resources acted as the official host during

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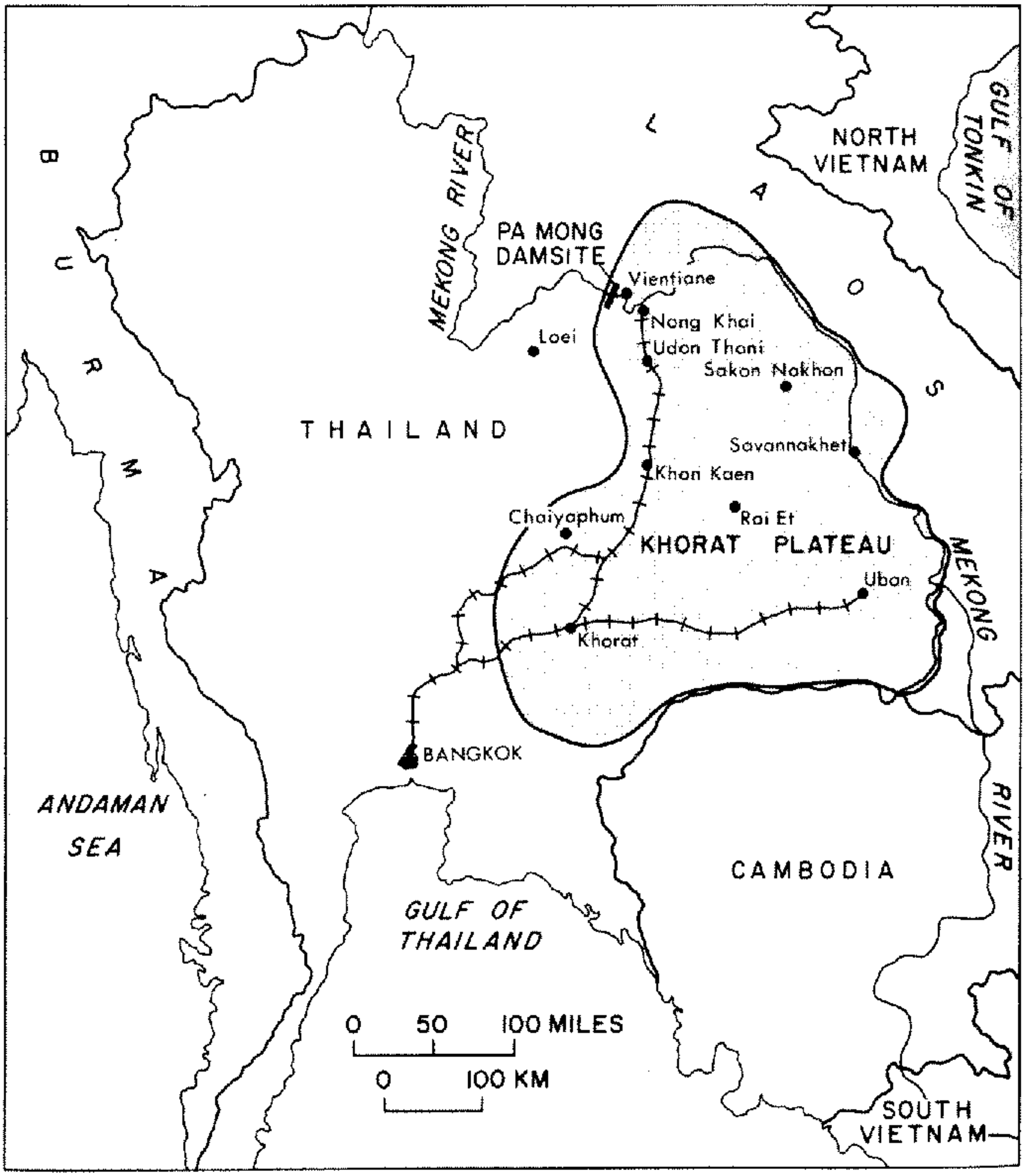


Figure 1. Index map of the Khorat Plateau. Shaded area shows extent of plateau.

the author's stay in Bangkok. In this Department, the Chief of Economic Geology, Sangob Kaewbaidhoon, acted as liaison officer. Thawat Japakasetr, and the author's counterpart, Prachon Chareonsri, both of the Economic Division, were especially helpful in arranging field trips, use of equipment, and transportation in Bangkok. Charoen Phiancharoen, Acting Chief of Ground Water Division, generously made office space available. The numerous discussions concerning drilling problems with Samrit Lelawongs and Suri Murigadat of the Engineering Division were extremely helpful. The support lent by M. Hayath of the Mekong Committee on numerous occasions greatly facilitated the work. Officials in the U.S. Agency for International Development, who rendered valuable assistance to the investigation, were G. N. Pierce, Carl Lee, Robert Hallagen and R. J. Hynes.

## OCCURRENCE OF EVAPORITES

The Khorat Plateau forms a large blocklike stable platform between two structurally complex orogenic belts which trend north-south along the plateau's east and west boundaries. The bedrock of the plateau is comprised of clastic beds of Mesozoic age which are fairly undeformed except along the Phu Phan uplift. This feature, which consists of a series of large gentle folds striking northwest-southeast across the plateau, divides the plateau into the Khorat basin on the south and the Sakon Nakhon basin on the north (Fig. 3). In size, about 170,000 $Km^2$, and structural configuration, the Khorat Plateau is strikingly similar to the Colorado Plateau of the Western United States. In the Khorat and Sakon Nakhon basins, regional dips probably average less than 2°. Very little faulting has been observed; however this may be due in part to poor exposures and lack of detailed mapping.

**Figure 2.** Photograph of typical Khorat Plateau topography. Rice paddies in foreground.

The evaporite deposits on the Khorat Plateau are found in rocks ranging from Paleozoic to Mesozoic age (Table I). The deposits of the Cretaceous age are better known, economically more important, and are treated in greatest detail in this paper.

### Paleozoic evaporites

Thick beds of anhydrite and gypsum have been penetrated in drill holes near Loei (Jacobson and others, 1969, p. 18) about 75 kilometers west of the Khorat Plateau. (See Fig. 1.) These deposits occur along the west-dipping limb of the Loei anticline in rocks apparently belonging to the Kanchanaburi Group. A similar deposit (Phichit) occurs about 200 kilometers to the southwest. The latter was assigned to the Maha Sarakam Formation in the Khorat Group by Gardner and others (1967, p. 14); however, its similarity to the deposit at Loei plus other geologic relationships suggest that it more likely belongs in the Kanchanaburi Group. The more recently discovered deposit at Nakhon Sawan, about 200 kilometers northwest of Bangkok, may also be correlative.

Outcrops of a redbed sequence were discovered by Borax and Stewart (1966, p. 15) between Loei and the escarpment of the Khorat Plateau. On the basis of stratigraphic position of these beds to nearby carbonates of the Ratburi Limestone, they felt that the beds belong in the Kanchanaburi Group and may be equivalent to the evaporites at Loei.

In summary, these relationships suggest that the Kanchanaburi Group, in addition to a thick section of marine carbonates, also contains a redbed-evaporite facies. This facies probably extends eastward into the Khorat Plateau. Whether the evaporite facies also contains halite deposits in the subsurface is unknown, but this certainly is a possibility.

### Mesozoic evaporites

The most extensive development of evaporites in the Khorat Plateau region occurs in rocks of Mesozoic age. These rocks belong to the Khorat Group and range in geologic age from Triassic to Cretaceous (Table I). The entire sequence is about 4,000 meters thick, consiting of redbeds and evaporites, and it forms the bedrock of the Khorat Plateau. The Khorat Group has been subdivided by numerous authors largely on the basis of topographic expression. For example, nonresistant siltstones and mudstones of the Sao Khua Formation are overlain and underlain by the resistant ridge-forming sandstones of the Phu Phan and Phra Wihan Formations. This cyclic alternation of resistant and nonresistant beds is highly significant in terms of prospecting for evaporites. The resistant, clean crossbedded sandstone probably represents, as Borax and

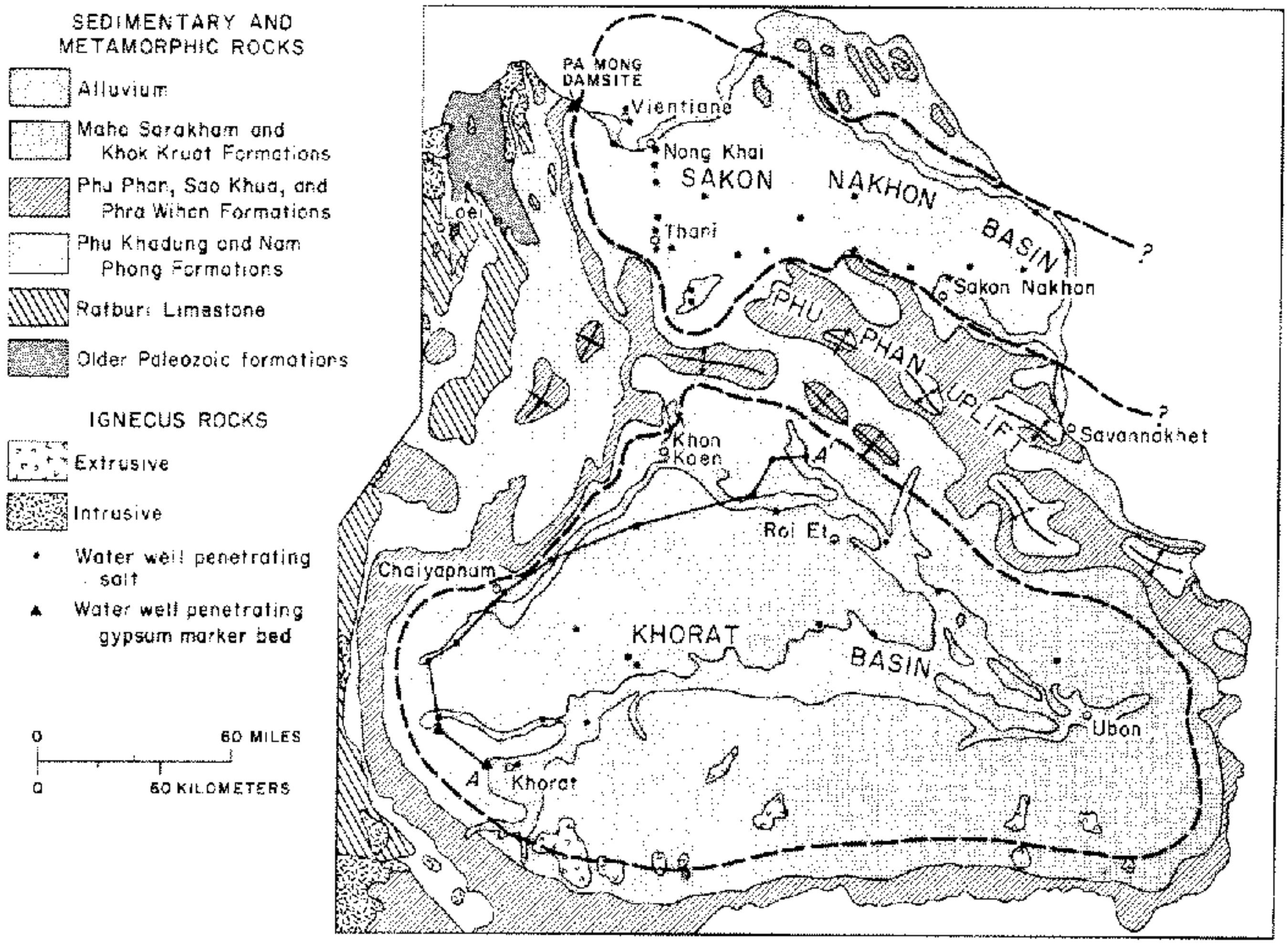


**Figure 3.** Geologic map of northeastern Thailand. Modified from Royal Thai Department of Mineral Resources Geologic Map of Thailand compiled by Jumchet C. Javanaphet.

Stewart (1965, p. 7) suggested, deposition by an advancing and retreating sea. To the author's knowledge there are no significant deposits of evaporites intimately associated with coarse-grained clastics. Evaporites are deposited in low-energy environments where transport of sediment particles larger than clay or silt size would be highly unusual. Evaporites then are most likely to be found in the formations characterized by finer-grained mudstones and siltstones. Formations of this type in the Khorat Group include the Phu Khadung, Sao Khua, and Maha Sarakam. Evaporites are well known in the Maha Sarakam Formation but few data are available on those in the other two formations. The remaining portion of this section of the report will be devoted to discussion of evaporite occurrence in these three formations.

*Phu Khadung Formation.* The Phu Khadung Formation, as measured by Ward and Bunnag (1964, p. 12) at the type locality, is over 1,000 meters thick. Their description of the formation is as follows: "The lower one half of the section is poorly exposed and is mostly soft, micaceous, reddish brown and grayish red siltstone with mottling of greenish gray in some beds. Thick, pale red sandstones that are fine to very fine grained, well cemented, slightly calcareous, micaceous, and partly crossbedded occur above the middle of the section in a zone about 120 meters thick. Interbedded, calcareous, micaceous siltstones and sandstones characterize the upper part of the formation."

The precise age of the Phu Khadung Formation is unknown; however the formation has been tentatively assigned to the Triassic by Borax and Stewart (1965) and by Ward and Bunnag (1964). This tentative age determination is based largely on correlation with strata in Laos and Cambodia that contain Triassic fossils.

At present, there is no absolute certainty of bedded evaporites occurring in the Phu Khadung Formation, but geologic evidence suggests this is a good probability. At the northwest corner of the Khorat Plateau, gypsum and

**TABLE 1**

Stratigraphy of the Khorat Plateau Region

| Age | Rock Unit | | | Character |
|---|---|---|---|---|
| Quaternary | | | Unnamed | Unconsolidated clay, sand, and gravel; laterite. |
| Tertiary | | | Unnamed | Basalt flows (only overlying Khorat Group on Khorat Plateau). |
| Cretaceous | Khorat Group | Upper | Maha Sarakam Formation* <br> Khok Kruat Formation | Sandstone, siltstone, shale, salt and anhydrite-gypsum. <br> Sandstone, siltstone, and shale. |
| Jurassic | Khorat Group | Middle | Phu Phan Formation <br> Sao Khua Formation* <br> Phra Wihan Formation | Massive sandstones with conglomeratic sandstone, siltstone, and shale. |
| Triassic | Khorat Group | Lower | Phu Khadung Formation* <br> Nam Phong Formation | Sandstone, siltstone, and conglomerate (including basal conglomerate). |
| | | | Unnamed | Andesite, rhyolite, tuff, agglomerate. |
| | | | Unnamed | Granodiorite and other intrusive rocks. |
| Permian | Kanchanaburi Group | | Ratburi Limestone | Massive limestone with shale and sandstone. |
| Carboniferous | Kanchanaburi Group | | Unnamed* | Sandstone, siltstone, shale, tuff, and limestone. |
| Devonian | | | Unnamed | Sandstone, quartzite, phyllitic shale, slate, and limestone. |
| Silurian and older | | | Unnamed | Argillite, quartzite, slate, phyllite, schist. |

Adapted from Jacobson and others, 1969. Formations marked by asterisk are known or thought to be halite bearing.

halite veins were found in drill core from these rocks at the Pa Mong damsite. A geologic report on the damsite (Stapledon and others, 1963, p. 23–25) refers to these evaporite-bearing rocks as the Sam Phan Na Formation which are here correlated with the Phu Khadung Formation. No bedded evaporites were found in any of the drill cores; however, the veins of evaporite minerals are typical of strata from which bedded salt deposits have been removed by solution. The Sam Phan Na Formation crops out at the damsite and has been penetrated by only a few shallow core holes at this location. Groun water moving downdip from the upturned edge of the outcrop has probably dissolved any salt beds that were originally present. Drill holes located further downdip, where this formation would be intersected at depths of at least 300 meters, might penetrate beds of salt.

Additional evidence suggesting evaporites in the Phu Khadung Formation are some of the large synclinal structures along the western edge of the Khorat Plateau. The most striking of these structures occurs about 135 kilometers southwest of the Pa Mong damsite, near the village of Phu Wiang (Fig. 3). The unusual saucer shape of this depression suggests that it may have formed as the result of dissolution of underlying evaporites. These evaporites should most likely occur in the Phu Khadung Formation although there is the possibility of older evaporites in the Kanchanburi Group in this area. It should also be noted that ground water with a higher than average chloride content occurs in the area of this structure (Haworth and others, 1964, pl. 23).

*Sao Khua Formation.* The Sao Khua Formation consists primarily of reddish-brown to grayish-red siltstone and minor amounts of yellowish-brown and pale-red sandstone. Many of the sandstone units are crossbedded. A few thin lenticular beds of conglomerate consisting of pebbles of calcareous siltstone are present. The formation weathers deeply and forms strike valleys between the more resistant underlying Phra Wihan Formation and the overlying Phu Phan Formation. According to Ward and Bunnag (1964, p. 16) the formation ranges in thickness from 400 to 700 meters. The Sao Khua correlates with the Pla Buk Formation at the Pa Mong damsite. The Pla Buk is also a weak siltstone unit and is about 350 meters thick at the damsite. The Pla Buk also contains some thin calcareous pebble conglomerates.

Although the Sao Khua Formation is sparsely fossiliferous a diagnostic fauna has been collected. This includes gastropods, pelecypods, and an icthyosaur tooth, and from this assemblage the formation is dated as Jurassic.

Similar to the Phu Khadung Formation, the Sao Khua is not known to contain bedded evaporites in the subsurface. At the Pa Mong damsite, shallow drill holes penetrated siltstone containing traces of halite in this unit (Pla Buk). These holes were located well within the leached zone on the outcrop edge of the formation. Where the Mekong River crosses the Sao Khua outcrop a conspicuous wide pool, called the Pla Buk pool, has formed. The origin of the depression forming the pool is thought by Gardner and others (1967, p. 16) to be the result of collapse following the dissolution of salt. Gardner and others (1967, p. 17) also mention that "brine springs and wells in the mountains of northern Thailand and adjacent parts of Laos suggest that salt is being dissolved from lower strata of the Khorat Group."

All this evidence suggests that if deeper wells are drilled on the Khorat Plateau they may penetrate beds of halite in the Sao Khua Formation.

*Maha Sarakam Formation.* The thick sequence of evaporites, nonresistant mudstones, siltstones, and minor sandstones forming the uppermost unit in the Khorat Group was named the Maha Sarakam Formation by Gardner and others (1967, p. 29). This formation is present only on the Khorat Plateau where it forms the bedrock of two large structural basins (Fig. 3). Within the smaller and more northern of these basins, the Sakon Nakhon, the Maha Sarakam Formation covers an area of about 21,000 square kilometers. Most of this area is in Thailand; however, along the Mekong River the formation crosses into Laos at the Vientiane Plain and the plain near Savannakhet. To the south in the second basin, the Maha Sarakam Formation covers about 36,000 square kilometers in the Khorat basin, (Fig. 3). These two basins are separated by the southeast-trending Phu Phan uplift.

The maximum thickness of the Maha Sarakam Formation is unknown, but Gardner and others (1967, p. 32) believed it may exceed 1,000 meters. In the Khorat basin the deepest drill hole penetrated 610 meters of the formation and was still in the formation at total depth. In the Sakon Nakhon basin several drill holes have penetrated as much as 450 meters without drilling through the formation. Estimates of thickness of the formation from surface exposures are unreliable, not only because of poor exposures but also because unknown thicknesses of halite have been leached from these outcrops.

Evidence for determining the age of the Maha Sarakam Formation is indefinite. Because it is transitional with the underlying Khok Kruat Formation, which has been dated as Early Cretaceous on the basis of a pelecypod fauna, Gardner and others (1967, p. 35) suggested that the formation is probably of Late Cretaceous age. The opportunity of determining a precise age seems best afforded by studies of fossil pollen content in the halite beds. This technique of palynological age determination has been described by Klaus (1970).

Although the halite deposits of the Maha Sarakam Formation are incompletely explored, they probably rank with some of the world's larger deposits. At present, about 46 water wells have penetrated halite deposits in the formation in both the Sakon Nakhon and the Khorat basins. Although many of these wells are widely separated, there is little evidence to suggest that the rock salt layers are not continuous between wells except where interrupted by structure. The present-day distribution of the halite deposits suggests that originally they were even more extensive. Several wells located along the margins of the present-day basins show that thick salt beds extend right up to the outcrop edge of the Maha Sarakam Formation (Fig. 3). This could mean that originally the depositional edge of halite deposits extended considerably beyond the present limits of the Maha Sarakam Formation. In fact, these deposits may have been continuous between the Khorat and Sakon Nakhon basins and may have been removed by erosion over the Phu Phan uplift.

At least three wells in the Sakon Nakhon basin have penetrated more than 240 meters of massive halite. Another well at Udon Thani (Fig. 1) penetrated 225 meters and was still in halite when abandoned. It is assumed that these wells penetrated a single vertically continuous bed of salt which may prove to be one of the thickest in the world. In the Khorat basin, the greatest continuous thickness of halite penetrated so far is more than 150 meters.

The total thickness of the halite facies in the Maha

Sarakam Formation is unknown; the location of the thickest part of this facies is unknown. Normally the thickest accumulation of evaporites is associated with the lowest depression in the basin at the time of deposition. Well data suggest, however, that the configuration of the present-day structural basins of the Khorat Plateau may not coincide with the configuration of the original basin or basins in which the evaporites were deposited. Thus far the greatest thickness reported for the halite facies in the Sakon Nakhon basin is 344 meters (well No. E4UD1) near Udon Thani. In the Khorat basin an even greater thickness, 423 meters, was penetrated near Maha Sarakam (Fig. 1) (well No. F34MS2). It should also be noted that both wells were still in the halite facies at total depth.

In addition to massive beds, the halite facies of the Maha Sarakam Formation includes zones described as disseminated salt (Gardner and others, 1967, p. 89). In these zones it has been assumed that the halite is disseminated through a matrix of mudstone and siltstone. In many wells these zones in actuality may be massive salt beds. In fairness to the geologists who logged the cuttings of these wells it should be pointed out these wells were drilled with fresh water and under these conditions salt beds can be drilled for many meters before halite is detected in the well cuttings. Halite is a very soluble mineral and until the drilling mud becomes saturated with sodium chloride it will not be found in the well cuttings. Even then, cavings from strata above the salt can so dilute the sample that the well geologist may assume that the halite is interbedded or disseminated in other rock types.

The halite facies of the Maha Sarakam Formation is characterized by depositional cycles similar to those of other marine evaporites (Fig. 4). The lithologic detail of a Maha Sarakam cycle has been recorded only at Chaiyaphum in the Khorat basin. In the core from five holes drilled in this area, two evaporite cycles can be observed. Lithologic units in the uppermost cycle consist of (A) red claystone and siltstone, (B) greenish-gray siltstone and claystone, and (C) gypsum with scattered dolomite crystals. In order, the vertical sequence in this cycle is A, B, C, B, and A. The underlying cycle is more complex, consisting of units A and B of the above cycle, unit C which includes an upper gypsum layer and a lower anhydrite layer, and (D) halite. The vertical sequence of units in this cycle in order is A, B, C, D, C, B, and A. A detailed description of this cycle is shown in Figure 5.

The halite rock of the lower cycle is typical of that found in most marine evaporite deposits. The gray to white halite rock is banded by darker laminae consisting of anhydrite and some organic matter (Fig. 4A). The laminae show no evidence of deformation. The halite is fairly pure, averaging about 97 percent NaCl (Jacobson and others, 1969, p. 70).

In both cycles the gradual change from the red sediments of unit A to the grayish-green sediments of unit B represents the change from aerobic to anaerobic conditions typical of the evaporite environment (Hite, 1970, p. 52). In the upper cycle, all the calcium sulfate (unit C) is in the hydrous form (gypsum). In the underlying cycle only the upper C unit is gypsum and the lower is anhydrite. This is probably the result of hydrating the original anhydrite by ground water. The basal anhydrite has been protected by the overlying impermeable layer of halite and is therefore unaltered. This may mean that the upper cycle originally contained a halite unit which was leached out by ground water. At greater depths, halite may be found in this cycle.

Another unusual aspect of both the evaporite cycles is the small amount of carbonate minerals present. In many evaporite deposits thick beds of limestone and dolomite are present in the vertical sequence of the evaporite cycle. This is expected because sea water first becomes saturated in respect to the carbonate minerals, and their precipitation must precede that of the more soluble sulfates and chlorides. It is possible that during the deposition of the Maha Sarakam evaporites, the carbonate minerals were deposited within the marine accessway and by the time the evaporite brine moved into the more distant reaches of the basin, it was depleted in these constituents.

## GEOCHEMISTRY OF MAHA SARAKAM HALITE

One of the major objectives of the first-phase investigation of the Khorat Plateau salt deposits was to test the possibilities of using bromide geochemistry as a potash exploration tool. The author was hopeful that, in addition to the halite cores from the five holes at Chaiyaphum, cuttings from water wells that penetrated halite would provide material suitable for bromine analyses. Unfortunately, because of the ravages of insects, high humidity, and floods, most well cuttings could not be used. Despite this limitation in sample materials, some very valuable data were obtained on bromine content of halite in the Maha Sarakam Formation.

Because the core holes at Chaiyaphum are located in a relatively small area, only samples from one core hole (DH-5) were chosen for analysis. One hundred sixty four samples composited from intervals approximately 0.6 meter thick were taken. These and halite picked from the cuttings from two wells drilled near Vientiane, Laos, were analyzed for bromine and $K_2O$ content. Analyses were made by X-ray fluorescence spectrometer in the U.S. Geological Survey Laboratories in Denver, Colo.

The bromine content of the halite at Chaiyaphum ranged from 30 to 150 ppm and the $K_2O$ from 20 to 160 ppm. When these values were plotted as statistically smoothed profiles (5-point moving averages) several significant relationships were observed (Fig. 6). The lower three-fourths of the bromine profile shows a slow but continuous increase in bromine content from the base toward

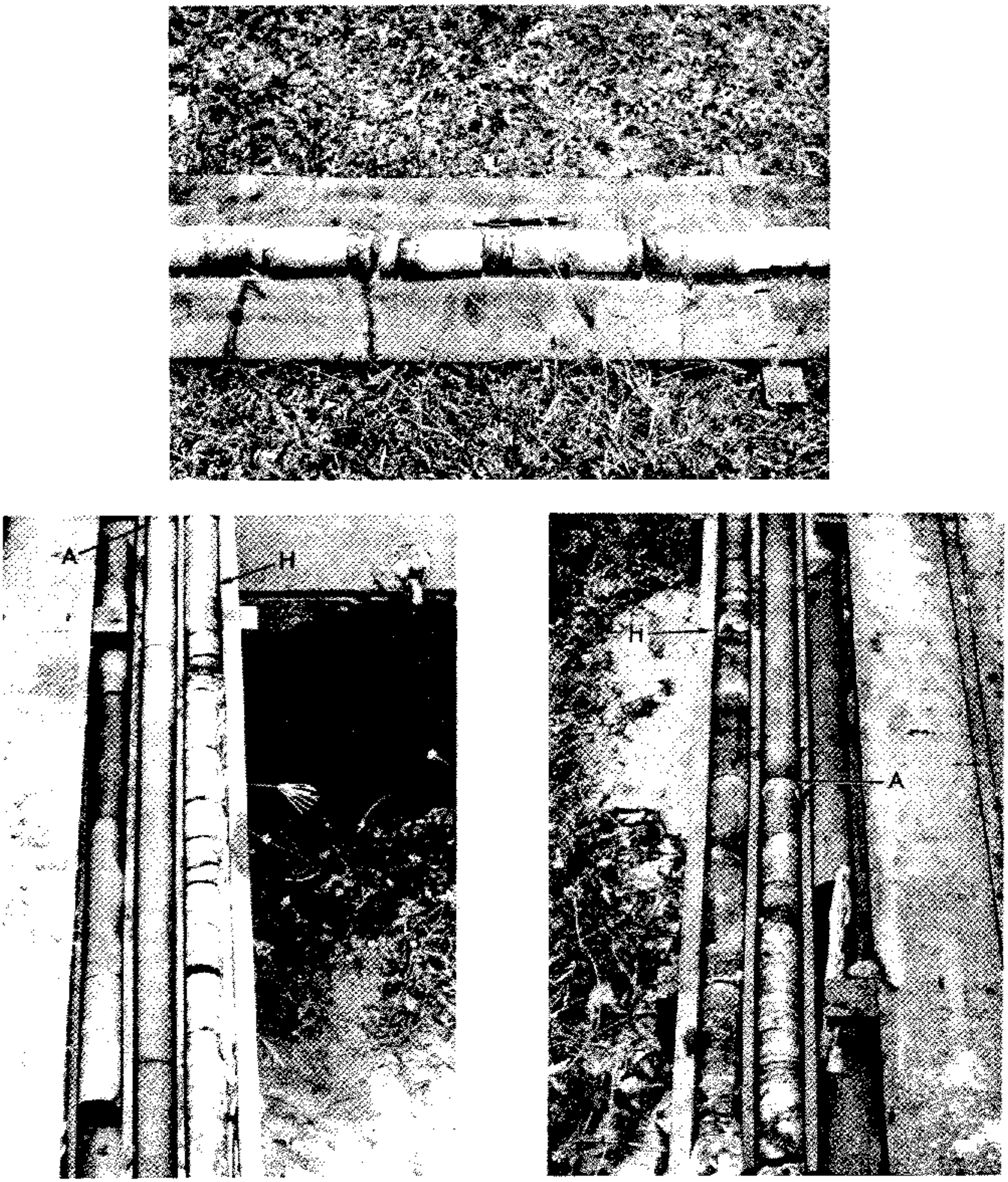


**Figure 4.** Photographs showing drill core from Maha Sarakam evaporite cycle. Stratigraphic base of core is at lower left of core trays. Letter A marks contact of anhydrite and siltstone. Halite-anhydrite contact marked by letter H.

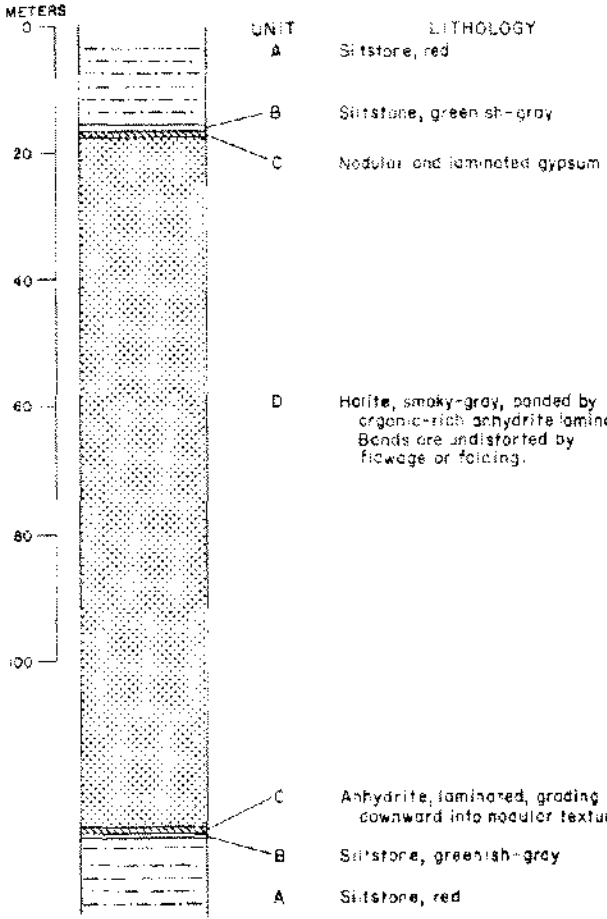


**Figure 5.** Evaporite cycle of the Maha Sarakam Formation.

the top of the salt bed. Through an interval of nearly 85 meters the bromine content increases only by about 20 ppm. This means that near equilibrium, conditions between influx salt and reflux existed in the evaporite basin during this period, and salinity was increasing at a very slow rate. Above this point the bromine content in the halite increases rapidly from about 55 to 150 ppm. This suggests that during the deposition of the last 18 meters of halite, circulation between the evaporite basin and the open ocean was severely restricted, perhaps completely cut off. As a result, salinities within the basin began to increase very rapidly and may have become high enough to precipitate potash. The general shape of this profile is very similar to bromine profiles of potash-bearing evaporite cycles in the Paradox Formation of the United States (Raup, 1966).

The two halite samples from Laos were picked from the cuttings of two water wells drilled on the Vientiane Plain near Vientiane. One sample, as marked, came from a depth of 253 meters and contained 127 ppm bromine. The other sample, which was a composite from a different well from the interval 283–380 meters, contained 172 ppm bromine. The salt bed from which these samples were obtained may correlate with the bed at Chaiyaphum; however, at present there are insufficient data to demonstrate this. The stratigraphic position of these samples in the salt bed at Vientiane is also unknown. The average depth to the top of the salt in this area is probably about 60 meters. Thus, these samples were probably collected from somewhere in the upper third of the bed. These samples represent a mixture of halite fragments that came from different depths in the hole and perhaps span a stratigraphic interval of at least 10 meters. Therefore, the sample that contained 172 ppm bromine may have been a mixture of halite fragments containing less than 172 ppm and some containing more than that amount. This factor, coupled with the problem that this well probably penetrated at least 10 meters of halite before the drilling fluid became salt saturated and halite fragments were preserved, strongly suggests that the halite at the top of the bed at Vientiane may contain well over 200 ppm bromine.

The analyses for trace amounts of potassium in closely spaced sample intervals in the halite bed at Chaiyaphum may be the first time a complete picture of potassium distribution through an evaporite cycle has been obtained. Ordinarily, halite rock is not analyzed for potassium unless potash minerals are known to be present and the potassium content is generally above 1 percent. Many complete chemical analyses of halite rock giving potassium content are published (see Jacobson and others, 1969, p. 90–91); however, these analyses are seldom carried out to the third decimal place, and generally are from random, stratigraphically unoriented samples. The manner in which trace amounts of potassium occur in halite is unknown. It is unlikely that it is in solid solution with NaCl. It may be in submicroscopic crystals of potash minerals; however, even the formation of those tiny crystals is governed by the established phase-equilibria of the sea-water system, which shows that potash minerals are not precipitated until a large amount of halite has already crystallized from the solution. Therefore, the basal halite of any evaporite cycle should not be expected to contain potash minerals, and the trace amounts of potassium present must be in some other form. The most likely form is in solution in the tiny fluid inclusions disseminated throughout all salt beds. These inclusions represent the mother brine from which the enclosing halite crystals grew. The brine was trapped in the halite as the crystalline mass grew and was compacted. The brine from which the first crystals of halite grew should contain about 3,125 ppm K or 3,764 ppm $K_2O$. Based on the assumption that the brine inclusions in the basal layer of halite at Chaiyaphum would contain a similar amount of $K_2O$, the 20 ppm reported in the analyses of this material would require that 0.53 weight percent of the sample consist of brine inclu-

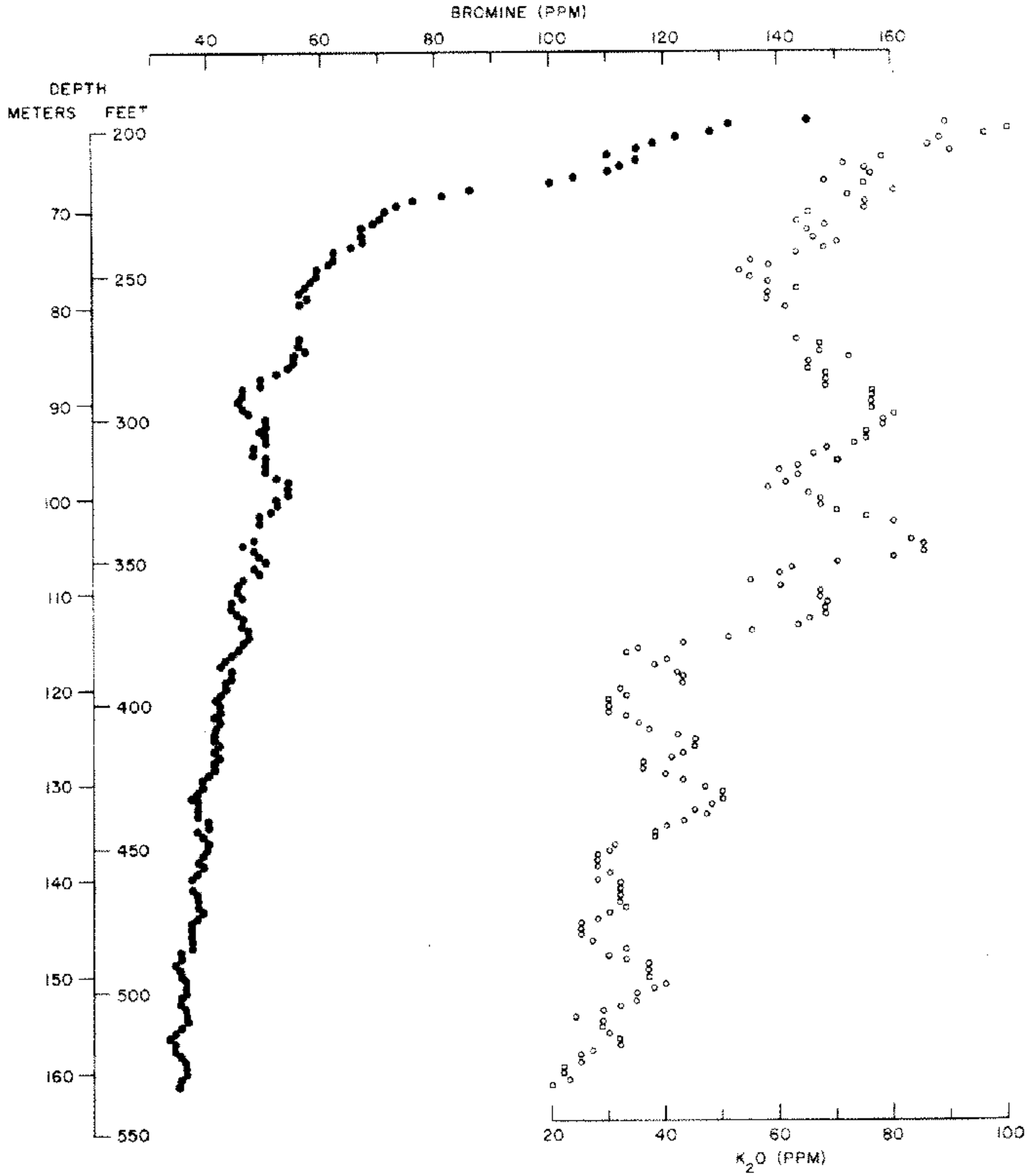


**Figure 6.** Bromine and $K_2O$ distribution through halite of core hole DH-5, Maha Sarakam Formation, Chaiyaphum, Thailand. Analyses by X-ray fluorescence spectrometer.

sions. This figure compares reasonably well with visual estimates of brine inclusions in halite of other evaporite deposits. The evidence cited here suggests that brine inclusions are the major source of trace $K_2O$ in the halite.

As more halite was deposited, the concentration of potassium in the parent brine would have increased, resulting in a corresponding increase in the trace amount of potassium in the solid phase. Thus, the trace potassium content would be a measure of paleosalinity of the brine. Note that on Figure 6 increasing potassium content (expressed as $K_2O$) corresponds closely to the bromine profile. The numbers of brine inclusions in a salt bed will probably vary somewhat from one layer to the next; however, the average amount should be relatively consistent. The somewhat ragged nature of potassium profile (Fig. 6), with numerous spikes showing amplitudes of about 25 ppm, is probably the result of vertical variations in numbers of brine inclusions. The highest $K_2O$ value on the profile was 160 ppm. If the number of brine inclusions in the upper part of the halite is about the same as for the base, then the $K_2O$ content represents a concentration factor of X8. On this basis the parent brine at the time the uppermost halite was deposited, would have contained about 25,000 ppm $K_2O$. Evaporation of modern-day sea water shows that brines containing this much $K_2O$ are nearly saturated in respect to potash and magnesium minerals. This suggests that the brine which deposited the uppermost halite at Chaiyaphum may have been saturated in respect to potash and magnesium minerals at some deeper point in the basin. This technique of using trace potassium as an exploration tool in prospecting for potash deposits could probably be used with similar success in other evaporite deposits.

## CORRELATION OF EVAPORITE CYCLES

Some investigators have suggested that some halite in the Maha Sarakam Formation is restricted to small local basins (Jacobson and others, 1969, p. 70). If this is true, exploration for potash deposits will be very difficult. Each small basin would have its own particular history of deposition. Some basins might contain potash and others might not, and a much greater density of drill holes would be required than if only one large basin were involved. It is the author's belief, however, that a halite bed such as penetrated at Chaiyaphum is continuous throughout both the Khorat and the Sakon Nakhon basins and perhaps originally was continuous between the two basins. Evaporite basins of small extent show the influence of runoff from surrounding land areas. In general, evaporites deposited in these basins have a high clay content and are poorly bedded. Periods of runoff causing repeated dilution of basin brine and resolution of salt are common and result in many intraformational disconformities. In addition, the bromine content in halite deposited in a small basin will show a much more erratic pattern of distribution. The salt at Chaiyaphum shows none of these characteristics. It contains very little, if any, clay; it is uniformly bedded (Fig. 4A); and as previously shown (Fig. 6), it has a bromide profile characteristic of a marine evaporite basin which was too large to be freshened by minor periods of runoff. Understandably, a case for discontinuity of beds can be made if lithologic logs from water wells penetrating the Maha Sarakam Formation are taken at face value. However, as previously discussed, the problems of accurately portraying the lithology of an evaporite sequence from well cuttings make it necessary to do some interpretation where regional correlation is involved.

This preliminary investigation suggests that with better data stratigraphic correlation in the Maha Sarakam Formation in both the Khorat and Sakon Nakhon basins may not be a problem. Available well data suggest that the upper anhydrite at Chaiyaphum may be continuous over both the Khorat and the Sakon Nakhon basins. A possible correlation of this bed and other units in the Maha Sarakam Formation are shown on Figure 7. If the anhydrite unit is as persistent as depicted, then it should be a key stratigraphic marker and can be used to guide future drilling on the Khorat Plateau.

## SUMMARY

The halite deposits in the Maha Sarakam Formation on the Khorat Plateau offer an attractive target for potash exploration. Although geochemical data are meager, they do suggest that at least one halite bed may contain a potash deposit. Despite the relatively high rainfall of the region, the halite deposits occur at remarkably shallow depths. One well near Sakon Nakhon penetrated halite at a depth of only 15 meters. Thus, if potash deposits are present on the Khorat Plateau, they might very well be the world's most shallow. Preliminary studies would also suggest that these deposits are relatively undeformed.

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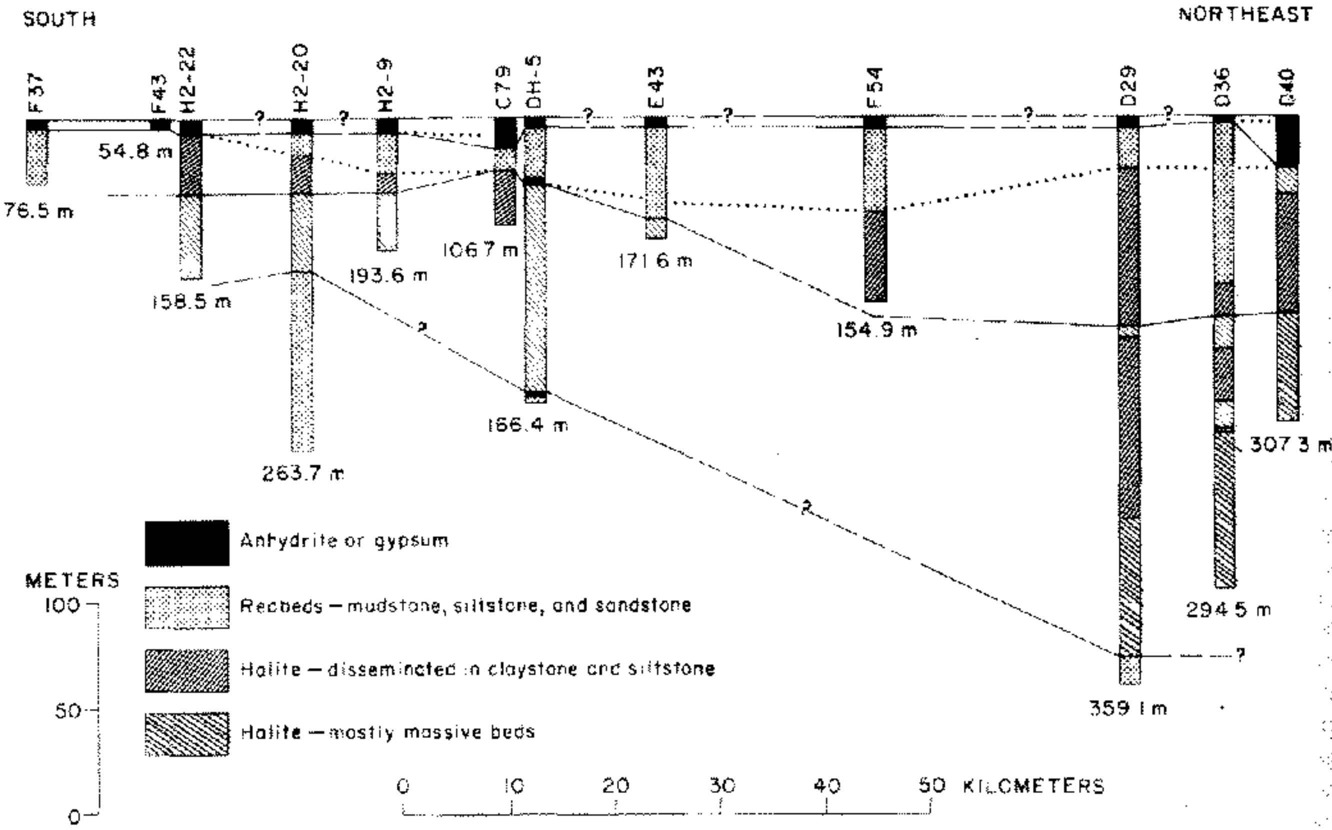


Figure 7. Stratigraphic cross-section through halite facies of Maha Sarakam Foundation, in western half of Khorat basin. Datum is upper anhydrite cycle. Solid and dashed lines show boundaries interpreted from driller's logs. Dotted line represents alternate interpretation. Line of section shown on Figure 3.

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