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REPORT ON THE WESTERN MIGRATION OF THE SOLUTION FRONT OF SALT

by

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Missing figs. 4-A, 4-B, 4-C, 6a, 6-b, and 8

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The Hutchinson salt member of the Wellington shale in Central Rice County, Kansas, near Lyons, will provide a demonstrably safe repository for radioactive wastes because of its depth, tectonic stability, and the impermeability of the zones directly above and below the member.

This member, as shown by hundreds of oil wells in Central Kansas, has north and west boundaries approximately coincident with original deposition as shown by the regular thinning of the member from a feather edge along the basin limits in north and west-central Kansas along an arc whose radii are about 50 miles north, 150 miles northwest, and 200 miles southwest of Lyons, Kansas.(Kulstead, 1959)

History of Salt Deposition

The Hutchinson salt was apparently deposited in a shallow inland sea in central Kansas and northern Oklahoma under conditions of rapid evaporation in an arid climate. The great thickness of the salt member, 300 to 700 feet, required an intermittant connection with the open sea allowing frequent recharging of the basin. It is assumed that evaporation of 80 feet of sea water produced 1 foot of salt. (Taft, 1946) Downwarping of this basin continued after deposition of salt and a cover of clayey shale of

low permeability was deposited over the salt, protecting it from dissolution. Additional Permian shale, siltstone, gypsum, anhydrite and dolomite beds were deposited over the upper Wellington shale covering the salt. A major period of erosion in early to late Mesozoic times removed part of the cover, leveling the tilted Permian rocks and leaving about 760 feet of impermeable deposits over the salt zones at Lyons, the deposits thickening to the west and thinning to the east. Deposition again dominated the area in early Cretaceous times. Remaining Cretaceous deposits over the Lyons salt area include 75 feet of marine and fresh water shale, clay, and sandstone.

Both erosion and deposition occurred intermittently and concurrently during Cenozoic time. A few feet of Tertiary deposits, including the capping "Algal limestone" of late Pliocene, are found sporadically throughout the county. Concordant elevations on this limestone indicate that central Kansas was reduced to a surface of low relief by the close of the Tertiary. (Frye, 1945)

A measure of erosion and channelling during the Pleistocene is the deep channel in the Chase channel area, 6 miles West of Lyons. Here an early Pleistocene channel eroded to a base level 200 feet beneath the top of the Algal limestone. Early Pleistocene channel erosion removed the Cretaceous rocks exposing the

Harper siltstone in west central and southern Rice County and, in the Little Arkansas Valley, the upper 130 feet of the Ninnescah shale. Later Pleistocene channelling, except in the headwater areas of the minor tributaries, has failed to remove the early to middle Pleistocene deposits in the channels.

During late Pleistocene in most of Rice County, deposition has predominated over erosion. The Lyons area and all of north-central Rice County is covered with 30 to 90 feet of silt and clayey silt underlain by a thin rubble zone of locally derived material. The silt blanket is mostly modified loess and ranges in age from Kansan near the base, through the Loveland and Peoria formations of Illinoisan and Wisconsinan age. A well developed Sangamon soil is evident between the Loveland and Peoria silts. The Bradey soil with the overlying Bignell formation can be differentiated near the surface at a few points. Central and northern Rice County has been a stable area of slow deposition throughout the upper Pleistocene.

The broad plain of the Arkansas River Valley, beginning near the south edge of Lyons, 1½ miles south of the Carey mine, has been an area of cut and fill since early Pleistocene. Deposition of sand and gravel has been predominant since Illinoisan time.

The present eastern limit of the salt is a solutional boundary, as evidenced by an abrupt face of 80 to 200 foot thickness found in wells near this margin; by the distortion of beds overlying the former salt horizon, and, by brine intrusion into alluvial gravel channelled into the shale at the stratigraphic position of the Hutchinson salt member. (fig. 1)

Deformation of Rocks Above the Hutchinson Salt Horizon

Rocks stratigraphically above the Hutchinson salt member and east of the present boundary of the salt generally show some distortion. Irregular minor folding of the Wellington shale in Saline, McPherson, Harvey, and Sedgwick Counties is generally considered to represent differential subsidence after removal of the salt. There are no recognizable index zones in the upper Wellington that can be traced at the surface and in drill holes. It is apparent, however, that this solution and deformation in the Wellington is a process that has continued to the present. Sink holes have developed within historic times in the Wellington from the east border of the salt to the east limit of the Wellington outcrop, below the stratigraphic position of the Hutchinson member. Part of this deformation of the Wellington beds results from solution of gypsum and the collapse of gypsum caverns. The sink holes most frequently occuring are those in

the alluvium and involve a sudden collapse of 10 to 1000 square feet of surface with a vertical displacement of a few feet to 10 or 20 feet. Drilling in and near this type of sink has shown piping of granular surface material into gypsum cavities of as much as 19 feet roof to floor measurement. (fig. 6)

There is some evidence of deformation of Cretaceous beds over the salt horizon. A fault in the Kiowa formation has been mapped 1½ miles south of Bennington in Ottawa County along the south bluff of the Solomon River, 3½ miles north of the Saline County line. (Mack, 1962) Southwestward from this fault, to the southwestern border of the Saline River Valley, the Permian-Cretaceous contact shows irregularity, indicating either an irregular deposional surface at the base of the Kiowa or distortion of this unconformable contact after deposition.

Some subsidence of the Cretaceous rocks over the salt horizon is indicated by the altitude of Kiowa-Permian contact lines normal to the Wellington outcrop band.

6 miles east of the southeast corner of Saline County, the base of the Kiowa is near the outcrop of the Carlton limestone, below the stratagraphic position of the Hutchinson salt member. The elevation of the Cretaceous-Permian contact at this point is about 1450 feet above sea level. The contact slopes

down to the west reflecting a gentle depression through 1400 foot altitude to a point 12 miles west of the southeast corner of Saline County where the base of the Kiowa is nearly 100 feet lower than its eastern outliers. Just west of the Smoky Hill River valley, at Coronado Heights, this contact is at 1430 feet and continues west past the west county line at about 1460 feet altitude. The general structure, assuming the outcrop of the Wellington presented a nearly level surface at the beginning of Kiowa deposition, indicates that post early-Kiowa solution and depression along this line was a little over 100 feet and occurred mostly at the extreme eastern edge of the Smoky Hill valley, adjacent to, or within 2 to 4 miles of, the early Pleistocene slumping in the valley. There is a rough correlation between the thick sandstone lenses in the basal Kiowa and this depressed contact line, indicating that solution of the salt, with a consequent topographic low, may have preceeded, or been concurrent with, Kiowa deposition and influenced the deposition of the sandstone along the line. An alternative hypothesis is that ground water circulation, enhanced by the occurrence of the sandstone lenses promoted solution of salt and gypsum sometime after Kiowa deposition.

A similar depression of the basal Cretaceous rocks is inferred near the north end of the abandoned McPherson Valley where the Kiowa-Permian contact is depressed about 120 feet compared to its elevation about 13 miles farther west where it overlies the undissolved salt ~~solution~~ section. Along this line (cross section A-A, plate 7, Williams and Lohman, 1949) the Cretaceous subsidence coincides approximately with the Pliocene channel and is 7½ miles east of the deepest part of the Kansan channel.

The depressed basal Cretaceous is also evident across the abandoned valley 6 miles south of this line where the Kiowa-Permian contact is more than 100 feet lower near the east boundary of the channel than on the west, over the salt section. The low point of the basal Cretaceous is here about 13½ miles east of the deepest Kansan channel. (Ibid, cross section B-B')

Pleistocene solution of the eastern edge of the salt is apparent along a north-south band about 25 miles east of Lyons, in western McPherson County, central Saline County, western Harvey County, and Central Sedgwick County. This eastern boundary marks the only natural dissolution of the Hutchinson member and the only point of immediate erosional attack on the stability of the salt at Lyons.

The rate of the retreat of the near-outcrop, eastern margin of the salt is measureable by a series of

Pleistocene channels that has migrated down-dip, parallel, to the salt face, following solution of the salt and solution and collapse of adjacent beds. Dating of the westward movement of these parallel Pleistocene channels, normal to the salt face, provides the most reliable measure of the rate of solution of the salt through the changing extremes of rainfall and temperature of the last two million years and is a measure of the probable retreat of the salt face through similar climatic conditions in the future. The channel migrations and subsidences reflect, not only the solution of the salt, but also solution of the thick gypsum sequence above and below the salt horizon, thus providing a rate considerably higher than is attributable to salt only. Solution and subsidence is still active in gypsum beds of the Wellington as far as 15 miles east of the present salt margin. (fig. 6)

McPherson Channel

The longest geologic record of westward migration of the eastern border of the salt, is reflected in a series of Pliocene to mid-Pleistocene channels through the McPherson channel in western McPherson and Harvey Counties. This area has been drilled extensively by the State Geological Survey and by municipal water users and oil companies. 354 logs of test holes in and near the McPherson channel are listed in bulletin 79 of the

State Geological Survey (Williams and Lohman, 1949) This Pleistocene sequence has been dated by buried soil-zones, (Frye and Fent, 1947) the Pearlette ash bed (Fent, 1950a) and invertebrate fossils. (Frye and Leonard, 1950) Pliocene channel deposits along part of the eastern edge of the valley have been dated by vertebrate fossils. (Hibbard, 1952)

Western channel migration in northern McPherson County includes a distance of 8½ miles from the center of the Delmore channel of Pliocene age to the center of the Meade channel of Kansan age. Six miles south of this line there is a 9½ mile distance between the apparent centers of the Delmore and the Nebraskan channels and 4 miles between the apparent center of the Nebraskan and the center of the basal Kansan channel. (fig. 2)

There is a possible maximum westward migration of channels in northern Harvey County of about 12 miles from the Pliocene channel to the Kansan channel.

A line of sink holes and undrained depressions, some developing within recent times, parallels the deepest part of the Kansan channel. These include the large "Big Basin", 5 miles west of McPherson, lake Inman, 8 miles south of Big Basin, and numerous small unnamed sinks 5 to 11 miles farther south. This line of sinks has been interpreted (Williams and

Lohman, 1949) as probable continued solution of the eastern margin of the salt. The center of the sinks in the McPherson channel above the Arkansas River valley are all within 2.5 miles of the center of the deepest Kansan channel and average 2 miles west of the deepest channel, probably indicating a migration of less than 2 horizontal miles of the active salt solution since Kansan time. (fig. 9) There is evidence of a post-Pearlette, pre-late-Illinoisan channel through the same area, (fig. 2) which indicates that the active solution area at present coincides with that of Illinoisan to recent age.

These undrained depressions are found farther west, within 4 miles of Hutchinson, where the deep valley fill of the Arkansas River joins the abandoned McPherson valley. (Williams and Lohman, 1949) It is known that some sinks of this type are caused by piping of granular materials into solution voids in gypsum stratigraphically near the salt horizon and others are surficial phenomena caused by piping of soil, silt, and shallow sand into coarse gravel of the channels.

Rate of Solution Retreat, Saline County

The Saline River valley, in northern Saline County, contains deposits of gravel that can be differentiated lithologically as early- and late-Pleistocene. The late Pleistocene gravel of the Saline valley after the capture of the additional headwater drainage from Wil-

son valley, contained a high proportion of western arkosic material.

The dating of the capture of this western drainage is well authenticated by paleonologic and stratigraphic evidence, including abundant outcrops of the Pearlette ash marker bed. The probably south and westward shifting of the Saline River axis, north of Salina, reflecting solution of the salt during the interval from Kansan to Illinoisan, is not more than 2 miles. (fig. 3)

Indications of slow subsidence in the lower Saline River, North of Salina, include extensive shallow water lake deposits with as much as 4 feet of silty peat over an area of about 2 square miles. (fig. 3) This peat is probably Illinoisan in age, as indicated by its position above arkosic gravel channelled into locally-derived Kansan deposits, and below channels of Wisconsinan age. The area underlain by peat is still subsiding as indicated by a ppor surface drainage in an area with a heavy clay top soil and surface depressions. An oil well, drilled near the eastern margin of the peat area, showed a few feet of salt near the base of the Hutchinson horizon, indicating that some of the sinking in this area still reflects salt removal.

Several test holes in a sink hole near the center of the NW¼, Sec. 34, T13S. R3W, cored 80 feet of

Hutchinson salt at 110 feet below the surface and 80 feet below the eroded top of the Wellington shale. A brine filled solution cavity of 0.6 feet was found at the top of the salt. (fig. 4) This actively sinking area is 3/4 mile west of the nearest known deposit of peat indicating a possible westward migration of the active solution and subsidence area of about 3/4 mile since late Illinoisan time. A test hole 1¼ miles west of this active sink encountered a brine-filled cavity above the salt at 10 feet higher elevation, but beneath 200 feet of Permian shale cover. No surface sinks are evident at this point. Less than ¼ mile west of this point the Permian is overlain by clayey shale of the Kiowa formation. Many tests have been drilled for water in the Ninnescah and Wellington formations along the eastern margin of the Kiowa overlap. Sporadic supplies are found in the Permian east of the Cretaceous cover, especially where the shale is overlain by permeable terrace gravel. No water wells are developed west of the Kiowa overlap, indicating a lack of ground water circulation where the Permian surface is protected by Kiowa shale.

Deformation of the Pre-Pleistocene Surface

Detailed drilling in the Salina River Valley north of Salina indicates a subsidence of the bedrock floor of the valley in post-Kansan time. The spacing of

wells and test holes indicates, but does not entirely preclude, a lack of drainage at the base of late Pleistocene gravel deposits. The bedrock contour map (fig. 7) shows closed contours below 1120 elevation to above 1130 elevation, indicating a subsidence of nearly 20 feet in late Pleistocene. The subsidence was probably one of general lowering of the bedrock floor, rather than the coalescence of numerous individual small sink holes. Recent small sinks in the Saline and Solomon River valleys have been shown to reflect no lowering of the bedrock floor beneath the surface expression but to be the result of piping sand into cavities in the Wellington. This phenomenon would lead to surface depression but would not contribute to lowering of the valley floor. Such piping, in the Wellington is shown to have been conducted vertically through 80 feet of shale in the western part of the Wellington area (fig. 4) and through 33 feet in the eastern part (fig. 8)

Near-vertical pipes and gravel-filled cavities in the Wellington shale can be seen in outcrop in the southwest corner of Sec. 9, T13S,R2E.

This outcrop is stratigraphically lower than the salt beds but demonstrates the competence of the shale in maintaining open fractures for the piping of gravel.

Smoky Hill River Valley

Subsidence during early Pleistocene in the south-

ern Saline county area is inferred by the abnormally broad pattern of Kansas alluvial gravel in the Smoky Hill River valley south of Salina and in the valley of Dry Creek and Mullberry Creek southwest and west of Salina.

Locally-derived gravel under silty clay of the Sappa formation extends to the valley margins. Several lenses of the Pearlette ash in the Sappa confirm the Kansan dating on the deposits. It is suggested that subsidence over the salt in the early Pleistocene allowed the development of abnormally wide alluvial deposits in these areas.

Late Pleistocene channels in central and southern Saline County show no evidence of westward migration. Well dated Kansas deposits, underlying the Pearlette ash marker bed, in the valleys of Dry Creek and the Smoky Hill River, show no distortion or elevation anomalies since deposition. (fig. 10)

Gravel deposits later than Kansan can be differentiated lithologically in the Smoky Hill valley between Lindsborg and Salina because of the predominance of locally-derived gravel before the capture of the upper part of the abandoned McPherson valley near Marquette, and by the abundance of arkosic material in the valley after its capture. (Fent, 1950,a)

Apparantly, there has been little or no solution of the salt west of this part of the valley since

early Kansan time. It is significant that the western margin of this broad valley coincides with a Cretaceous cover, mostly clayey Kiowa shale.

Additional evidence to the stability of the salt along the Smoky Hill River south of Salina is in the general absence of brine at the elevation of the salt horizon in this part of the valley. Chlorides in the ground water of the Smoky Hill River south of Salina have been generally less than 100 parts per million until recent spot intrusions of brine near oil operations. The salt is probably associated with shallow disposal of oil field brine and leakage in the vicinity of oil wells. (fig. 1)

Bedrock contours in the Smoky Hill valley south of Salina also show a regular pattern, indicating a lack of distortion since Kansan. These contours are consistent with the erosional history of the valley except north of the extreme northeast corner of Salina, (near the SE corner of Sec. 1, T14S, R3W), where some distortion of the post-Kansan surface is reflected. (fig. 5)

Lower Solomon Valley

Lack of lithologically distinct deposits in the terraces and alluvium of the lower Solomon River valley precludes interpretation of the solution rate of the salt in this area. However, the presence of strong brine in the alluvium, and the coincidence of the point of brine origin with a zone of active sink holes

and with buried peat deposits indicates that there may be active solution of salt in an eastern outlier of salt in this valley. A few oil well logs report salt just west of this area.

It is significant that the uplands immediately west of this eastern outlier are protected by a cap of Kiowa formation of very low permeability. Most of the Kiowa here is an impervious dark fissile shale with only minor quantities of fine, silty sandstone. Holes drilled into the upper Wellington shale in this upland generally encounter little or no water, but do penetrate many gypsum zones. Water wells just off the margin of the Kiowa encounter water sporadically in solution channels in these gypsum zones.

Apparently the capping of Kiowa shale is effective in retarding circulation of water from the uplands into the Wellington and, the eventual solution of the salt. This factor is of importance in extending the rate of solution of the salt westward towards Lyons. The increase in cover of Cretaceous clays and Permian shales of low permeability above the Wellington will slow the rate of ground water circulation as it progesses westward.

Solution-subsidence, Arkansas River Valley:

Late Pleistocene to Holocene solution and subsidence in the deeper channels of the Arkansas River valley is indicated by a series of closed contours on the surface

of the Wellington shale in Sedgwick County. (Lane and Miller, 1965) The 1140 feet altitude bedrock contours close down-stream at several points in the buried channel southwest and northwest of Wichita. About 12 miles northwest of Wichita, bedrock contours close at the 1120 and 1140 foot altitude. (fig. 9) The base of these channels is interpreted by Lane and Miller as of Pliocene age. The present line of surface sink holes is only 2 to 4 miles west of these channel-solutional lows, and would indicate a maximum retreat of the salt solutional border of only about 4 miles since Pliocene channeling. However, these channels from the north (Williams and Lohman, 1949) and from the west (Bayne, 1956) have been interpreted as early Pleistocene. The deeper part of the Chase Channel, in western Rice County, has been traced by test drilling through southern Rice County and central Reno County and is continuous with the Sedgwick County channels. In Rice County the material is no older than early Pleistocene as evidenced by its dissection 200 feet below adjacent outcrops of Algal limestone capping the Pliocene deposits. (Fent, 1950,b) A salt front retreat of only 4 miles since early Pleistocene is more nearly compatable with evidence from other parts of the salt margin.

The rather low rate of retreat in this area may also be due to the thick, protective cover of clastics during early and middle Pleistocene that "overfilled"

the Arkansas River valley in Sumner and Cowley Counties raising the ground water gradient and retarding subsurface drainage from the water in contact with the salt face. Early Pleistocene gravels increase in relative altitude, compared to the later gravel as the southern border of the state is approached, (Bayne, 1962) indicating relatively recent valley lowering and renewed ground water circulation from the salt horizon.

Solution west of the eastern salt margin:

Several undrained depressions and some areas of distortion of surface rocks west of the recognized eastern border of the salt and overlying the thicker salt deposits have been attributed to possible solution within the main body of the salt. These include a natural depression of 8 miles diameter and smaller depressions of several hundred feet to less than 10 feet in diameter. Some of the smaller sinks, developed within historic times are associated with drilling activities.

Cheyenne Bottoms is an undrained depression in Barton County of about 60 square miles that was, at one time, believed to have been caused by solution of the Hutchinson salt. Test drilling by the State Geological Survey, (Fent, 1950,b) has shown the Cheyenne Bottoms to be part of a buried stream channel, blocked on the southeast by alluvial and aeolian sedements.

Numerous surface faults in northern Ellis County, in townships 11, and 12S, R20W, have been shown by Merriam (1963, p.193) to be shallow features and overlie

salt of normal thickness and concordant elevation.

The Mitchell County sinks, lying near the northern border of the Hutchinson salt have been shown by Landes (1932) to be of surficial origin.

Many natural salt seeps and springs that overlie the main body of the Hutchinson salt have been attributed, incorrectly, to solution of this member. These chlorides have a source in the Cretaceous rocks and, apparently, have no connection with the Permian salt.

Salt marshes in Republic and Cloud Counties, known since the earliest recorded history of the area, receive brine from the Dakota formation. (Logan, 1897)

Salt Springs in northwest Mitchell County, used before European settlement in the area, have been proved to have a Dakota source. (Hodson, 1959)

The Dakota formation is also the source of brines in streams, including the Saline River, and marshes in Lincoln County. (Berry, 1952)

The Kiowa and Cheyenne formations in Barton and Stafford Counties contribute much salt to the Arkansas River alluvium and to deep channels in these counties. The high chloride water in the salt marshes and in Rattlesnake Creek is mostly derived from the Cheyenne sandstone. (Latta, 1950).

The high static head on brines in the Cretaceous formations precludes a Hutchinson salt source for the water/

Some brines and sink holes southwest of the main body of the Hutchinson salt member are thought to have originated in the salt deposits in the Nippewalla Group, 200 to 600 feet above the Stone Corral formation. The Meade Basin and the Meade "salt sink" are ascribed to this process by Frye and Schoft. (1942) This solution is thought to have been initiated by faulting in the vicinity of Crooked Creek in Meade County.

Other sink holes in southwestern Kansas, in Meade and Clark Counties, and in extreme western Kansas, in Hamilton and Wallace Counties are postulated by various authors as originating in the salt of the Nippewalla group.

Existing evidence indicates that this salt zone, stratigraphically above the Hutchinson member, is undergoing solution in its eastermost area of occurence. Evidence is lacking to prove or disprove the possibility of deep seated solution in extreme western Kansas.

The only evidence of solution of the Hutchinson salt member, with the exception of the eastern margin, is that associated with oil drilling activities. Several areas of solution of this member around oil wells have been investigated and the salt solution confirmed.

Oil Well Sink Holes:

The most extensively investigated solution-subsidence feature connected with oil field activities is

in the NW corner, SW¼, Sec. 2, T14S, R15W, Russell County, This sink, about 700 to 800 feet in diameter, has maximum subsidence of about 20 feet below the original land surface and includes a portion of Interstate Highway 70. A potential threat to the road structure; this sink was investigated by the Kansas State Highway Department. (oral communication, Wallace K. Taylor, 1970)

The depression, as shown by a series of aerial photographs taken from 1951 through 1957, first became evident at the surface in 1954. A series of elevations taken on highway structures shows it to be subsiding at a rate of 0.7 feet per year.

Test holes drilled in and near the sink show a depression of Cretaceous and Permian formations that increase with depth to the top of the Hutchinson salt member. Drilling records, including records of loss of fluid, indicate extensive solution in the upper part of the salt, and collapse of the shale immediately above it. The base of the salt below the sink is at an elevation concordant with that in the area surrounding it. The sink is associated with an oil well completed in 1936 and later converted to a brine disposal well. Records of a reworking attempt on the oil well indicate a break in the casing within the salt zone and excessive quantities of cement grout

lost at this horizon. Recovery attempts parted the casing in the salt zone. An inadequate seal in the upper part of the hole allowed water from Cretaceous sandstone to reach the salt and travel through the well into deep production and disposal zones. (Taylor, Ibid)

A similar sink, ½ mile west of this one, developed in 1957 when another oil well of the same age was plugged and abandoned. This sink, in the NW corner, SE¼ sec. 3, T14S, R15W, is about 800 feet wide and has a maximum depression of 4.5 feet in the center. This area has subsided at a rate of 3½ feet in 4 years. The depression of the rock structure has been verified by State Highway Department by core drilling and by contouring on a Cretaceous marker bed.

This sink also contains an abandoned oil well with a casing break at about 1300 feet depth in the Wellington salt. Reports of casing deterioration in the salt zone are common in this area. Effective salt solution appears to be confined to a radius of about 400 feet from the oil wells. A well drilled in 1968, 660 feet from the faulty oil well casing had no circulation loss in the salt.

Grouting of these wells has been proposed as a method of stopping further solution of salt beneath the highway. The repair of points of fresh water circulation through the salt zone, and into the Arbuckle, may become important in some areas, not only

to protect the salt from solution, but also to preserve fluid disposal space in the Arbuckle rocks.

A third example of Hutchinson salt solution through a broken oil well casing has been investigated by Bruce Latta, Chief Geologist of the Oil Field and Subsurface Disposal Section of the Kansas State Department of Health. An oil well, in the SE¼, Sec. 2, T20S, R11W, in Barton County was completed to 3281 feet as a producer in 1938. Surface pipe was set and cemented at 190 feet. The well was converted to brine disposal in 1946 by deepening to 3850 feet and cementing, through casing perforations, at 2500 feet. A cavity in the Hutchinson salt member existed at this time as evidenced by an abnormally large volume of cement used in grouting the well. A 150 foot section of the salt took 1000 sacks of cement without establishing surface circulation. The well was used for oil field brine disposal for 10 years by injecting water through the 6 inch casing. It was abandoned and plugged April 14, 1959. Subsidence had begun late in 1958 and a sudden surface cave-in occured on April 24, 1959. (Latta, personal communications, 1970)

This area is underlain by about 20 feet of water-bearing Pleistocene gravel and 13 feet of Kiowa sandstone which would furnish water to contribute to the movement of surfical material through the oil well

into the cavity in the salt and into the Arbuckle solution zones. An eye-witness to the early stages of the cave-in reported that shale was visible in the bottom of the sink before it filled with water. The Hutchinson salt member is in the interval between 975 feet to 1245 feet below the surface near this well. This well may still be transmitting fresh water from the Kiowa and the alluvium, through the salt horizon and into the Arbuckle. Continuing distortion of the protective fence around this sink in 1970 shows that the surface area involved is increasing.

The point nearest the Carey Mine of suspected uncontrolled solution of the salt member is beneath a slowly developing subsidence about 9 miles west of Lyons. Here, a subsidence area of about 500 feet diameter, surrounds 2 abandoned oil field disposal wells in the SW¼, Sec. 6 T20S, R9W. A maximum lowering of 10 feet, developed gradually, between 1948 and 1964. It is postulated by the State Department of Health that solution of the salt in the Wellington was effected either by the escape of brine from one well circulating through salt and into the other well, or that fresh water from unconsolidated deposits might be seeping in the annular space around the casing of either well and into the salt. (Latta, personal communication, 1970) More than 100 feet of saturated, unconsolidated material

is present over the consolidated rocks in this area. (Fent, 1950,b)

Available information indicates that solution of the salt in the Rice County area has occurred only through man-made holes penetrating the overlying beds. Salt water disposal wells have been responsible for the known uncontrolled solution, although producing wells, developing leaks in contact with both salt and with shallow aquifers, have undoubtedly contributed to the solution of the salt in small areas around wells. A survey of casing and a corrective grout program in oil wells near the Carey mine may be desirable to preclude the possibility of water circulation through the salt.

Surface Hydrology

Most of Rice County is drained by the Arkansas River and its tributaries, Cow Creek, and the Little Arkansas Riber. About 14 square miles only, in the extreme northeastern part of the county, are drained by tributaries of the Smoky Hill River.

This part of central Kansas has a drainage history of intermittent northward migration of the Arkansas River throughout the Pleistocene. In general, minor streams north of the Arkansas River have eroded the local, fine-grained sedimentary rock until their headwater areas intersect the gravel-laden channel of the Arkansas River.

Once the Arkansas River is captured into the path of a northern stream, (one of the Arkansas River's own northern tributaries) deposition of arkosic material is predomitant over erosion and the new valley is filled with sand and gravel. A continuation of this trend in the future, in a period of time and climate similar to the Pleistocene, would involve a similar northward sheet-like deposit of gravel over central and northern Rice County, its base graded to the elevation of the Smoky Hill River near Salina at an elevation about 1350 feet leaving more than 500 feet of impermeable shale cover over the top of the salt at Lyons. This assumes no erosion control structures by man and no tectonic movements greater than those of the post-Tertiary.

Ground water hydrology

Large potable ground water supplies in Rice County are limited to the late Pleistocene deposits in the Arkansas River valley and the Chase Channel. Yields exceeding 1000 gallons per minute are pumped for irrigation from wells of 50 to 100 foot depth penetrating coarse gravel of the alluvium. Highly mineralized water is encountered in the gravel of the early Pleistocene channels of about 200 feet depth and in shallow alluvium near Rattlesnake Creek in southwestern Rice County. Mineralized water is found in recent alluvium near the Arkansas River.

Mineralized water is also found sporadically in all aquifers near oil fields and in an area 1 to 1½ miles wide and 5 miles long southeast of Lyons. This

area starts at the American Salt Company plant in southeast Lyons and extends along the northeast border of the alluvium to near Saxman, 5 miles southeast of Lyons.

Most of the upland loess area of central and northern Rice County is underlain by sandstones lenses of the Dakota and Kiowa formation. Wells of nearly 100 gallons per minute of potable water can be developed where a sufficient thickness of sandstone is found.

The dissected area bordering the Little Arkansas River in northeastern Rice County slopes irregularly, beveling Dakota and Kiowa sandstone near the uplands and exposing the lower shale of the Kiowa and Permian formations near the alluvium of the River. Water supplies range from adequate near the uplands to very meager near the alluvium.

Where the Harper siltstone, Stone Corral formation and the Ninnescah shale crop out in the lower Little Arkansas River valley, supplies are often inadequate for farm use.

The alluvium of the Little Arkansas River supplies small supplies of very hard water. Yields range from a few gallons per minute to about 30 gallons per minute.

Ground water movement over the country is in a general southeasterly direction but also moves from recharge areas in high terraces, sand dunes and outcrops of Cretaceous sandstones, toward surface streams. The

detailed ground water movement is usually from the highest topography to the streams, and parallel to the flow of the streams.

There are no known, measurable quantities of ground water in the Permian formations above the salt in Rice County except for shallow, meager quantities near the outcrop of these Permian formations. A few oil wells have reported water in small quantities from the Stone Corral in the north-central part of the county where the Cheyenne sandstone intersects the pre-Cretaceous erosional surface of the Stone Corral formation.

The Stone Corral formation, near the Carey mine, more than 500 feet above the top of the salt section, may carry small quantities of water in the upper part.

No water has been found in the Wellington shale above or below the salt. Permeability in the Wellington is found only near its outcrop about 20 miles east of Lyons where it is not covered by younger Permian or Cretaceous shale.

Erosional History of the Central Kansas Salt Area:

The general rate of retreat of the eastern boundary of the salt was about 4 miles per million years in the early Pleistocene and about 2 miles per million years in late Pleistocene. The faster rate in the early Pleistocene is probably attributable to two factors. First, post-Pliocene and Nebraskan erosion may have been more severe in central Kansas in response to tectonic movements near the beginning of the Pleistocene

Also, the earlier Pleistocene channels reached the salt-solution area at shallower depths, on the eastern, near-outcrop margin of the salt.

Late Pleistocene erosion was slowed in central Kansas by the influx of heavy deposits of arkosic gravel provided by captures of streams whose headwater areas reached into thick Tertiary deposits of western Kansas and eastern Colorado.

The Arkansas River advanced northward into the southern part of the Great Bend Prairie in Kansan time, occupying and filling a series of deep Nebraskan channels as far north as central Reno County. Coarse arkosic clastics of Kansan age were spread over much of south-central Kansas by aggrading, shifting streams. In the late Pleistocene additional captures of the Arkansas River carried the shifting cover of coarse clastics north to the extreme northern border of the Great Bend Prairie, several miles north of the present position of the river, occupying part of an old channel of Nebraskan and Kansan deposits through the eastern drainage of the Cheyenne Bottoms outlet and Chase Channel in west and west-central Rice County, (Fent, 1950,b) Late Pleistocene river avulsions have moved the channel back to the south of its northermost position, leaving a wide cover of Illinoisan and Wisconsinan clastics.

Later Pleistocene erosion by the ancestral Arkansas River failed to cut as deeply as the earlier local streams in southwestern and central Kansas. It has tended rather, to "over-fill" the older valleys, covering many former local divides between streams to form the broad plain of sand and gravel known as the Great Bend Prairie. (Fent, 1950,b)

The Smoky Hill River also changed to an aggrading stream across the outcrop belt of the Wellington shale in Saline County, reducing exposure of the shale overlying the salt horizon and reducing the base level for ground water movement in post-Yarmouth time. An arkosic sand terrace of probable late Illinoisan age along the Smoky Hill valley near Salina is 80 to 100 feet above the deposits of the Pearlette Ash overlying locally derived Kansan gravel. Wisconsinan and Holocene deposits cover the ash horizon with about 40 feet of material. The base of the deeper channels of late Pleistocene are cut slightly below the elevation of the deeper ash deposit but, in the valley south of Salina not as deep as the channels. (Bayne and Fent, 1963) The "overfill" of this part of the Smoky Hill valley followed the capture of the longer headwater area from the former course of the Smoky Hill River through the McPherson valley. The "overfill" with its protective cover and consequent raising of the base level for ground water

circulation may have been the principle reason for the apparent stagnation of the solution and collapse process since Kansan times along this section of the valley.

The Saline River, also involved in a post-Kansan capture of a western source of abundant arkosic material, but with a much smaller headwater area than that of the Smoky Hill, has cut below its old Kansan base level. This deeper channel may account for continued late Pleistocene solution of salt in notthern Saline County by providing a renewed deeper ground water circulation during this time. (fig. 3)

The lower Solomon River, during early Illinoisan alluviation, deeply buried these Kansan deposits but renewed erosion of the Wellington shale floor of the valley in late Illinoisan and Wisconsinan. Brine is now being discharged into the lower part of this valley near an area of active sink holes and peat deposits. (fig. 1)

The large area of high chloride water in the Smoky Hill River alluvium south of the confluence with the Solomon River is probably derived from the Hutchinson salt member west of Salina. Brine entering the base of the alluvium in the area of closed bedrock contours has probably traveled through shale fractures to the large solution channels in gypsum near the base of the Wellington shale. Extensive test drilling in the valley

12 miles northeast of Salina has disclosed Wellington gypsum cavities of 19 feet height, partly filled with sand and gravel and saturated with strong brine. (fig. 6) Salt was produced commercially from this area in 1867. Surface sink holes are numerous in this area and several sink holes have developed in the last few decades. These sink holes do not reflect a collapse of the shale overlying the cavities but develop from piping of the granular material into the gypsum voids.

Continued solution along the west side of the abandoned McPherson Valley, as evidenced by the undrained depressions in this area, may also be caused by deeper ground water circulation. While post-Kansan erosion has not cut as deeply as the lowest Kansan channels in the abandoned valley proper, late Pleistocene dissection of both the north and the south end of the valley have allowed increased ground water drainage from the channel.

In the lower Arkansas River valley, in eastern Sumner and western Cowley Counties, the river has been actively eroding the bedrock floor of the valley during Wisconsinan time. Strong chloride brines issue from the Wellington shale at the valley base in the vicinity of Belle Plain in northeastern Sumner County near the Kansas-Oklahoma border.

Brine issuing from the Wellington shale at the horizon of the Hutchinson member in southeastern Sumner County raises the chloride content of Slate Creek from 81 parts per million 4 miles east of Wellington to 13,700 parts per million south of Adamsville near the east county line.

Water in Salt Creek 2 miles west of Gueda Springs contains 124 parts per million chloride and at Gueda Springs, on the east county line, 8 miles north of the Oklahoma line, it contains 19,800 parts per million chloride. (Walters, 1961)

The coincidence of deeper channeling and lower ground water drainage base with high chloride and surface depressions along the eastern border of the salt; and the apparent stability of the border of the salt where base for drainage has been raised, suggests that the primary accelerating factor in solutions of the salt is increased circulation of ground water.

This indicates that factors that might increase the dissolution of the salt, other than natural stream degradation of the bedrock base, would include river channel dredging, increased ground water pumping or drainage, and increased disposal of liquids into the "lost circulation zone" of the Wellington shale near

the eastern margin of the salt.

At present municipal and irrigation uses in the extensive gravel deposits just east of the eastern border of the salt are increasing. Some areas of lowered water table are evident in areas of heavy usage. The Wichita Municipal wells (Lane and Miller, 1965) have caused measurable lowering of the water table in a 100 square mile area. Increased withdrawals of fresh water for municipal, industrial and agricultural uses will help to inerease circulation of ground water and acfelerate solution of the salt.

Shallow brine disposal along the eastern margin of the salt is generally into porous gypsum beds near the salt horizon or, in some cases, the porour top af the Hutchinson salt. Brine injection is permitted at depths below 225 feet. Oil field brines, most of which are not saturated, will also add to the dissolution of the salt.

Other oil drilling activities are adding to salt dissolution along the eastern margin. Many oil wells, especially those drilled through thick Pleistocene gravel, leak water through broken casing or imperfect surface seals into corroded openings at the salt horizon. A few uncased holes penetrating both the fresh water aquifers and solution cavities in and

near the salt have provided permanent ground water conduits to increase the solution of the salt.

It is possible that man's withdrawal and drainage of water east of the Hutchinson salt and his additions of water west of the salt border can effect more increase in solution rate than natural geologic processes.

Methods of Refining Dating on Salt Retreat

The apparent westward migration of the area of active salt solution in the Saline River valley could probably be dated more precisely by obtaining actual ages on the peat deposits that mark an area of late Pleistocene activity. Possibly this peat can be dated by radio-carbon measurements.

There is an abundant fossil moluscan fauna directly above and below the peat. Large diameter cores of the peat and adjacent clay beds could be obtained for analysis.

Vertical displacement of more than 20 feet as indicated by the closed contours on the Wellington north and northeast of Salina can be proved by close spacing of test holes along two lines for possible outlet gradients. Two or three test holes of 50 to 100 feet are needed near the southwest corner of section 31, T1, T13S, R2W, and 4 to 6 holes along the east line of the same section. It is emphasized that the finding

of such a channel would indicate less salt solution in the late Pleistocene and alter the salt dissolution estimate toward the safe, slower rate.

Chloride contents of the ground water at the base of the alluvium have been measured at many points east of the Hutchinson member in the last few decades. A few observation wells could be installed near points of these older measurements and periodic sampling and testing conducted to determine any increase in rate of salt solution. Any increase would reflect not only possible additional salt dissolution, but also any other sources of chloride contamination. They might, however indicate areas for future corrective grouting or other abative measures.

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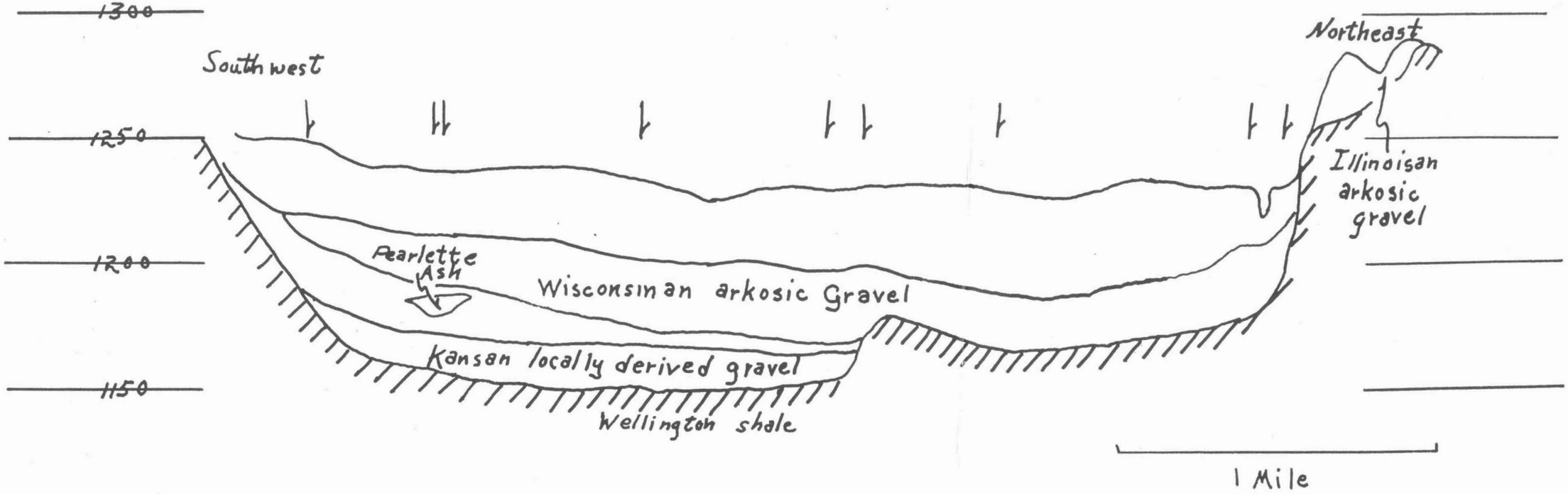
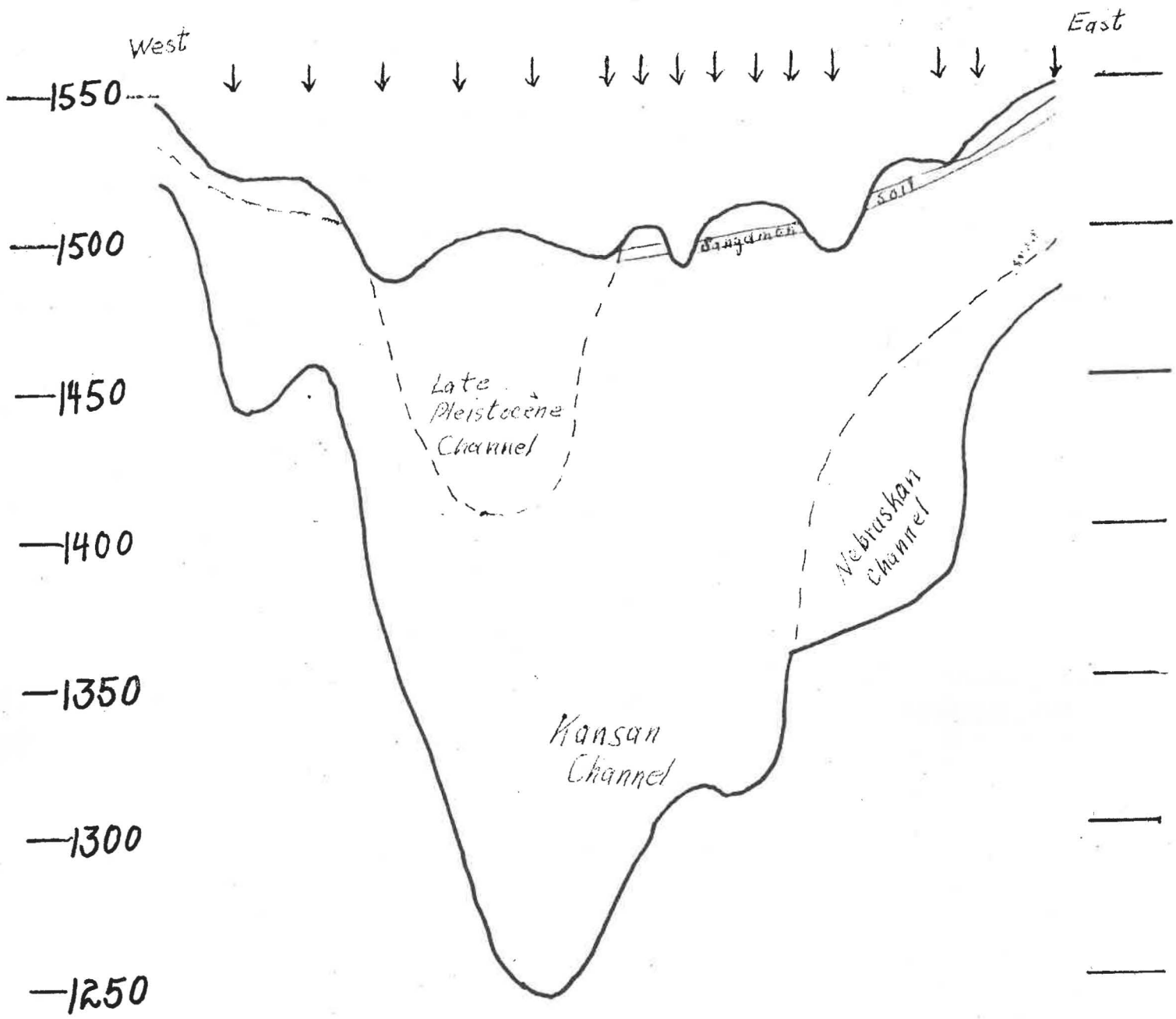


Cross section through the Smoky Hill River Valley south of Salina, Kansas
Arrows indicate test holes

Figure 10

Kansas Geological Survey
Open-file Report 70-4
figure 10



Cross Section Near North End of McPherson Channel
Modified from Williams and Lohman, 1949, plate 6
Top arrows indicate test holes
Horizontal Scale, 1 inch = 2 miles

Fig. 2

Kansas Geological Survey
Open-file Report 70-4
figure 2

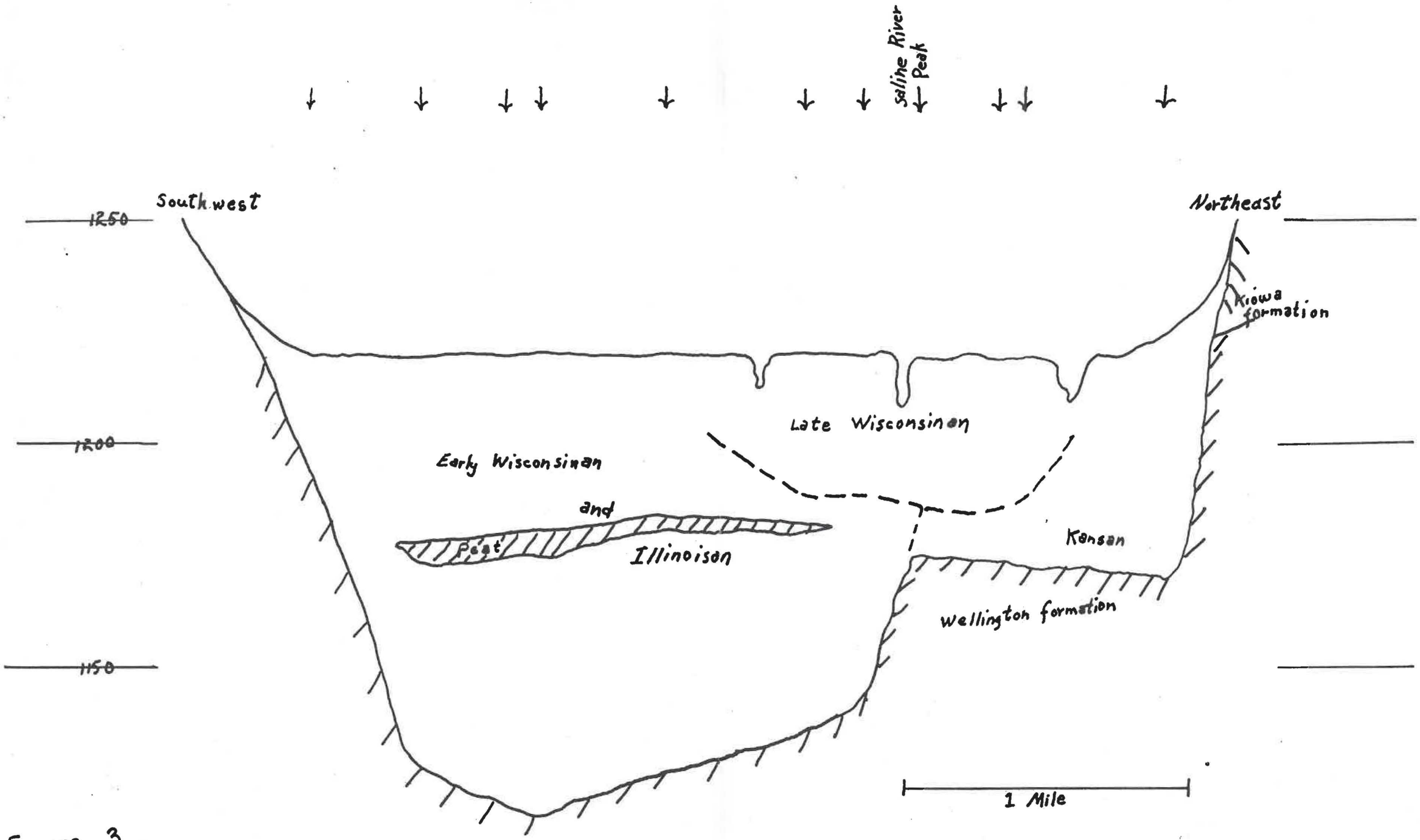


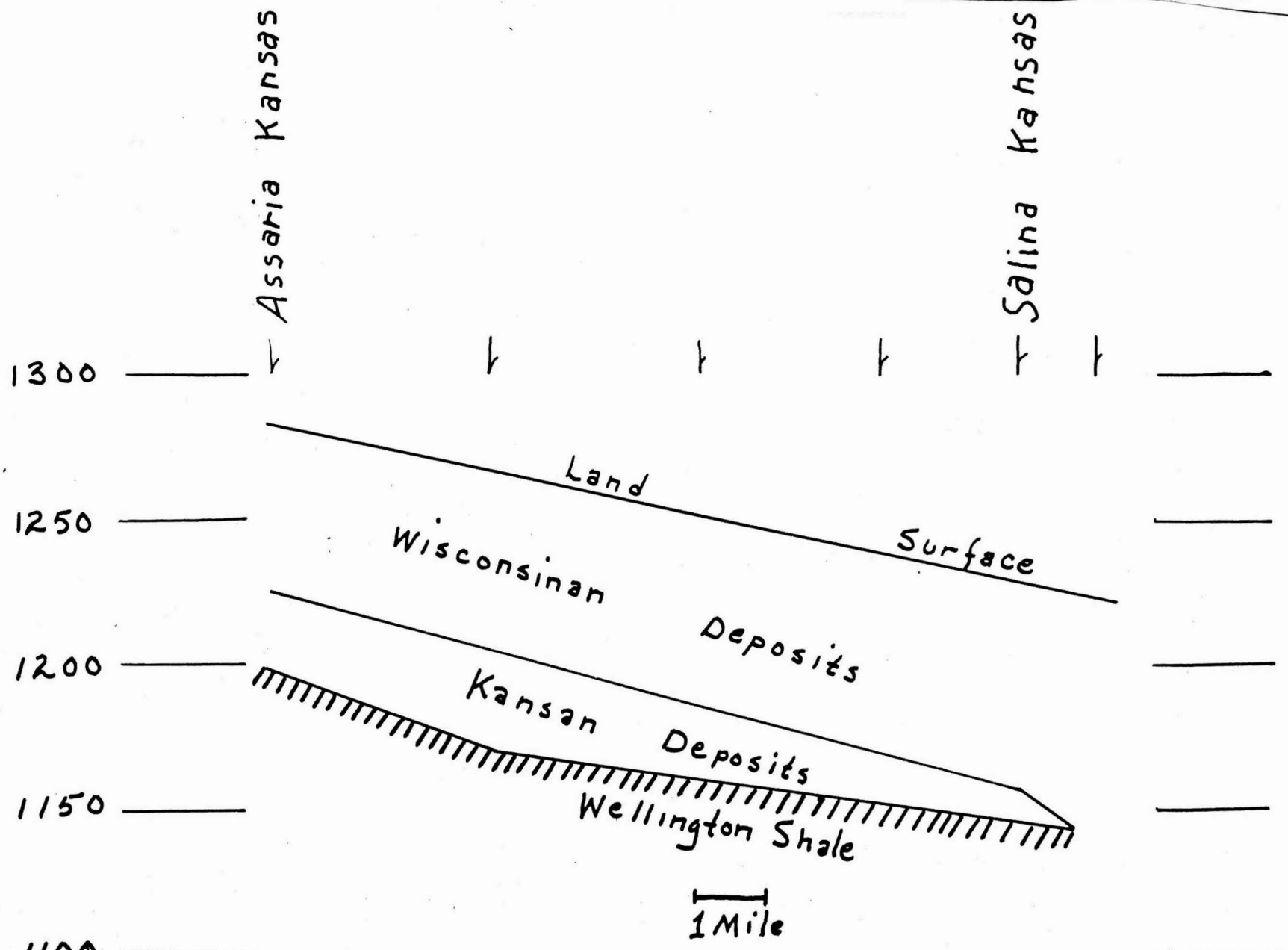
Figure 3

Cross section of Saline River Valley North of Salina, Kansas

Arrows indicate test holes

Horizontal scale 2½ inches = 1 mile

Kansas Geological Survey
Open-file Report 70-4
figure 3

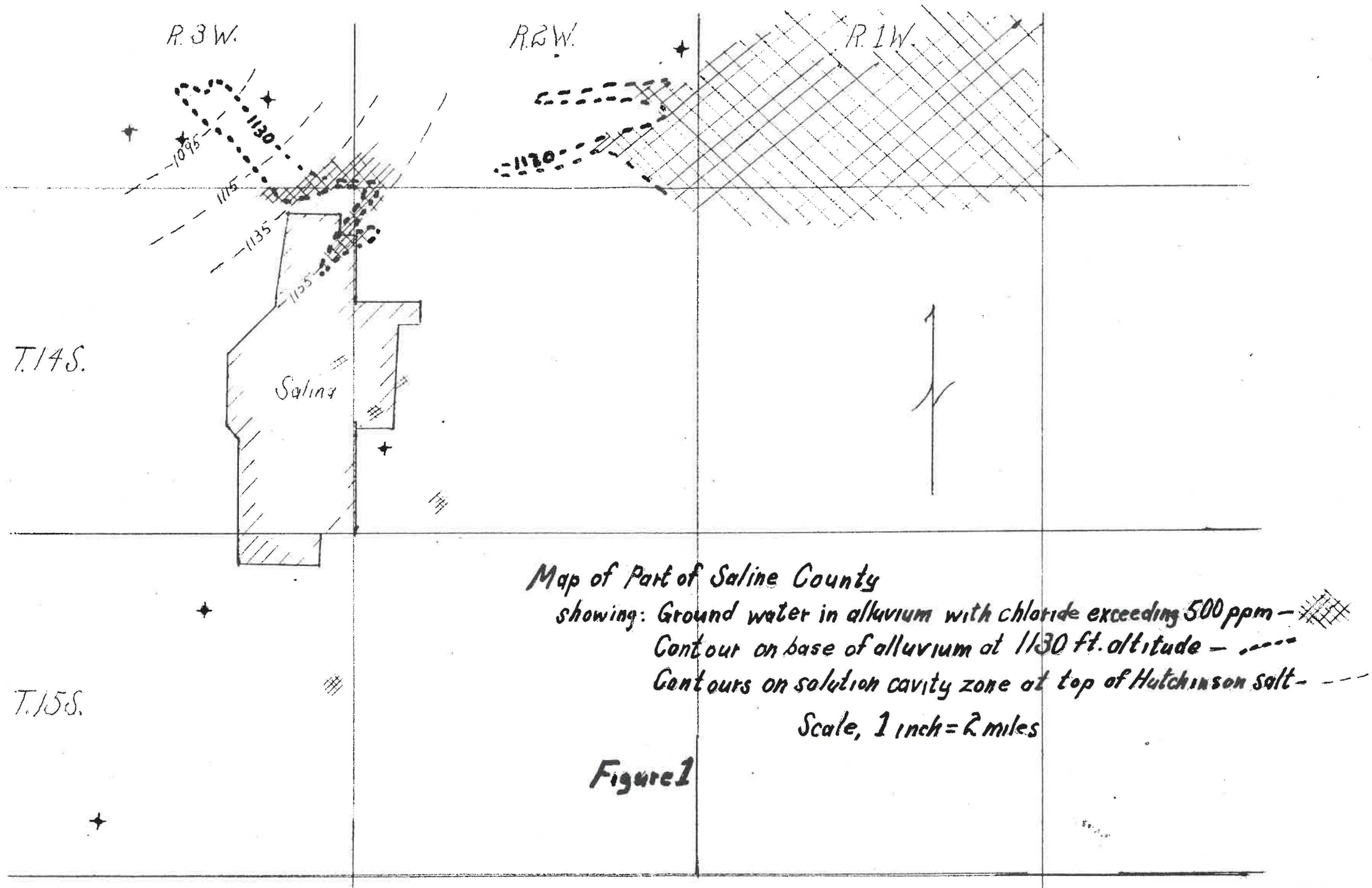


Longitudinal cross section along the Smoky Hill River Valley from Assaria, Kansas to Salina, Kansas

Arrows indicate test holes or groups of test holes

Figure 5

Kansas Geological Survey
Open-file Report 70-4
figure 5



Map of Part of Saline County
showing: Ground water in alluvium with chloride exceeding 500 ppm –
Contour on base of alluvium at 1130 ft. altitude – ----
Contours on solution cavity zone at top of Hutchinson salt- ----

Scale, 1 inch = 2 miles

Figure 1

Kansas Geological Survey
Open-file Report 70-4
figure 1