HYDROGEOLOGY IN THE ADJACENT UPLANDS OF THE SALINE, SMOKY HILL AND SOLOMON RIVERS IN SALINE AND DICKINSON COUNTY

by

LLOYD E. DUNLAP

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Henry V. Beck
Major Professor

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INTRODUCTION

Purpose of Investigation

The Kansas Water Resources Board and the U. S. Geological Survey are currently investigating saline effluents into the Saline, Smoky Hill, and Solomon River Valleys between Salina and Abilene, Kansas. This salt emission has direct effect on the water supplies used by more than a fifth of the state's population. The saline waters occur in the alluvium along the Smoky Hill River from east of New Cambria, Kansas, to west of Abilene, Kansas. This investigation of the hydrogeology and ground-water quality of the uplands adjacent to and above the sale emission area was made to obtain a better understanding of the relation of the hydrogeology of the uplands to the sale emission area on the floodplain. Any correlation should aid in establishing the location, areal extent, and cause of the saline-effluent problem, and help in formulating a plan for control of effluent seepage into the river.

The adjacent uplands have a history of low-quality ground water. This study should aid in locating future water supplies for agricultural, domestic, and rural water districts needs.

Location of Area

Approximately 430 square kilometers (170 square miles) excluding the valley floors of the Solomon and Smoky Hill Rivers were investigated in the uplands in Saline and Dickinson Counties, Kansas (Fig. 1). The study area including the river valleys, is 27 to 29 kilometers (17 to 18 miles) long, 14 to 16 kilometers (9 to 10 miles) wide and is bounded on the west by Salina, Kansas, on the north by Ottawa County, on the east by Sand Springs, Kansas, and on the south by Township 15 South.

Previous Investigations

Latta (1949) studied the geology and ground-water resources of the Smoky Hill River valley. He determined the ground-water quality in the floodplain and found that the alluvium of the Smoky Hill and Solomon River valleys had been contaminated by highly mineralized water from the underlying Wellington Formation near Solomon, Kansas. Latta constructed cross-sections from test borings in the river valley to show the thickness of the valley aluvium and depths to the several formations.

Bell (1974) studied the ground-water quality in the floodplain from Sand Springs to Enterprise, Kansas, and included extensive chemical analyses of ground water in the area. Bell attributed the high sulfate concentrations to the solution of gypsum in the Wellington Formation and Doyle Shale, and the high sodium and chloride concentrations to solution of evaporites or salt bring moving up-dip from the Hutchinson Salt Member of the Wellington Formation.

Fent (1970) reported on the Hutchinson Salt Member of the Wellington Formation. He described the geology and the water-yielding capabilities of the Wellington and Kiowa Formations in the study area.

Mack (1962) reported on the geology and ground-water resources of Ottawa County, Kansas. He described the Dakota Formation and Kiowa Formation and their ability to yield water to wells.

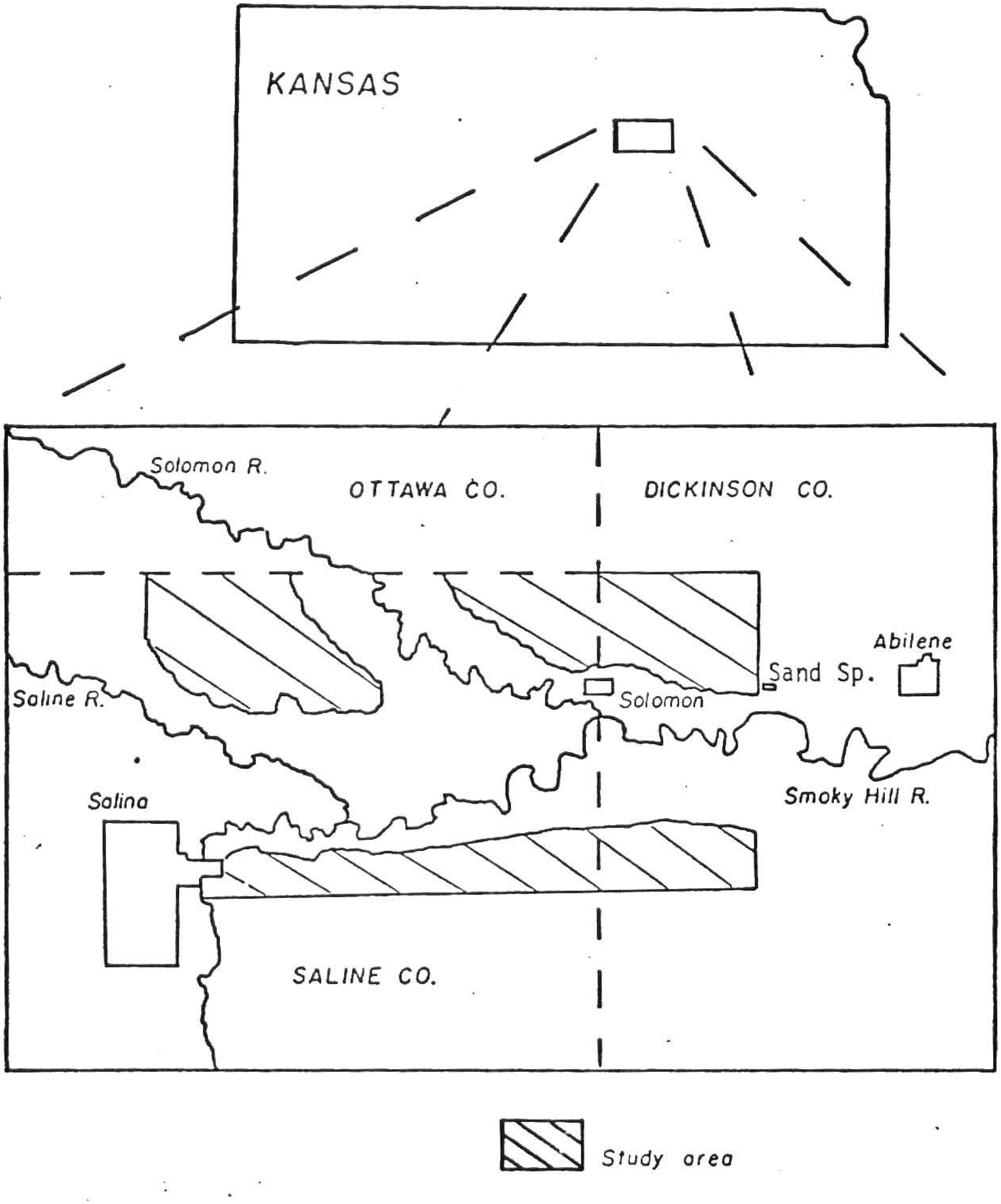


Fig. 1. Location of study area

Kulstad (1956) reported on gypsum deposits in the Wellington Formation. Kulstad gave locations on gypsum mines in the study area and described the stratigraphy of the gypsum in the area.

Well Location and Numbering System

Well locations are numbered using the General Land Office surveys in the following order: township, range, section, quarter section, quarter-quarter section, quarter-quarter-quarter section 4 hectare (10 acre) tract. Where two or more wells are within the same 4 hectare (10-acre) tract, the well locations are numbered serially according to the order in which they were studied. The well number designates the quarter section, quarter-quarter section and 4 hectare (10 acre) tract by a, b, c, and d in a counter-clockwise direction, beginning in the northeast corner with "a". For example a well that has a number 10 6E 9ddd, is in the SE¼, SE¼, SE¼, Sec. 9, T.10 S., R.6 E. Well locations are in Figure 2.

Water samples were numbered using the well number followed by a letter designating the order in which the samples were collected from a single well, starting with the letter "a" and proceeding alphabetically. For example two consecutive samples taken from the same well would be labeled: 10 6E ddd#a and 10 6E 9 ddd#b.

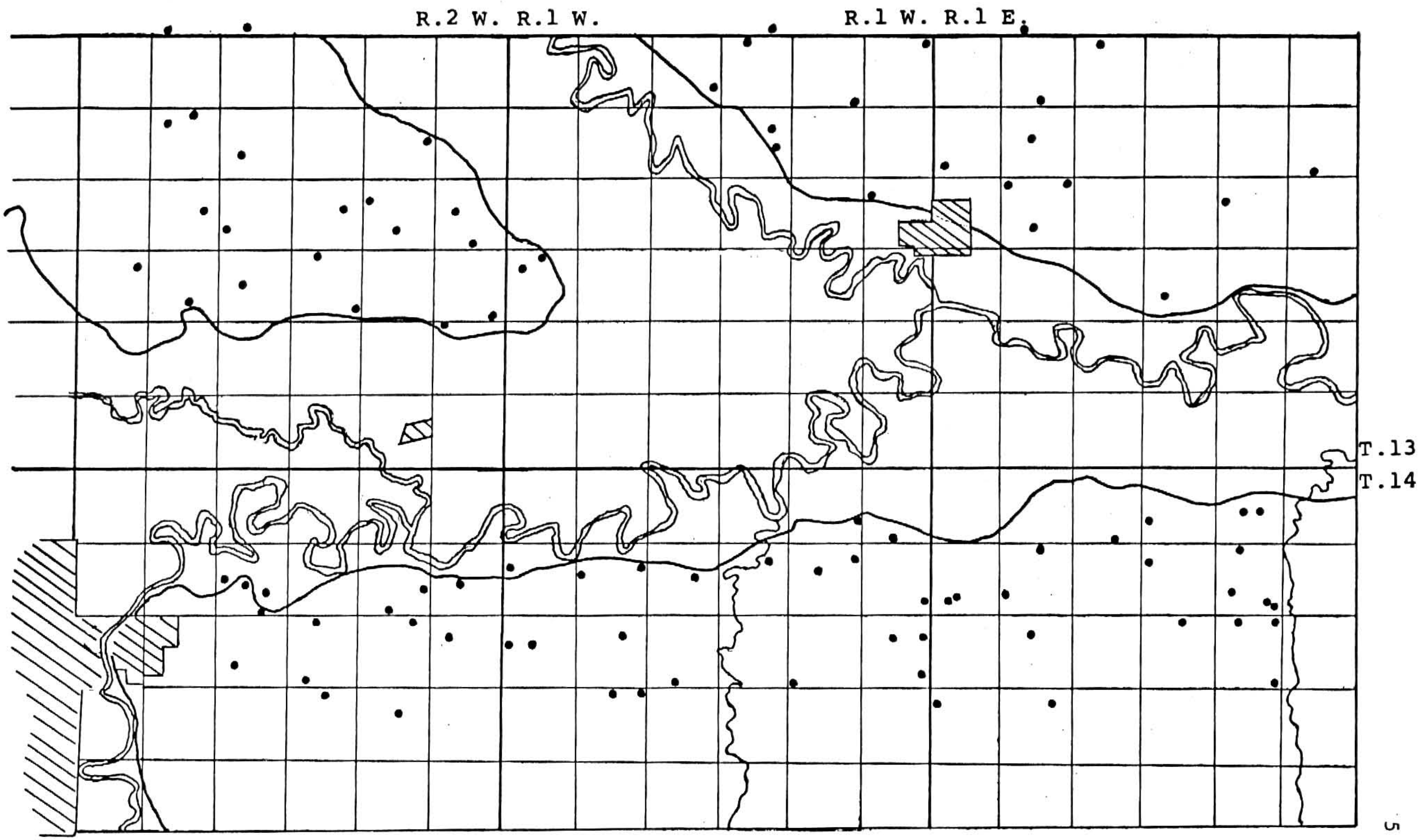


Figure 2. Location of wells

RELATION OF GEOLOGY TO GROUND WATER

Bedrock

The Wellington Formation and Kiowa Formation are exposed in the uplands adjacent to the salt emission area (Fig. 3). The Wellington Formation of the Summer Group, Cimarronian Stage, Permian System is the lower of the two formations (Plate 1). The Wellington Formation is about 212 meters (700 feet) thick and consists chiefly of gray shale, with red and green shale in the lower part. The shale contains discontinuous beds of rock gypsum and limestone (Figs. 4-7). The Hutchinson Salt Member of the Wellington Formation has been dissolved near the surface so that its eastern subsurface extent lies west of Salina, Kansas. The salt dissolution is thought to be the source of the salt emissions to the ground water in the study area.

The Wellington Formation is a poor aquifer, because the shale has low permeability. Some water wells that tap the shale have yields of only a few gallons per minute and may go dry during drought. In some places the small lenticular beds of gypsum have been dissolved, resulting in channels and cavities for the flow of ground water. Water from the Wellington Formation is frequently of poor quality because of the large amounts of soluble minerals in the formation.

Differential subsidence after removal of the salt from the Wellington Formation has caused irregular minor folding in the shale. Sink holes are in the Wellington Formation from the eastern extent of

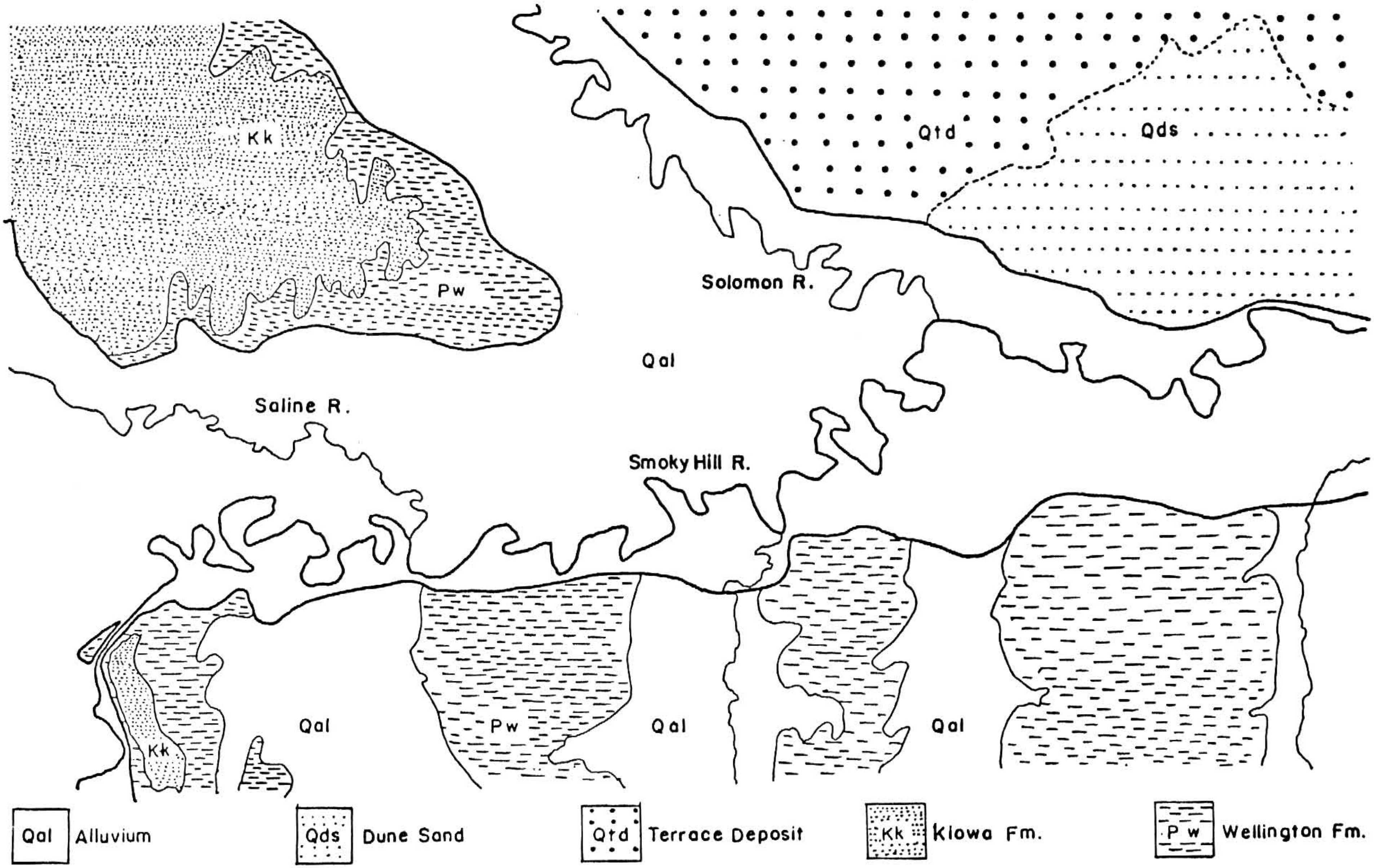
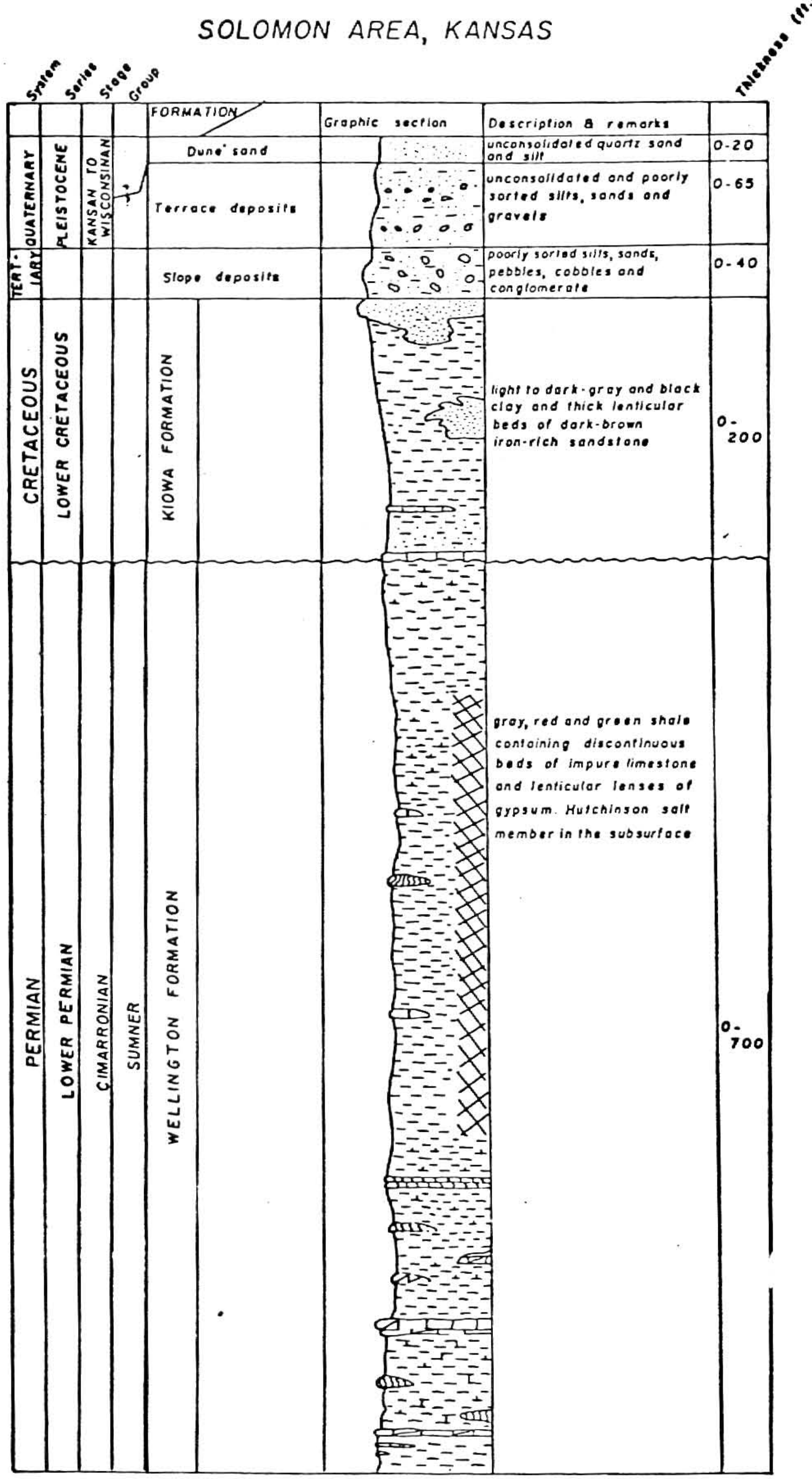


Fig. 3. Areal geology of study area
modified from Franks, 1968 and Latta, 1949.

PLATE I

GENERALIZED STRATIGRAPHIC SECTION
SOLOMON AREA, KANSAS



(modified from Zeller, 1968)

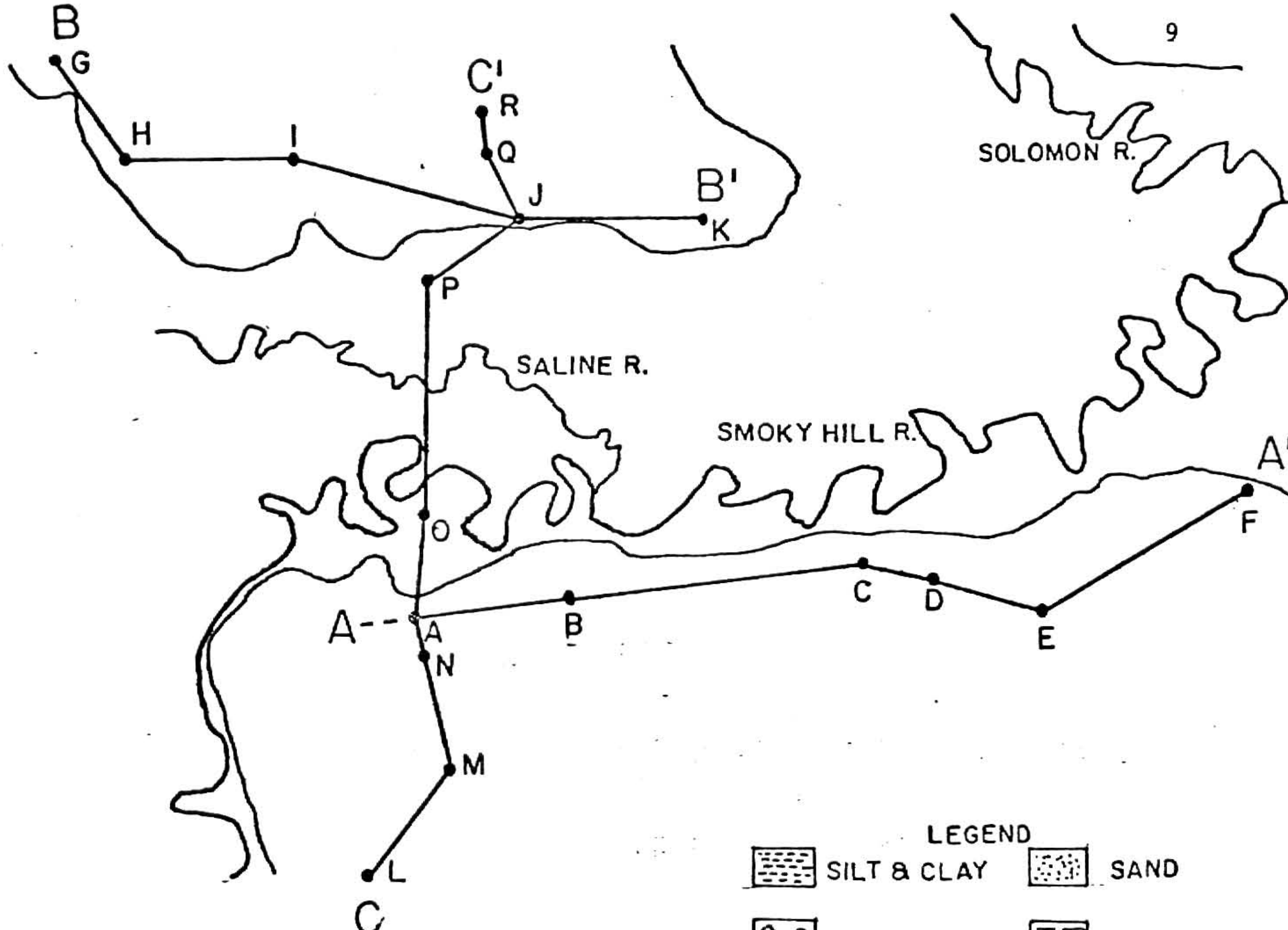


Fig. 4. Location of cross sections

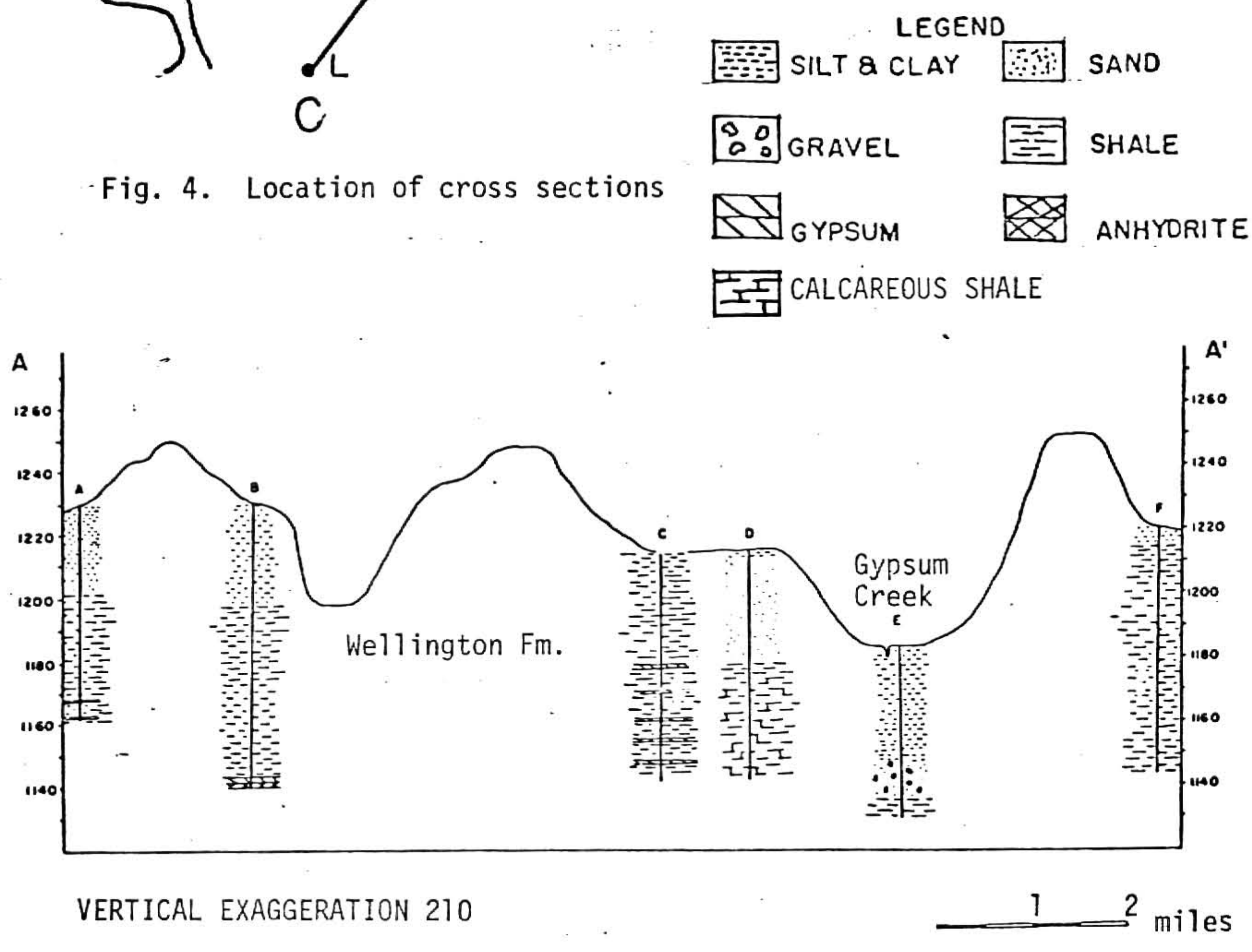


Fig. 5. Geologic cross section A-A'

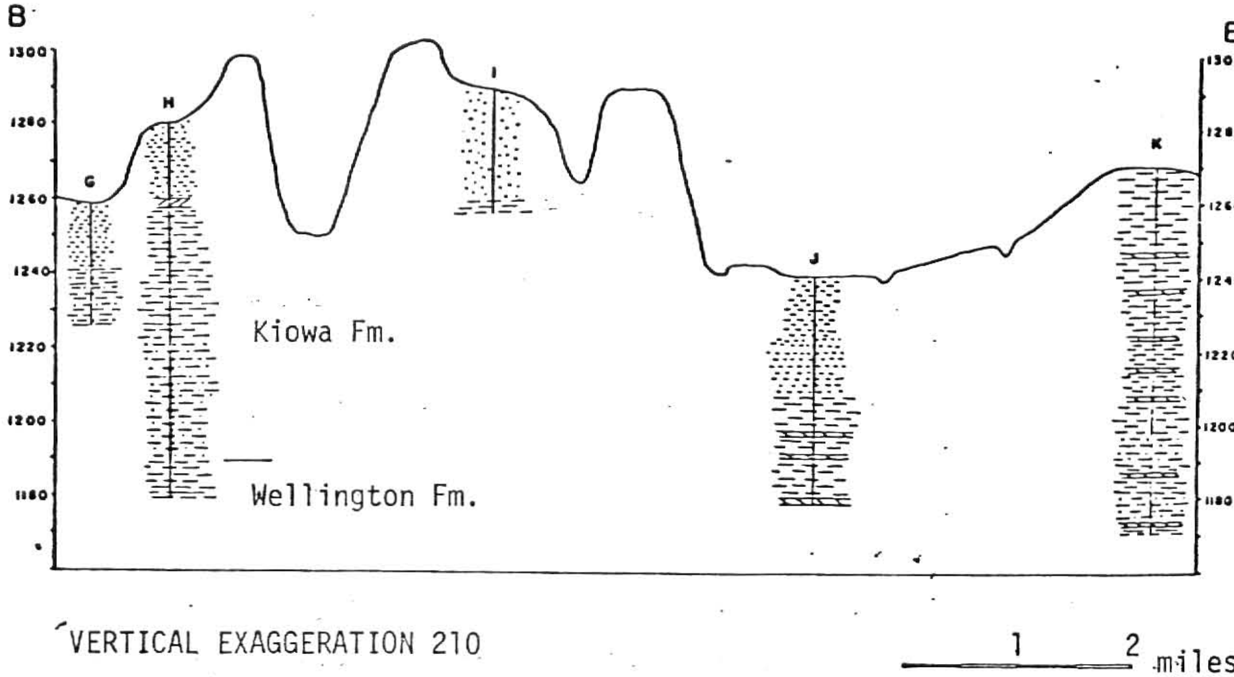


Fig. 6. Geologic cross section B-B'

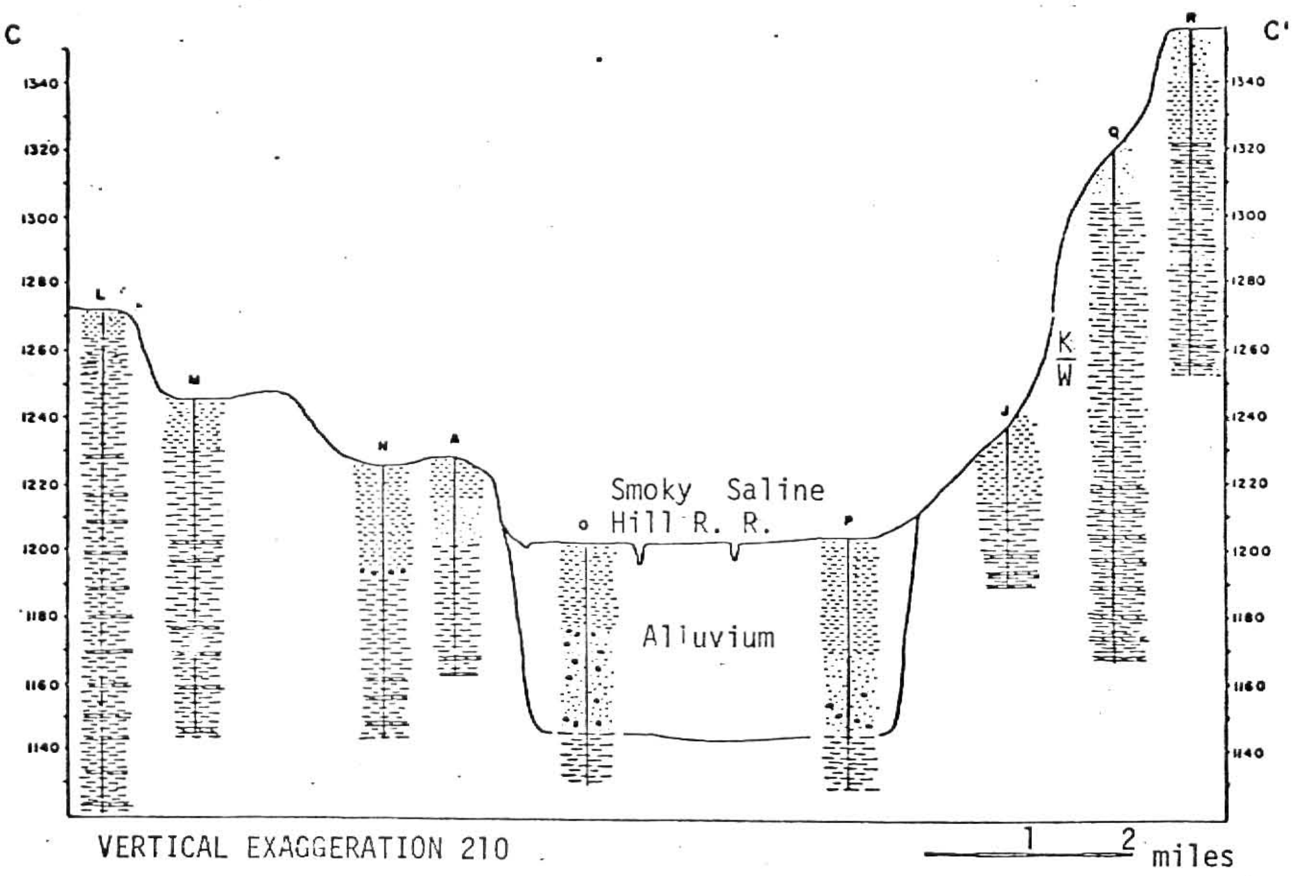


Fig. 7. Geologic cross section C-C'

the salt to the eastern limit of the Wellington Formation outcrop. These sinks can be attributed to solution of gypsum and the collapse over gypsum caverns in the shale. Sink holes are most frequent in the alluvium of the Saline, Solomon and Smoky Hill river valleys. The sinks involve a collapse of 1 to 92 square meters (10 to 1000 square feet) of surface with a verticle displacement of up to 6 meters (20 feet) (Fent, 1970, p. 5).

The Kiowa Formation of the Comanchean Series, Creteaceous System, nonconformably overlies the Wellington Formation in the divide between the Saline and Solomon River valleys (Fig. 3). Maximum thickness of the Kiowa Formation is 60 meters (200 feet). The shale consists of clay and shale and thick lenticular beds of iron-rich sandstone. The sandstone beds are resistant and crop out along the hillsides.

The Kiowa Formation, like the Wellington Formation, is impermeable and is a poor source of water, but the sandstone lenses, are good aquifers. Wells that penetrate the sandstone lenses generally yield an adequate supply of water for domestic and stock uses (Latta, 1949, p. 28).

Water wells drilled through the Kiowa Formation into the upper Wellington Formation penetrate many gypsum zones but encounter little or no water. This indicates a lack of ground-water circulation where the Wellington Formation is protected from percolation through the Kiowa Formation. Near the margin of the Kiowa-Wellington contact, some water wells encounter water in solution channels that have formed in the Wellington Formation gypsum zones (Fent, 1970, p. 12).

According to Fent, some subsidence of the Kiowa Formation over the salt horizon is indicated by the shape of the Kiowa-Wellington contact in southern Saline County. Going from east to west this contact slumps nearly 304 meters (100 feet) over a distance of 32 kilometers (20 miles). Fent proposed that post-Kiowa Formation solution of the salt and gypsum in the Wellington Formation may have caused the subsidence.

Remnants of the Dakota Formation overlie the Kiowa Formation in an area between the Saline and Solomon Rivers. The remnants have an area of less than 1 square kilometer (one-half square mile) and are not indicated on the areal geology map. The Dakota Formation remnants are above the water table and are not considered in this report.

Tertiary and Quaternary Slope Deposits

Slope deposits of silt, sand, gravel and conglomerate occur in the uplands in southern Saline County south of the Smoky Hill River (Figs. 4-7). These deposits overlie the Wellington Formation and usually cap the hills. The sediment of these deposits were derived locally from sheetwash and soil creep at and for a short distance beyond the base of the westward-retreating Cretaceous rock (Latta, 1949, p. 29).

Poorly sorted clayey sand and gravel with small grains of sand, ironstone, shale, and caliche nodules are in the lower sections of the deposit. In some places, the sand and gravel have been firmly cemented to form a conglomerate. The upper sections of the deposit consist of sandy silt with pebbles and cobbles of sandstone, ironstone, shale and caliche irregularly distributed throughout. Although these deposits range from a few meters to about 12 meters (few feet to about 40 feet) thick, they are commonly less than 3 meters (10 feet) thick (Latta, 1949, p. 29).

Although the exact age of the deposits is not know, they probably were first deposited in the Tertiary Period when erosion of the Kiowa Formation and Dakota Formation began. These deposits are not known to be aquifers because they are above the piezometric or watertable surface in the study area. These deposits are along the tributaries south of the Smoky Hill River and are not differentiated from the alluvial deposits on the areal geology map (Fig. 3).

Terrace Deposits

Fluvial terrace deposits of Pleistocene Epoch overlie the Wellington Formation between Solomon and Abilene, Kansas (Fig. 3). The terrace deposits consist of clay, silt, sand and pebbles of quartz sandstone and ironstone from the Dakota Formation. The deposits range from 15 to 19 meters (50 to 65 feet) thick under the dune sand near the Smoky Hill River and thin from the Smoky Hill to the north (Latta, 1949, p. 30-31). The conditions that caused the Smoky Hill to "over-fill" and deposit these sediments are not exactly known. The highest deposits are more than 30 meters (100 feet) above the floodplain.

The silts, sands, and gravels form lenses that overlap one another irregularly. Lenses of sands and gravels range from a few centimeters to 4 meters (few inches to 5 feet) thick and are common in the lower part of the terrace. Pebbles of ironstone and sandstone are near the base of the deposit. Some pebbles are cemented with calcite forming a conglomerate. (Latta, 1949, p. 30-31).

The sands and gravels of this terrace deposit form good aquifers for the sand hills area north of Sand Springs. The cover of highly dune sand in the Sand Springs area is an excellent recharge area for the terrace.

Dune Sand

Dune sand covers a large area north of Sand Springs in the northeast portion of the study area. The dune sand consist of quartz sand and a large amount of silt. The dune sand ranges from .9 to 4 meters (3 to 15 feet) thick (Latta, 1949, p. 31). The dune sand is at the surface and above the water table in the area.

METHODS OF INVESTIGATION

Field Methods

Measurement of the Water-Table. Measurements of depth-to-water were made on several wells in the study area to the nearest 0.03 meter (0.01 foot) with the surveyor's steel tape. Elevations of the wells were surveyed to the nearest 0.15 meter (0.5 foot) using an automatic level and elevations at section corners or half-sections lines on quadrangle maps of the U. S. Geological Survey as benchmarks.

Maps and Cross Sections. Quadrangle maps, 7.5 minute series, from the U. S. Geological Survey were used to establish well locations. Concentration maps indicate concentrations of dissolved constituents in the gound water at the depth the water entered the well. Cross sections were constructed from well logs provided by O. S. Fent.

Collection of Water Samples. Water samples were collected in 500 milliliter polyethylene sample bottles from wells. Each well was flushed thoroughly by pumping and the sample bottle rinsed three times before collection. The first samples collected (designated as "a") were filtered through a 0.45μm membrane filter in the laboratory approximately 15 days after collection. Subsequent samples collected were filtered in the field immediately after collection. These latter samples were divided into two parts, one remained untreated and the other was acidified with two milliliters of 8N HNO_3 per liter.

Analysis of Water

Only dissolved constituents that constituted a major contamination problem in the area were analyzed. All analyses were performed on filtered samples. Specific conductivity was measured after allowing the samples to reach room temperature. Hardness was calculated by determining concentrations of calcium and magnesium by atomic absorption spectrophotometry. Chloride activities were measured using a specific-ion electrode and converted to concentrations by activity coefficient corrections. The activity coefficients were based on estimates of ionic strength taken from the specific conductivity data. Sulfate concentrations were determined by a turbidimetric method described by Taras (1974, p. 334).

DISCUSSION AND INTERPRETATION OF DATA

General Characteristics of Ground Water

Subsurface water. Ground water is defined as that part of the subsurface water that is in the zone of saturation. The water in the soil and in the unsaturated zones above the water table is called vadose water, and moves downward under the influence of gravity when soil moisture exceeds field capacity.

Vadose water terminates below the capillary fringe. The surface of the capillary fringe is irregular and constantly changes with variations in water level. The upper part of the capillary fringe contains many air pockets. In the lower part of the fringe the sediment is fully saturated.

Phreatic water or the zone of ground water begins at the water table. The water table is a theoretical surface in unconfined material along which the hydrostatic pressure is equal to the atmospheric pressure. This is the approximate elevation that the water would rise in a well that penetrates the phreactic zone. (Davis and DeWiest, 1966, p. 39-42).

Ground-water recharge. Ground water is derived from precipitation. Part of the precipitation runs off directly into streams and ponds and a large part is retained by the soil where most evaporates or is transpired by vegetation. The soil water that is not absorbed by plants or evaporated may percolate down through the soil (if soil moisture is high enough) and underlying sediment until it reaches the water table. Most of the recharge in the phreatic zone of the Wellington Formation comes from percolation through the vadose zone. Evidence for this is that cavities in the gypsum that contain water are not found in the Wellington Formation where it is overlain by the impermeable Kiowa Formation (Fent, 1970, p. 12). Gypsum cavities in the Wellington Formation located close to a stream may be recharged by surface water.

Hydrogeology of the Wellington Formation

Shale. Most fine-grained terrigenous rocks such as shale and siltstone have relatively high porosities, but low permeabilities. Shales, claystones and most argillites develop closely spaced joints if the rocks are near the surface. Rocks severely distorted such as the Wellington Formation will result in faults and fractures which permit water movement. Most shales are barriers to the movement of water and act as confining beds for artesian systems.

Gypsum. The gypsum, anhydrite and halite in the Wellington Formation was apparently deposited in a shallow inland sea in Central Kansas and Northern Oklahoma. After the deposition of the halite and gypsum beds in the Wellington Formation, a cover of clay and silt was deposited protecting the evaporites from dissolution.

The part of the Wellington Formation stratigraphically above the Hutchinson Salt Member is distorted east of the eastern extent of the salt. Small irregular folds in the Wellington Formation in the study area were formed by differential subsidence during removal of the Hutchinson Salt Member.

Cross sections (Figs. 4-7) show poor lateral continuity of gypsum beds between well logs. This is due to the distortion of the Wellington Formation. Sink holes have been reported by farmers in many regions of the study area which indicates that gypsum dissolution and the collapse of gypsum caverns has continued to the present.

Little water for wells is found in the Wellington Formation west of where the Wellington is overlain by the Kiowa Formation. This indicates that the shale in the Kiowa Formation is very impermeable and little water is percolating from the Kiowa Formation into the Wellington Formation. This also suggests that water in the Wellington Formation is usually found in gypsum cavities where the different amounts of gypsum have dissolved due to ground water circulation. Where the Kiowa Formation overlies the Wellington Formation, this circulation of ground water is virtually absent resulting in undisturbed lenses of gypsum (Fent, 1970, p. 12).

Fent's (1970) contour map of the bedrock surface below the Saline River shows closed contours below 340 meters (1120 feet) above sea level to above 343 meters (1130 feet) above sea level which indicates subsidence of nearly 6 meters (20 feet) in the Late Pleistocene. This subsidence occurred as a general sinking of the bedrock floor, rather than as the coalescence of several individual sink holes (Fent, 1970, p. 12).

Several small sink holes have been observed on the surface in the Saline and Solomon River valleys, but these sinks are probably the result of funneling of silt, sand and gravel into gypsum cavities of the Wellington Formation beneath the alluvium. The filling of gypsum cavities by alluvium has been reported through 24 meters (80 feet) of shale in the western part of the study area and through 10 meters (33 feet) of shale in the eastern part of the study area. These gypsum cavities indicate open fractures through which the alluvium travels (Fent, 1970, p. 13).

Fulstad (1956), in a series of cross sections made from electric logs, showed that gypsum beds exist in the subsurface in Saline and Dickinson Counties. His cross sections indicated that gypsum at an unspecified depth is laterally persistent and can be traced over several miles. Kulstad stated that near the surface in the zone of weathering, gypsum is not persistent and slumping is observed in the Wellington Formation where gypsum has been dissolved.

In T. 14 S., R. 1 W., Sec. 3, dad, there is a measurable exposure of gypsum interbedded with shale. Gypsum was formerly mined from an underground shaft near this outcrop. Grimsley and Bailey (1899, p. 58) gave the following description of what was known as the Solomon Mine:

> "The mine entrance is 15 feet above the water in the creek, and the stratum worked is 5 feet thick, underlaid by about 4 feet of shaly limestone. Below this there is a series of shales with a 3-foot stratum of gypsum. The roof of the mine is a compact, dark shale with thickness of 3 feet. Above this come 2½ feet of buff shales and gypsum to the top of the hill. The shales with the intercalated gypsum layers are folded and broken. The folds extend down into the mine, causing the shales of the roof to cut out the gypsum in many places, so that the mine has now, in 1898, been abandoned. The dip of the gypsum is north, toward the creek."

Grimsley and Bailey (1899, p. 59), correlated this outcrop with another gypsum bed at a gypsum mine 32 kilometers (20 miles) to the southeast near Hope, Kansas, and a gypsum bed at a gypsum mine two miles south of Salina, Kansas. According to Grimsley and Bailey the gypsum bed had a dip of 1.2 to 1.8 meters (four to six feet) to the west. Comparison with a 1955 U. S. Geological Survey Quadrangle map indicates that an error of over 15 meters (50 feet) in the elevation of the gypsum outcrop at the Solomon Mine exists in the report by Grimsley and Bailey, thus little reliance is given to this westward dip. According to the electric log cross sections of Kulstad (1956) as many as five gypsum beds occur in the subsurface. Whether these beds were differentiated by Grimsley and Bailey is not clear in their report.

Lee, Leatherock and Botinelly (1948, p. 111) showed 30 to 45 meters (100 to 150 feet) of anhydrite beds underlaying the salt where the salt occurs west of Salina. They stated:

> "The combined thicknesses of the parts of the Wellington above and below the salt lentil are essentially the same as outside the area of salt deposition. The salt therefore accumulated in a basin formed by the downwraping of the nearly flat surface of the 'anhydrite zone'."

Surface and shallow subsurface data from oil well logs in Kulstad's report (1956) suggested that gypsum beds in the study area correlate with the anhydrite zone found below the Hutchinson Salt Member west of Salina. These logs also show a regional dip (over three counties from Ellsworth to Dickinson) to the west. Therefore, the anhydrite zones are downdip from the gypsum in the study area. The alteration from anhydrite to gypsum could be explained by hydration of the anhydrite in the zone of weathering or by original deposition.

High chloride water in the Smoky Hill River alluvium is probably derived from the Hutchinson Salt Member west of Salina. The brine probably originates from the solution of the salt by water traveling down through fractures in the shale to the gypsum-anhydrite zone. The brine could travel east through previously formed solution cavities in the anhydrite or gypsum, and discharge into the alluvium in the Smoky Hill River valley near New Cambria and Solomon, Kansas.

Oil well logs in Kulstad's report (1956) indicate that there are two gypsum-anhydrite zones in the Wellington. The lower zone, stratigraphically below the Hutchinson Salt Member, is the zone mentioned in the previous paragraph. The upper zone, stratigraphically above the salt, has slumped over on top of the lower gypsum zone after the dissolution of the salt in the study area. This upper zone also contains cavities where the gypsum has dissolved away. Distinguishing these two zones is difficult; the only difference is that the upper zone may be more distorted due to the slumping after removal of the salt. The following observations indicate that the aquifers in the study area are mainly the gypsum cavities of the upper and lower zone. 1) According to several owners, many wells have continued to produce water even during heavy drought periods. This suggests a greater storage coefficient and permeability than for fractured shale. 2) Water well drillers usually find very small quantities of water in the Wellington Formation unless a gypsum cavity or an occasional thin limestone bed is encountered. When a driller does drill through a gypsum cavity, chances of the well yielding substantial water are greatly improved. 3) Slumping and sink holes in the area indicate the formation of cavities by gypsum dissolution. Cavities in the phreatic zone are most likely to be filled with water.

Quality of Ground Water

The specific conductance of natural water is the ability of the water to conduct an electric current and is given in micromhos. Specific conductance increases as the concentration of dissolved minerals in the water increases. The specific conductance of a particular sample depends on the number, type and charge of ions, their mobility or rate of movement and the temperature of the water. Figures 8 and 9 show the relationships between sulfate vs. specific conductance, and chloride vs. specific conductance for ground waters in the study area.

Highly mineralized ground water containing mainly sulfate, chloride, calcium, and magnesium is found in the uplands. The source of the dissolve sulfate is gypsum ($CaSO_4 \cdot 2H_2O$) or anhydrive ($CaSO_4$), both of which are readily soluble in water. Sulfate is complex ion and can associate with calcium, magnesium, and sodium to form the ion pairs $CaSO_4^o$, $MgSO_4^o$, and $NaSO_4^o$. When the sulfate concentration increases in water, an increasing proportion of the sulfate becomes associated (Hem, 1970, p. 162-170). If the concentrations of dissolved magnesium sulfate (Epsom salt) and sodium sulfate (Glauber's salt) are high enough, they have a laxative effect on persons not accustomed to the water (Johnson Division, 1975, p. 66-67). The U. S. Public Health Service recommends that sulfate in drinking water not exceed 250 mg/l.

The source of chloride is halite or residual connate water deposited in the Wellington Formation. The concentration of chloride in ground water in the uplands was found to be less than the chloride concentration in allubial waters. The source of the brine in the alluvium is the dissolution of the Hutchinson Salt Member where it is near the land surface. The U. S.Public Health Service recommends that drinking water not exceed 250 mg/l chloride. Dissolved calcium in water of the uplands is from dissolution of gypsum, limestone, dolomite and dolomitic limestone typical of the Wellington Formation.

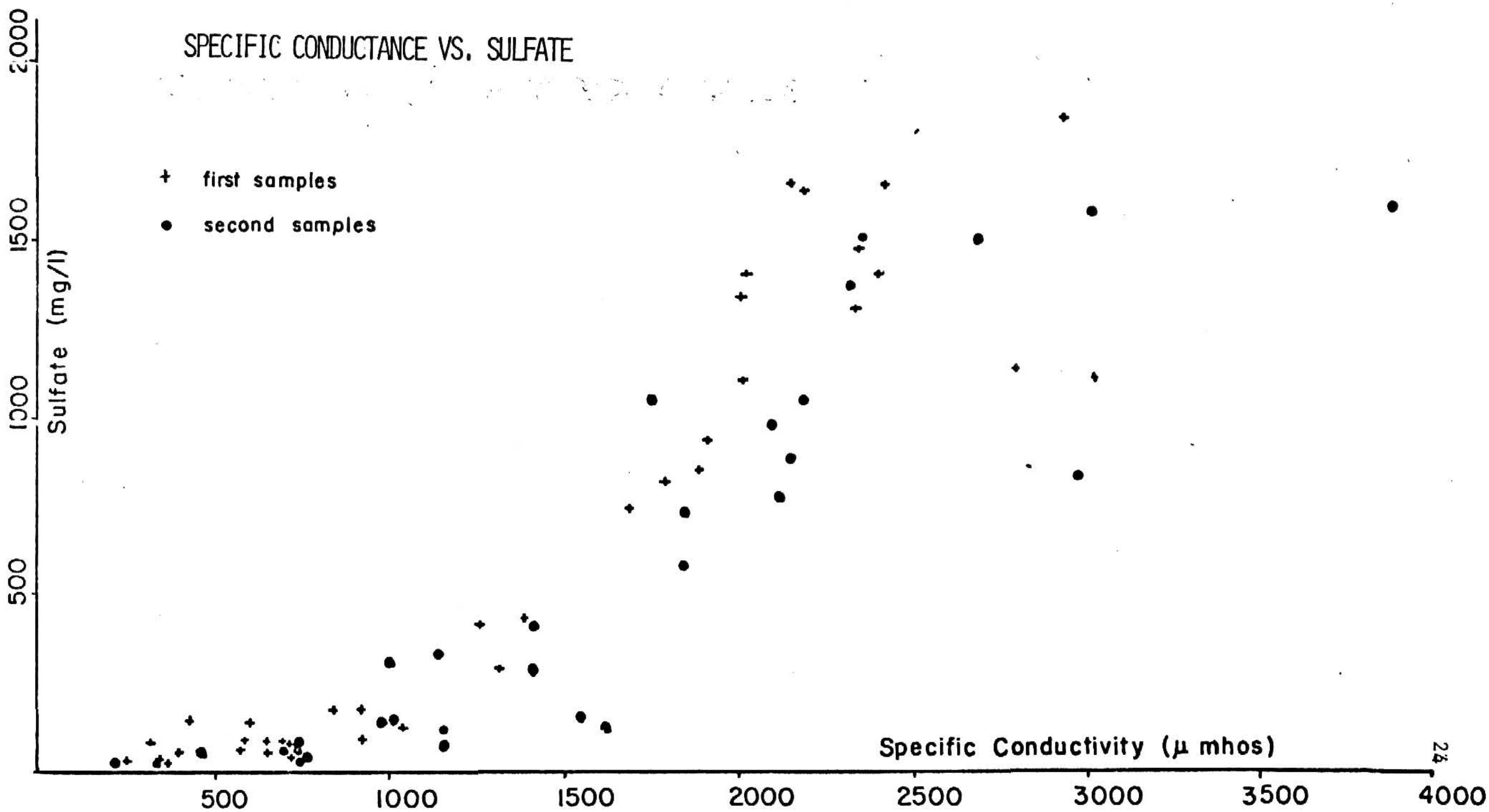

SPECIFIC CONDUCTANCE VS. SULFATE
first samples
second samples
Sulfate (mg/l)
500
1000
1500
2000
Specific Conductivity (μ mhos)
500
1000
1500
2000
2500
3000
3500
4000

Figure 8.

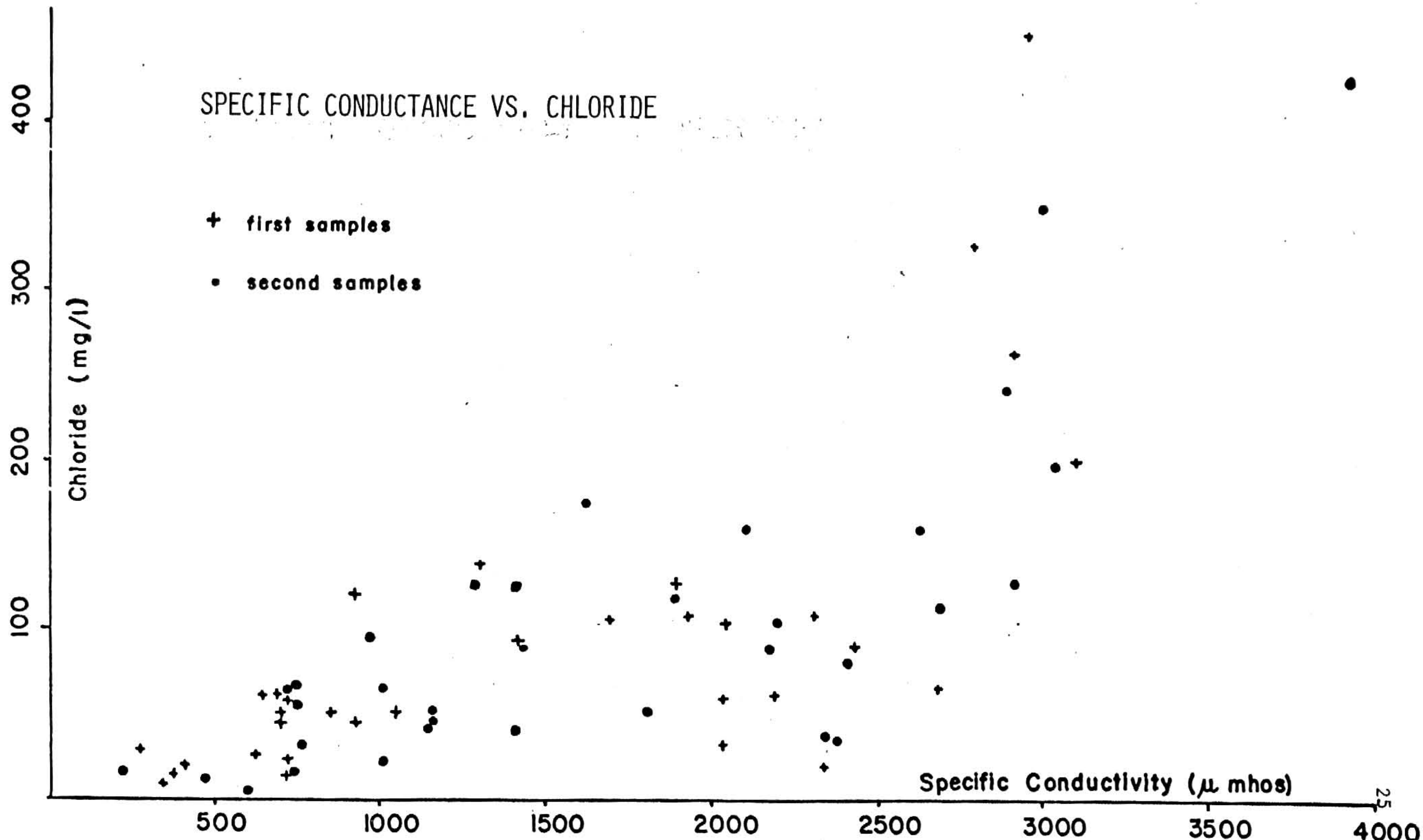

SPECIFIC CONDUCTANCE VS. CHLORIDE
+ first samples
• second samples
Chloride (mg/l)
100
200
300
400
Specific Conductivity (μ mhos)
500
1000
1500
2000
2500
3000
3500
4000

Figure 9.

Total hardness of water, which is the measure of calcium and magnesium content and usually expressed as the equivalent of calcium carbonate, can be divided into carbonate and non-carbonate hardness. Carbonate hardness is defined as the calcium and magnesium equivalent to the bicarbonate and carbonate. Most of this hardness can be removed by boiling the water (Johnson Division, 1972, p. 66-67). The non-carbonate hardness is the difference between the total hardness and carbonate carbonate hardness. It includes the calcium and magnesium equivalent to chloride, sulfate and nitrate ions that are present. The U. S. Public Health Service recommends that for drinking water the concentration should not exceed 200 mg/l calcium and 125 mg/l magnesium. (Johnson Division, 1972, p. 66-67).

Sulfate, chloride, calcium and magnesium concentrations in well waters of the study area are in Figures 10-13. No obvious pattern of concentrations of dissolved constituents in the well waters exists in the study region, therefore no isocon lines were drawn. The main aquifer of the Wellington Foramtion is probably cavities of various sizes formed by water moving through the gypsum. The greater the residence time of the water in the gypsum, the more highly mineralized the water becomes.

Wells 14 1E 7cbd#2 suggest that cavities that are closer to the surface have smaller amounts of gypsum. Water from well 14 1E 7cdb#2, (bottom of the well at 347 meters (1143 feet) above sea level), and a sulfate concentration of 1050 mg/l, while water from well 14 1E 7cdb#2, (bottom of the well at 354 meters (1163 feet) above sea level), contained only 725 mg/l of sulfate. Upper cavities would be closer to percolation and should have more gypsum dissolved away. Lower cavities

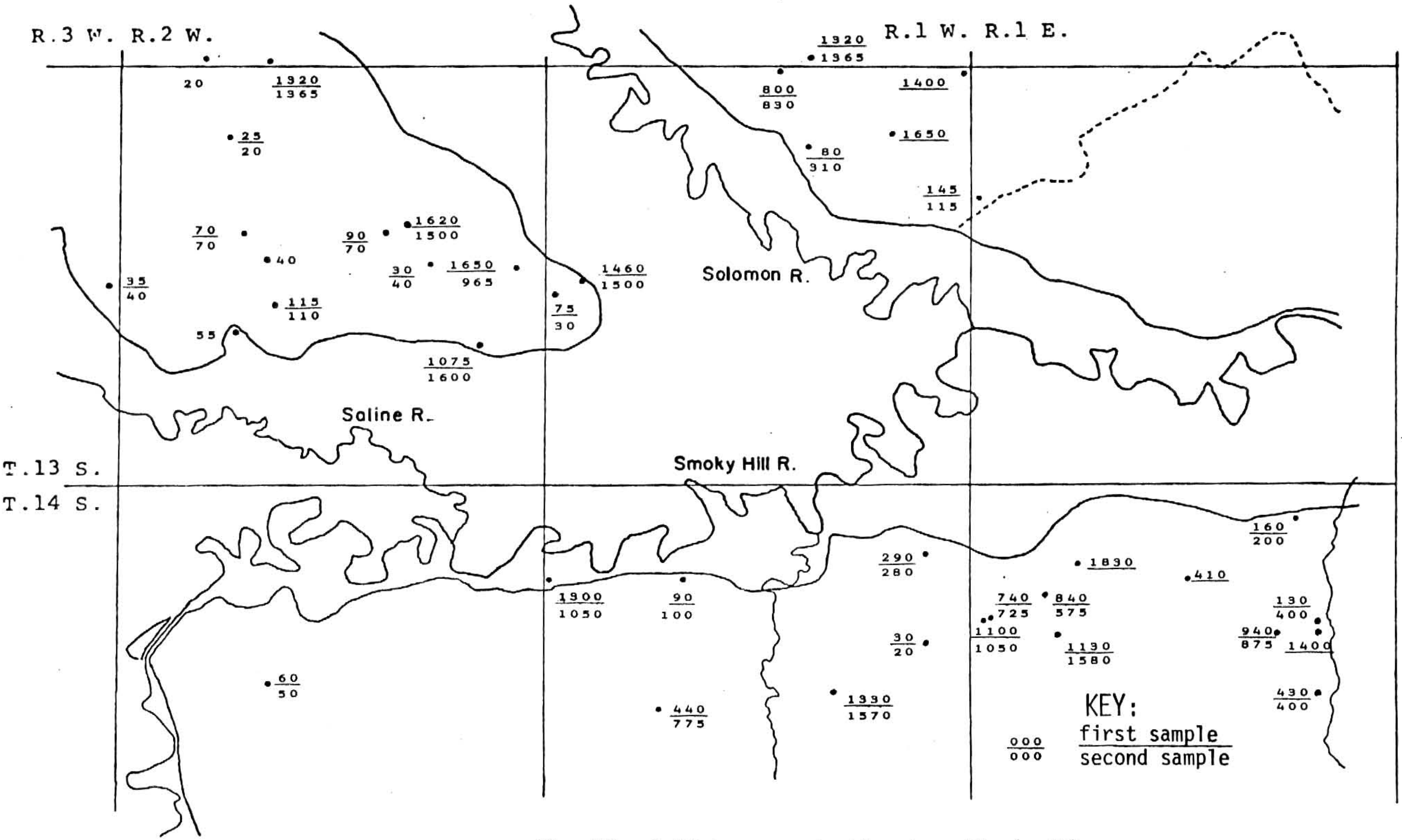


Fig. 10. Sulfate concentration in wells (mg/1)

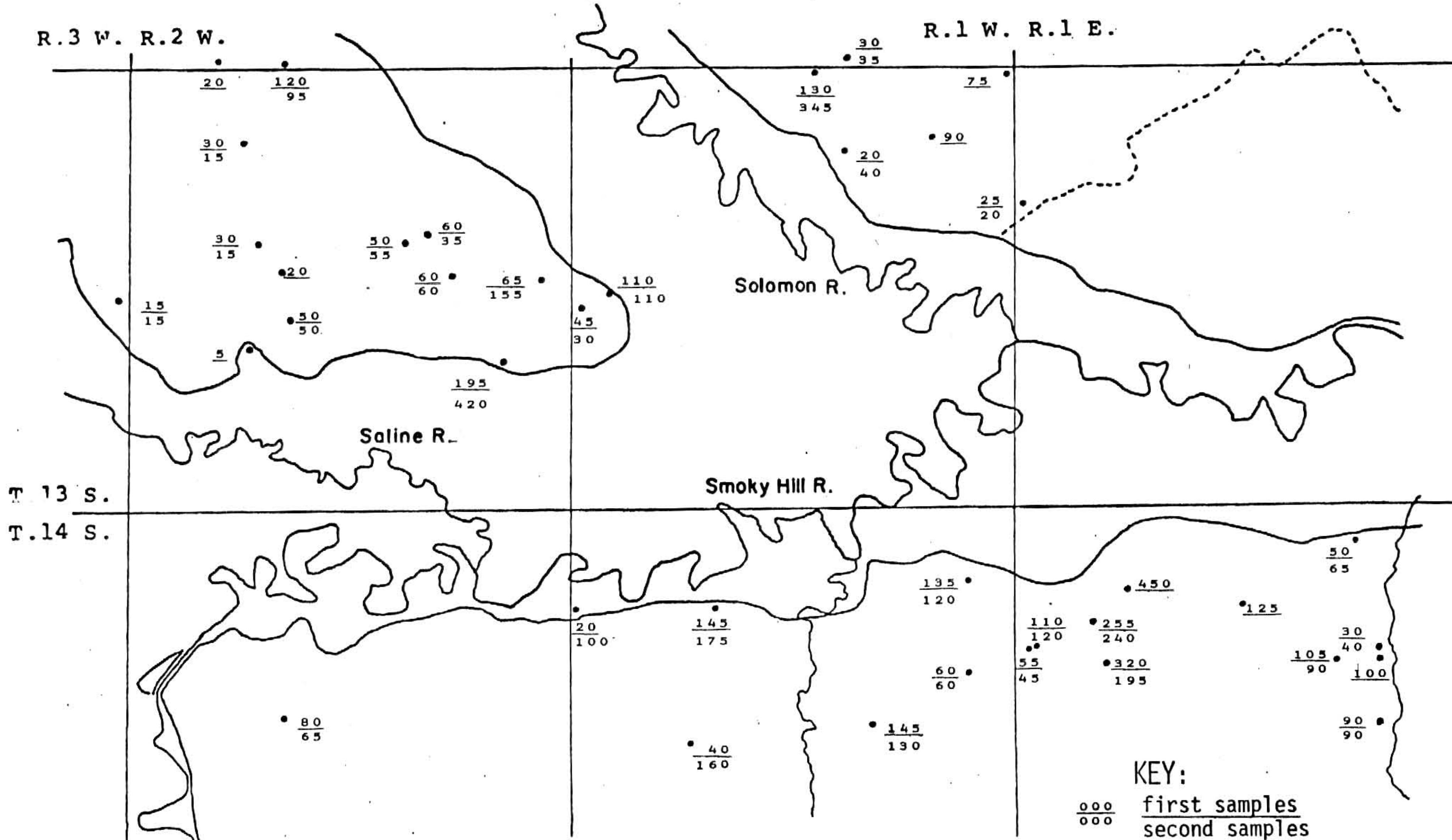


Fig. 11. Chloride concentration in wells (mg/l)

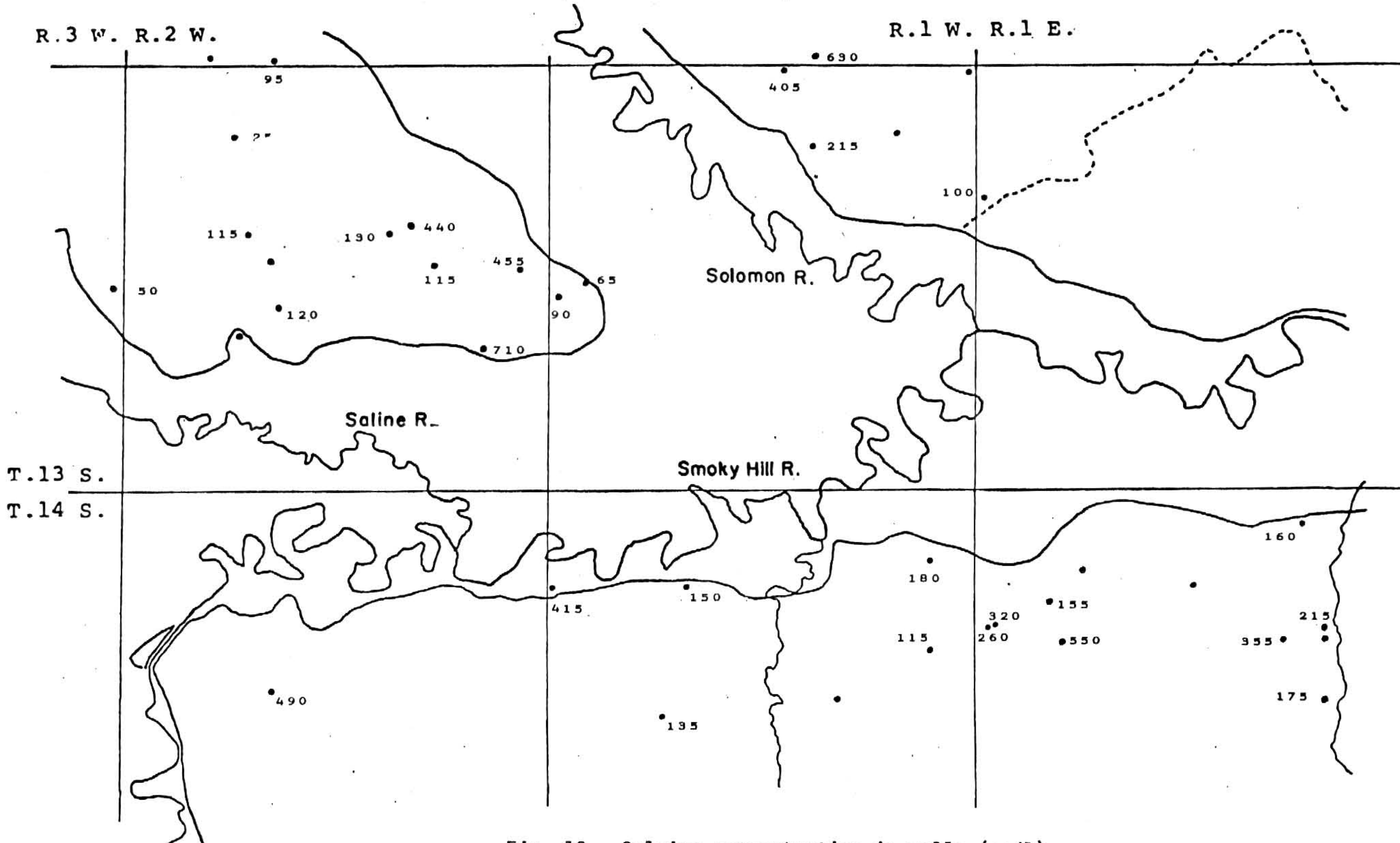


Fig. 12. Calcium concentration in wells (mg/l) for second series of samples.

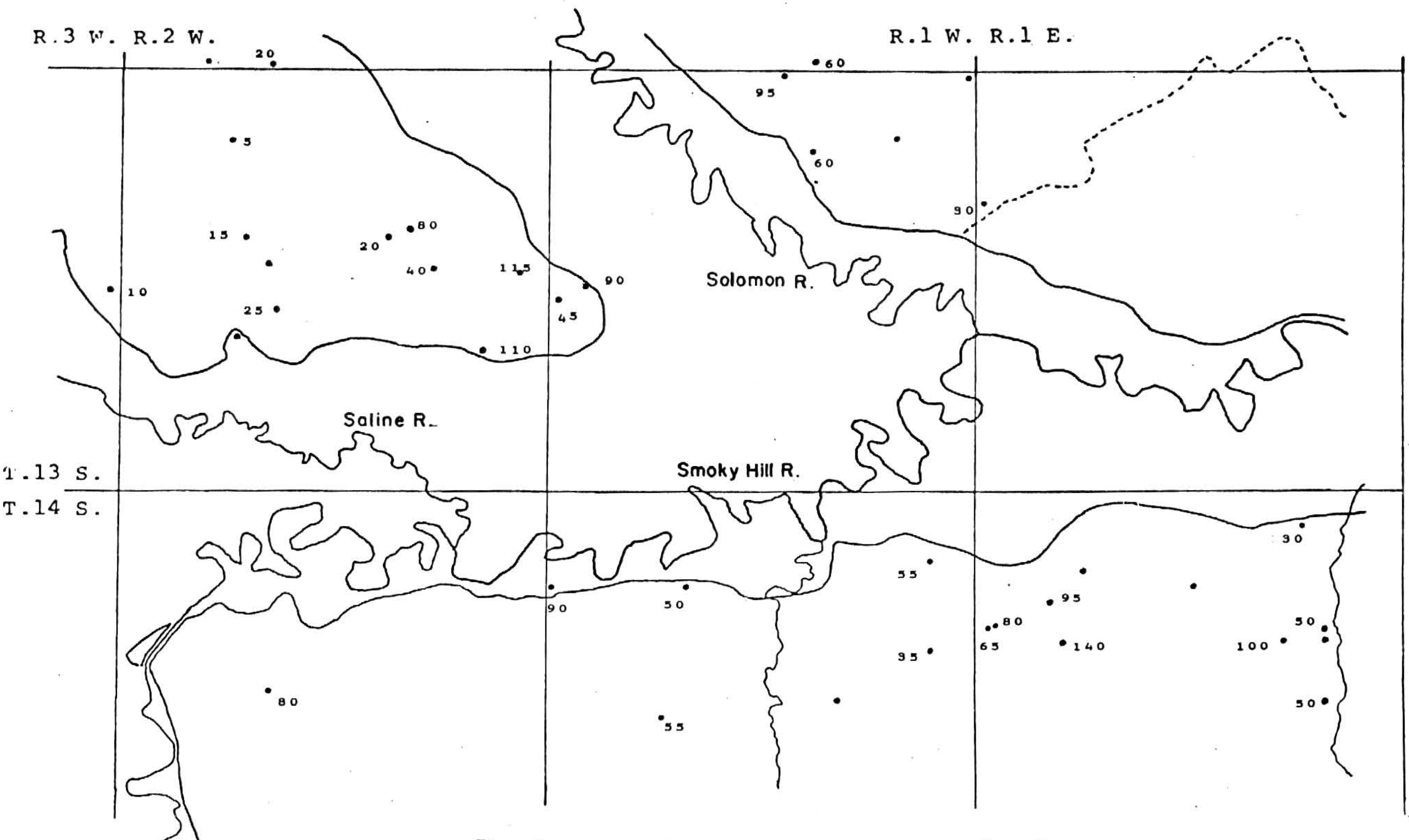


Fig. 13. Magnesium concentration in wells (mg/l) for second series of samples.

would contain water with a longer residence time resulting in a higher concentration of total dissolved solids. Thus gypsum would dissolve at a slower rate at greater depths.

Concentrations of dissolved constituents cannot be correlated between well locations or with respect to depth due to the lack of connection of cavities between wells. Cross sections (Figs. 4-7) show little lateral continuity from one well to another. The lack of connection between gypsum beds appears to be a near-surface phenomena. Kulstad (1956) showed continuous gypsum beds at depth in cross sections based on electric logs. Distortion could be caused by collapse and slumping of near surface gypsum cavities formed by ground-water circulation. Slumping is presently occurring as evidenced by a history of sink hole development in random areas over the study area. Near surface distortion could also have been caused by the much larger dissolution of the Hutchinson Salt Member. This would mean that these gypsum cavities are stratigraphically above the Hutchinson Salt Member. Slumping of the shale could have been as much as 60 meters (200 feet), depending on the thickness of the salt before dissolution. The differential dissolution along the salt front, as indicated west and south of Salina, increased the distortion of the shale and gypsum above the salt.

It is difficult to predict where or how deep to drill to locate a water-filled gypsum cavity due to the distortion. It is even more difficult to predict where to drill for water with a sufficient yield and quality for domestic or livestock needs. For example, if a well driller boring for water in gypsum cavities at shallow depths but continues deeper to obtain a higher yield, he may obtain poorer quality water. Water at the lower depth could be in contact with more gypsum and therefore have a higher total dissolved solids.

The eastern extent of the Hutchinson Salt Member is at Salina and along the Saline River in norther Saline county (Walter, 1976, p. 6). Thus the salt has completely dissolved in the study area. Latta (1949, p. 72) reported a chloride concentration of 47,000 parts per million in well 102 located at 13 1W 19 in the alluvium at an elevation of 341 meters (1124 feet) above sea level. The high chloride concentration occurs at the bottom of the alluvium near the point of the divide between the Saline and Solomon Rivers. Chloride concentrations in the surrounding wells were considerably lower. This indicates a location where salt brine is migrating through gypsum cavities from the salt near Salina. Well 13 1W 19abb of this study is .8 kilometers (one-half mile) in the uplands northwest of Latta'a well, and has a sulfate concentration of 1500 mg/l and a chloride concentration of 115 mg/l. The bottom of the well is at 351 meters (1155 feet) above sea level, 10 meters (31 feet) above where the high chloride concentration occurs in Latta's well. Another well in this study (13 1W 19bbd) is one mile west of Latta's well in the uplands, and has a sulfate concentration of 30 mg/l and a chloride concentration of 30 mg/l. The bottom of this well is at 352 meters (1160 feet) above sea level. If water in the Wellington Formation occurs in gypsum cavities, it appears what the denser salt brine is in the lower cavities, (shown by salt brine in the alluvium at 341 meters (1124 feet), water high in dissolved sulfate occurs in the upper section of the cavities at 351 meters (1155 feet), whereas good quality water occurs at even higher levels in the cavities. Lower cavities that carry salt brine are most likely close to the valley wall of the Smoky Hill River where the increased circulation of water from the alluvium has caused the weathering zone to be deeper. Away from the valley wall in the uplands, the weathering zone has not developed as deeply resulting in undisturbed gypsum lenses at depth which are not hydraulically connected to the salt to allow the migration of salt brine.

Thus, a test hole drilled deeply enough in the uplands close to the valley wall in the divide could encounter salt brine in gypsum cavities coming from the Hutchinson Salt Member. The exact depth to the brine under the valley wall would be useful in locating the source of high chloride concentrations in the alluvium.

Water in wells in the Kiowa Formation had lower concentrations of sulfate and chloride than in the Wellington Formation. The shale in the Kiowa Formation yields very little water and is not considered to an aquifer (O. S.Fent, 1976, per. comm.). However, the sandstone lenses in the upper parts of the formation yield some water which is generally low in sulfate, chloride, and total hardness.

Well 13 2W 14bcb, in the Kiowa Formation, had a sulfate concentration of 1500 mg/l and a chloride concentration of 35 mg/l. Comparison of the elevation of the Wellington-Kiowa contact near the well in cross section B-B' with the well depth shows that the well was drilled through the Kiowa Formation and penetrated the Wellington Formation. Only smaller quantities can be pumped from the Wellington because the shale lacks open cavities when overlain by the Kiowa Formation. The owner of the well reported pumping the well only for a short time at a low rate before going dry.

Selected wells were sampled twice to determine variations in groundwater chemistry in the study area. The first set of water samples was collected on August 17, 1976; the second set was collected on January 14 and 15, 1977. During this period precipitation was far below normal.

The sampled wells were divided into three categories: 1) domestic wells that supplied water for the houses, 2) stock wells which supplied water for livestock, including wells in barnyards and windmills in pastures, and 3) wells which had been abandoned, but had handpumps that were still in operating condition.

During the five months between the two sampling sets, 54 percent of the domestic well waters decreased, 15 percent increased, and 31 percent remained relatively the same in chloride concentration. Sulfate concentrations showed a similar trend in domestic wells: 62 percent decreased, 7 percent increased, and 31 percent remained relatively the same in sulfate, allowing ± five percent variation in samples.

In stock wells the water chemistry as a whole did not show any increasing or decreasing concentration trends over the five months. In 33 percent, 42 percent and 25 percent of the wells chloride concentrations decreased, increased, and remained relatively the same, respectively. Sulfate concentration decreased in 46 percent, increased in 38 percent and did not change significantly in 16 percent of the stock wells.

Concentrations of chloride and sulfate in abandoned wells tended to increase over the five months; 75 percent of the wells increased, whereas 25 percent decreased in chloride concentration, and 75 percent increased in sulfate concentration whereas 25 percent decreased in sulfate.

Domestic wells, with continued or frequent pumping to supply water needs, generally decreased in concentration, whereas the abandoned wells, with little or no pumping, increased in chloride and sulfate concentration. The lack of general trends in the stock wells is not surprising because of the different amounts that a stock well would be pumped. Certain stock wells are pumped frequently while others are dormant for long periods if not needed.

These results show a tendency toward increased sulfate and chloride concentrations in abandoned wells. A possible reason is slow movement of ground water in the aquifer which increased the residence time of water in the gypsum cavity and allowed more gypsum and other minerals to be dissolved in the ground water.

The domestic well that is pumped continually having a faster flow of ground water in the cavity near the well. The increased flow may result in the extraction of better quality water from a different area or a higher cavity, thus decreasing the chloride and sulfate concentration in the water. Stock wells with their varied pumping would show tendencies of both domestic and abandoned wells with increased and decreased concentrations.

These data may indicate that better quality water could be obtained from wells that are continually or frequently pumped.

Piezometric Surface

The piezometric surface is the deviation which water will rise in a well under hydrostatic head above the aquifer; thus the piezometric surface is influenced by pressure within the aquifer. A water-table contour map was constructed from depth- to- water measurements and land surface elevations. The map shows lines of equal elevations of the piezometric surface above sea level (Fig. 14). The direction of flow of ground

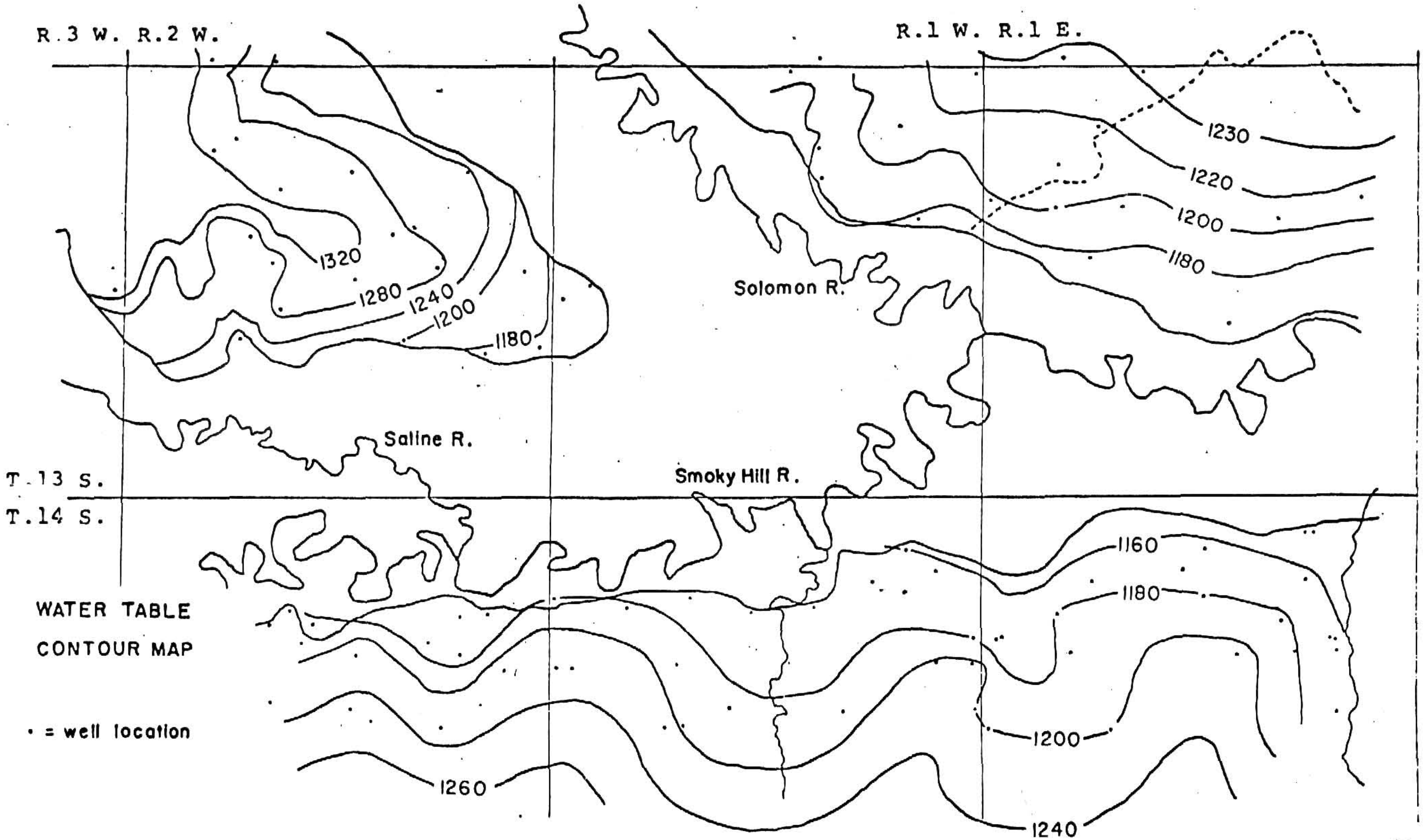

R.3 W.
R.2 W.
R.1 W.
R.1 E.
T.13 S.
T.14 S.
1320
1280
1240
1200
1180
Solomon R.
1230
1220
1200
1180
Saline R.
Smoky Hill R.
1160
1180
1200
1240
1260
WATER TABLE
CONTOUR MAP
• = well location

Figure 14.

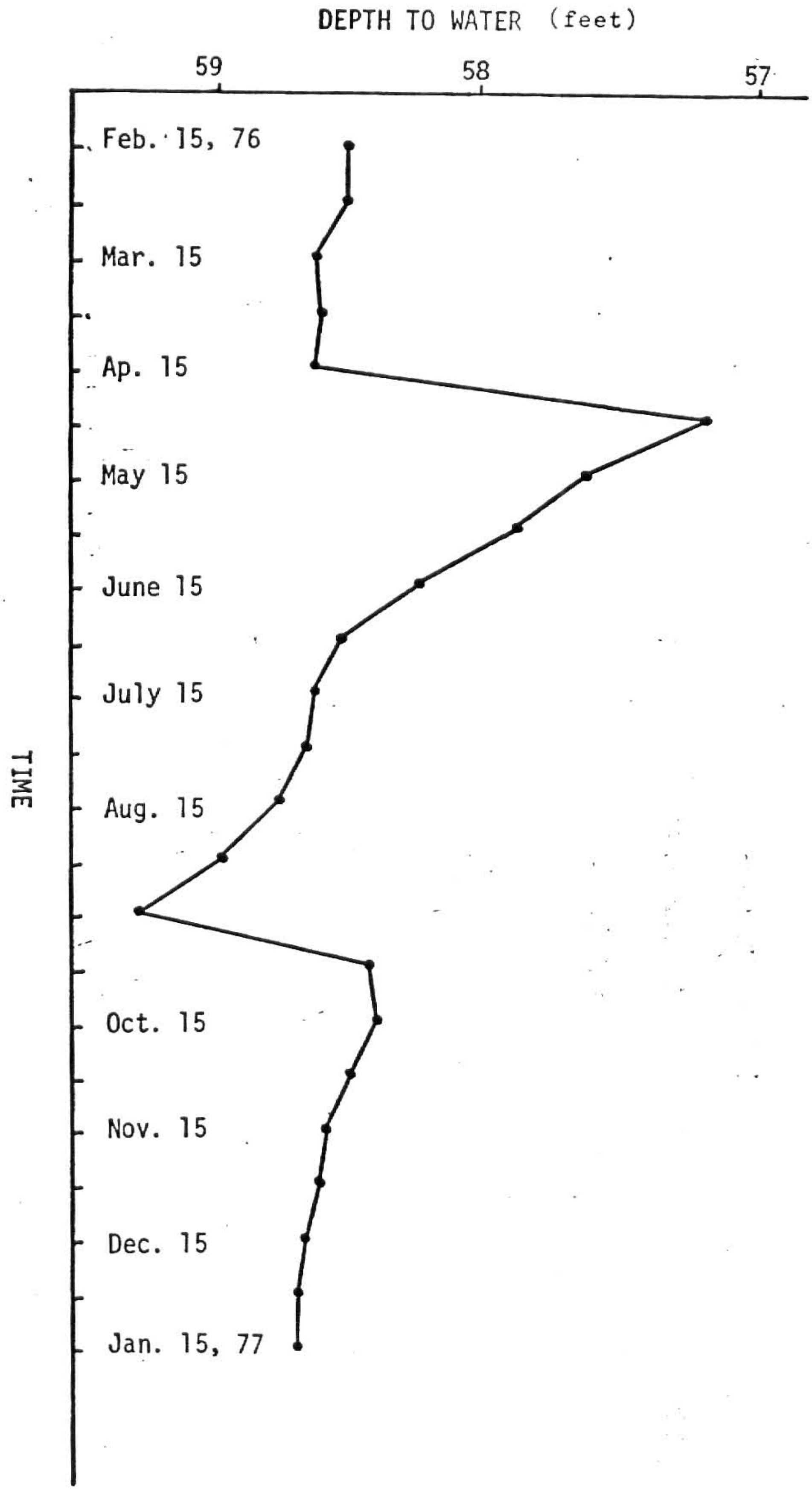


Figure 15. WELL HYDROGRAPH. well located at T.14 S., R.1 W., Sec. 8 bbd. U.S. Geol. Su vey observation well.

water is perpendicular to lines of equal water elevation in a down slope direction in homogeneous, isotropic sediment. The contours in the study area slop gently downward toward the river and into downstream direction indicating recharge of the rivers from the uplands.

Depth-to-water measurements in the uplands were taken in span of four to six weeks in July and early August, 1976. To determine whether the water level changed significantly during the time span between measurements, a record was obtained from a continuous recording well in the upland south of the Smoky Hill River (T.14 S., R.1 W., Sec. 8, bbd). The well is in the Wellington Formation and is maintained by the U. S. Geological Survey and the Kansas Water Resources Board. During the time span of July and August, 1976, the well showed a decline of less than 0.060 meter (0.2 feet) in water level (Fig. 15). Thus, if this well is representative of the area, the errors in elevations of the water table contour map are probably within 0.060 meter (0.2 feet).

SUMMARY

Gypsum cavities in the phraetic zone are the major aquifers of the Wellington Formation in the study area. These cavities contain from good quality to highly mineralized water depending on the amount of gypsum still in the cavity. In the cavities closer to the surface most of the gypsum has been dissolved so that the quality of water is higher. Lower cavities deeper in the weathering zone, have larger quantities of gypsum resulting in highly mineralized water. The major dissolved constituents in the ground water are sulfate, chloride, calcium, and magnesium.

The upper gypsum beds (stratigraphically above the Hutchinson Salt) are highly distorted and can not be correlated laterally in cross sections. Distortion could be caused by collapse and slumping of gypsum cavities near the surface due to ground-water circulation or slumping after differential dissolution of the Hutchinson Salt Member.

Sulfate and chloride concentrations of wells near the point of the divide between the Saline and Solomon Rivers indicate a location where salt brine migrates from the Hutchinson Salt Member near Saline through gypsum cavities. Elevations of the bottom of wells indicate that close to the valley wall, denser salt brine travels in lower gypsum cavities, whereas highly mineralized sulfate water moves in gypsum cavities above the salt brine and good quality water flows in the upper gypsum cavities close to the surface. Deep cavities that carry salt

brine are most likely close to the valley wall where the increased circulation of water from the alluvium has caused a deeper weathering zone than in the uplands. Away from the valley wall in the uplands, the weathering zone has not developed as deeply resulting in undisturbed gypsum lenses at depth which are not hydraulically connected to the salt to allow the migration of salt brine. Therefore high chloride water is not found in the uplands.

Well water in the Kiowa Formation contained lower concentrations of sulfate and chloride than those in the Wellington Formation. The aquifers in the Kiowa Formation are sandstone lenses in the upper portion of the formation.

Changes in concentrations of dissolved sulfate and chloride sampled twice indicate that slow movement of ground water in the cavities increases the residence time and allows more gypsum to be dissolved. Near a frequently pumped well increased flow of water through cavities obtain better quality water either from a different area of higher cavity thus decreasing the sulfate and chloride concentrations in the water.

The piezometric suface or water table contours indicate that ground water in the uplands is flowing towards the Saline, Solomon and Smoky Hill Rivers.

REFERENCES

Bell, T. C., Ground-water quality of the Abilene area, Kansas: Kansas State Univ. M. S. thesis, 93 p.

Davis, S. N., and DeWiest, R. J., 1966, Hydrogeology: New York, John Wiley and Sons, 463p.

Fent, O. S., 1970, "Written communication."**

Fent, O. S., 1977, "Personal communication."

Franks, P. C., 1966, Petrology and Stratigraphy of the Kiowa and Dakota Formations (basal Cretaceous) north-central Kansas: Kansas Univ., Ph.D. dissertation, 234p.

Grimsley, G. P. and Bailey, E. H. S., 1999, Special report on gypsum and gypsum cement plasters: University Geol. Survey of Kansas Bull. 5, 183p.

Hem, J. D., 1970, Study and interpretation of the chemical characteristics on natural water: U. S. Geol. Survey Water-Supply Paper 1473, 363p.

Johnson Division, Universal Oil Products Co., 1972, Ground Water and Wells: Saint Paul, Minn. 440p.

Kulstad, R. O., 1956, Gypsum in Kansas: Kansas Geol. Survey Bull. 154, 145p.

Latta, B. F., 1949, Ground-water conditions in the Smoky Hill Valley in Saline, Dickinson, and Geary Counties; Kansas Geol. Survey Bull. 84, 152p.

Lee, W., Leatherrock, C., Botinelly, T., 1948, The stratigraphy and structural development of the Salina Basin of Kansas: Kansas Geol. Survey Bull. 74, p. 1-155.

Mack, L. E. 1962, Geology and ground-water resources of Ottawa County, Kansas Kansas Geol. Survey Bull. 154, 145p.

Tara, M. J., 1974, Standard methods for the examination of water and wastewater: American Public Health Assoc., Washington, D. C., 875p.

Walters, R. F. 1976, Land Subsidence in Central Kansas Related to Salt Dissolution: Solution Mining Research Inst. Inc., Flossmoor, Ill., 144p.

Zeller, D. F., 1968, The stratigraphic succession in Kansas: Kansas Geol. Survey Bull. 189, 81p.

** see Appendix III

APPENDIX I

LOGS OF WELLS AND TEST HOLES

A. Log of test hole in T.14 S., R.2 W., Sec. 16 a. Drilled by O. S. Fent. Surface altitude 1,230 feet.

Description of Material	Thickness in Feet	Depth in Feet
Top Soil	1.5	1.5
Silt and clay, sandy, red-tan	12.5	14.0
Sand, fine to coarse	2.5	16.5
Sandstone, well cemented	4.0	21.5
Sandstone, poorly cemented	1.5	23.0
Sandstone, poorly cemented with well cemented zones	4.0	27.0
Shale, silty, fairly hard, blue-gray	23.0	50.0
Shale, silty, fairly soft, reddish-brown	10.0	50.0
Gypsum with interbedded shale	7.0	67.0

B. Log of test hole in T.14 S., R.1 W., Sec. 19, ad. Drilled by O. S. Fent. Surface altitude 1,230.

Description of Material	Thickness in Feet	Depth in Feet
Alluvium:		
Clay, silty, gray	23.0	23.0
Clay, yellow, silty	5.0	28.0
"Mortor" hard calcite	1.0	29.0
Gravel, medium to fine clay silty, partly cemented	3.0	32.0
Permiam:		
Shale, yellow	12.0	45.0
Shale, gray	27.0	72.0
Shale, gray-green and light gray, soft	10.5	82.5
Gypsum, white; shale light gray	1.5	84.0
Gypsum and anhydrite	4.0	88.0

C. Log of test hole in T.14 S., R.1 W. Sec. 8, dbb. Drilled by O. S. Fent. Surface altitude 1,220 feet.

Description of Material	Thickness in Feet	Depth in Feet
Silt, soft, reddish-brown	4.0	4.0
Shale, soft, gray-green, red	22.0	26.0
Shale, silty, hard, blue-gray	14.0	40.0
Gypsum cavity, open		
Shale, gypsum interbedded	7.0	47.0

D. Log of test hole in T.14 S., R.1 W., Sec. 9, c. Drilled by O. S. Fent. Surface altitude 1,210 feet.

Description of Material	Thickness in Feet	Depth in Feet
Colluvium:		
Silt, clayey, brown and gray	5.0	5.0
Silt, sandy, tan-buff	31.0	36.0
Permian:		
Shale, blue-gray, firm	3.0	39.0
Shale, hard, blue-gray	1.0	40.0
Shale, alternating gray, white, thin-bedded firm and dark gray; contains thin hard porous calcarious zones	29.0	69.0

E. Log of test hole in T.14 S., R.1 W., Sec. 15, bab. Drilled by Bruce Latta, Kansas Geological Survey. Surface altitude 1,181.2 feet.

Road fill	4.0	4.0
Quaternary		
Salt and clay, dark buff, gray, and gray green; contains some fine to medium sand in lower part	30.0	34.0
Gravel, fine to coarse; contains some light-gray sand and silt	12.0	46.0

F. Log of test hole in T.14 S., R.1 W. Sec. 1, db. Drilled by O. S. Fent. Surface altitude 1,222 feet.

Silt, clay, tan	7.0	7.0
Shale, hard, gray-green	20.0	27.0
Shale, hard white, yellow gray, silt, hard thin bedded	19.0	46.0
Shale, soft, yellow-gray	21.0	67.0
Shale, blue-gray, thin bedded	9.0	76.0

G. Log of test hole in T.13 S., R.3 W., Sec. 14, aa. Drilled by O. S. Fent. Surface altitude 1,257 feet.

Silt, sandy, tan	7.5	7.5
Sand, medium-fine; gravel, fine to coarse	8.5	16.0
Kiowa Formation		
Shale, blue-gray; Siltstone interbedded	19.0	35.0

H. Log of test hole in T.13 S., R.3 W., Sec. 24, ab. Drilled by O. S. Fent. Surface altitude 1,282 feet.

Kiowa Formation		
Silt, buff	2.0	2.0
Sandstone, fine, yellow-brown	2.0	4.0
Clay, silty, yellow-brown	9.0	13.0
Clay, gray	7.0	20.0
Quartzite, hard, fine, translucent, some pyrite	4.0	24.0
Shale, dark gray	3.0	27.0
Siltstone, light gray	0.5	27.5
Shale, dark gray	30.5	58.0
Cheyene "Longford Siltstone"	32.0	91.0
Wellington Formation		
Shale	9.0	100.0

I. Log of test hole in T.13 S., R.2 W., Sec. 20, ab. Drilled by O. S. Fent. Surface altitude 1,290 feet.

Silt, brown, tan	2.0	2.0
Kiowa Formation		
Sandstone, soft, medium-grained yellow	11.0	13.0
Sandstone, hard, medium-grained brown	2.0	15.0
Sandstone, soft, medium-grained yellow	16.5	31.5
Wellington Formation		
Shale, blue-gray	2.5	34.0

J. Log of test hole in T.13 S., R.2 W., Sec. 22, dd. Drilled by O. S. Fent. Surface altitude 1,238 feet.

Silt, buff	23.0	23.0
Shale, reddish-green	18.0	41.0
Shale, dark gray and red, some gypsum, white	6.5	47.5
Gypsum and interbedded shale, some gypsum cavities with water	2.5	50.0

K. Log of test hole in T.13 S., R.2 W., Sec. 24, d. Drilled by O. S. Fent. Surface altitude 1,270 feet.

Wellington Formation		
Shale, green, red, yellow	22.0	22.0
Shale, dark gray; gypsum	50.0	72.0
Siltstone	7.0	79.0
Shale, dark gray; gypsum	9.0	88.0
Shale, gypsum, siltstone	12.0	100.0

L. Log of test hole in T.14 S., R.2 W., Sec. 28, ccd. Drilled by O. S. Fent. Surface elevation 1,272 feet.

Description of Material	Thickness in Feet	Depth in Feet
Clay, green	5.0	5.0
Clay, gray	3.0	8.0
Clay, gray-green, yellow	17.0	25.0
Wellington Formation		
Shale, dark gray	17.0	42.0
Shale, dark gray, interbedded with gypsum	111.0	153.0
Gypsum, hard, banded	8.0	161.0
Shale, interbedded with gypsum, hard	70.0	231.0

M. Log of test hole in T.14 S., R.2 W., Sec. 22, cb. Drilled by O. S. Fent. Surface elevation 1,245 feet.

Colluvium		
Silt and clay	10.0	10.0
Clay, tan	6.0	16.0
Wellington Formation		
Shale, gray, yellow	6.0	22.0
Shale, dark gray, red	18.0	40.0
Shale, blue-gray, interbedded with gypsum	10.0	50.0
Shale, gray	15.0	65.0
Shale, blue-gray, interbedded with gypsum	29.0	94.0
Gypsum	5.0	99.0
Shale, gray	3.0	102.0

N. Log of test hole in T.14 S., R.2 W., Sec. 16, daa. Drilled by O. S. Fent. Surface elevation 1,225 feet.

Top soil	0.5	0.5
Clay, brown	4.5	5.0
Clay, yellow	10.0	15.0
Clay, yellow; gravel	17.0	32.0
Sand and gravel	3.0	35.0
Limestone, sandstone, shale and gravel fragments	2.0	37.0
Wellington Formation		
Shale, gray-green	28.0	65.0
Gypsum, interbedded with shale	16.0	81.0
Shale, gray	1.0	82.0

O. Log of test hole in T.14 S., R.2 W., Sec. 4, ddd. Drilled by Bruce Latta, Kansas Geological Survey. Surface elevation 1,199.7 feet.

Description of Material	Thickness in feet	Depth in feet
Quaternary		
Alluvium		
Silt and clay, gray, yellow gray, and blue gray	22.0	22.0
Sand and gravel, fine to medium	3.0	25.0
Silt, clayey, blue gray	1.0	26.0
Sand, fine, to coarse gravel	31.0	57.0
Permian		
Wellington Fromation		
Shale, soft, blue-gray to gray white	13.0	70.0

P. Log of test hole in T.14 S., R.2 W., Sec. 28, add. Drilled by Bruce Latta, Kansas Geological Survey. Surface elevation 1,208.9 feet.

Quaternary		
Alluvium		
Sand, fine to coarse	4.0	4.0
Silt, dark gray to buff gray	21.0	25.0
Silt, sandy, soft, yellow gray	10.0	35.0
Silt, soft, blue gray	2.0	37.0
Gravel, fine to coarse; contains some sand	24.0	61.0
Permian		
Wellington Formation		
Shale, light to dark gray	9.0	70.0

Q. Log of test hole in T.13 S., R.2 W., Sec. 22, ab. Drilled by O. S. Fent. Surface elevation 1,320 feet.

Silt, sandy	2.0	2.0
Kiowa Formation		
Sandstone, fine	13.0	15.0
Shale, yellow-gray	5.0	20.0
Shale, gray, yellow-gray; siltstone; quartzite	40.0	60.0
Siltstone, pyrite, very hard	1.0	61.0
Wellington Formation		
Shale, gray-green	18.0	79.0
Shale and siltstone, gray, red and green	15.0	94.0
Shale, dark gray; gypsum	61.0	155.0

R. Log of test hole in T.13 S., R.2 W., Sec. 15, cda. Drilled by O. S. Fent. Surface elevation 1.355 feet.

Top soil	3.0	3.0
Sand, fine to medium, brown, clayey	12.0	15.0
Clay, gray-yellow-brown	18.0	33.0
Shale, gray; gypsum zones	7.0	40.0
Shale, gray; siltstone, gray	6.0	46.0
Shale, clayey, gray, blue-gray	5.0	51.0
Shale, gray; pyrite; sandstone, silty	5.0	56.0
Shale, clayey, medium to dark gray, soft	7.0	63.0
Lignite, pyritic	1.0	64.0
Siltstone, gray; sandstone, light gray	6.0	70.0
Shale, silty, gray	10.0	80.0
Shale, clayey, red to light gray	8.0	88.0
Shale, light green	5.0	93.0
Shale, medium gray, interbedded with gypsum	6.5	99.5
Siltsone, hard, light gray	3.5	103.5

APPENDIX II

RECORDS AND WATER ANALYSES OF WELLS

Well[a]	Owner	Type[b]	Depth (feet)	Elev. of land surf. (ft.)	Depth to Water (ft.)	SO_4 mg/l	Cl mg/l	Ca mg/l	Mg mg/l	Sp. C[c] µmhos/cm
12-1E-32ccd	J. Teasteys	S	90	1307	81.8					
12-1W-34dcd#a	G. Webb	D	29	1208	17.0	1320	30			2030
12-1W-34dcd#b						1365	35	630	60	2330
12-2W-32ccd#a	?	D	100	1335	18.0	20	20			375
12-2W-33ccd#a	D. Barr	D	25	1254	17.9	160	120			930
12-2W-33ccd#b						135	95	9	20	995
13-1W-4bbz	D. Oetting	D	84	1272	36.4					
13-1E-5dcc	V. Sheonake	D	60	1250	31.0					
13-1E-7ccc#a	T. Winter	D	?	1224	30.4	145	25			440
13-1E-7ccc#b						115	20	100	30	1010
13-1E-8bcc	R. Denman	S	27	1256	15.0					
13-1E-12cdc	U.S.G.S.	O	23	1227	19.4					
13-1E-14-bcb	U.S.G.S.	O	56	1240	32.7					
13-1E-17aaa	U.S.G.S.	O	24	1205	13.0					
13-1E-17bbb	U.S.G.S.	O	42	1225	28.5					
13-1E-22cda	".S.G.S.	O	40	1195	24.5					
13-1E-22cac	U.S.G.S.	O	42	1170	22.5					
13-1W-1aaa#a	R. Fitzwater	D	80	1271	43.0	1400	75			2410
13-1W-ddd#a	E. Fuller	S	75	1244	33.2	1650	90			2430
13-1W-baa#a	G. Hummel	D	55	1213	30.0	800	130			1800
13-1W-baa#b						830	345	405	95	2980
13-1W-4dad	F. Calaham	S	37	1196	30.0					
13-1W-10adb#a	C. Riordan	S	44	1210	23.0	80	20			720
13-1W-10adb#b						310	40	215	60	1150

Well[a]	Owner	Type[b]	Depth (Feet)	Elev. of land surf. (ft.)	Depth to Water (ft.)	SO_4 mg/1	Cl mg/1	Ca mg/1	Mg mg/1	Sp. C[c] μmhos/cm
13-1W-10dca	G. Riordan	S	?	1184	3.0					
13-1W-13bcb	F. Funston	D	70	1199	25.1					
13-1W-19abb#a	D. Hiedrick	D	50	1205	33.0	1460	110			2350
13-1W-19abb#b						1500	100	65	90	2700
13-1W-19bbd#a	H. Jungel	D	60	1220	?	75	45			735
13-1W-19bbd#b						30	30	90	45	780
13-2W-8aba#a	N. Johnson	D	20	1311	18.2	25	30			270
13-2W-8aba#b						20	15	25	5	225
13-2W-8bbd	N. Knudsen	S	40	1336	29.3					
13-2W-9cac	T. Martin	S	55	1341	38.0					
13-2W-10cba	H. Jett	S	46	1326	26.5					
13-2W-11add	D. Janseen	O	110	1265	23.0					
13-2W-13dcc#a	R. Mathson	S	90	1232	49.3	1650	65			2170
13-2W-13dcc#b						965	155	455	115	2110
13-2W-14bcb#a	T. Sanderson	D	100	1323	50.7	1620	60			2205
13-2W-14bcb#b						1500	35	440	80	2380
13-2W-14cda!a	G. Divilbiss	S	?	1313	26.0	30	60			660
13-2W-14cba#b						40	60	115	40	720
13=2W-15acd#a	A. Nelson	D	53	1344	35.8	90	50			930
13-2W-15acd#b						70	55	130	20	1180
13-2W-16ccb#a	H. Crowther	S	30	1308	19.4	40	20			400
13-2W-17adc#a	C. Smith	D	?	1298	19.0	70	30			710
13-2W-17adc#b						70	15	115	15	750
13-2W-20bdc#a	W. Bruce	D	20	1233	11.5	55	5			590
13-2W-21bdc#a	L. Hagadorn	D	50	1349	41.0	115	50			1050
13-2W-21bdc #b						110	50	120	25	1130
13-2W-22baa	U. Richmond	S	45	1346	30.5					
13-2W-22dda	S. Nelson	S	?	1241	41.2					
13-3W-25bbb#a	E. Brown	S	60	1202	38.2	1075	195			3130
13-3W-25bbb#b						1600	420	710	110	3900
13-3W-24aad#a	G. Wallerius	S	75	1341	17.0	35	15			355
13-3W-24aad#b						40	15	50	10	480

Well[a]	Owner	Type[b]	Depth (Feet)	Elev. of land surf. (ft.)	Depth to Water (ft.)	SO_4 mg/l	Cl mg/l	Ca mg/l	Mg mg/l	Sp. C.[c] µmhos/cm
13-2W-24ddc	K. Stauffer	D	39	1205	30.8					
13-2W-25bbb#a	E. Brown	S	60	1202	38.2	1070	200			3130
13-2W-25bbb#b						1600	420	710	110	3900
14-1E-wcaa	E. Ade	S	?	1180	25.9					
14-1E-2dbb#a	E. Ade	S	?	1170	?	160	50			850
14-1E-2dbb#b						200	65	160	30	1000
14-1E-3cbc	L. Lauer	S	38	1190	18.8					
14-1E-4ddc	C. Klover	S	80	1226	48.0					
14-1E-7cdb#a#1	G. Meagrer	D	60	1203	?	1100	55			2050
14-1E-7cdb#b#1						1050	45	260	65	1800
14-1E-7cdb#a#2	G. Meagrer	S	40	1203	?	740	110			1700
14-1E-7cdb#a#2						725	120	320	80	1900
14-1E-8abb#a	W. Shirack	D	78	1234	68.5	1830	450			2950
14-1E-8cbc#a	C. Kolman	S	?	1210	29.6	840	255			1900
14-1E-8cbc						575	240	155	95	1890
14-1E-10bcb#a	D. Fink	S	66	1225	44.2	410	125			1310
14-1E-11baa	C. Sextan	D	35	1192	27.0					
14-1E-11cbc	A. Clover	S	43	1205	15.3					
14-1E-11ddd#1	C. Sextan	D	45	1187	25.5					
14-1E-11ddd#a#2	C. Sextan	D	50	1171	?	130	30			620
14-1E-11ddd#b#2						400	40	215	50	1420
14-1E-13ada	C. McArty	D	36	1237	35.4					
14-1E-14aaa#a	W. Miller	S	15	1186	4.7	1400	100			2030
14-1E-14bab#a	C. Morrison	D	60	1194	?	940	105			1930
14-1E-14bab#b						875	90	355	100	2170
14-1E-14ddd#a	A. Howie	S	30	1183	17.8	430	90			1400
14-1E-14ddd#b						400	90	175	50	1430
14-1E-15abb	M. Fink	S	28	1199	11.0					
14-1E-17bab#a	C. Kohman	S	64	1230	?	1130	320			2800
14-1E-17bab#b						1580	195	550	140	3020

Well[a]	Owner	Type[b]	Depth (feet)	Elev. of land surf. (ft.)	Depth to Water (ft.)	SO_4 mg/1	Cl mg/1	Ca mg/1	Mg mg/1	Sp. C.[c] µmhos/cm
14-1E-19bbc	B. Shirack	S	53	1245	45.0					
14-1E-20aac	P. Schwartz	S	35	1229	28.7					
14-1W-1cdd#a	R. Zerbe	S	65	1211	46.7	290	135			1320
14-1W-1cdd#b						280	120	180	55	1430
14-1W-2daa	D. Hasker	S	57	1203	45.0					
14-1W-7bcb#a	G. Johnson	S	36	1192	12.0	1300	20			2360
14-1W-7bcb#b						1050	100	415	90	2200
14-1W-8ada#a	P. Ryan	S	43	1200	27.6	90	145			600
14-1W-8ada#b						100	175	150	50	1640
14-1W-8bcc	C. Bockofer	S	21	1203	15.5					
14-1W-9acd	R. Long	S	28	1186	19.9					
14-1W-10aca	T. Walker	S	29	1181	15.6					
14-1W-11aad	J. Martin	S	77	1232	58.6					
14-1W-11baa	M. Burns	S	51	1200	27.7					
14-1W-12dda	G. Meagher	S	35	1197	17.5					
14-1W-13bda#a	G. Meagher	S	?	?	?	30	60			730
14-1W-13bda#b						20	60	115	35	780
14-1W-13dda	C. McArty	S	42	1237	37.0					
14-1W-14ccc#a	J. Martin	S	?	?	?	1330	145			
14-1W-14ccc#b						1570	130	560	120	2920
14-1W-15cdd	J. Show	S	?	1197	11.8					
14-1W-17aca	V. LeDuc	S	51	1224	34.7					
14-1W-18bcc	D. Nelson	D	43	1228	4.7					
14-1W-18bdd	D. Nelson	S	20	1236	6.1					
14-1W-20aaa	J. Blankenship	S	28	1213	17.3					
14-1W-20abb#a	J. Blankenship	D	29	1238	9.9	440	40			600
14-1W-20abb#b						775	160	135	55	2110
14-2W-9bdd	R. Murray	S	40	1223	31.5					
14-2W-9cbb	R. Graham	S	55	1220	22.2					

Well[a]	Owner	Type[b]	Depth (feet)	Elev. of land surf. (ft.)	Depth to Water (ft.)	SO_4 mg/1	Cl mg/1	Ca mg/1	Mg mg/1	Sp. C[c] µmhos/cm
14-2W-9dbd	J. Roesner	S	32	1199	15.5					
14-2W-dcd	J. Hilton	S	26	1202	9.9					
14-2W-11cdd	J. Carlson	S	87	1217	41.4					
14-2W-11dab	W. Shank	S	68	1205	28.9					
14-2w-12caa	P. Donmeyer	D	66	1216	41.1					
14-2W-13bdb	B. Kelly	S	69	1257	41.4					
14-2W-14aab	D. Sleek	S	42	1203	29.0					
14-2W-15baa	A. Weber	S	23	1223	12.6					
14-2W-15ccd	R. Hemmy	S	27	1273	18.2					
14-2W-16ccb#a	G. Eck	S	51	1260	27.9	60	80			700
14-2W-16ccb#b						50	65	490	80	740
14-2W-22abb	M. Thelander	S	23	1272	8.2					
14-2W-23abc	F. Shelby	S	50	1236	12.1					

[a]#a=first sample (August 17, 1976; #1=first well in same 10-acre tract;
#b=second sample (January 14 & 15, 1977; #2=second well in same 10-acre tract.

[b]D=domestic well; O=observation well; S=stock well.

[c]specific conductance at 25°C.

APPENDIX III

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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 occurring are those in

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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."

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

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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 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 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 and through 33 feet in the eastern part.

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."

HYDROGEOLOGY IN THE ADJACENT UPLANDS OF THE SALINE, SMOKY HILL AND SOLOMON RIVERS IN SALINE AND DICKINSON COUNTY, KANSAS

by

LLOYD E. DUNLAP

B.S., University of Kansas, 1975

AN ABSTRACT OF A MASTER'S THESIS

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Saline effluents are currently contaminating the Saline, Smoky Hill, and Solomon River valleys between Salina and Abilene, Kansas. The hydrogeology of the adjacent uplands to the salt emission area was studied to obtain a better understanding of the relation of the uplands to the salt emission area on the floodplain. Dune sand, terrace deposit and slope deposits are in the uplands along with the Kiowa Formation of Lower Cretaceous Series, and the Wellington Formation, Sumner Group, Cimarronian Stage, of the Lower Permian Series.

Elevations of the water table or piezometric surface were measured and ground-water samples collected from wells in the study area. Gypsum cavities in the phreatic zone by part or complete dissolution of gypsum are the major aquifers of the Wellington Formation. The cavities contain good quality to highly mineralized water depending on the amount of gypsum still present. The concentrations of sulfate, chloride, calcium and magnesium in the ground water ranged from 20-1830,5-450, 9-710, and 5-140 mg/l respectively.

Gypsum beds stratigraphically above the Hutchinson Salt Member of the Wellington Frrmation are highly distorted and cannot be correlated laterally. The distortion is caused by collapse and slumping of gypsum cavities or differential solution of the Hutchinson Salt Member to its subsurface extent west of the study area. Sulfate and chloride concentrations of the wells near the point of the divide between the Saline and Solomon Rivers indicate a location where salt brine is migrating from the salt near Salina through gypsum cavities. Close to the valley wall, lower cavities carry denser salt brine while upper cavities contain good quality water.

Well waters in the Kiowa Formation had lower dissolved sulfate and chloride concentrations than the Wellington Formation. The aquifers in the Kiowa Formation are sandstone lenses in the upper portion of the formation.

The piezometric surface or water table contours show that ground water in the uplands is generally flowing towards the Saline, Solomon and Smoky Hill Rivers.