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A PRACTICAL APPLICATION OF THEORETICAL SOIL MECHANICS TO EXPANSIVE SOILS

by

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INTRODUCTION

Statement of Problem

The properties of expansive clay soils have long been recognized and studied. These studies are generally concerned with the distress caused by the swelling of dry clays, but a few cases of soil shrinkage due to trees extracting water from the soil have been reported.

This report gives the details of a failure caused by the shrinkage of a clay soil due to extraction of water by a faulty underfloor heating and air conditioning air return, the testing and analysis required to evaluate the correction procedures, and the subsequent remedial repairs by rewetting the soil. A thorough search of the literature indicated that this is the first time the procedure has been used on an existing structure.

The project developed from an initial request from the director of the Community Memorial Hospital in Marshall County at Marysville, Kansas, for an examination of distress in the internal walls and floors of the hospital. The purpose of this examination was to determine the cause and possible correction of the settlement and to especially evaluate the safety of the structure since its continued use was critical to the community.

The location of Marshall County, Kansas, is shown in Fig. 1, and the location and topography of Marysville is

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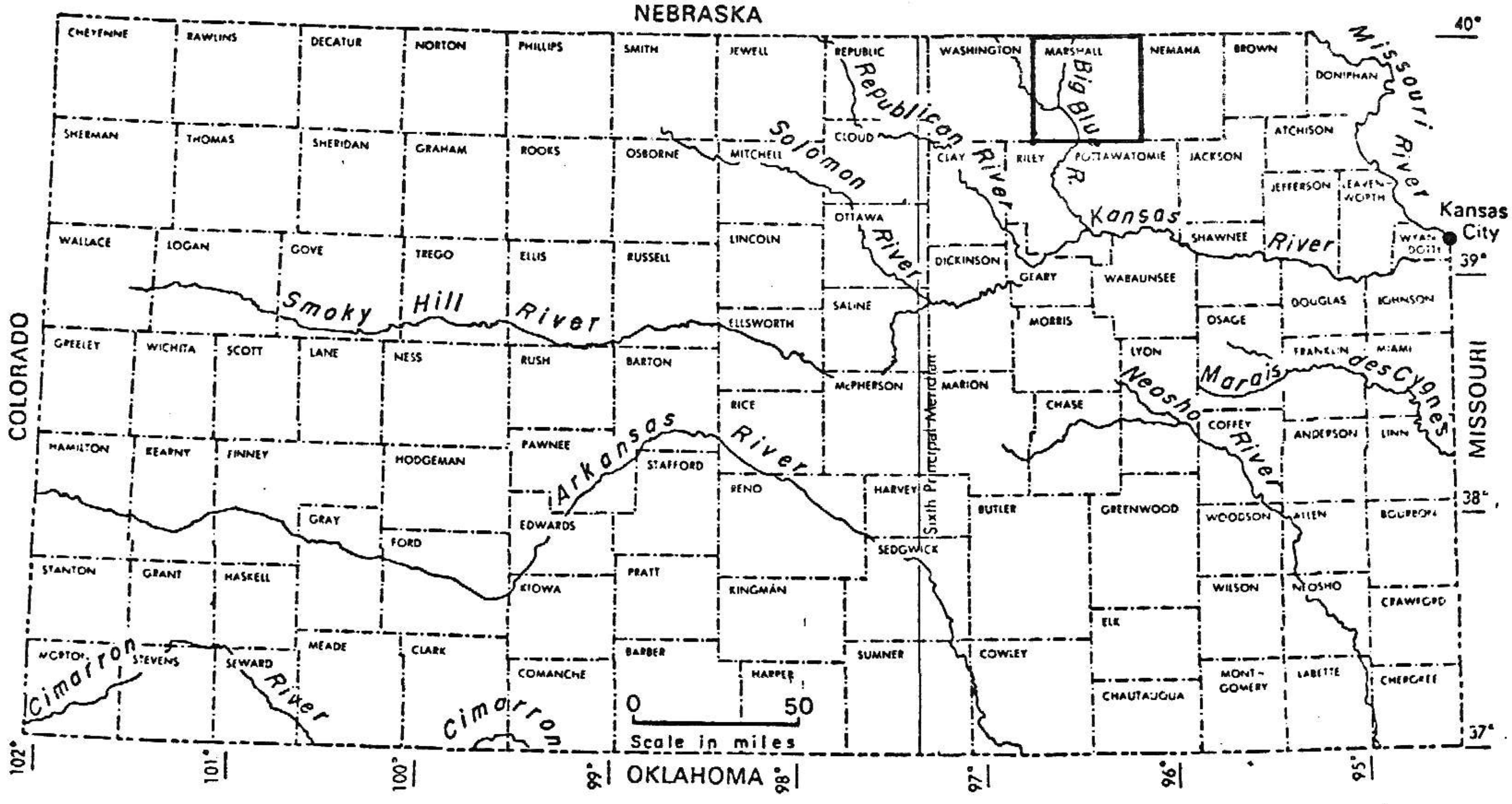

Figure 1. Location of Marshall County, Kansas

shown in Fig. 2. The hospital is located on the upland to the east of the Blue River near the northeast corner of the town.

The hospital is a single story brick structure in a gently sloping park-like setting and has a capacity of 61 beds. It consists of an original structure constructed in 1958, an addition to the south built in 1964, and a later addition to the north completed in 1970. Severe distress of the floor and internal walls, as evidenced by cracking, disjointment, and warping, has occurred in the original structure over the past seven years as shown in Figs. 3 through 6. The exterior of the hospital showed no evidence of settlement and all exterior surfaces are in excellent condition.

Internally the distress is most severe in the areas critical to the hospital operation, especially surgery, the emergency rooms, laboratory and pharmacy, located along the south corridor as shown in Fig. 7.

Structure

The hospital is a single story brick structure built in the shape of a T with the main wing extending in an east-west direction. The internal partitions are concrete block supported by the floor slab. The asphalt roof is supported by steel I beams resting on pipe columns. The floor rests on a 6 inch sand blanket over the undisturbed soil which had been cleaned of vegetation. The floor slab was placed

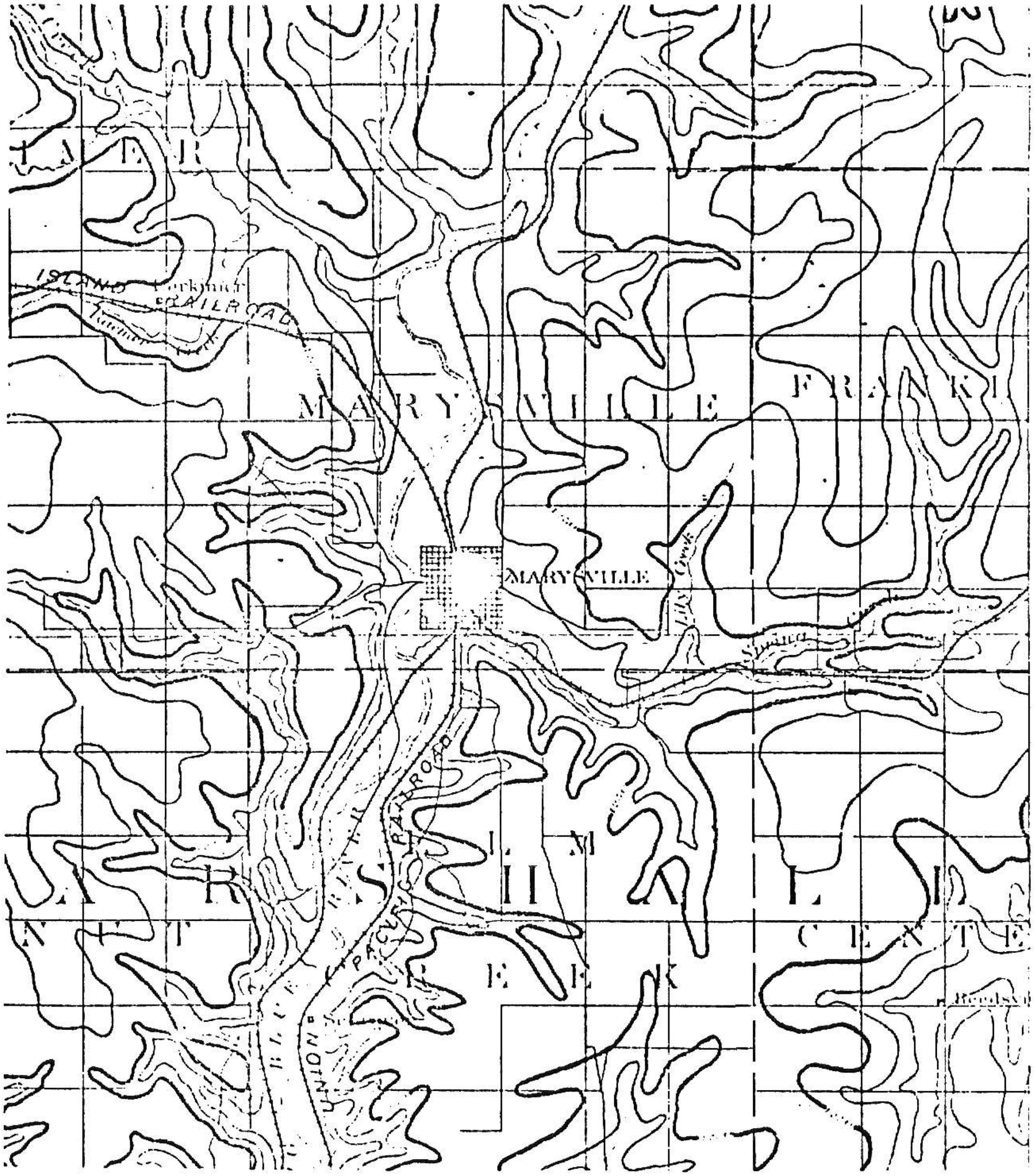

Figure 2. Location and Topography of the Marysville, Kansas area

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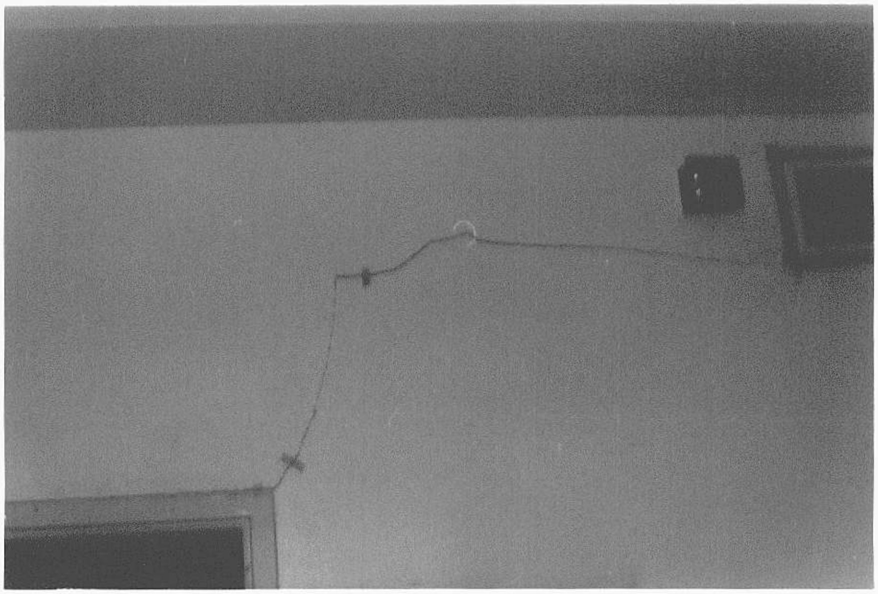


Fig. 3. Crack in Wall Above Door to Surgery

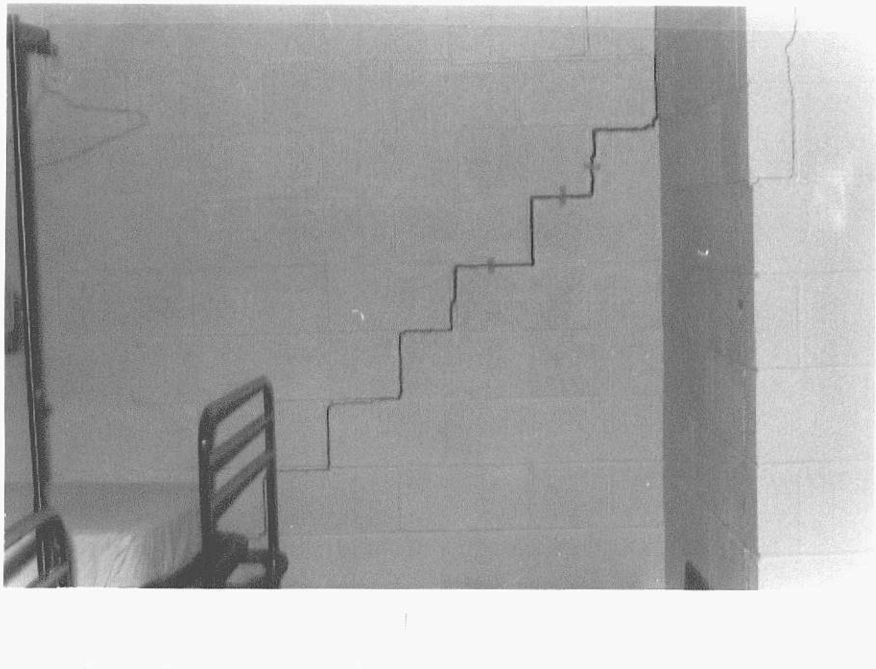


Fig. 4. Crack in South Wall of Recovery Room

Fig. 5. Crack in Wall and Misalignment of Recovery Room Doors

Fig. 6. Disjointment of South Corridor Floor

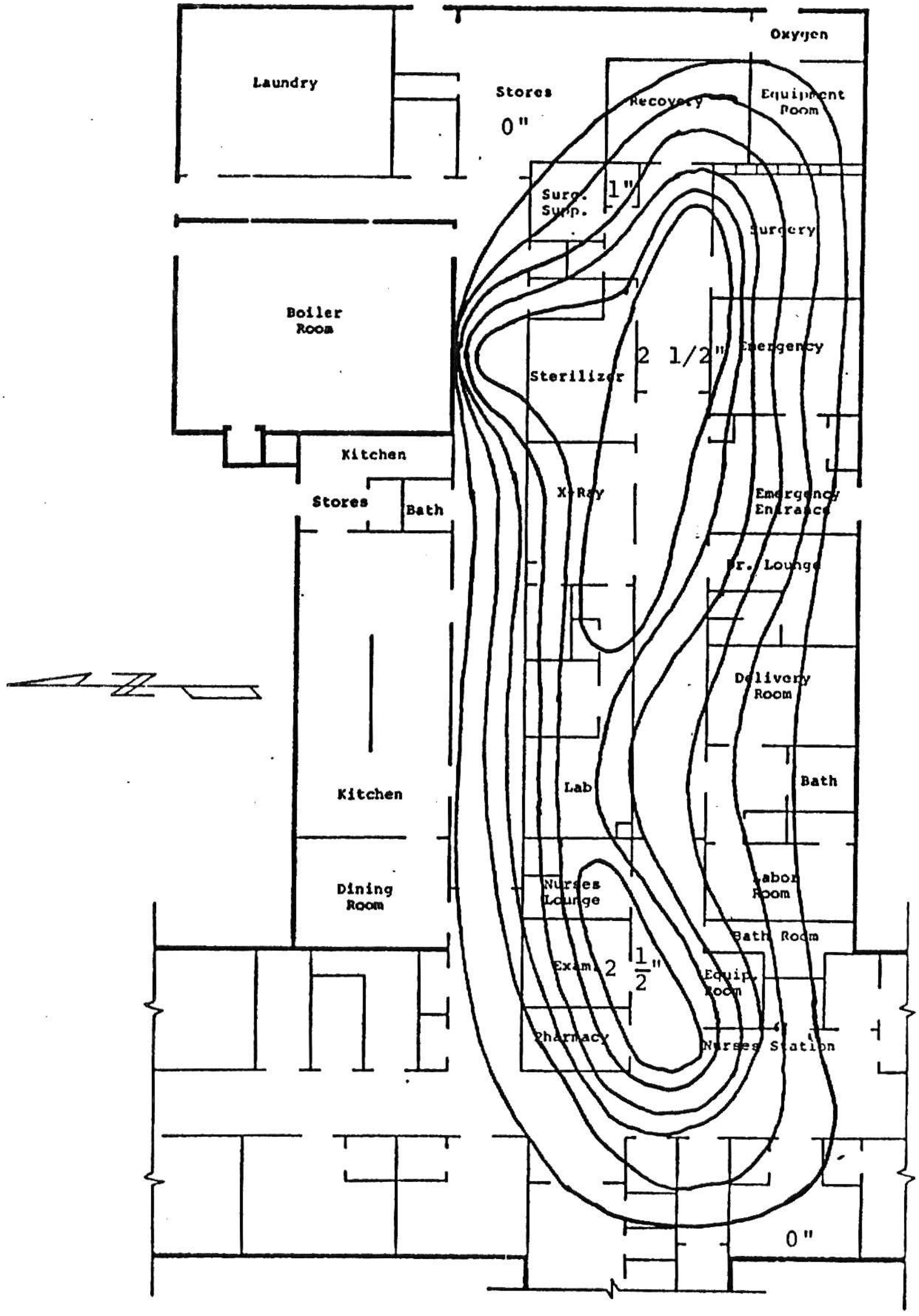


Figure 7. Floor Slab Settlement. Community Memorial Hospital. Marysville, Kansas

simultaneously with, and is thus connected to the external wall and interior columns. The exterior wall extends downward to a continuous spread footing 5 feet below ground surface. The interior columns are founded on a square footing, also 5 feet below ground level. A contact soil pressure of some 2,000 pounds per square foot was used for the design of the footings.

The water supply pipes, air ducts, and electrical conduits for lighting are located above the ceiling. Other electrical conduits, air ducts, and sanitary sewer lines are located below the floor. The temperature of the air in the hospital is controlled by 4 independent units which circulate air in 5 systems, as shown in Fig. 8. All of the systems except the system serving the lobby area have an overhead forced air and an underfloor air return. The air circulates in an opposite manner in the lobby system. The underground heating and cooling air conduits are paper tubing (sonotube) encased in light weight concrete. They vary from a diameter of 8 inches to 26 inches.

Extent of Damage

A careful survey of the roof surface indicated that no appreciable deflection of the roof had occurred. A survey of the floor slab inside the hospital indicated downward deflection of the floor slab in excess of two inches. Along the south side of the east wing the settlement of the floor

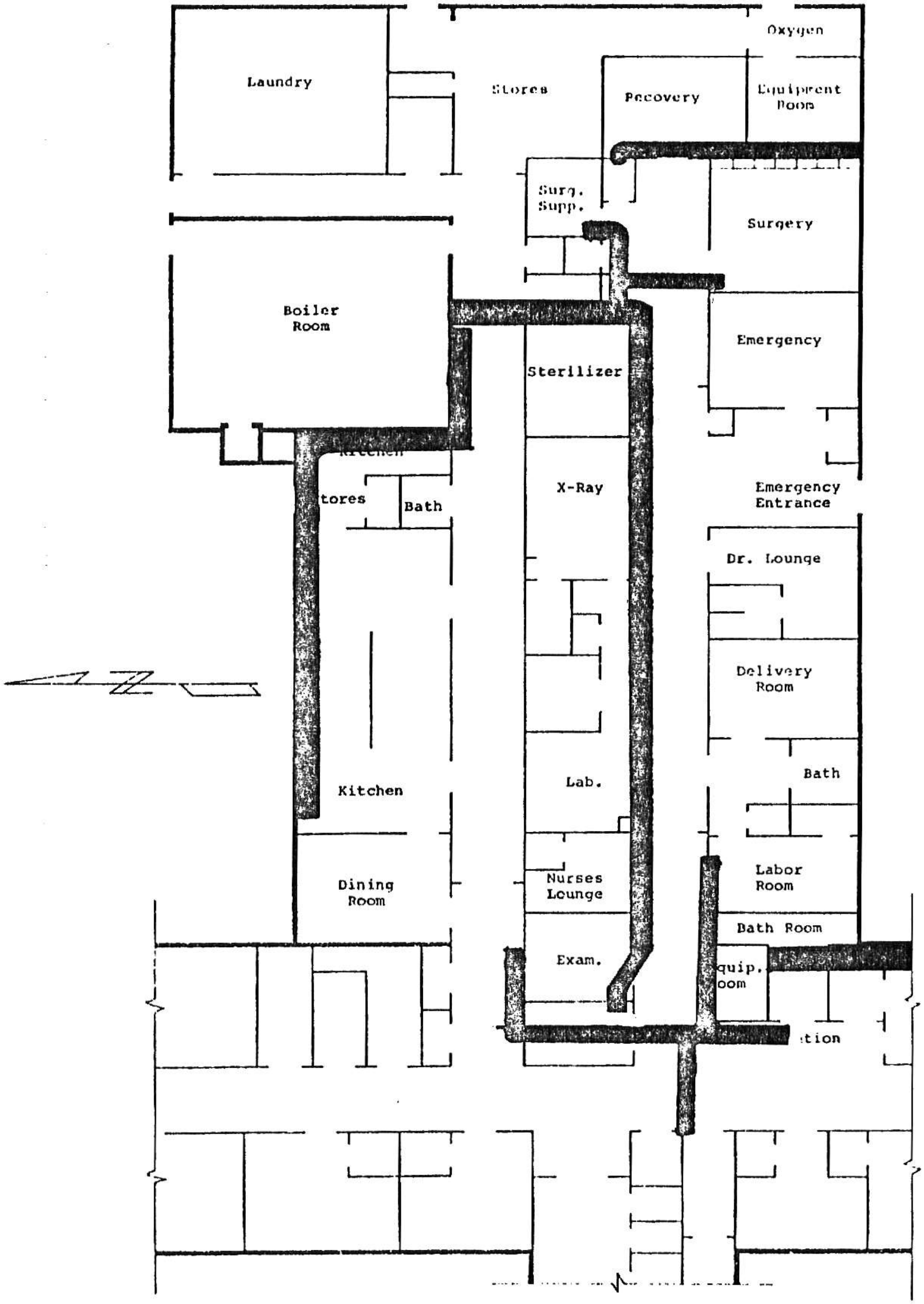


Figure 8. Underground Air Ducts. Community Memorial Hospital. Marysville, Kansas.

varied from zero near the south wall to a maximum of 2.5 inches along the return air duct buried beneath the south corridor.

The internal partitions have yielded with the floor with subsequent cracking near each opening, but hang suspended near the columns and at wall intersections. These walls appear to be slowly yielding downward, thus widening the cracks in a progressive failure. Combined with the continued settlement of the floor, cracking of the structure has been extended over several years and appeared to be apt to extend into the future.

Most of the doors in the distressed area could not be closed because of a misalignment of the door and jamb. In some cases, the steel frame of the door jamb was rigid enough to cause severe crushing of the plaster, as the wall on one side only settled.

In the surgical area the cabinets for the surgical supplies had settled with the floor, leaving unpainted walls and/or cracks exposed.

The floor showed little cracking and disjointment, except in the area of central stores and near the west end of the south corridor.

Scope of the Study

The scope of this study was developed as the investigation progressed. This development of the scope proceeded by the following steps after the review of the structure and the building plans indicated that the failure resulted from settlement of the soil:

1. A soil investigation to determine the character of the soil strata present and for the collection of soil samples.

2. Determination of the physical characteristics of the soil samples by laboratory testing.

3. A review of the existing literature in the areas of clay mineralogy, identification, physical characteristics, and especially the nature of swelling and shrinkage of natural soil deposits due to changes in moisture since the first two phases indicated the condition to have been caused by shrinking soils.

4. Analysis of the collected data to determine the feasibility of raising the structure to restore it to the original position by rewetting the soil.

5. The correction of the settlement by rewetting the soil, the progress of which was determined by careful measurements of the elevation of the floor and the frequent collection of soil samples to measure the moisture changes.

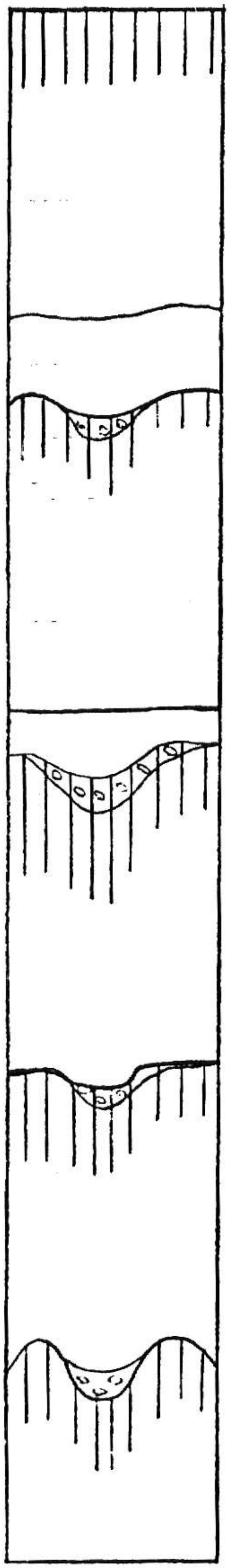
For convenience and continuity, this information is not presented in this order in the body of the report.

LITERATURE REVIEW

Glaciation

The upland in the Marysville, Kansas, area is underlain by soil materials deposited by the ice during the glacial periods of the Pleistocene period. The relationships of the various glacial epochs are shown in Fig. 9, taken from the Pleistocene of Kansas (1).

Glacial materials are ground up rock materials resulting from erosion of the existing soil and rock materials of the north near the initial source of formation of the glacier and deposition of this debris by the ice and flowing meltwater as the glacier retreated by melting. The particles range in size from very large blocks of stone some 10's of feet in size to clay size. The silt and fine sand sizes predominate in most glacial deposits. Material deposited directly by the ice without the action of the meltwater is called till and may be readily identified by the great range of particle sizes intimately mixed without sorting or stratification. The till commonly consists of a matrix of fine sand, silt, and clay particles with numerous pebbles and boulders interspersed throughout. Materials deposited by the meltwater from the glaciers are commonly called outwash deposits and have all the sorting and stratification characteristics of alluvial deposits.



Wisconsin Till. Well developed soil profile at the surface. Glacial Till shows little precompression and consists of rock fragments in a matrix of rock floor of silt size. Age, 10,000 years±

Peorian Loess and Sangamon Interglacial deposits.

Illinoian Till. Buried soil horizon and overcut and refilled valleys at the top. Till shows precompression of 1 tsf± and consists of a dense mixture of rock fragments in clay. Age, 125,000 years±

Loveland Loess and Yarmouth Interglacial Deposits

Kansan Till. Similar to Illinoian Till except that buried soil horizon is very high in clay and is commonly called a gumbotil. Gravel in refilled valleys are called the Buchanan gravels. Precompression 1 to 2 tsf. 500,000 years.

Nebraskan Till. Similar to the Kansan Till. The interglacial separating the Kansan and Nebraskan is called the Aftonian and the gravel in the refilled valleys is also designated the Aftonian gravels. Precompression, 2-4 tsf. Age, 1,000,000 years.

Weathered bedrock with a relief in excess of 400 feet.

Fig. 9. Relationship of the Glacial and Interglacial Soil Deposits of North America

The existence and delineation of the glacial deposits is accepted completely today and it is difficult to realize that this has been so only since 1900. The glacial deposits of Switzerland were described by Sussure in 1786 (2), but he ascribed them to deposition by water which was corrected by James Hutton in 1788 (3). In 1821, Charpentier (4) correctly identified the Swiss deposits as ice deposited, while Esmark in 1824 (5) described the ice deposited materials of Norway. The theory of glaciation was improved and strengthened by Venetz in 1841 (6) and Agassiz is 1840 (7). Multiple periods of glaciation were recognized by Chamberlain in 1890 (8), and Geikie classified and named the glacial epochs of Europe in 1895 (9) while Chamberlain published a similar classification for North American glaciers in 1895 (10). Tyrell gave these deposits the name Pleistocene in 1839 (11). The last objection to today's accepted theory of glaciation was a 1500 page argument by Howorth in 1905. The theories of glaciation accepted today were formalized by Tyndall (12) in 1896, Penck and Bruckner (13) in 1909, and Hobbs (14) in 1911.

Today, four major periods, separated by relatively long interglacial periods, are recognized. Numerous authors have defined the maximum extension of these four glaciers as evidenced by the glacial deposits. Prominent among these are Anteus (15) 1929, R. F. Flint (16) 1945, and Flint (17) 1957. The extent of the ice sheets in Kansas are shown in Fig. 10.

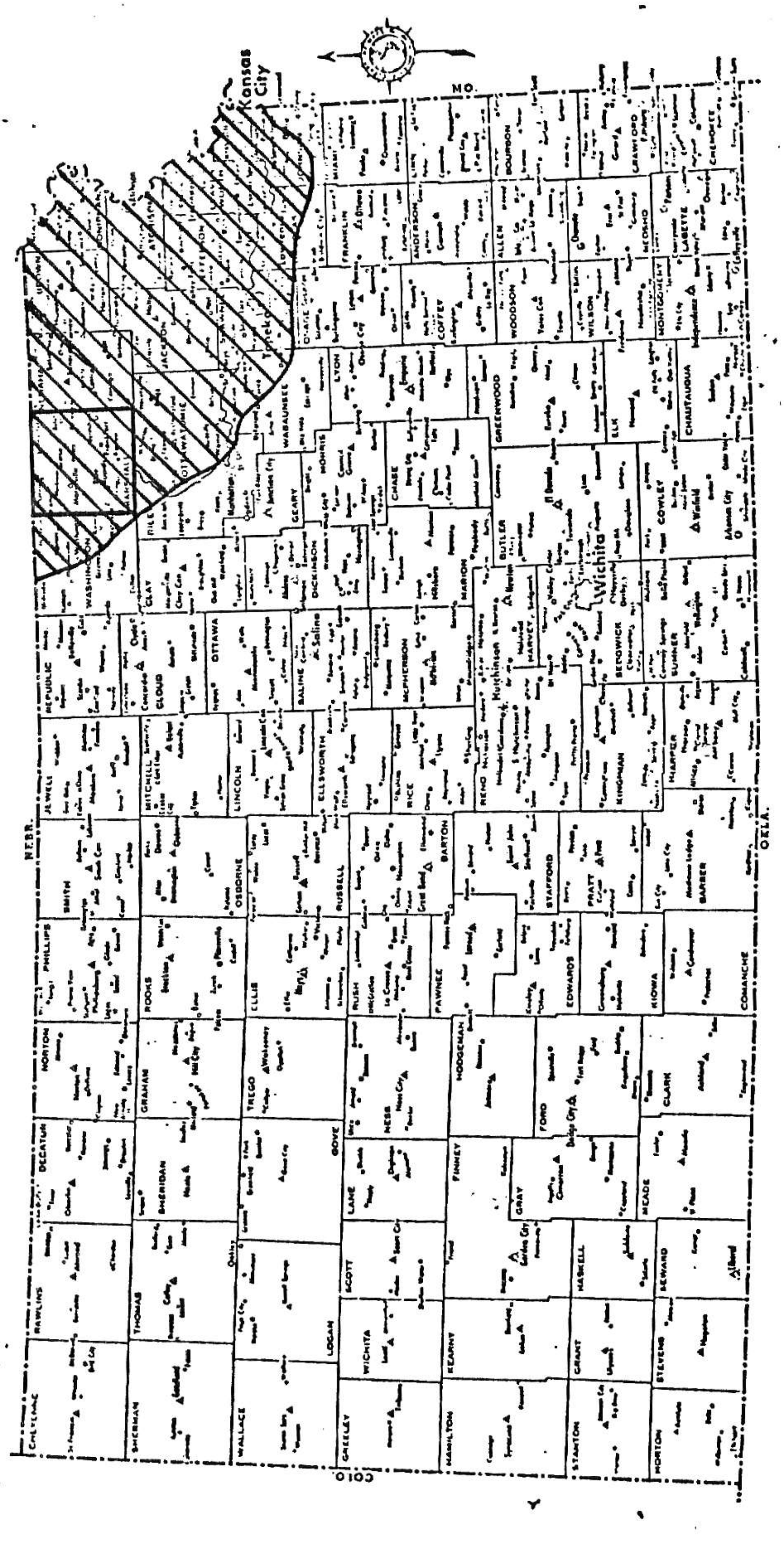


Figure 10. Extent of glaciation in Kansas

A great step forward was made by Arnold and Libby (18) in developing a method of radiocarbon dating, which has helped greatly in accurately dating the glacial tills. Although radiocarbon dating would not be used to date the older tills, the method was adapted to the use of other radioactive isotopes, and it is generally agreed that the Kansas glacier advanced some half million years ago and thus the surface of this till has had a very long weathering history.

This is evident in the Marysville area from the thickness of the "A" and "B" horizons in the soil profile each being some three feet in thickness. Although no effort was made in this study to date the till deposit, these thicknesses indicate a very long period of weathering.

Mineralogy

The material deposited by the glacier is simply an accumulation of the rock and soil debris picked up by the ice. In the Marysville area, the coarser rock fragments are clearly the Sioux Falls quartzite from near Sioux City, Iowa, the pink and grey granites found commonly around Pipestone, Minnesota, and numerous unidentifiable fragments of limestone and metamorphic schists and gneisses from the Northern Minnesota or Canadian areas. An excellent opportunity to study the coarser rock fragments is found in the outwash deposit some 3 miles south of Marysville on Highway No. 77, which is presently being worked for road metal.

The glacial till in the upland around Marysville is approximately 60 feet in thickness and consists of a matrix of almost equal portions of sand, silt, and clay containing gravel and rock fragments.

The till has a well developed soil profile on the surface with an "A" horizon 3 to 4 feet in thickness and a "B" horizon 4 to 6 feet in thickness. The glacial till is oxidized throughout its full depth, but the alteration of the primary minerals to clay is limited to the soil profile. The "A" horizon is high in organic humus and has soil grains predominantly of silt size. The "B" horizon is a so-called gumbotil with a very high clay content. Willman, Glass, and Frye (19) in 1963 showed that the Kansan ice sheet advanced over North America from both the Western Keewatin Center and the Eastern Labordorean Center. Their study further showed that of the clay fraction, the Illitic clay mineral predominates in the Labordorean till, while Montmorillonite is more abundant in the Keewatin deposits. Since the till at Marysville was deposited from the Keewatin Center, this study would indicate that Montmorillonite should predominate and X-ray diffraction studies indicate this to be true.

The reactive portion of the till is the clay minerals. The word clay comes from the Anglo-Saxon word Claeg which came from the Latin word glus meaning glue. For a number of centuries the word, with reference to soils, was used for those soil materials possessing cohesion. The word today carries three implications:

1. Natural occurring mineral grains smaller than 0.005 millimeter in diameter.
2. Inorganic crystalline minerals composed of hydrous aluminum or magnesium silicates.
3. Plastic properties.

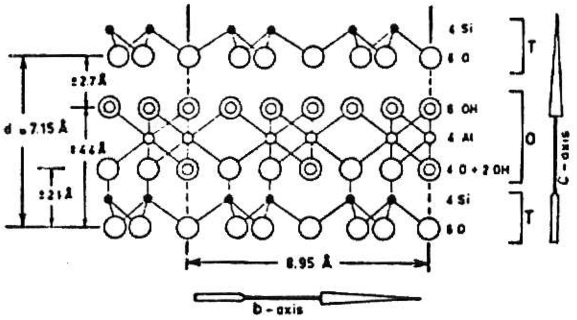
In addition, it is recognized that clay minerals are formed by weathering of the primary minerals. Clays may be separated into a large number of individual minerals, but these can all be grouped into three distinct families:

1. Kaolinite
2. Montmorillonite
3. Illite.

In 1847, Damour and Salvetat (20) as reported by Brown (21) separated clay into groups naming and describing Montmorillonite as having a composition of 4 $[(SiO_2)(Al_2O_3)(1+X)(H_2O)]$. Later in 1888, Van Bemmlen (22) described and named a clay material from the Kauling Hills near Jauchau-Fu, China as Kaolinite with a formula 2 $[Al_2(OH)_4(Si_2O_5)]$.

In 1930, Pauling (23) first described a so-called mica-clay that was later named Illite by Grim, et. al. (24) in 1937.

The structure of these three principal clay minerals is shown in Fig. 11.

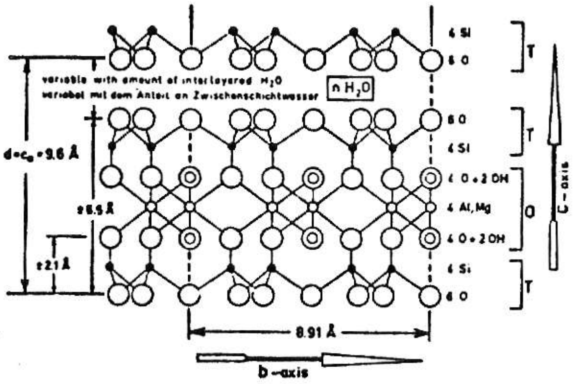


KAOLINITE – G.W. BRINDLEY and K.ROBINSON (1946)

$2\left[Al_2(OH)_4 \mid Si_2O_5\right]$

TRICLINE $a_0 = 5.14$ Å, $b_0 = 8.93$ Å, $c_0 = 7.37$ Å, $\alpha = 91°48'$, $\beta = 104°30'$, $\gamma = 90°$

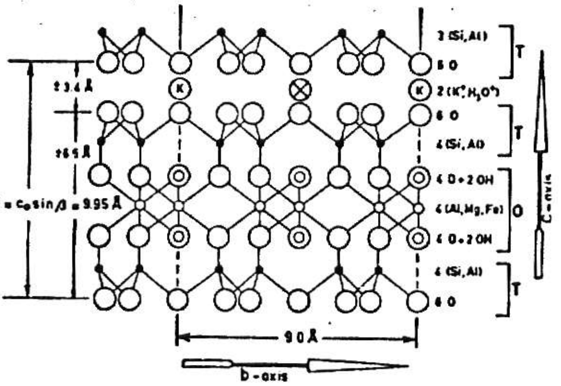
$d = c_0(1 - \cos^2\alpha - \cos^2\beta)^{1/2} = 7.15$ Å.



MONTMORILLONITE – U.HOFMANN et al.(1933)

$$2\left[\begin{matrix}(Al.Mg)_2(OH)_2 \mid Si_4O_{10} \\ (Na^+, Ca^{2+})\end{matrix}\right] n\,H_2O$$

RHOMBIC $a_0 = 5.095$ Å, $b_0 = 8.83$ Å, $c_0 = 9.6$ Å



ILLITE – R.E.GRIM et al.(1937)

$2\left[(K,K^+,H_3O^+) \mid (Al,Mg,Fe)_2(OH)_2 \mid (Si,Al)_4(O,OH)_{10}\right]$

MONOCLINE $a_0 = \sim 5.2$ Å, $b_0 = \sim 9.0$ Å, $c_0 = \sim 10.0$ Å, $\beta = \sim 95°30'$

Fig. 11. Structure of the Principal Clay Minerals

Identification of Clay Minerals

The beginnings of clay mineral identification are obscure, but it is known that prehistoric man was able to select the proper clays for pottery making. By the late nineteenth century, clays had been subdivided into three general groups: the Kaolinites, Montmorillonites, and the mixed layer or Illitic clay minerals. It was early recognized that a petrographic or grain size analysis was not sufficient to even separate and identify the individual groups. It was found that the consistency limits established by Atterberg (25) in 1912 could be used to determine qualitatively the presence of Montmorillonite and/or Illite, but could not be used to separate these two clay minerals.

Today there are three techniques in common use for clay mineral identification: differential thermal analysis, X-ray diffraction, and electron microscopy. The use of infra-red and flame spectroscopy have had a great promise, but shows little practical use.

The differential thermal analysis was first used by Ramsay (26) in 1877 for the examination of the silicate minerals based on the technique of Hannay (27) also in 1877. The technique was further improved by Le Chatelier (28) 1887, Mellor and Holdcraft (29) 1911, Brown and Montgomery (30) 1912, Wallach (31) 1913, L. Navais (32) 1923, McGee (33) 1927, Agafonoff (34) 1935, Insley and Ewell (35) 1935, Grim and Bradley (36) 1940, and Brindley (37) 1949.

The use of X-ray for identification was pioneered by Pauling (38) in 1930, Ross and Kerr (39) in 1931, and Gruner (40) in 1932. This and later work was summarized and applied by Grim (41) in 1953 and later by Brown (42) in 1961.

The electron microscope is used to identify clay minerals, but its principal use lies in the study of the fabric of the soil materials.

The electron microscope was used for the identification of clay minerals by Eitel, et. al. (43) in 1939. The use was further explored by Jacob and Loofman (44) 1940, Eitel (45) 1941, Humbert (46) 1942, and Kelley and Shaw (47) in 1943 in rapid succession. The source literature was so numerous that bibliographies were prepared by Marton and Sass (48) in 1945, Rathburn, et. al. (49) in 1946, and Cosslett (50) in 1951. An atlas of electron microscopy of clay materials and their admixtures was prepared by Beutelspacher and Van Der Marel (51) in 1961, which shows actual photographs of the various clay minerals. This volume is available with English translation and is valuable in electron microscope mineral identification.

Volume Change in Clay Soils

Large areas of the earth's surface is underlain by soil deposits containing clays which have volume change with changing water content. These soil deposits include the glacial tills, residual soils, and the over-consolidated clay shales. Two distinct factors must be present if a swelling soil deposit is to cause problems to structures.

1. The soil must contain an appreciable quantity of the Montmorillonite or Illite clay minerals.

2. The soil moisture regimen must be such that great changes in the water content of the soils can occur after the structure is completed.

Early studies indicated that this effect was general in colloids and the phenomena was first recorded by the colloidal chemists. The general nature of the colloids was described by Duclaux (52) in 1926. This work was applied to expansive soils by Terzaghi (53) 1931, Simpson (54) 1934, and Winterkorn (55) 1936. Today the literature on expansive soils is so extensive that it is almost impossible to cover all of it.

This literature generally falls into the following general categories:

1. Practical examples of the phenomena (56, 57, 58, and 59).

2. The character and identification of expansive soils (60, 61, 62, and 63).

3. The stabilization or control of expansive soils (64, 65, 66 and 67).

Much of this literature on expansive soils is repetitious with a series of papers, for example, giving the details of settlement caused by drying due to Poplar, Oak, Elm, and Beech trees. Many of them deal in a very loose fashion with the swelling pressures of a confined clay or the expansion of an unconfined clay that can be applied only to a very specific soil strata. In general, there is almost a complete absence of practical applications, except for stabilization of expansive soils in highway construction.

DESIGN OF EXPERIMENT

Unlike the typical research project, this study proceeded by a series of steps from an examination of an existing distressed structure, through the discovery of the cause, and finally to the correction of the settlement by the application of the theories of classical soil mechanics. During each phase, it was necessary to discover the facts necessary to guide the study to the next step, and step by step to the final solution.

The true extent, nature, and causes of the settlement were, at first, quite obscure. After a careful examination of the plans of the structure and the extent and nature of the settlement, it was obvious that the only possible cause for the settlement was the soil under the floor.

After the cause of settlement was determined to be shrinkage due to drying of the soil, a series of tests was conducted to determine the following characteristics:

1. The volumetric increase in the soil when wetted from an oven dry state to complete saturation under a confining load of 1/4 tsf.

2. The confining pressure required to prevent swelling of the soil by saturating an oven dry sample.

3. The volumetric amount of water required to saturate a unit volume of soil from the natural water content.

A series of test holes was planned that would secure representative samples both inside and outside the hospital. Three holes were planned outside at the general extremities of the T shaped structure. A total of eighteen holes was drilled inside the structure. A careful log of each drill hole was prepared.

The testing procedures included the determination of the following for each soil sample:

1. Void ratio (e) and natural water content (w).
2. The liquid limit (L_L) and plastic limit (P_L).
3. Grain size analysis.

Representative samples were chosen from each of the soil strata encountered for the following determinations:

1. Mineralogy by X-ray diffraction of each soil stratum.
2. Strength as measured by direct shear with the angle of internal friction (ϕ) and cohesion (c) being reported.
3. Compressibility determined by the consolidation test.

Engineering Characteristics

The Engineering Properties of the soil were initially determined from soil samples representing each one foot soil layer to a depth of ten feet from the existing surface at six different locations. The soil boring logs summarizing the subsurface soil strata inside and outside the hospital are shown in Figs. 12 and 13. The soil strata were found to be uniform throughout the area, except that the soil under the structure was much dryer and denser, as shown in Table 1.

Date June 24

Project Community Memorial Hospital

Weather Clear Hot

Location Marysville, Kansas

Hole No. inside

Location General log for soil inside of hospital

Wl Dry

Driller M. Williams

Observers W. Williams

Depth				Description
4"				Concrete floor
6"				Fill sand - fine, dry
1				Black organic silt topsoil similar to same stratum outside except w = 3-5% and e = 0.45. very large random shrinkage cracks extending throughout the stratum.
2				
3				
4				Brownish yellow silty clay. Similar to same stratum outside except w = 5-7% and e = 0.52 shrinkage cracks from layer above extend downward into this layer to a depth of same 5 feet.
5				
6				
7				Dark brown glacial till. Similar to same stratum outside.
8				
9				
10				

Figure 12 Log of the soil strata inside the Marysville, Kansas hospital.

Date June 21, 1971

Project Community Memorial Hospital

Weather Clear Hot

Location Marysville, Kansas

Hole No. outside

Wl Dry

Location General log for soil outside of hospital

Driller Fred Williams

Observers Wayne W. Williams

Depth				Description
1				Black organic silt topsoil $w=27\%$, $e= 0.85$, sand = 22% Silt= 74%, clay = 4%, $L_L= 42$, $P_L= 28$, $\phi= 22°$, C = 14 Psi.
2				
3				
4				Brownish yellow silty clay $w = 25\%$, $e = 0.70$, sand = 10% Silt = 68%, clay = 22%, $L_L = 56$, $P_L = 22$, $\phi = 18°$, c = 22 Psi.
5				
6				
7				Dark brown glacial till $w = 20\text{-}25\%$, $e = 0.61$, sand - 32% silt = 59%, clay = 9, $L_L = 45\%$ $P_L = 28\%$, $\phi = 32°$, c = 16 Psi.
8				
9				
10				

Figure 13 Log of the soil strata outside the Marysville, Kansas hospital.

Depth in Feet	Avg. Water Content		Avg. Void Ratio		Avg. Density Pcf.	
	Outside	Inside	Outside	Inside	Outside	Inside
0 - 1	12%	1%	.72	.39	108.4	121.0
1 - 2	25%	3%	.78	.36	117.0	126.2
2 - 3	24%	6%	.81	.43	114.1	123.5
3 - 4	23%	7%	.80	.47	114.4	121.3
4 - 5	22%	11%	.75	.53	116.2	120.8
5 - 6	20%	18%	.73	.65	115.5	121.2
6 - 7	20%	23%	.72	.68	116.2	121.9
7 - 8	22%	20%	.72	.70	118.2	117.6
8 - 9	25%	25%	.74	.73	118.7	120.4
9 - 10	23%	24%	.71	.71	119.8	120.8

Table 1. Comparison of Soil Moisture, Void Ratio, and Moist Density of Soil Outside to Soil Inside the Structure.

Classification

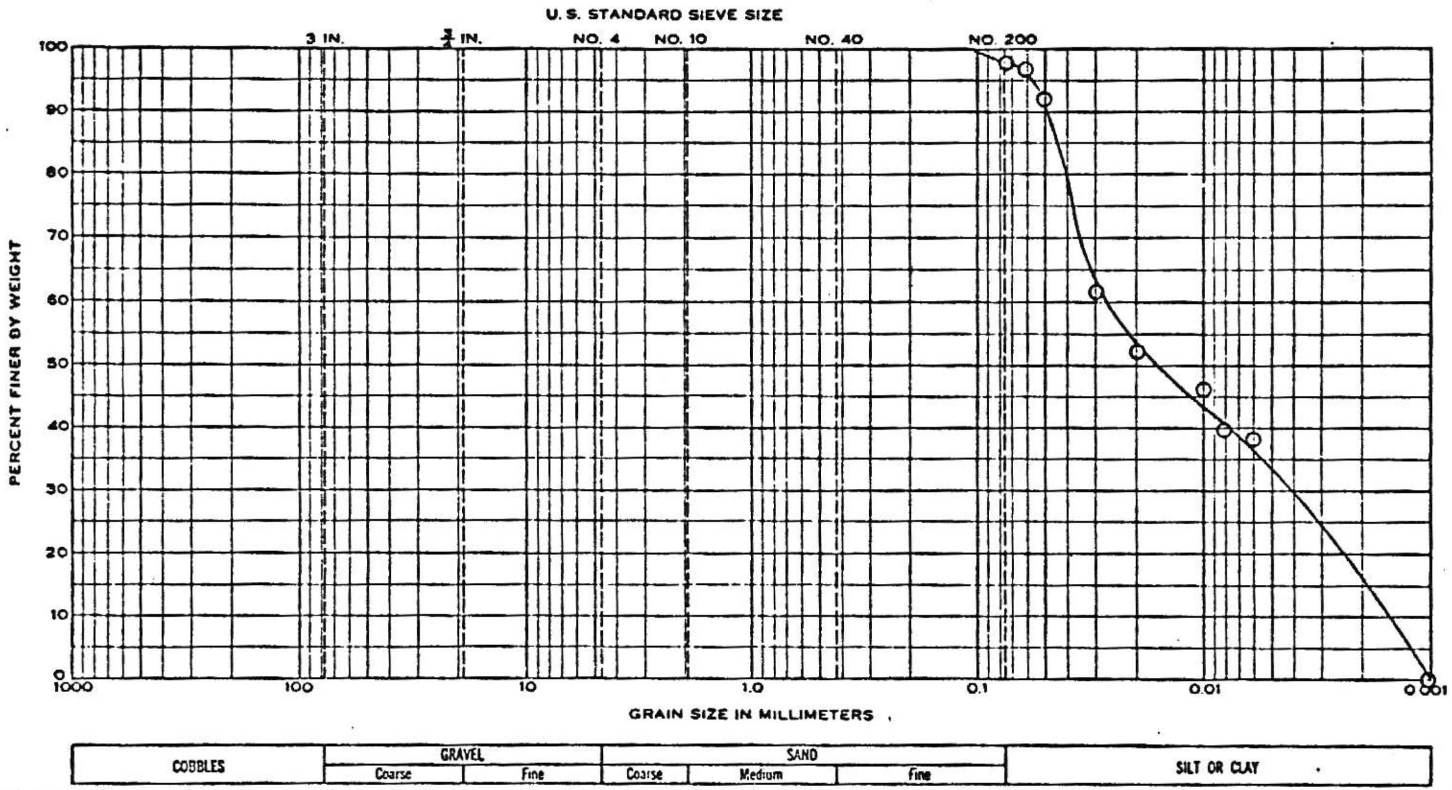
The gradation and Atterberg limits of each one foot layer of soil are shown in Fig. 14 through Fig. 23. These indicate that the material is predominantly silt size particles varying from 58% to 78% in the extreme samples. The content of sand never exceeded 8% in any of the samples. The clay fraction varies from 15% to 38% in the various layers. To a depth of four feet the clay fraction was coarser than .001 mm. while below that depth, there was a significant amount of clay finer than .001 mm.

The liquid limit varied from a high of 59 to a low of 46 with the layers which contained a higher percentage of particles smaller than .001 mm. having a higher liquid limit. The plastic index varied in a similar manner from a high of 33 to a low of 20.

The soil layers classified as ML (silt with low plasticity) to a depth of four feet and MH (silt with a high plasticity) below the four foot level. The system used for this classification was the Unified Soil Classification System as shown in Table 2.

Shear Strength

The shear strength of each one foot soil layer was determined from the surface to a depth of ten feet. A summary of this information is summarized in Table P41 3, and the individual test results are shown in Figs. 24 through 33.

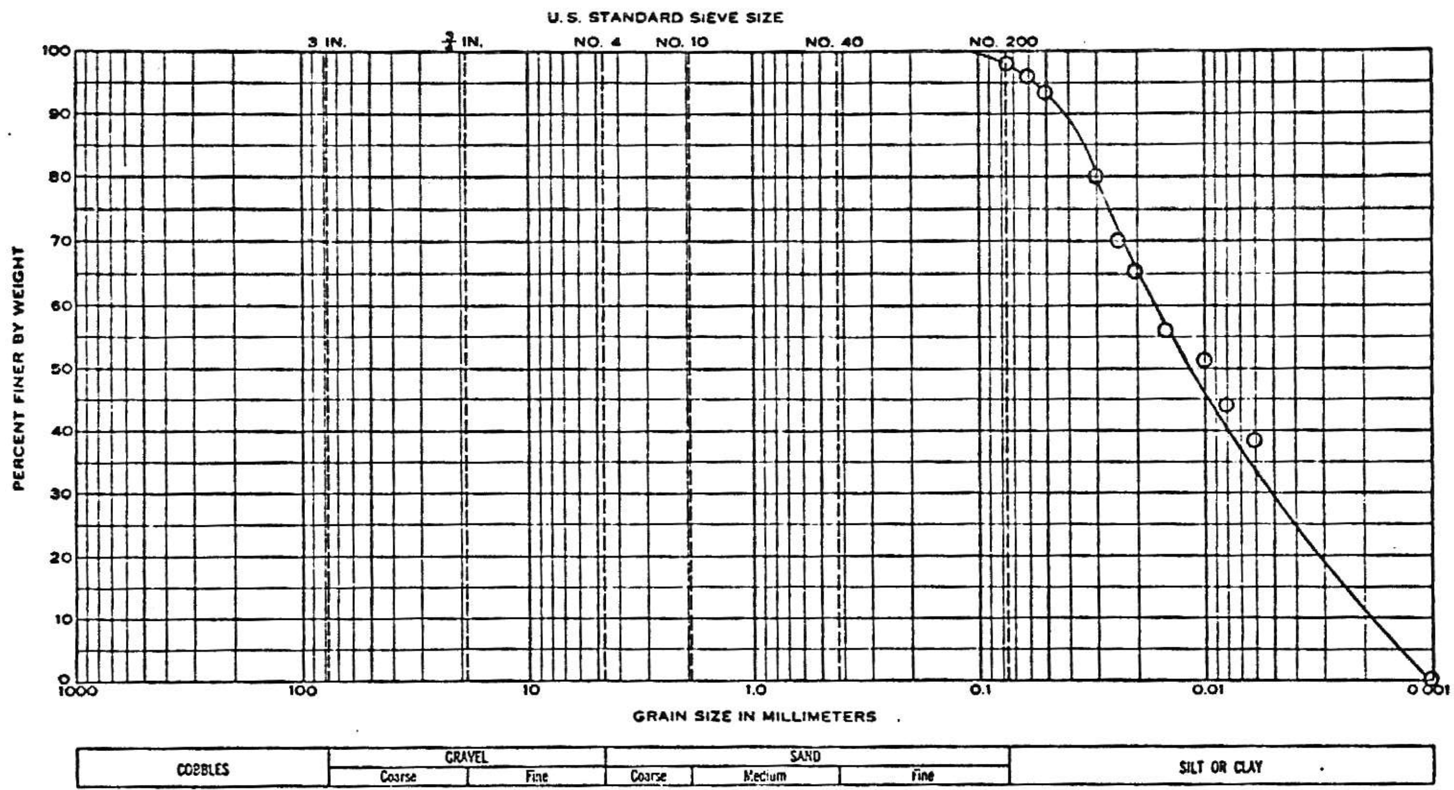


Sample No.	Elev or Depth	Classification	NatWC	LL	PL	PI	
Outside	0-1 ft.	Unified ML	26%	46	26	20	34% Clay
							64% Silt
							2% Sand

GRADATION CURVES

Project Community Memorial Hospital, Marysville, Kansas
Area South
Boring No. One
Date February 23, 1972

Figure 14 Physical characteristics of the soil from zero to one foot.



Sample No.	Elev or Depth	Classification	NatWC	LL	PL	PI	
Outside	1-2 ft.	Unified ML	28%	48	24	24	30% Clay
							68% Silt
							2% Sand

GRADATION CURVES

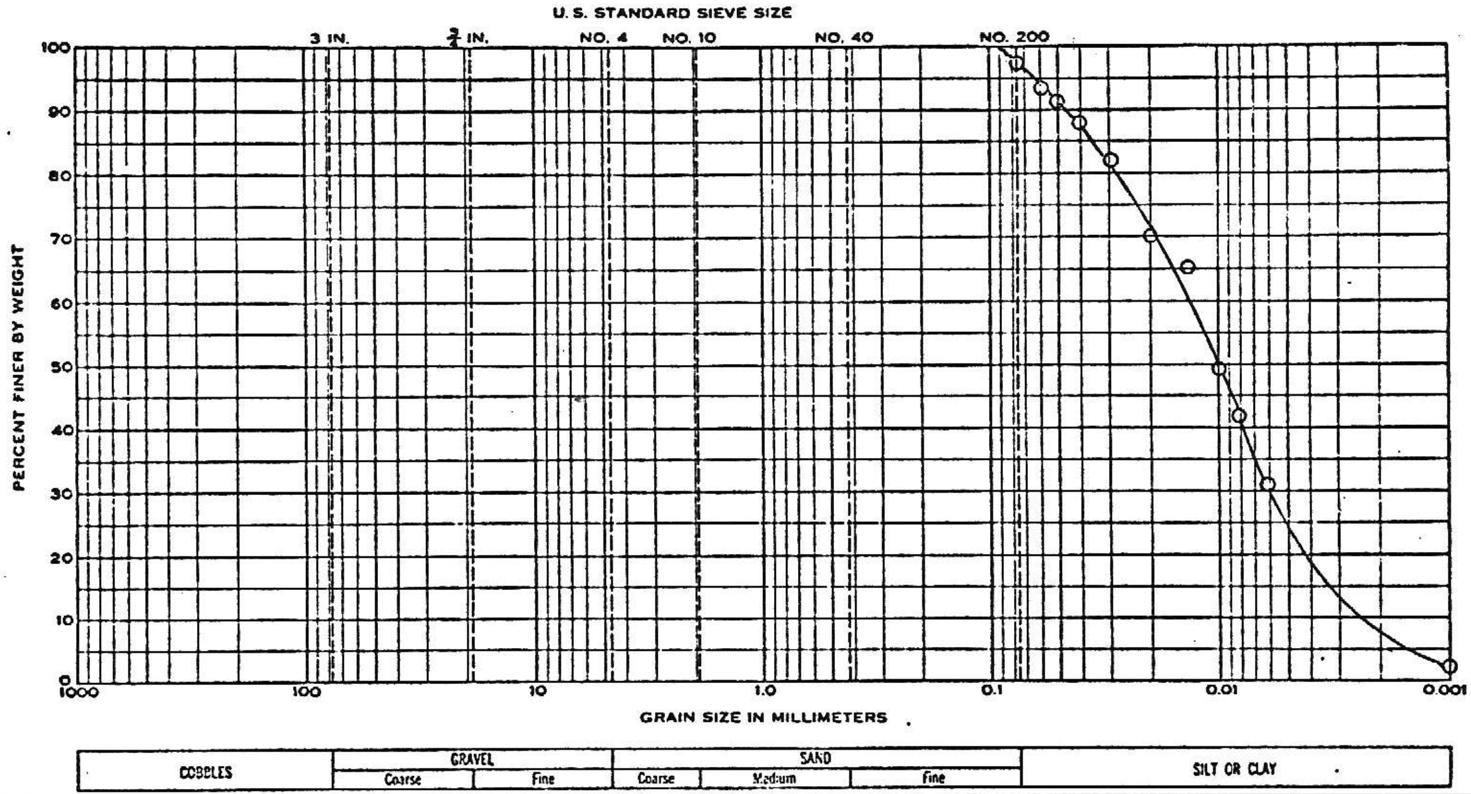
Project Community Memorial Hospital, Marysville, Kansas

Area South

Boring No. One

Date February 23, 1972

Figure 15 Physical characteristics of the soil from one to two feet.



Sample No.	Elev or Depth	Classification	NatWC	LL	PL	PI	
Outside	2-3 ft.	Unified ML	32%	46	26	20	24.5% Clay
							73.0% Silt
							2.5% Sand

Project Community Memorial Hospital, Marysville, Kansas

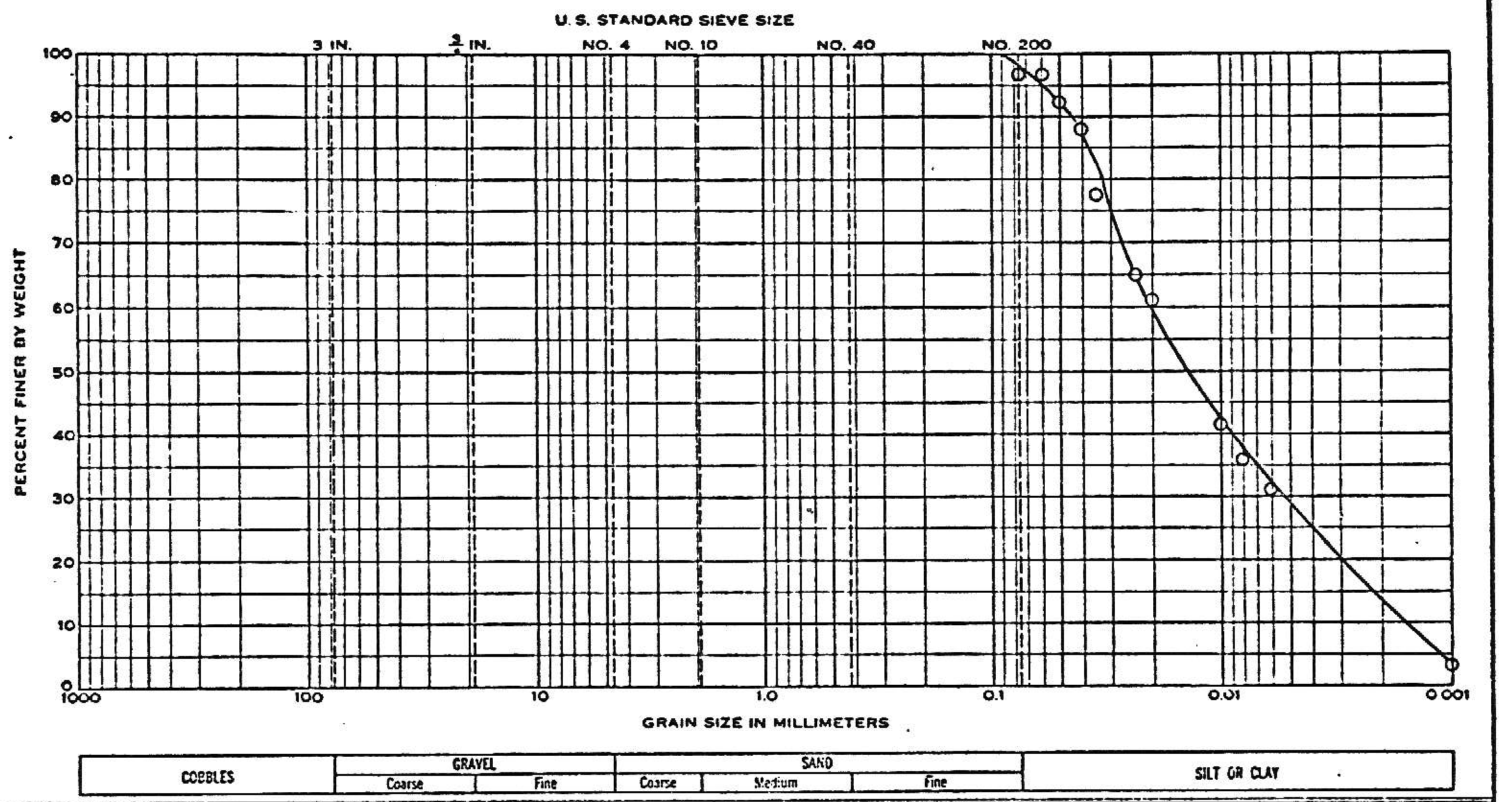
Area South

Boring No. One

Date February 23, 1972

GRADATION CURVES

Figure 16 Physical characteristics of the soil from two to three feet.

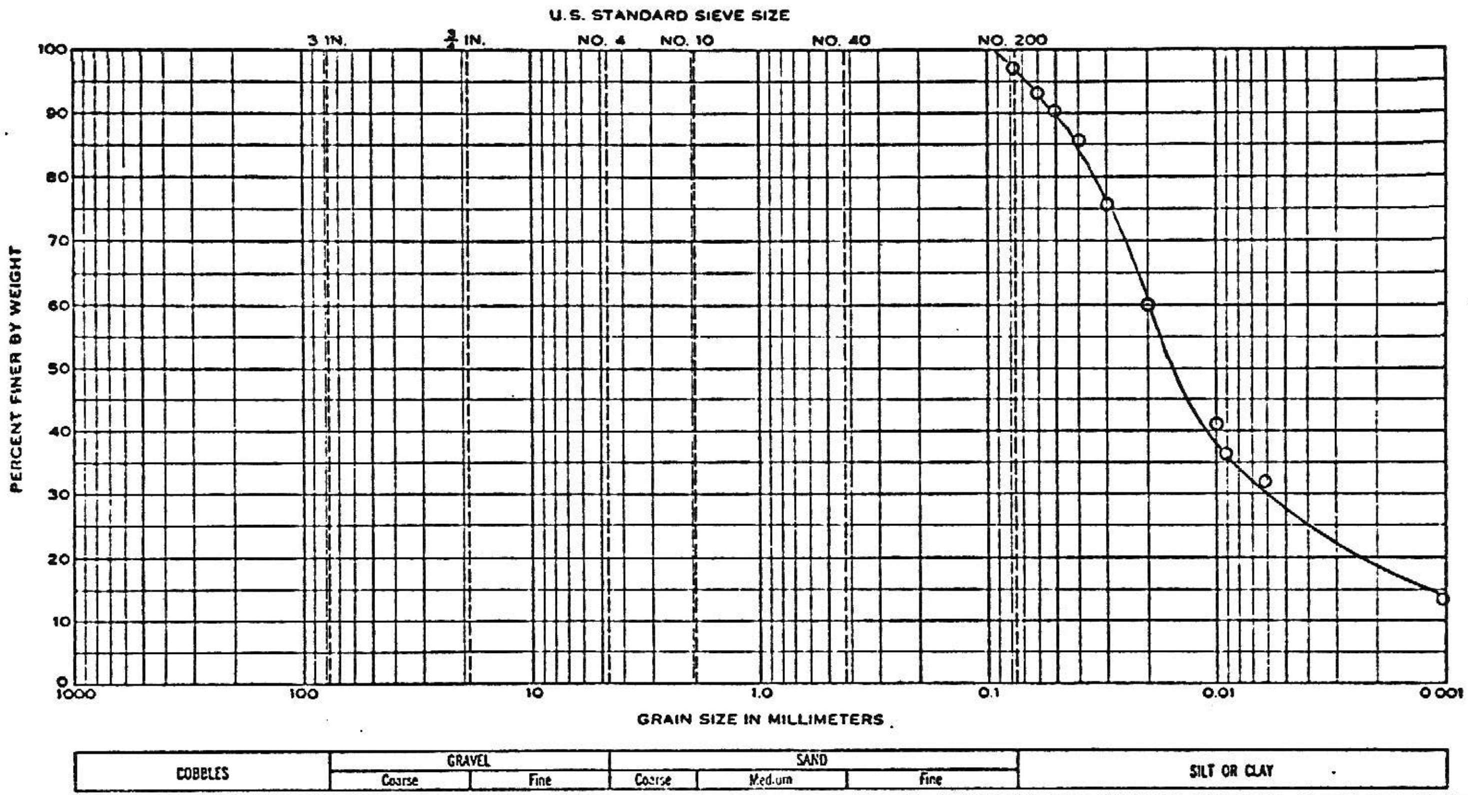


Sample No.	Elev or Depth	Classification	NatWC	LL	PL	PI	
Outside	3-4 ft.	Unified MH	26%	58	28	30	28% Clay 69% Silt 3% Sand

GRADATION CURVES

Project Community Memorial Hospital, Marysville, Kansas
Area South
Boring No. One
Date February 23, 1972

Figure 17 Physical characteristics of the soil from three to four feet.



Sample No.	Elev or Depth	Classification	NatWC	LL	PL	PI	
Outside	4-5 ft.	Unified MH	27%	57	28	29	38% Clay
							58% Silt
							4% Sand

Project Community Memorial Hospital, Marysville, Kansas

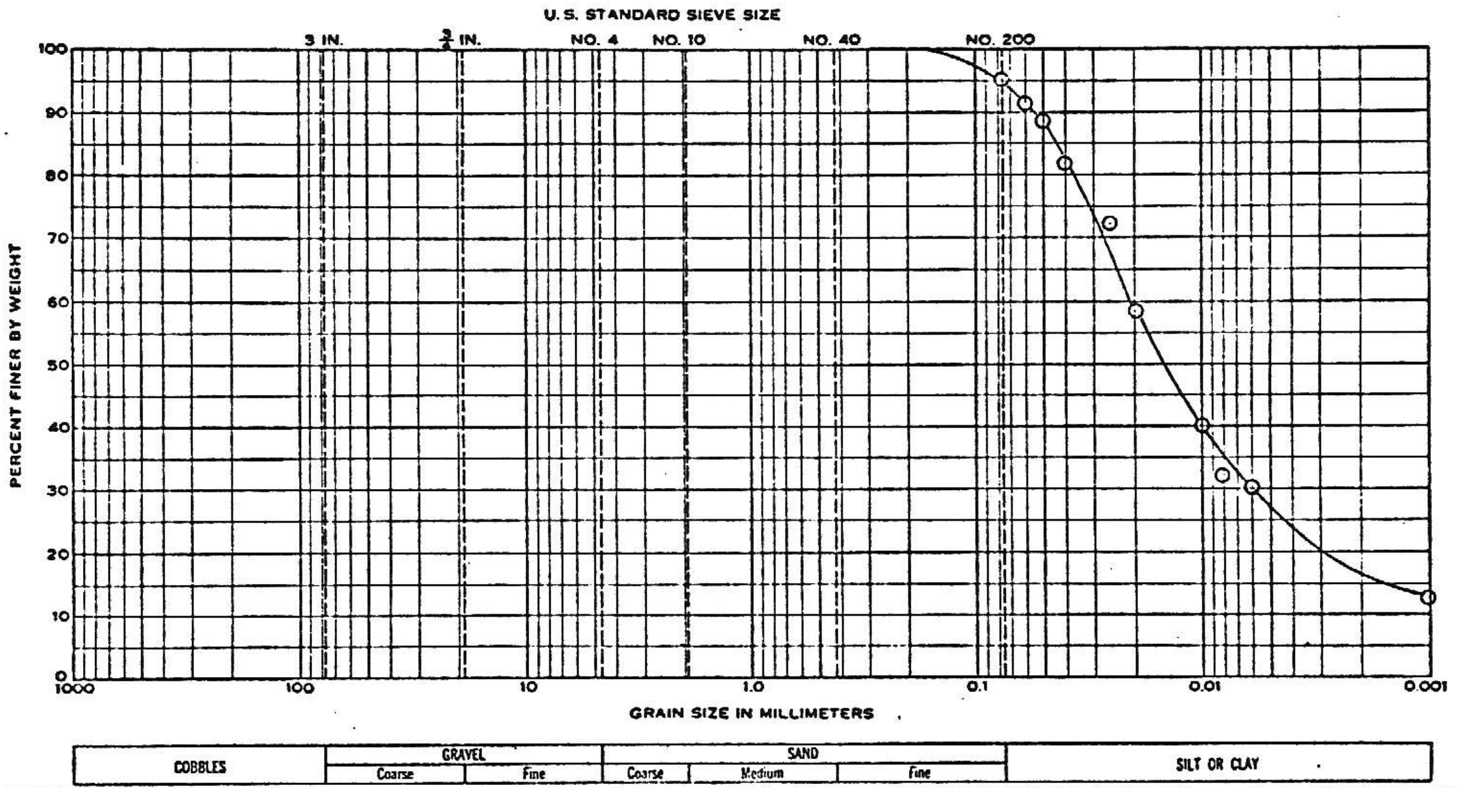
Area South

Boring No. One

Date February 23, 1972

GRADATION CURVES

Figure 18 Physical characteristics of the soil from four to five feet.

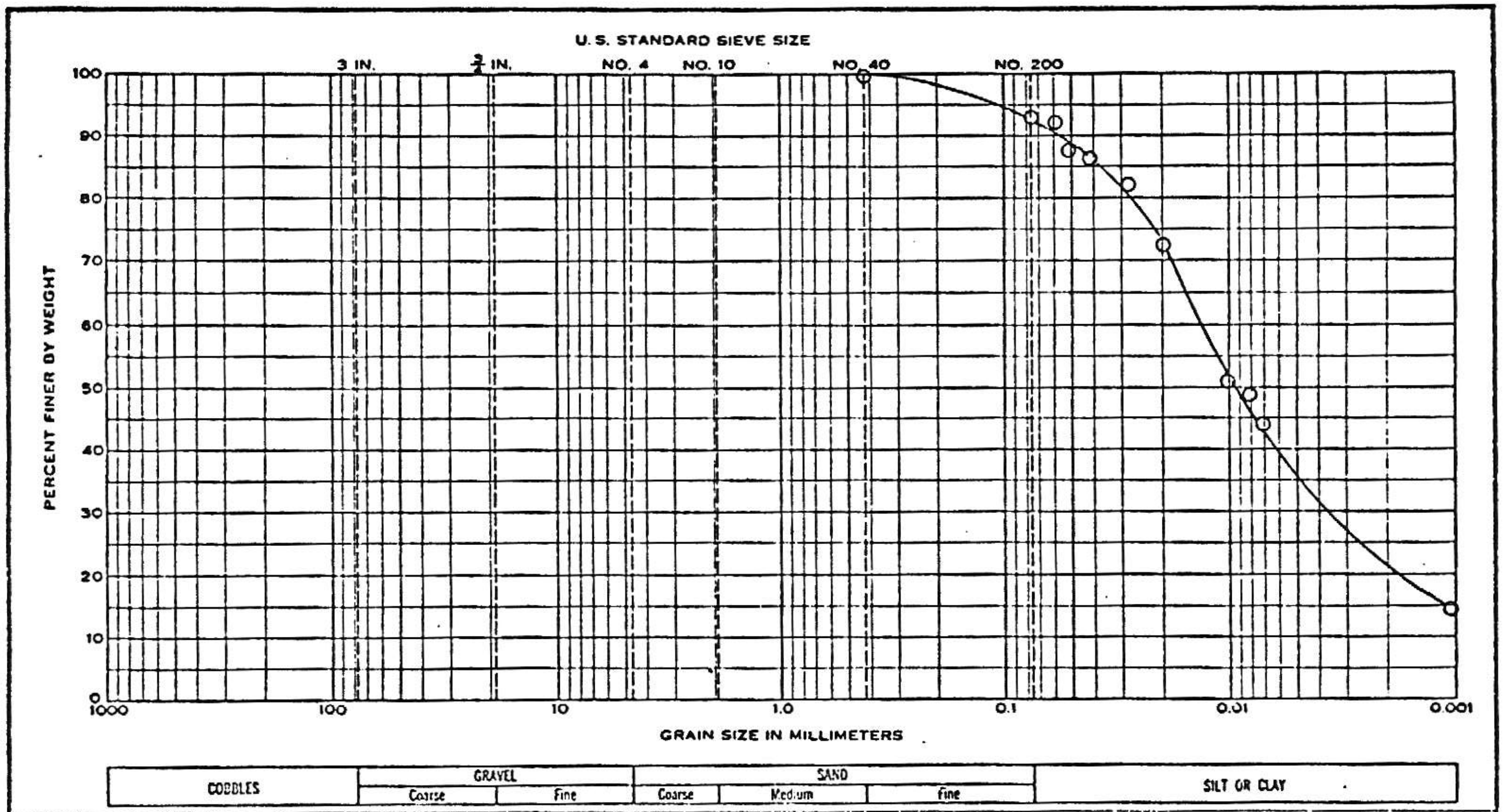


Sample No.	Elev or Depth	Classification	NatWC	LL	PL	PI	
Outside	5-6 ft.	Unified MH	26%	58	27	31	27% Clay
							68% Silt
							5% Sand

GRADATION CURVES

Project Community Memorial
Hospital, Marysville, Kansas
Area South
Boring No. One
Date February 23, 1972

Figure 19 Physical characteristics of the soil from five to six feet.



Sample No.	Elev or Depth	Classification	NatW/C	LL	PL	PI	
Outside	6-7 ft.	Unified MH	26%	57	30	27	15 % Clay
							78.5% Silt
							7.5% Sand

Project Community Memorial Hospital, Marysville, Kansas

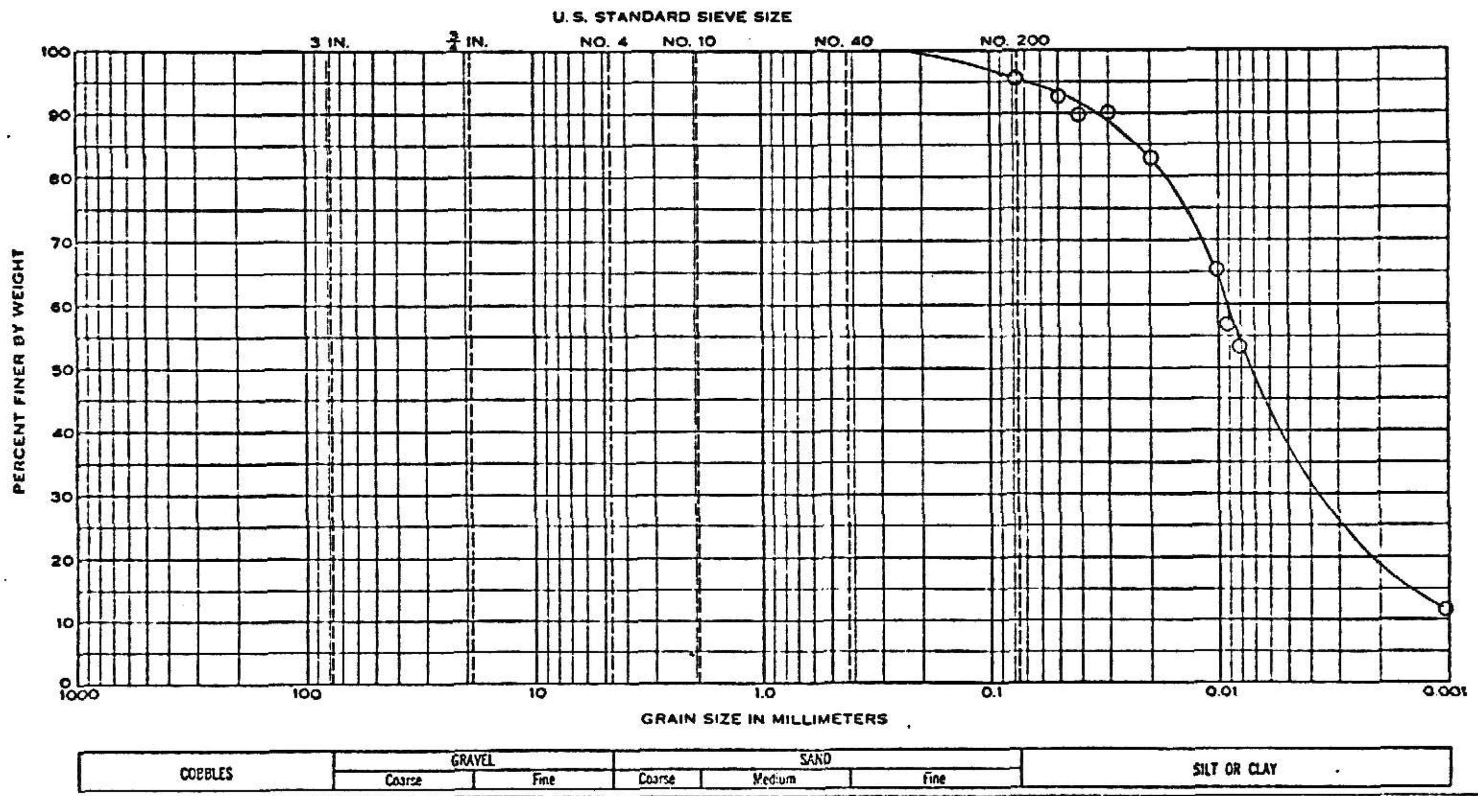
Area South

Boring No. One

Date July 23, 1971

GRADATION CURVES

Figure 20 Physical characteristics of the soil from six to seven feet.



Sample No.	Elev or Depth	Classification	NatWC	LL	PL	PI	
Outside	7-8 ft.	Unified MH	26%	59	26	33	38% Clay
							58% Silt
							4% Sand

GRADATION CURVES

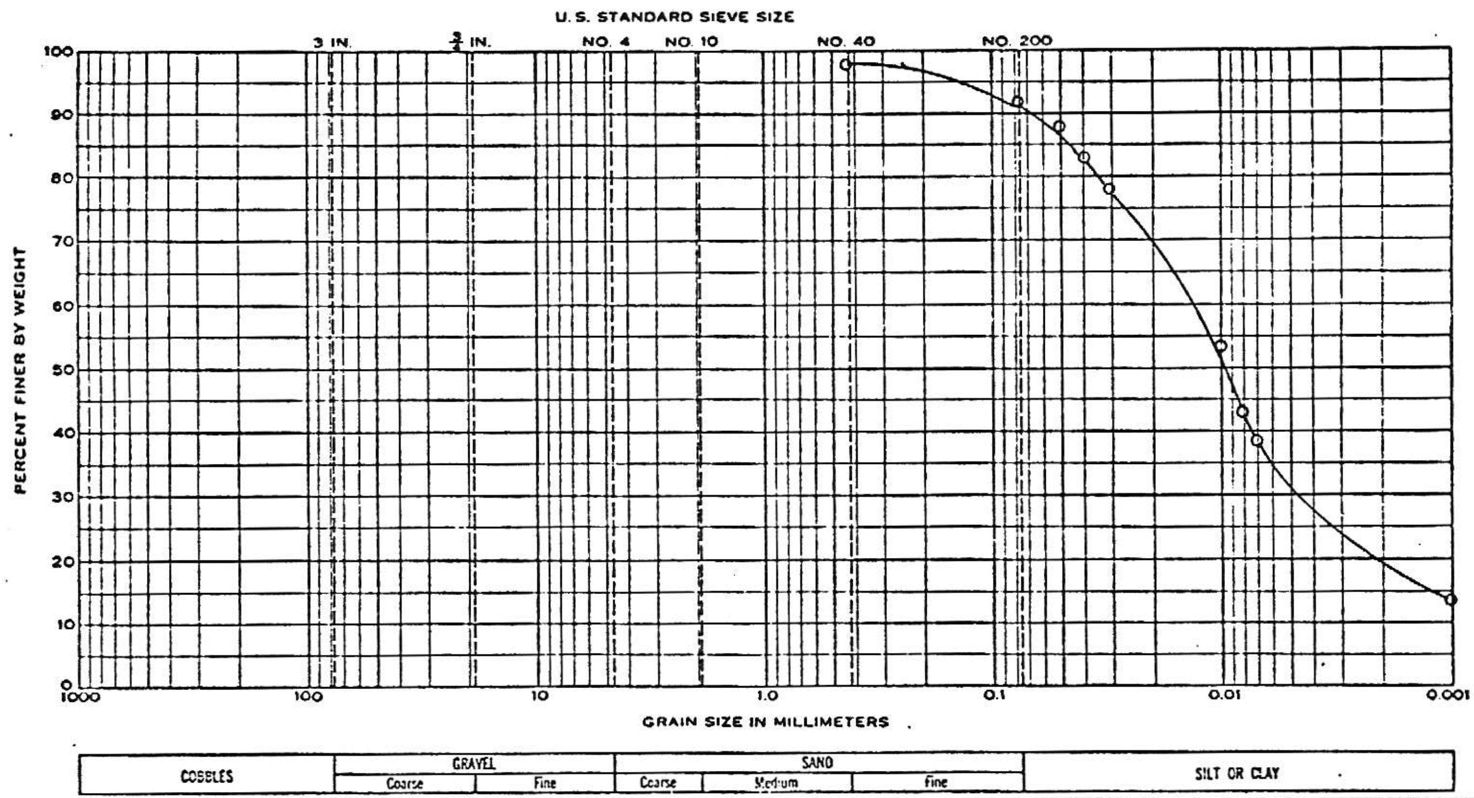
Project Community Memorial Hospital, Marysville, Kansas

Area South

Boring No. One

Date July 23, 1971

Figure 21 Physical characteristics of the soil from seven to eight feet.



Sample No.	Elev or Depth	Classification	NatW/C	LL	PL	PI	
Outside	8-9 ft.	Unified MH	24%	56	28	28	31% Clay
							61% Silt
							8% Sand

Project Community Memorial Hospital, Marysville, Kansas

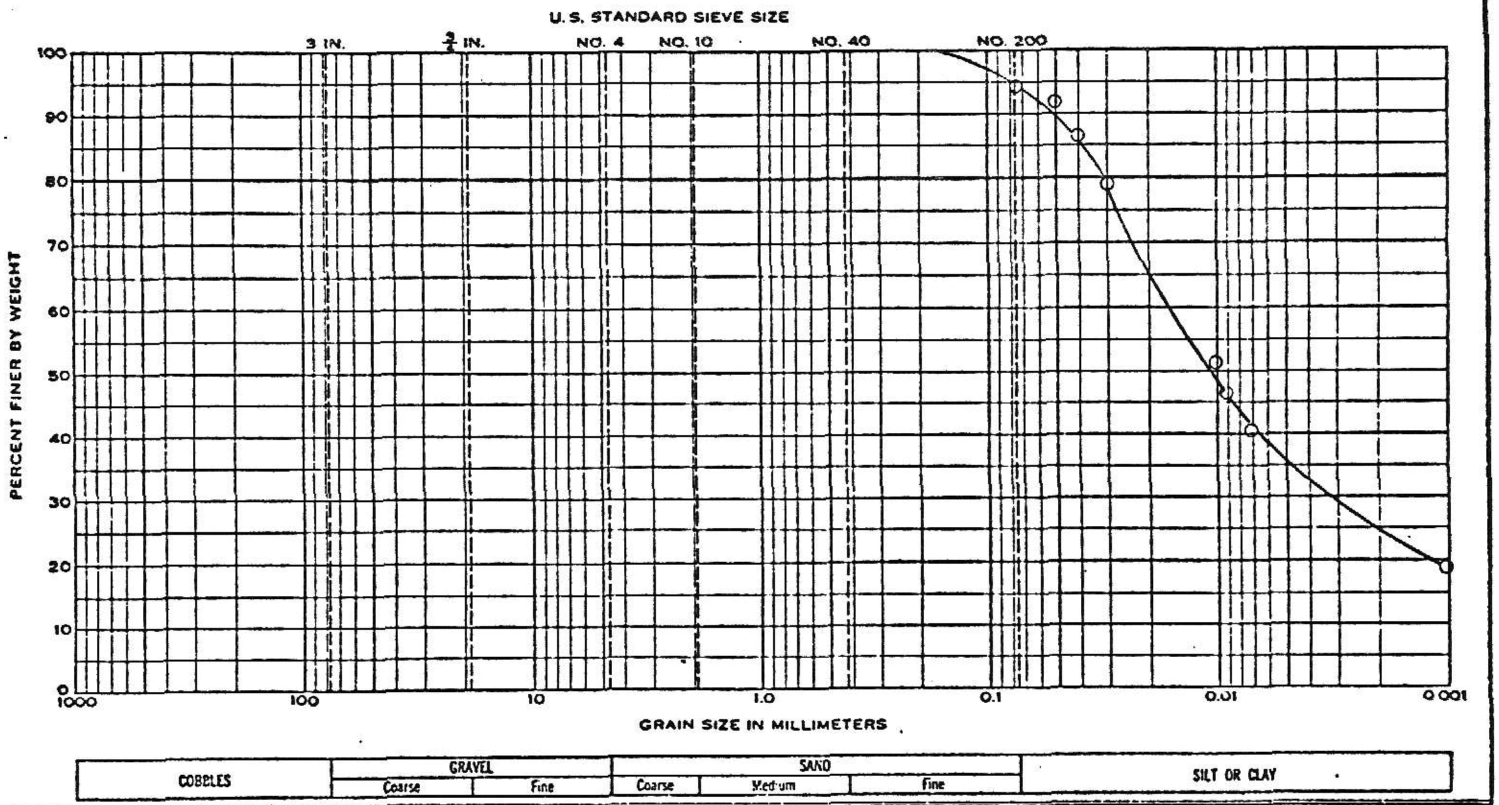
Area South

Boring No. One

Date July 23, 1971

GRADATION CURVES

Figure 22 Physical characteristics of the soil from eight to nine feet.



Sample No.	Elev or Depth	Classification	NatWC	LL	PL	PI	
Outside	9-10 ft.	Unified MH	26%	52	28	24	35% Clay 60% Silt 5% Sand

Project Community Memorial Hospital, Marysville, Kansas

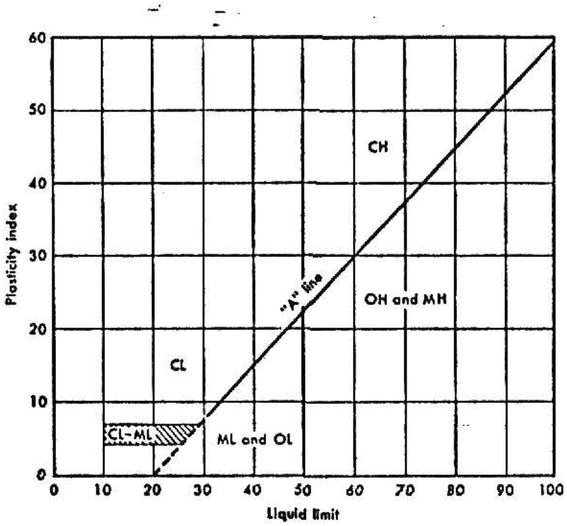
Area South

Boring No. One

Date July 23, 1971

GRADATION CURVES

Figure 23 Physical characteristics of the soil from nine to ten feet.

Major divisions			Group symbols		Typical names	Laboratory classification criteria		
Coarse-grained soils (More than half of material is larger than No. 200 sieve size)	Gravels (More than half of coarse fraction is larger than No. 4 sieve size)	Clean gravels (Little or no fines)	GW		Well-graded gravels, gravel-sand mixtures, little or no fines	Determine percentages of sand and gravel from grain-size curve. Depending on percentage of fines (fraction smaller than No. 200 sieve size), coarse-grained soils are classified as follows: Less than 5 per cent............GW, GP, SW, SP More than 12 per cent............GM, GC, SM, SC 5 to 12 per cent............Borderline cases requiring dual symbols**	$C_u = \frac{D_{60}}{D_{10}}$ greater than 4; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3	
			GP		Poorly graded gravels, gravel-sand mixtures, little or no fines		Not meeting all gradation requirements for GW	
		Gravels with fines (Appreciable amount of fines)	GM*	d u	Silty gravels, gravel-sand-silt mixtures		Atterburg limits below "A" line or P.I. less than 4	Above "A" line with P.I. between 4 and 7 are *borderline* cases requiring use of dual symbols
			GC		Clayey gravels, gravel-sand-clay mixtures		Atterburg limits above "A" line with P.I. greater than 7	
	Sands (More than half of coarse fraction is smaller than No. 4 sieve size)	Clean sands (Little or no fines)	SW		Well-graded sands, gravelly sands, little or no fines		$C_u = \frac{D_{60}}{D_{10}}$ greater than 6; $C_c = \frac{(D_{10})^2}{D_{10} \times D_{60}}$ between 1 and 3	
			SP		Poorly graded *sands*, gravelly sands, little or no fines		Not meeting all gradation requirements for SW	
		Sands with fines (Appreciable amount of fines)	SM*	d u	Silty sands, sand-silt mixtures		Atterburg limits below "A" line or P.I. less than 4	Limits plotting in hatched zone with P.I. between 4 and 7 are borderline cases requiring use of dual symbols.
			SC		Clayey sands, sand-clay mixtures		Atterburg limits above "A" line with P.I. greater than 7	
Fine-grained soils (More than half of material is smaller than No. 200 sieve)	Silts and clays (Liquid limit less than 50)		ML		Inorganic silts and very fine sands, rock flour, silty or clayey fine sands, or clayey silts with slight plasticity			
			CL		Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays			
			OL		Organic silts and organic silty clays of low plasticity			
	Silts and clays (Liquid limit greater than 50)		MH		Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts			
			CH		Inorganic clays of high plasticity, fat clays			
			OH		*Organic* clays of medium to high plasticity, organic silts			
	Highly organic soils		Pt		Peat and other highly organic soils			

Plasticity Chart

*Division of GM and SM groups into subdivisions of d and u are for roads and airfields only. Subdivision is based on Atterburg limits; suffix d used when L.L. is 28 or less and the P.I. is 6 or less; the suffix u used when L.L. is greater than 28.

**Borderline classifications, used for soils possessing characteristics of two groups, are designated by combinations of group symbols. For example: GW-GC, well-graded gravel-sand mixture with clay binder.

Table 2 Unified Soil Classification

Depth	Angle of friction ϕ	Cohesion c	Unit wt. γ
0 - 1	29°	8.5	121.0
1 - 2	23.5°	14.0	126.2
2 - 3	23°	11.5	123.5
3 - 4	15°	16.5	121.3
4 - 5	13°	18.5	120.8
5 - 6	26°	6.0	121.2
6 - 7	28°	7.0	121.9
7 - 8	29.5°	6.0	117.6
8 - 9	30°	3.5	120.4
9 - 10	29°	4.5	120.8

Table 3. Comparison of Angle of Friction, Cohesion, and Moist Unit Weight of the Soil Layers

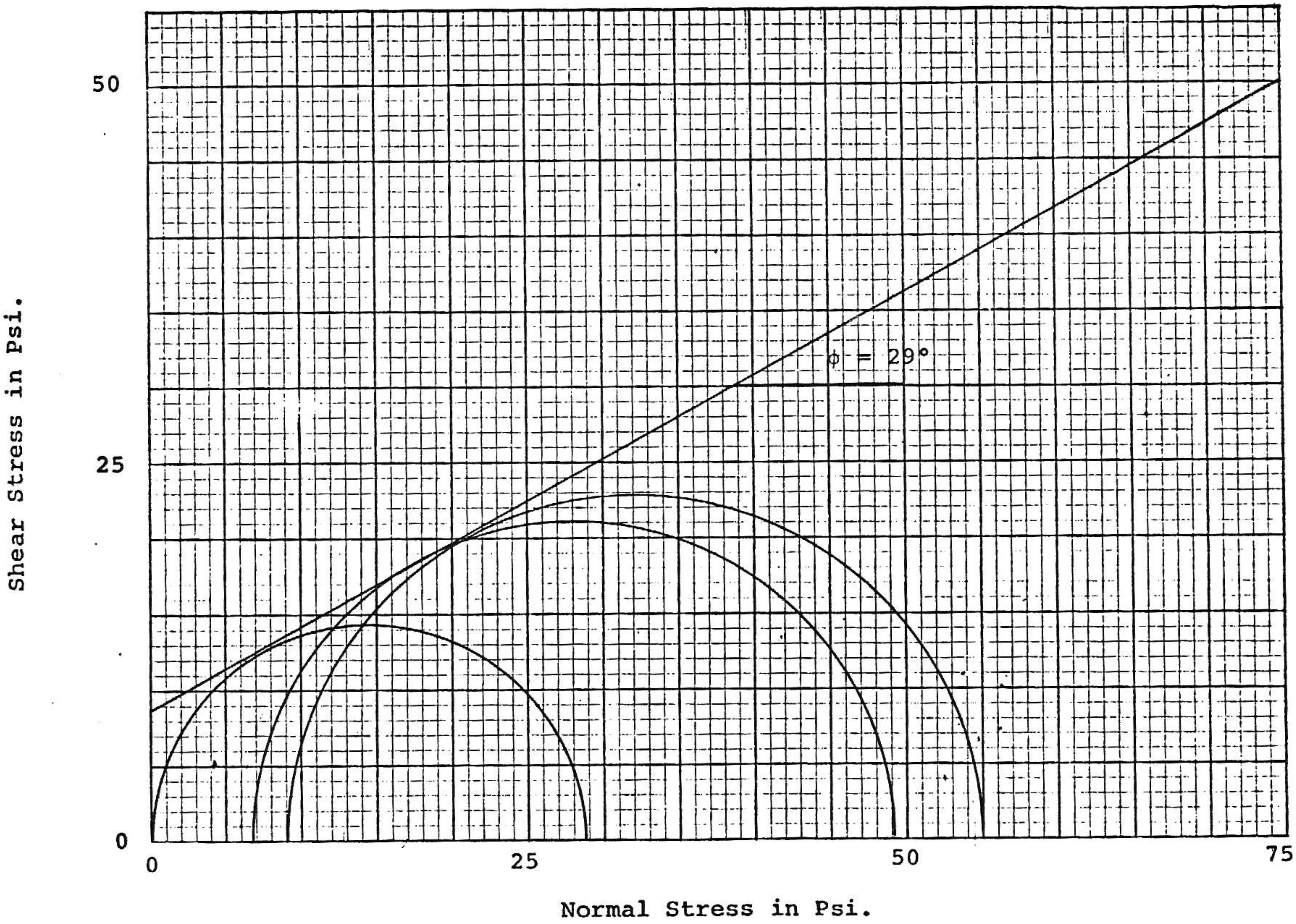


Figure 24 Failure envelope for soil zero to one foot Community Memorial Hospital, Marysville, Kansas

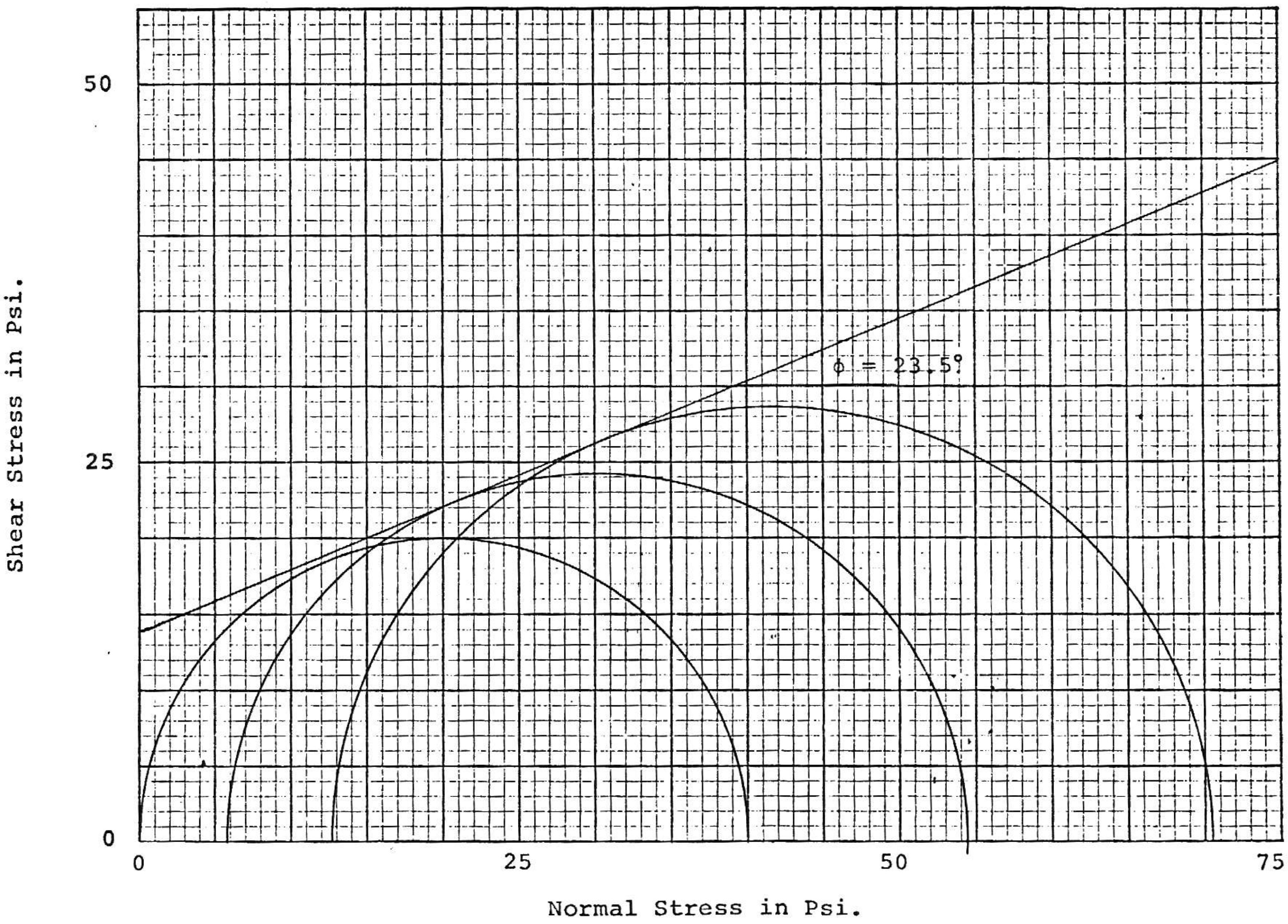


Figure 25 Failure envelope for soil one to two feet Community Memorial Hospital, Marysville, Kansas

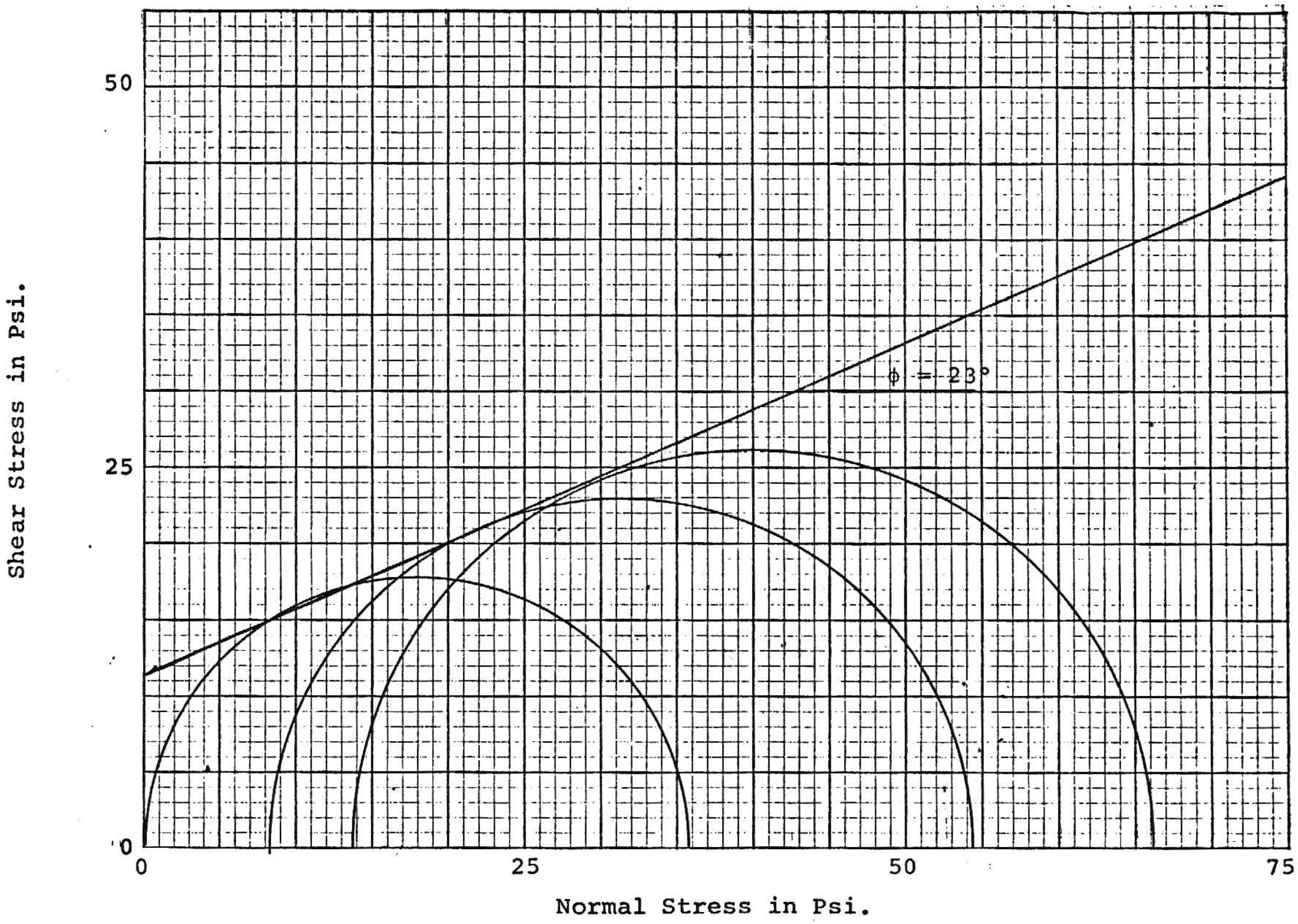


Figure 26 Failure envelope for soil two to three feet Community Memorial Hospital, Marysville, Kansas

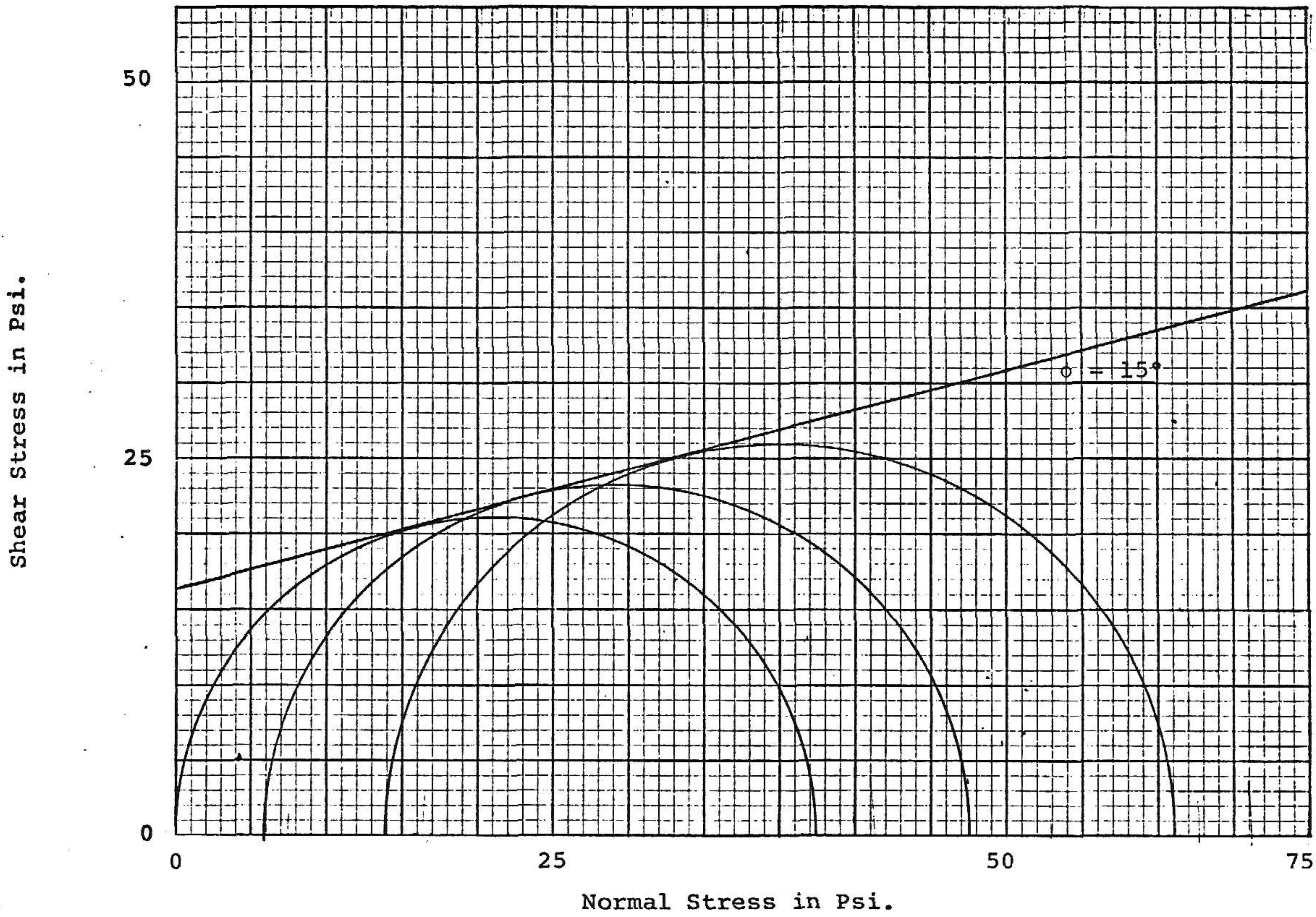


Figure 27 Failure envelope for soil three to four feet Community Memorial Hospital, Marysville, Kansas

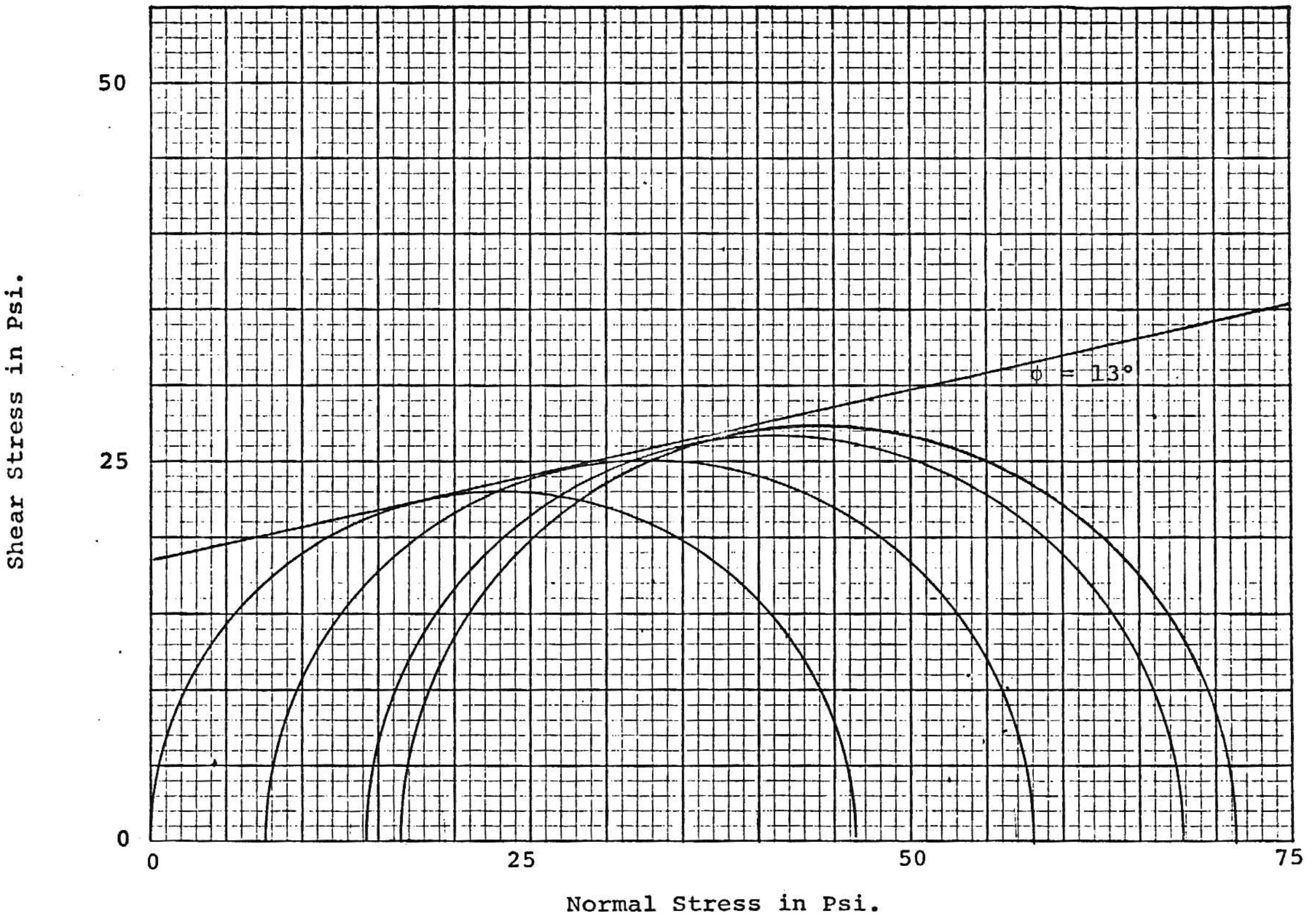


Figure 28 Failure envelope for soil four to five feet
Community Memorial Hospital, Marysville, Kansas

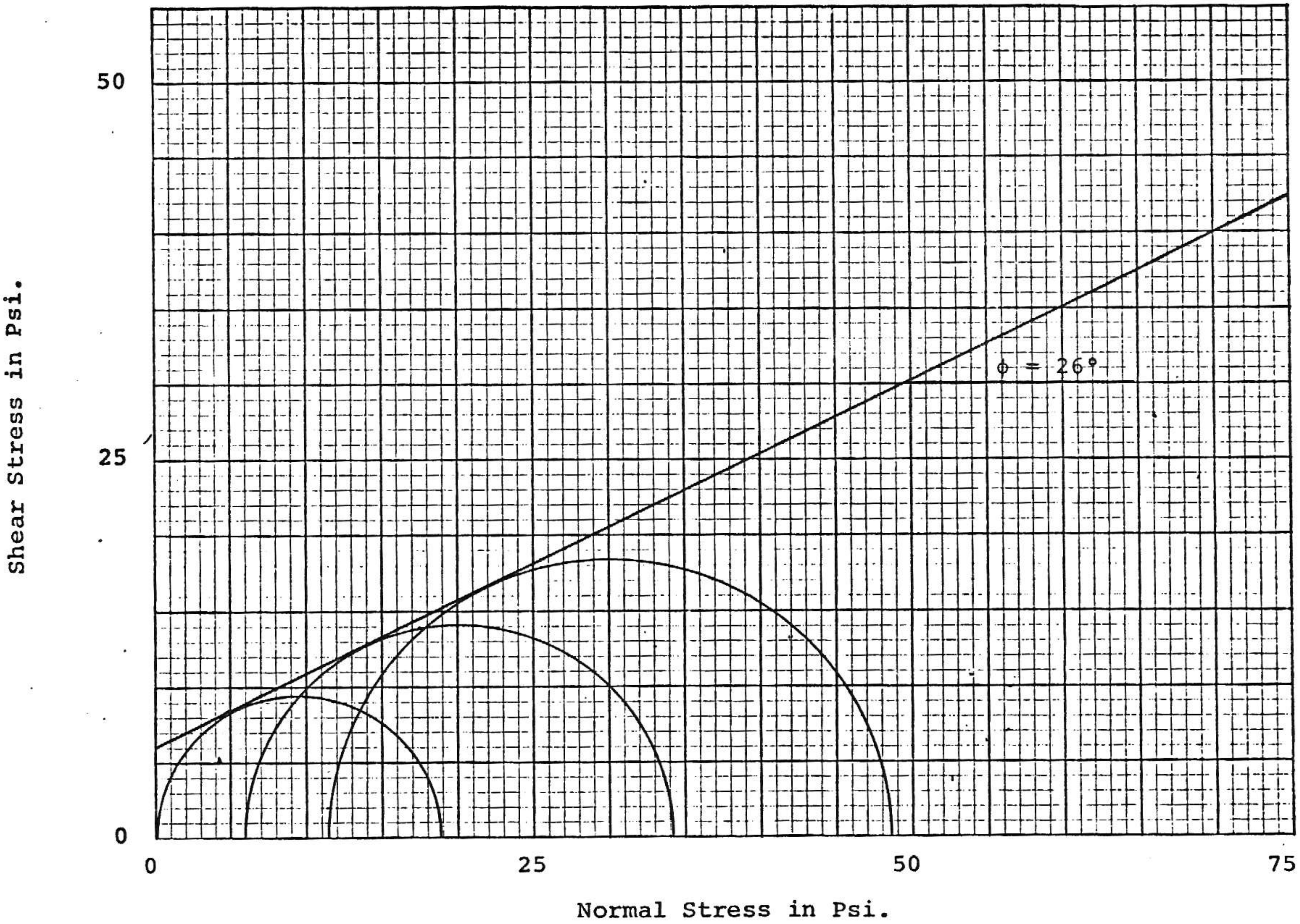


Figure 29 Failure envelope for soil five to six feet Community Memorial Hospital, Marysville, Kansas

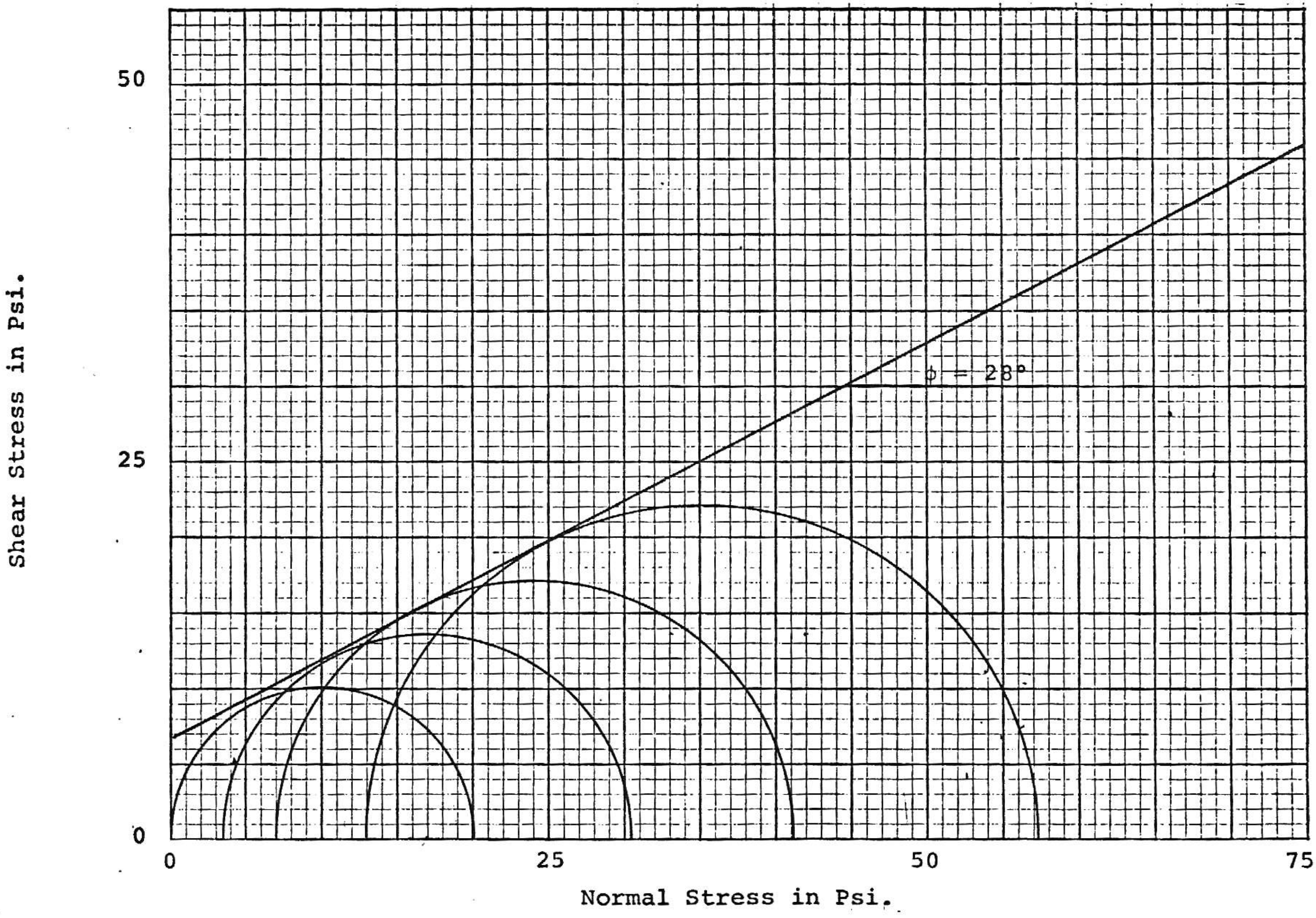


Figure 30 Failure envelope for soil six to seven feet Community Memorial Hospital, Marysville, Kansas

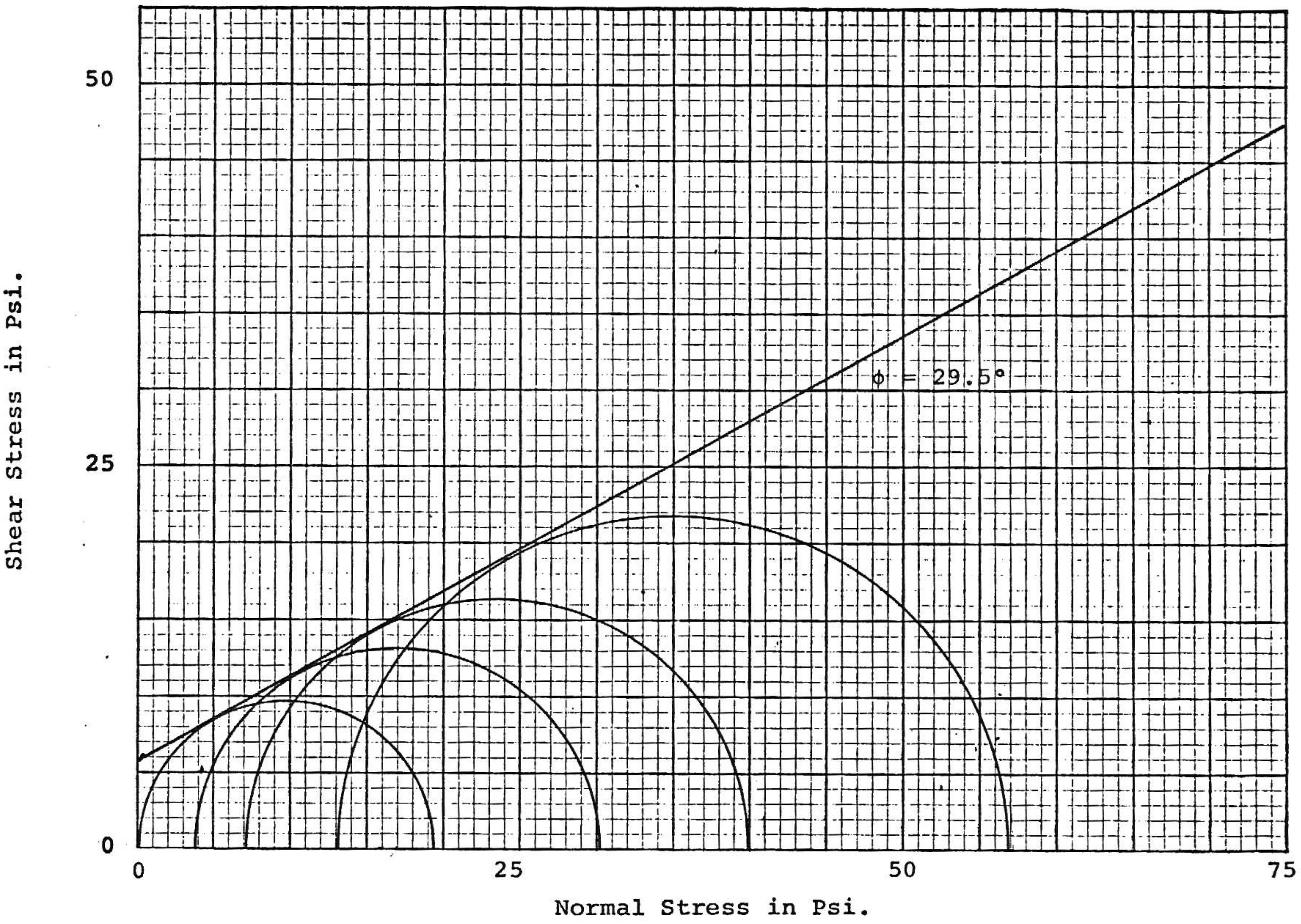


Figure 31 Failure envelope for soil seven to eight feet Community Memorial Hospital, Marysville, Kansas

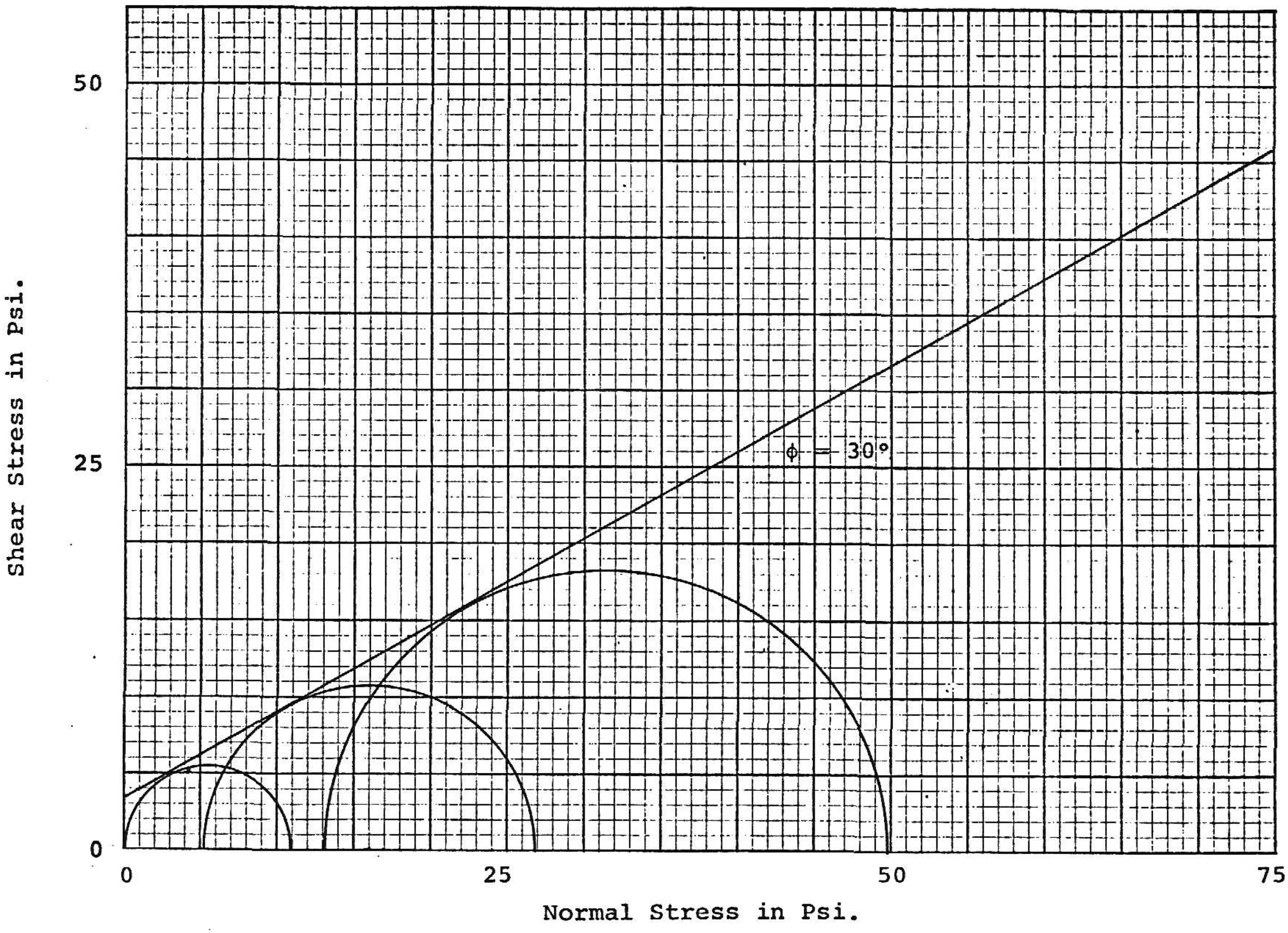


Figure 32 Failure envelope for soil eight to nine feet Community Memorial Hospital, Marysville, Kansas

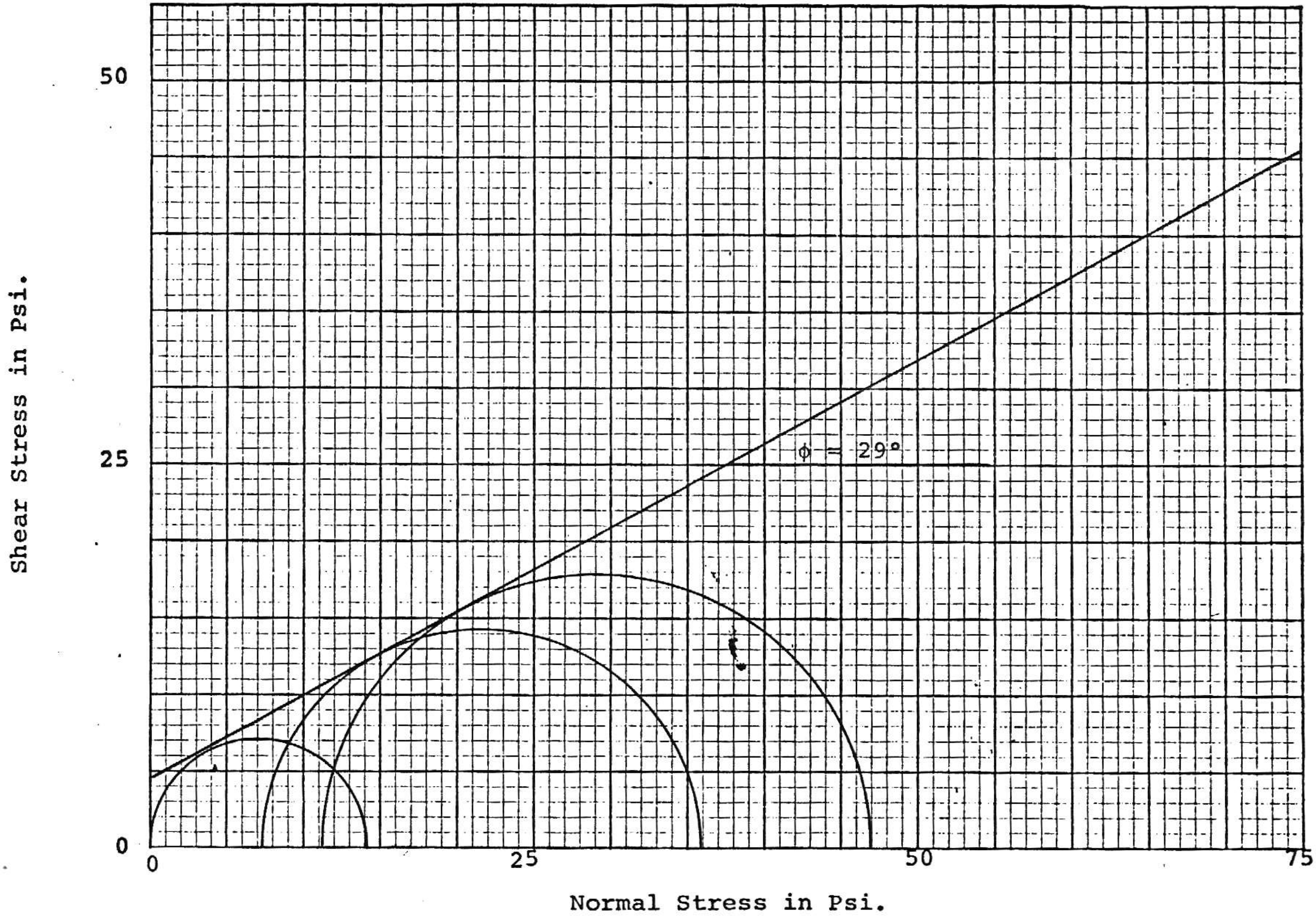


Figure 33 Failure envelope for soil nine to ten feet
Community Memorial Hospital, Marysville, Kansas

The load carrying capacity of the existing foundation was analyzed for safety by the Terzaghi formula, which in its general form is:

$$Qu = CN_c + \gamma\ d_f N_q + 0.5\ \gamma' bN_\gamma$$

Qu = ultimate strength of the soil

C = unit cohesion

N_c, N_q, and N_γ = bearing capacity factors based on the angle of friction

γ = average unit weight of the soil above the base of the foundation

d_f = depth of burial of the footing

γ' = average unit weight of the soil within the stressed zone beneath the footing

b = width of the footing

The ultimate load carrying capacity of the soil under the interior column footings in tons per square foot:

$$Qu = \frac{(860)(25.1) + (122)(5)(12.7) + (0.5)(120)(5)(9.7)}{2{,}000}$$

$$= \frac{21{,}586 + 7{,}747 + 2{,}910}{2{,}000} = \frac{32{,}243}{2{,}000} = 16.12 \text{ tsf}$$

For the 5' x 5' footing = 400 tons ultimate load. Since the column loading from the original plans is shown to be 50 tons, the safety factor = $\frac{400}{50}$ = 8 and for the exterior wall spread footing

$$Qu = \frac{(860)(25.1) + (122)(5)(12.7) + (0.5)(120)(2)(9.7)}{2{,}000}$$

$$= \frac{21{,}587 + 7{,}747 + 1{,}164}{2{,}000} = \frac{30{,}498}{2{,}000} = 15.3 \text{ tsf}$$

With a wall loading of 4 tons per lineal foot taken from the original plans, the

$$\text{Safety factor} = \frac{30}{4} = 7.5$$

The existing footings could thus carry some 7.5 for the exterior and 8.0 for the interior, times the imposed load. It is customary to design footings for a safety factor of 3 so these are very conservative and thus in no danger of shear failure.

Compressibility of the Soil Strata

The compressibility of the soil stratum immediately below the footing was determined by two consolidations tests as shown in Figs. 34 and 35.

Both tests indicate a precompression pressure of some 2.5 tsf, which is above the imposed loading. The exact settlement could be computed by the formula:

$$\Delta H = 2b \frac{Cc}{1+e} \log \left(1 + \frac{\Delta P}{Pi}\right)$$

where: b = width of the footing

Cc = compression index

e = void ratio

ΔP = pressure increase

Pi = initial pressure

The two consolidation tests indicate a $Cc = 0$ for the pressure increment of 1/4 to 2 tsf and thus, settlement would be expected to be near zero. A study of the structure, except for the floor, indicates the validity of this computation.

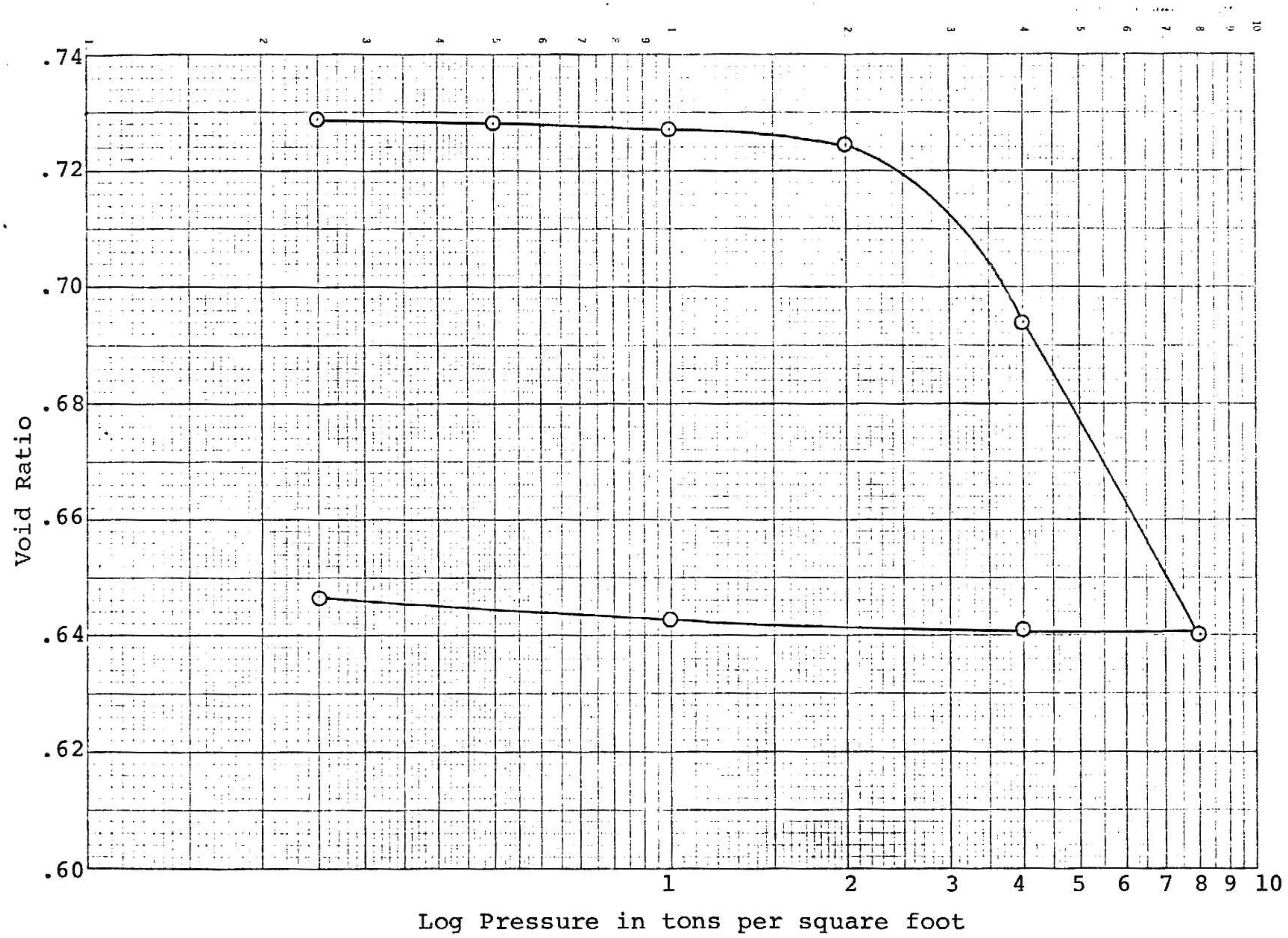


Figure 34. Compression characteristics of the soil outside the structure at a depth of five feet.

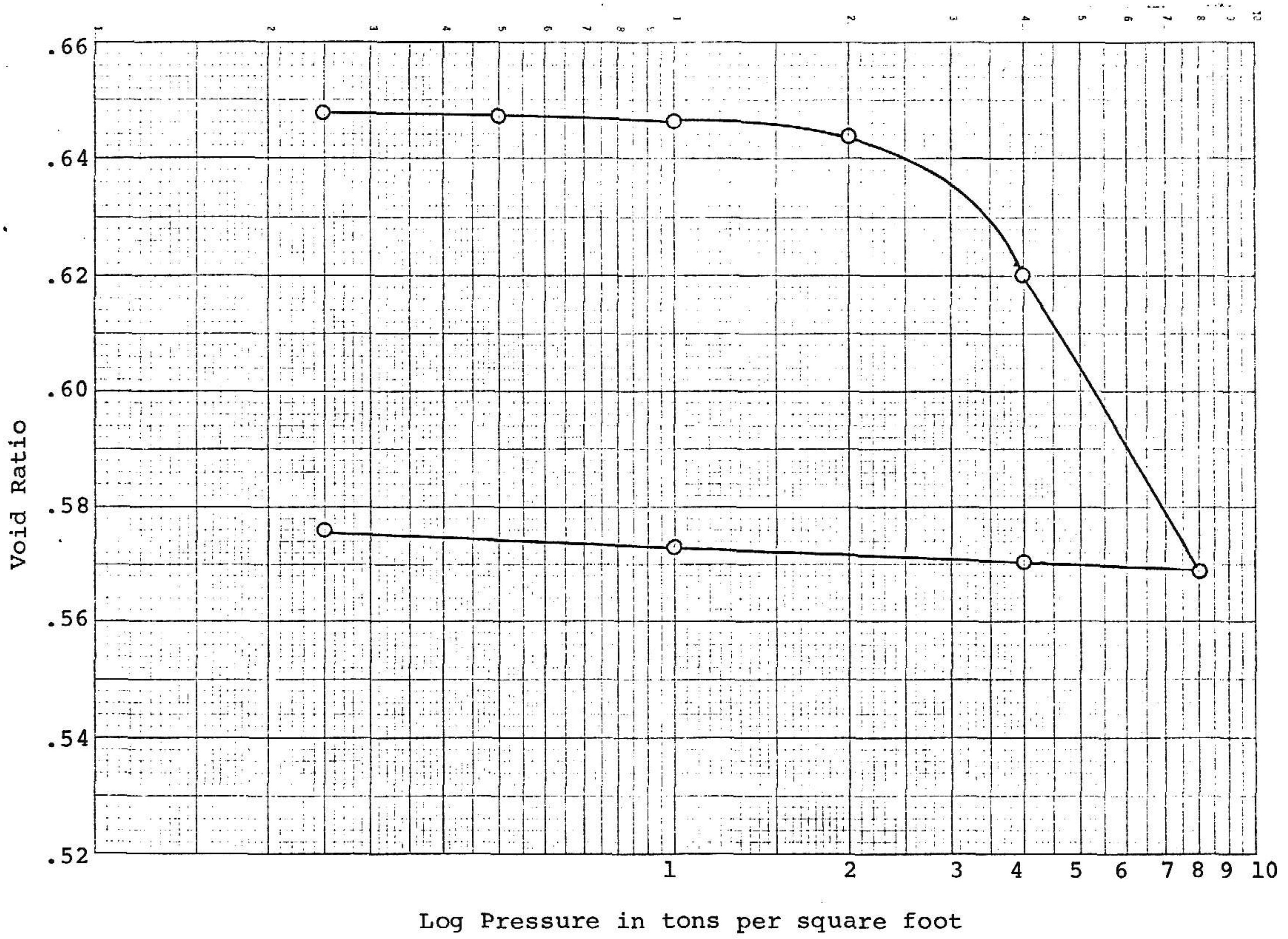


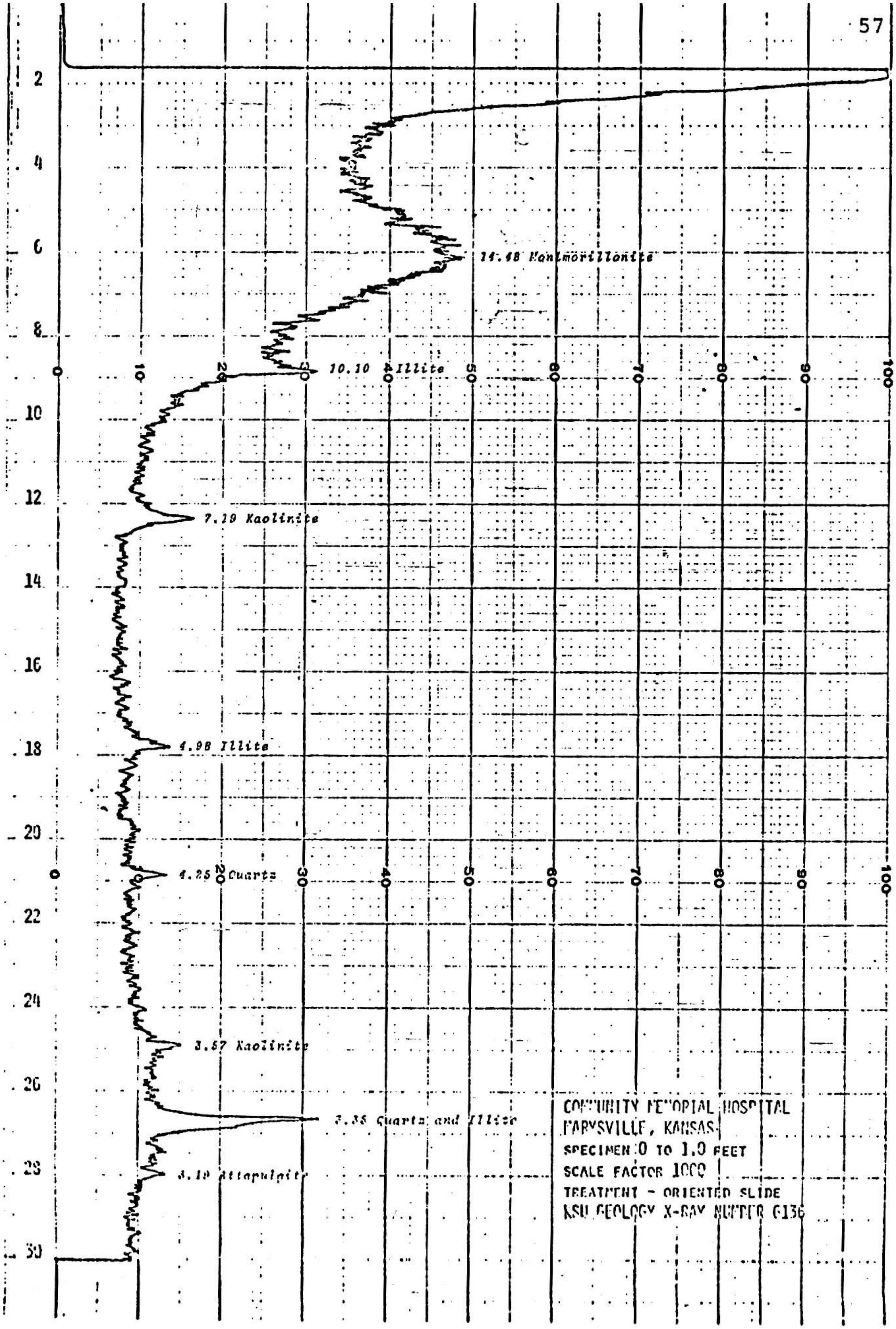
Figure 35. Compression characteristics of the soil inside the structure at a depth of five feet.

The shear and compressibility tests confirmed that the causes of failure were not overstressing of the soil. The extreme dryness of the soil inside the structure indicated that the source of the settlement was shrinkage of an expansive soil. The gradation analysis of the soil indicated that an appreciable quantity of clay minerals was present. The liquid limit near 50 indicated a borderline case since most investigators have reported that soils having a liquid limit under 50 will not be found to be troublesome by shrinkage and swelling. The work of Willman, et. al. (19) indicated that the till in the western area should predominate in Montmorillonite, and it is well known that this mineral exhibits more volume change with changing moisture conditions than any of the clay minerals.

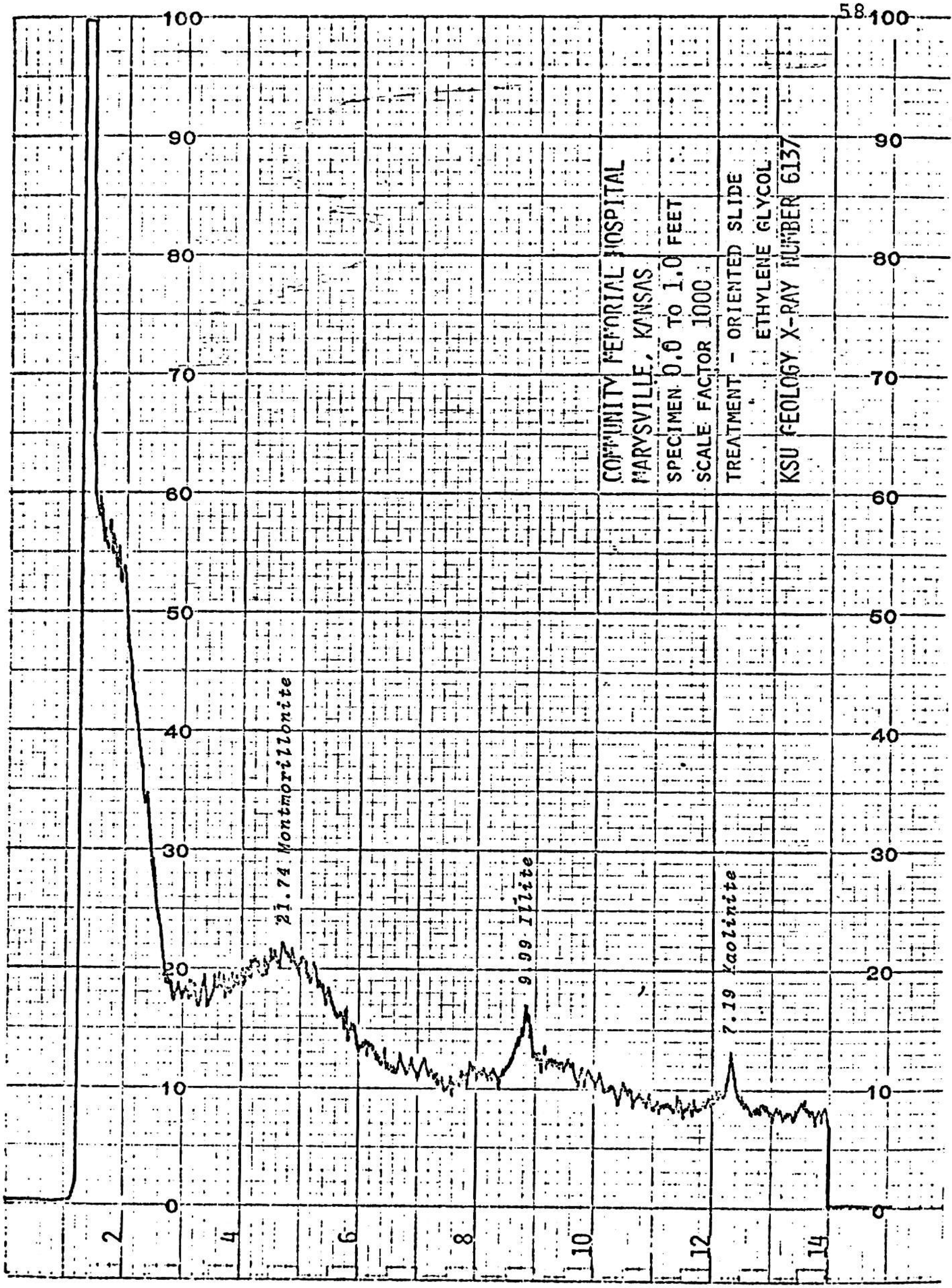
X-Ray Diffraction

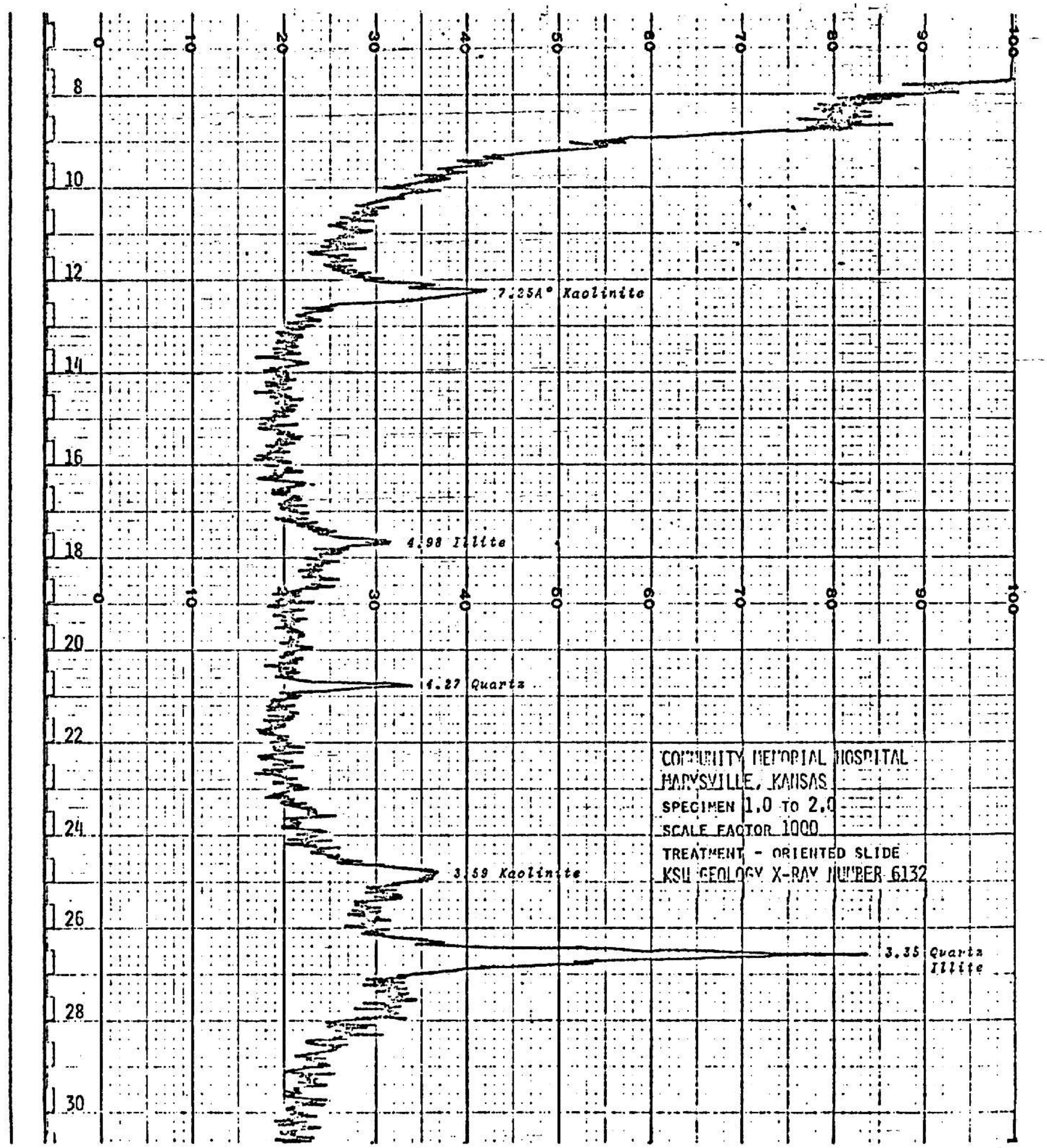
The samples for each one foot layer were tested by X-ray analysis to determine the type and amount of clay minerals present. A complete series of oriented, oriented and treated with ethylene glycol, and a partial set of 600°C heat treated slides were run on the KSU Department of Geology X-ray machine.

The data collected is presented in Fig. 36 through Fig. 52. An analysis of this data indicates that Montmorillonite, Illite, and Kaolinite are present in that order of relative abundance. Based on the work of Post and Sloane (68),

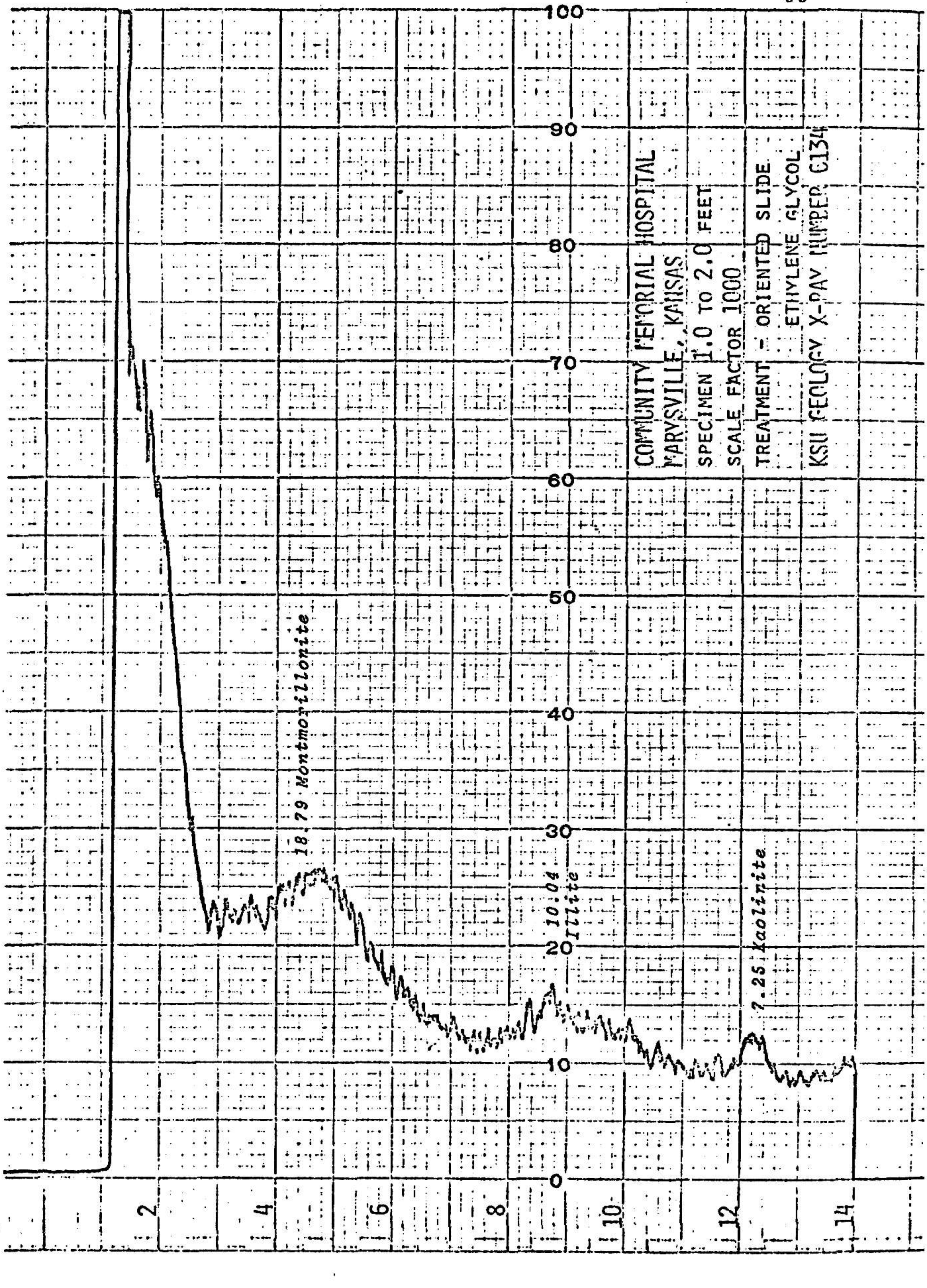


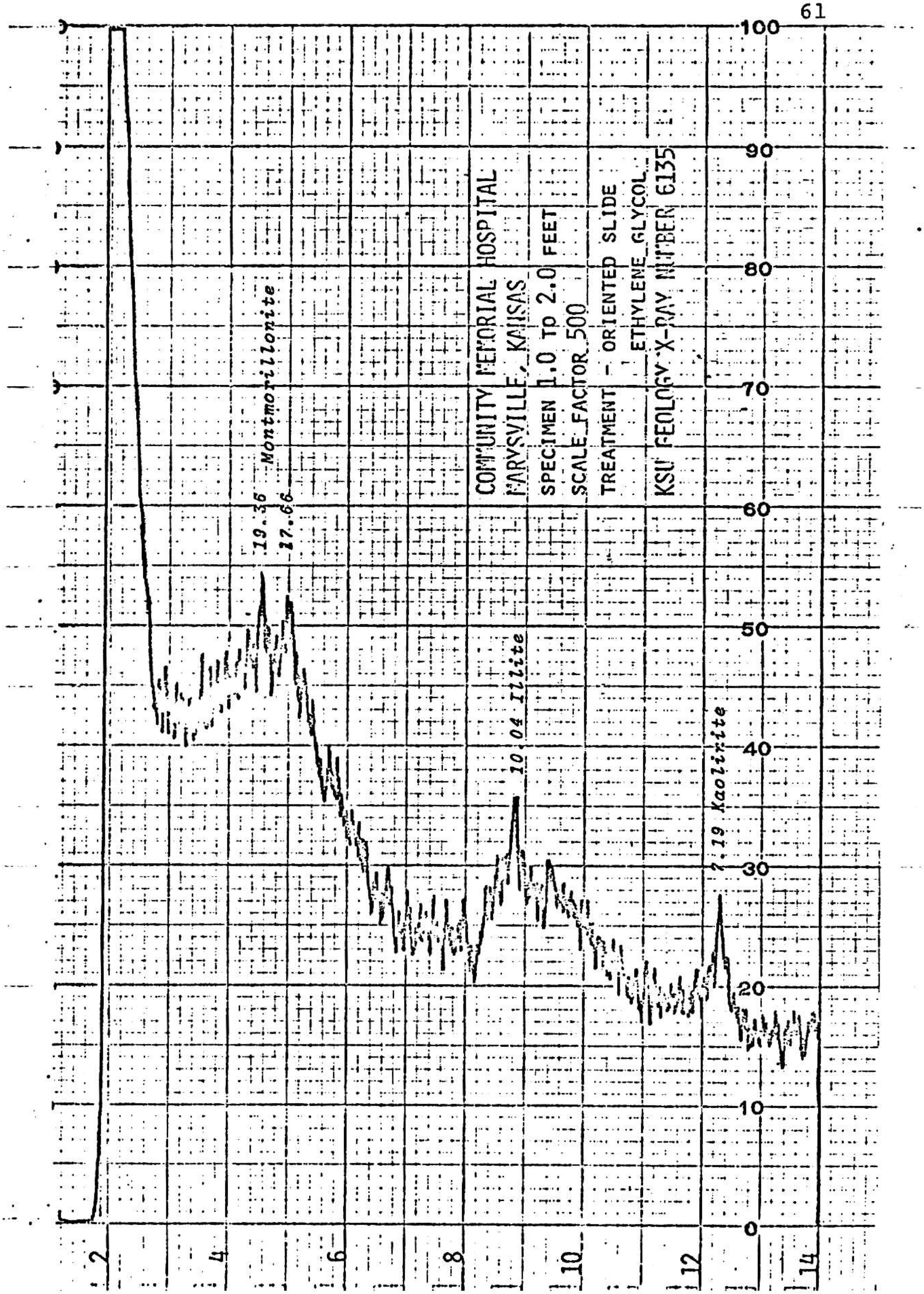
COMMUNITY MEMORIAL HOSPITAL
MARYSVILLE, KANSAS
SPECIMEN 0 TO 1.0 FEET
SCALE FACTOR 1000
TREATMENT - ORIENTED SLIDE
KSU GEOLOGY X-RAY NUMBER G136

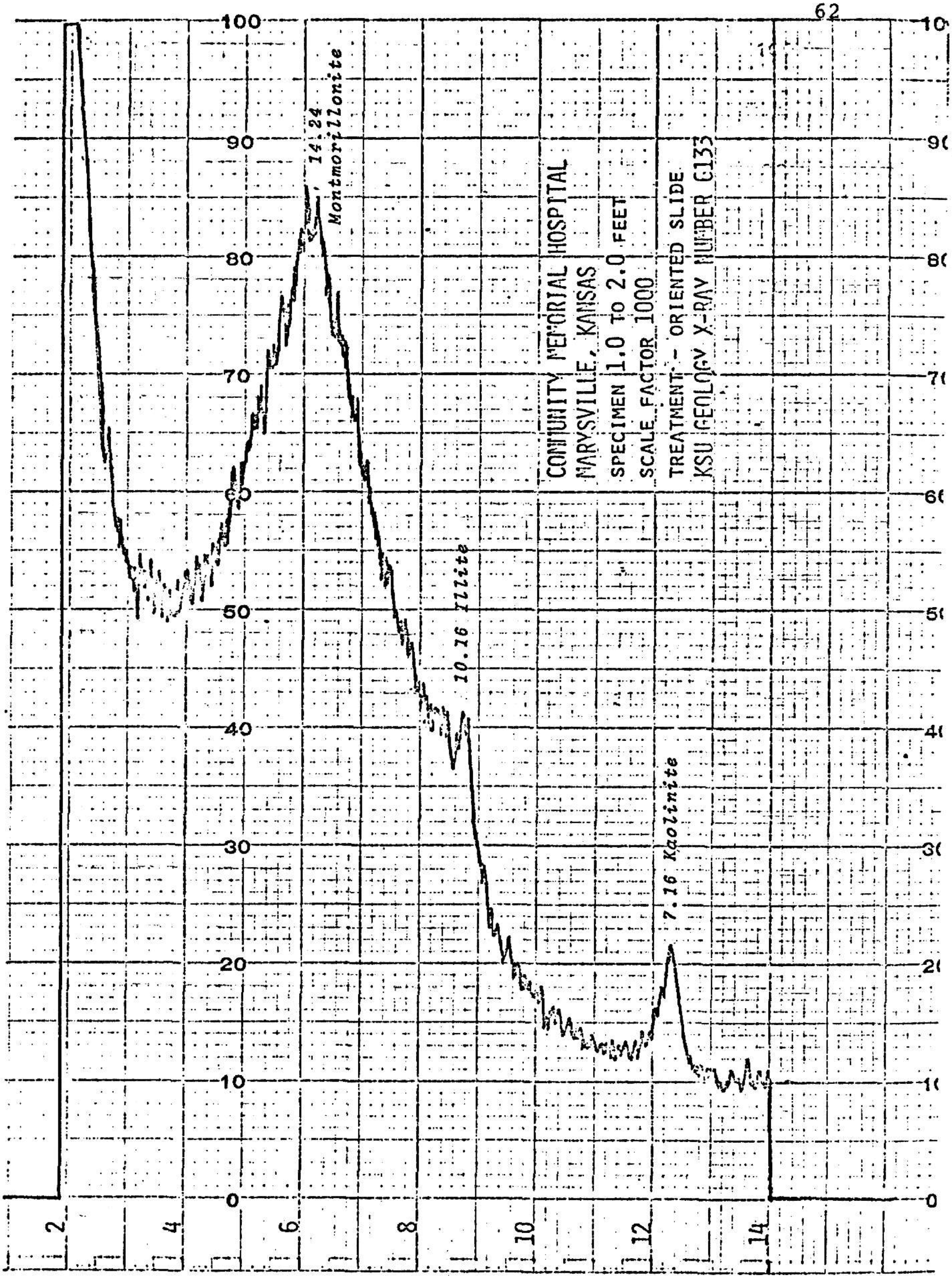

COMMUNITY MEMORIAL HOSPITAL
MARYSVILLE, KANSAS
SPECIMEN 0.0 TO 1.0 FEET
SCALE FACTOR 1000
TREATMENT - ORIENTED SLIDE
ETHYLENE GLYCOL
KSU GEOLOGY X-RAY NUMBER 6137
21.74 Montmorillonite
9.99 Illite
7.19 Kaolinite
100
90
80
70
60
50
40
30
20
10
0
2
4
6
8
10
12
14

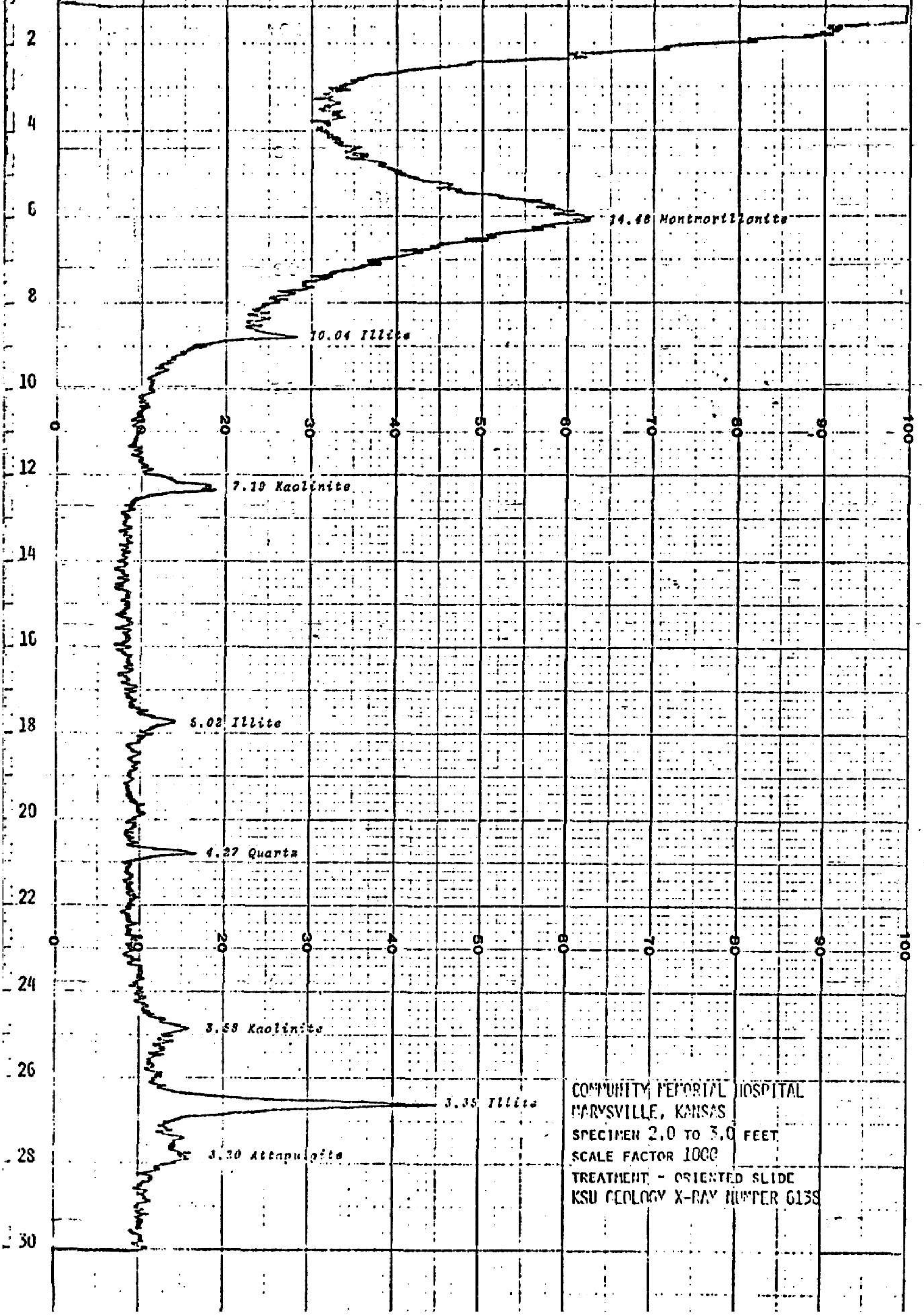


COMMUNITY MEMORIAL HOSPITAL
MARYSVILLE, KANSAS
SPECIMEN 1.0 TO 2.0
SCALE FACTOR 1000
TREATMENT - ORIENTED SLIDE
KSU GEOLOGY X-RAY NUMBER 6132

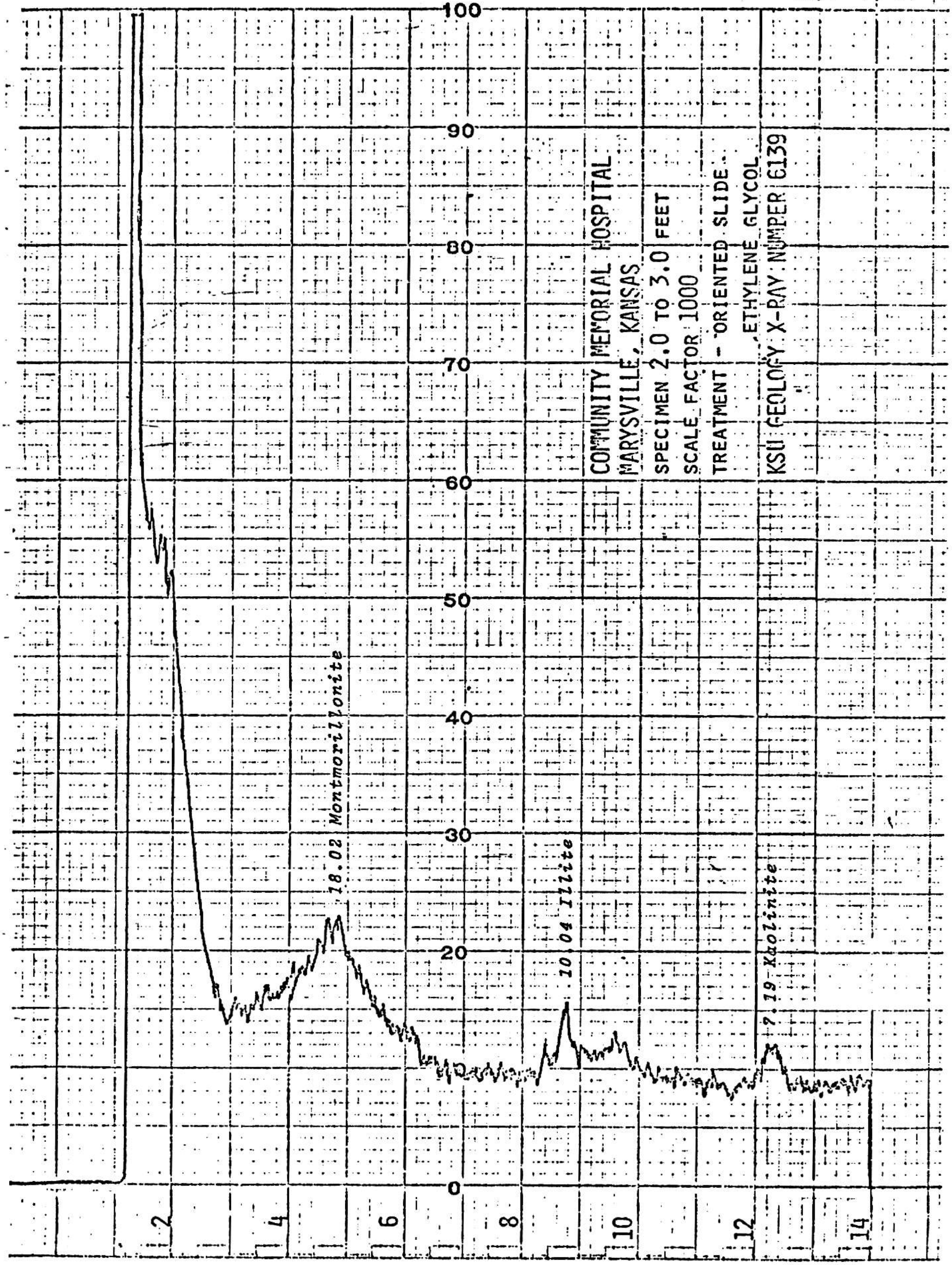

COMMUNITY MEMORIAL HOSPITAL
MARYSVILLE, KANSAS
SPECIMEN 1.0 TO 2.0 FEET
SCALE FACTOR 1000
TREATMENT - ORIENTED SLIDE
ETHYLENE GLYCOL
KSU GEOLOGY X-RAY NUMBER C134
18.79 Montmorillonite
10.04 Illite
7.25 Kaolinite
100
90
80
70
60
50
40
30
20
10
0
2
4
6
8
10
12
14

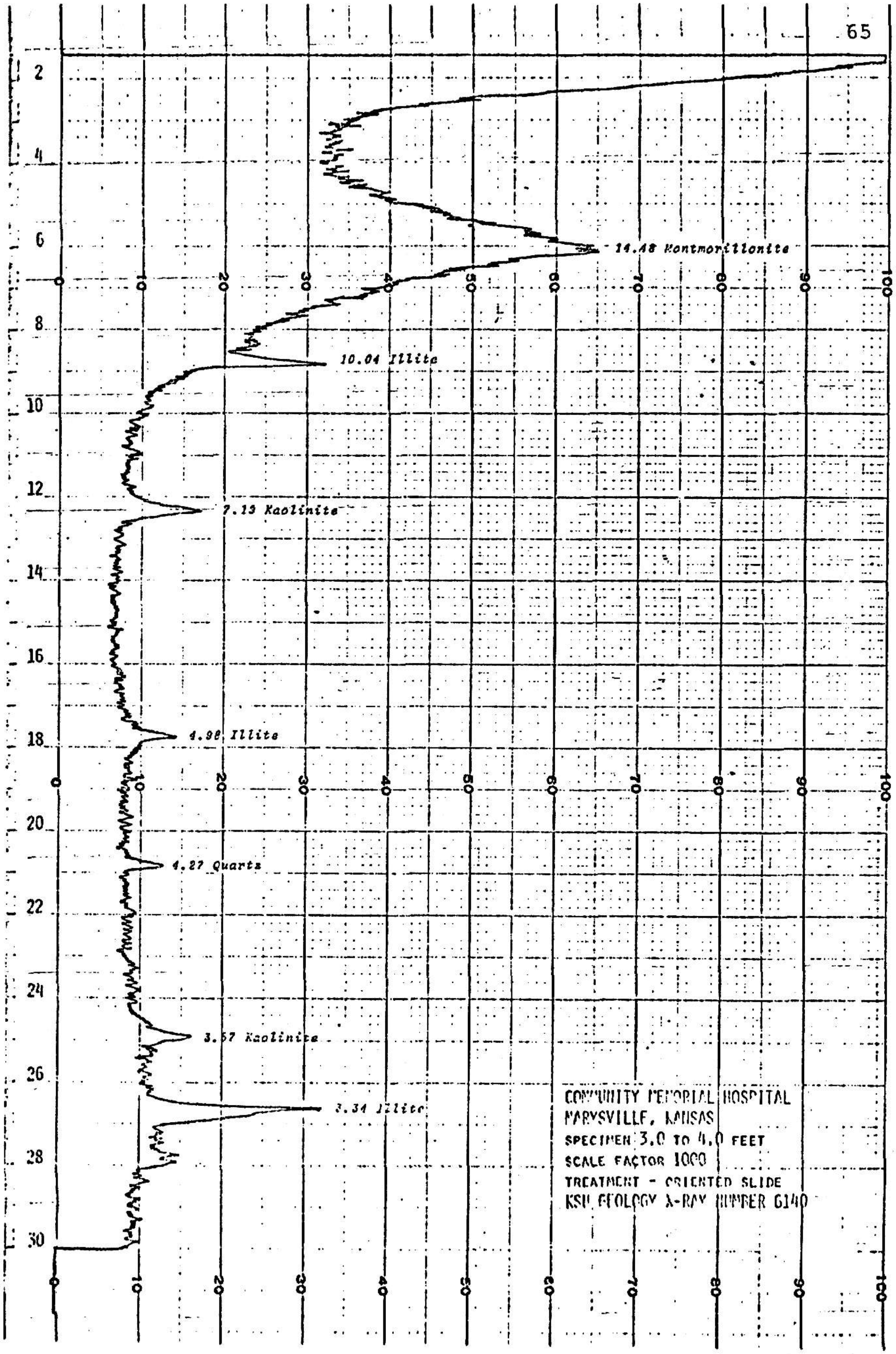

COMMUNITY MEMORIAL HOSPITAL
MARYSVILLE, KANSAS
SPECIMEN 1.0 TO 2.0 FEET
SCALE FACTOR 500
TREATMENT - ORIENTED SLIDE
ETHYLENE GLYCOL
KSU GEOLOGY X-RAY NUMBER 6135
19.36 Montmorillonite
17.66
10.04 Illite
7.19 Kaolinite
100
90
80
70
60
50
40
30
20
10
0
2
4
6
8
10
12
14


14.24 Montmorillonite
10.16 Illite
7.16 Kaolinite
COMMUNITY MEMORIAL HOSPITAL
MARYSVILLE, KANSAS
SPECIMEN 1.0 TO 2.0 FEET
SCALE FACTOR 1000
TREATMENT - ORIENTED SLIDE
KSU GEOLOGY X-RAY NUMBER C133
100
90
80
70
60
50
40
30
20
10
0
2
4
6
8
10
12
14

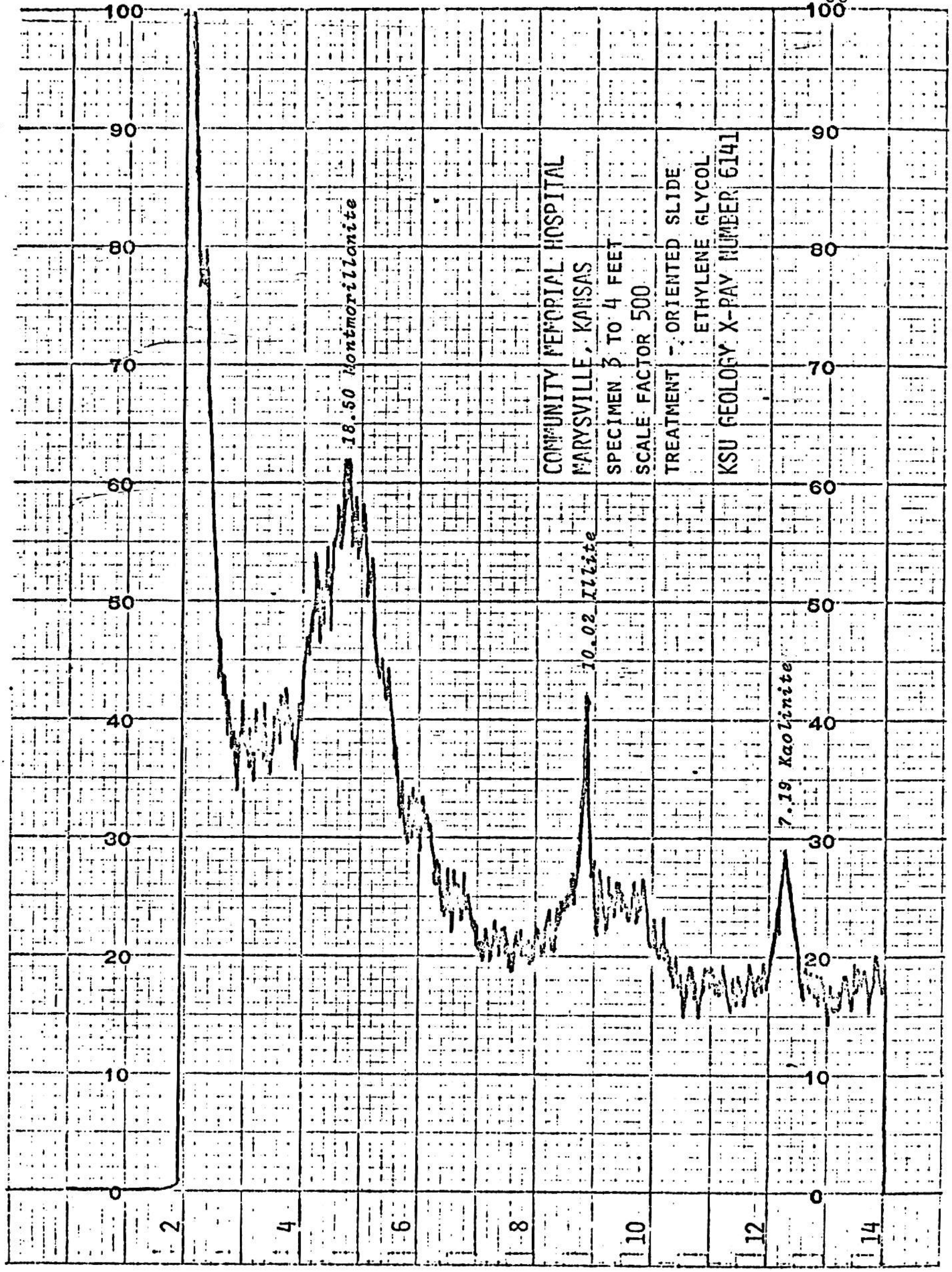


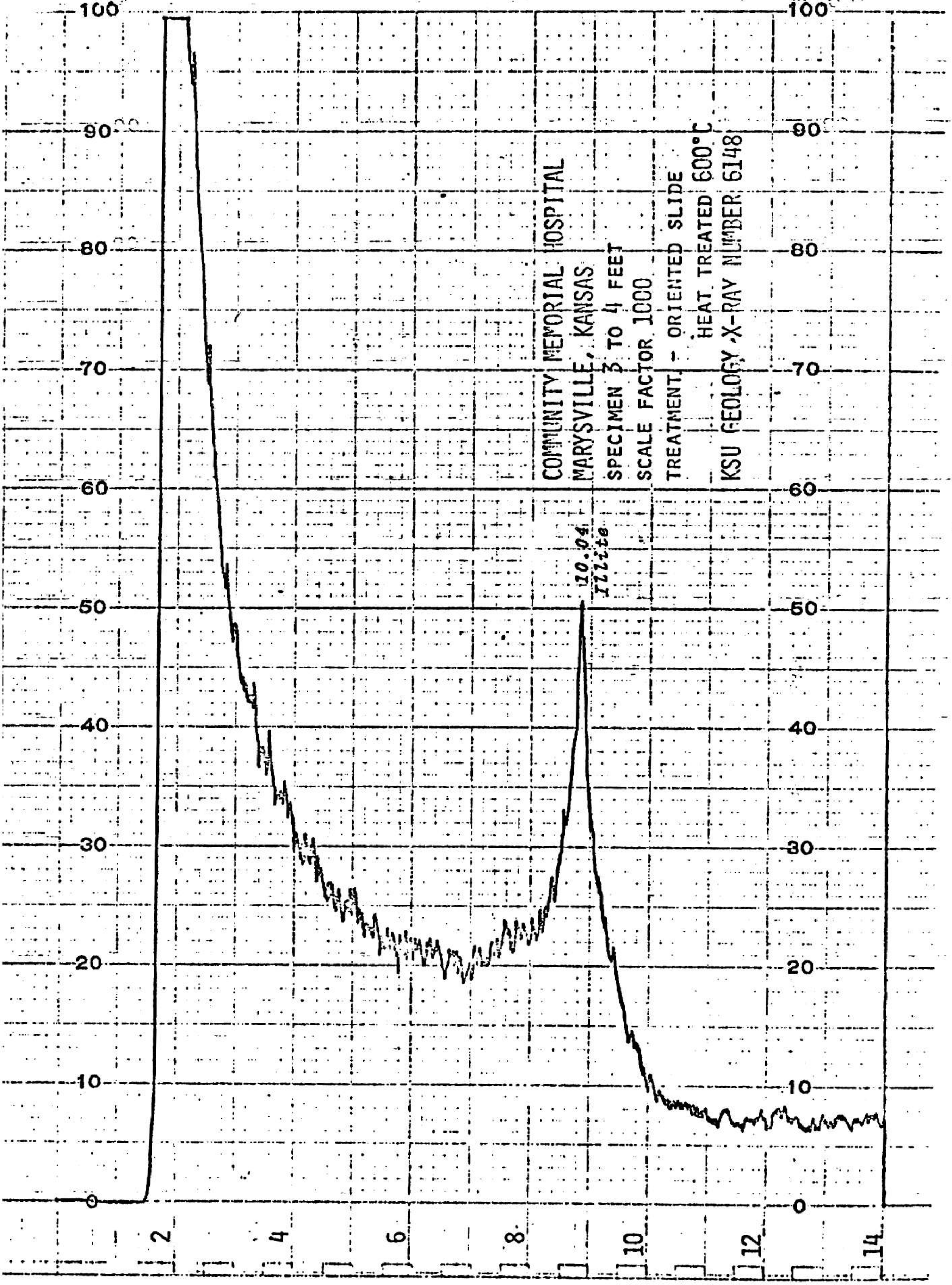
COMMUNITY MEMORIAL HOSPITAL
MARYSVILLE, KANSAS
SPECIMEN 2.0 TO 3.0 FEET
SCALE FACTOR 1000
TREATMENT - ORIENTED SLIDE
KSU GEOLOGY X-RAY NUMBER 6138

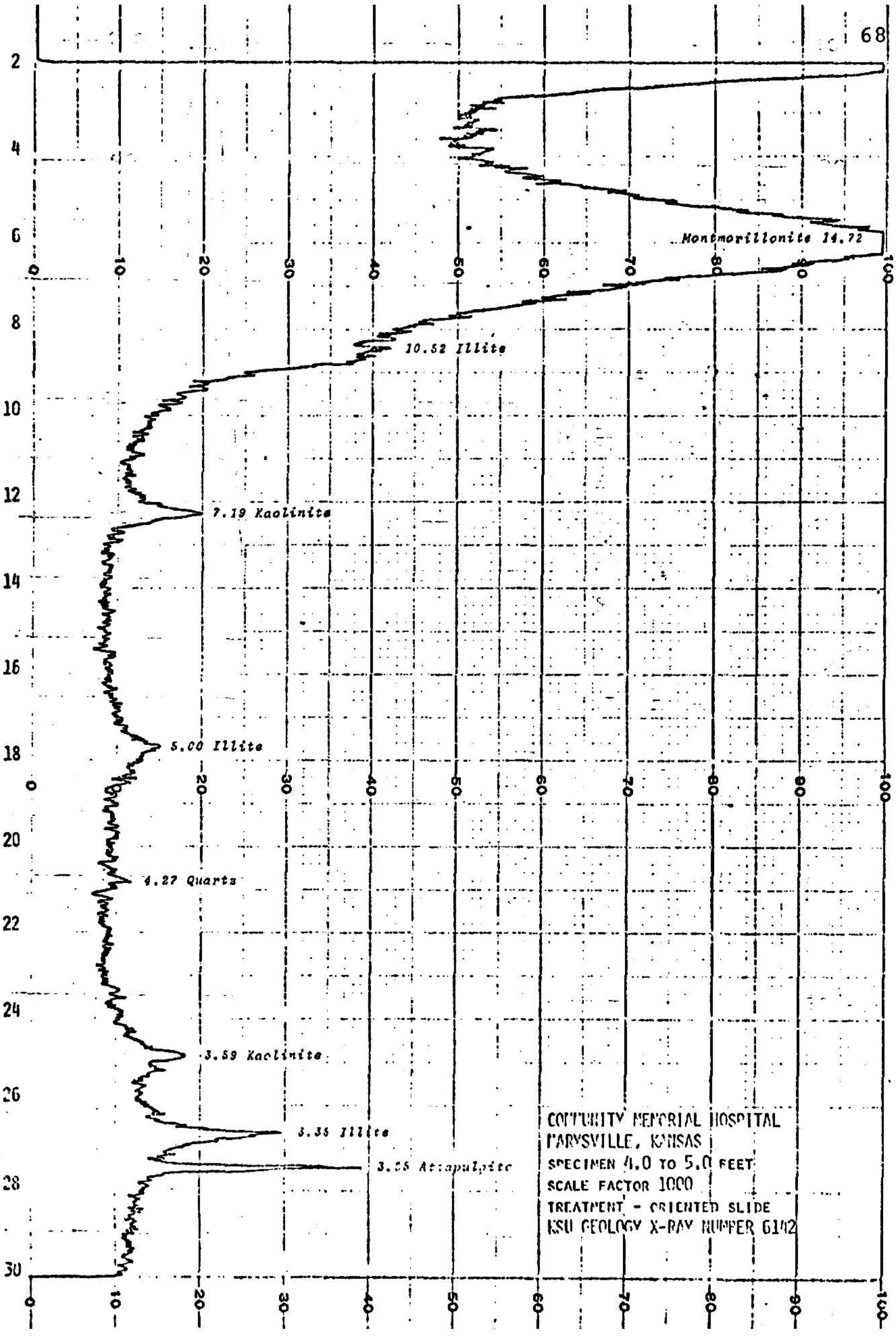

COMMUNITY MEMORIAL HOSPITAL
MARYSVILLE, KANSAS
SPECIMEN 2.0 TO 3.0 FEET
SCALE FACTOR 1000
TREATMENT - ORIENTED SLIDE
ETHYLENE GLYCOL
KSU GEOLOGY X-RAY NUMBER 6139
18.02 Montmorillonite
10.04 Illite
7.19 Kaolinite
100
90
80
70
60
50
40
30
20
0
2
4
6
8
10
12
14



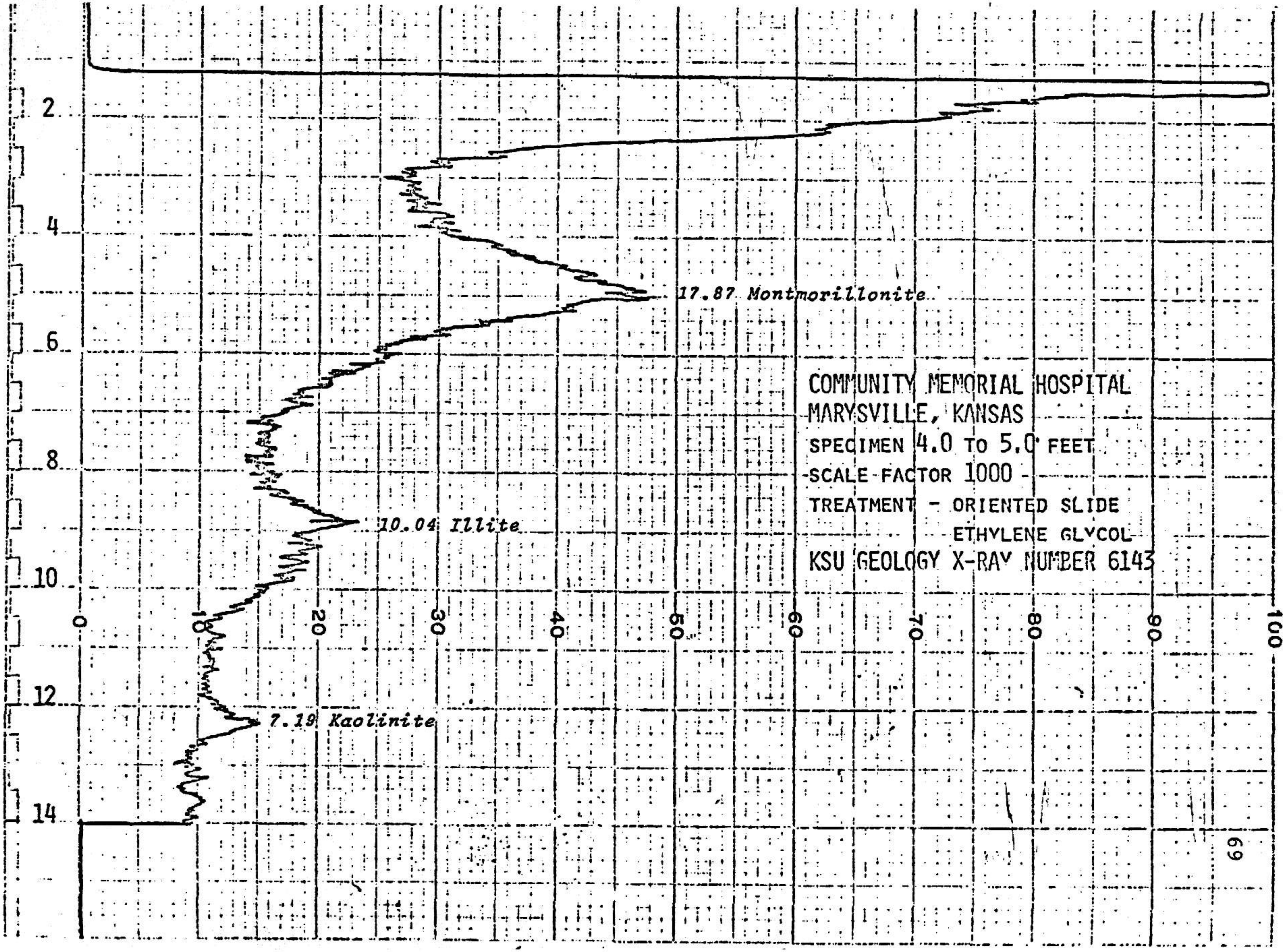
COMMUNITY MEMORIAL HOSPITAL
MARYSVILLE, KANSAS
SPECIMEN 3.0 TO 4.0 FEET
SCALE FACTOR 1000
TREATMENT - ORIENTED SLIDE
KSU GEOLOGY X-RAY NUMBER 6140

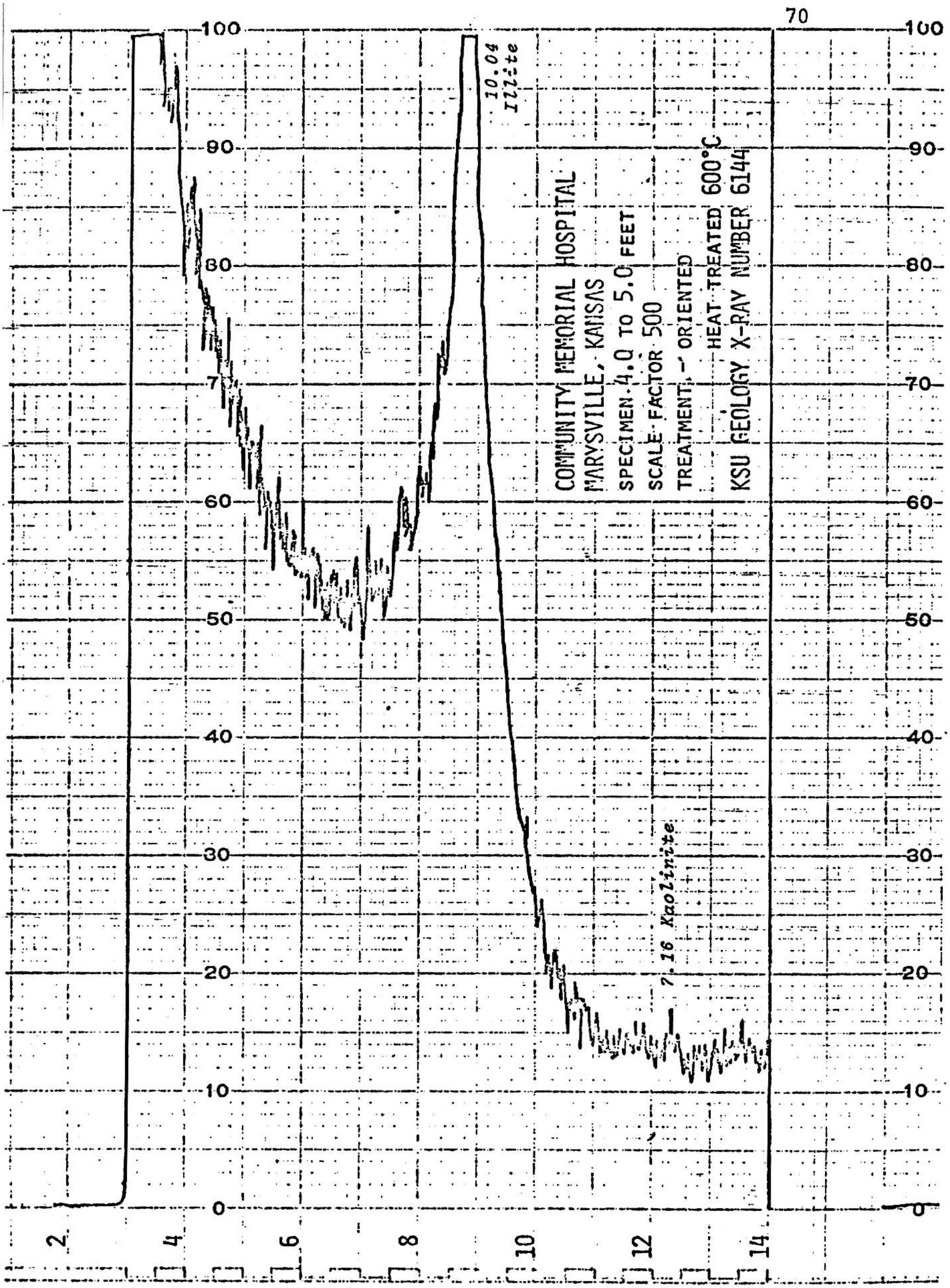

100
90
80
70
60
50
40
30
20
10
0
2
4
6
8
10
12
14
18.50 Montmorillonite
10.02 Illite
7.19 Kaolinite
COMMUNITY MEMORIAL HOSPITAL
MARYSVILLE, KANSAS
SPECIMEN 3 TO 4 FEET
SCALE FACTOR 500
TREATMENT - ORIENTED SLIDE
ETHYLENE GLYCOL
KSU GEOLOGY X-RAY NUMBER 6141


COMMUNITY MEMORIAL HOSPITAL
MARYSVILLE, KANSAS
SPECIMEN 3 TO 4 FEET
SCALE FACTOR 1000
TREATMENT - ORIENTED SLIDE
HEAT TREATED 600°C
KSU GEOLOGY X-RAY NUMBER 6148
10.04
Illite
100
90
80
70
60
50
40
30
20
10
0
2
4
6
8
10
12
14

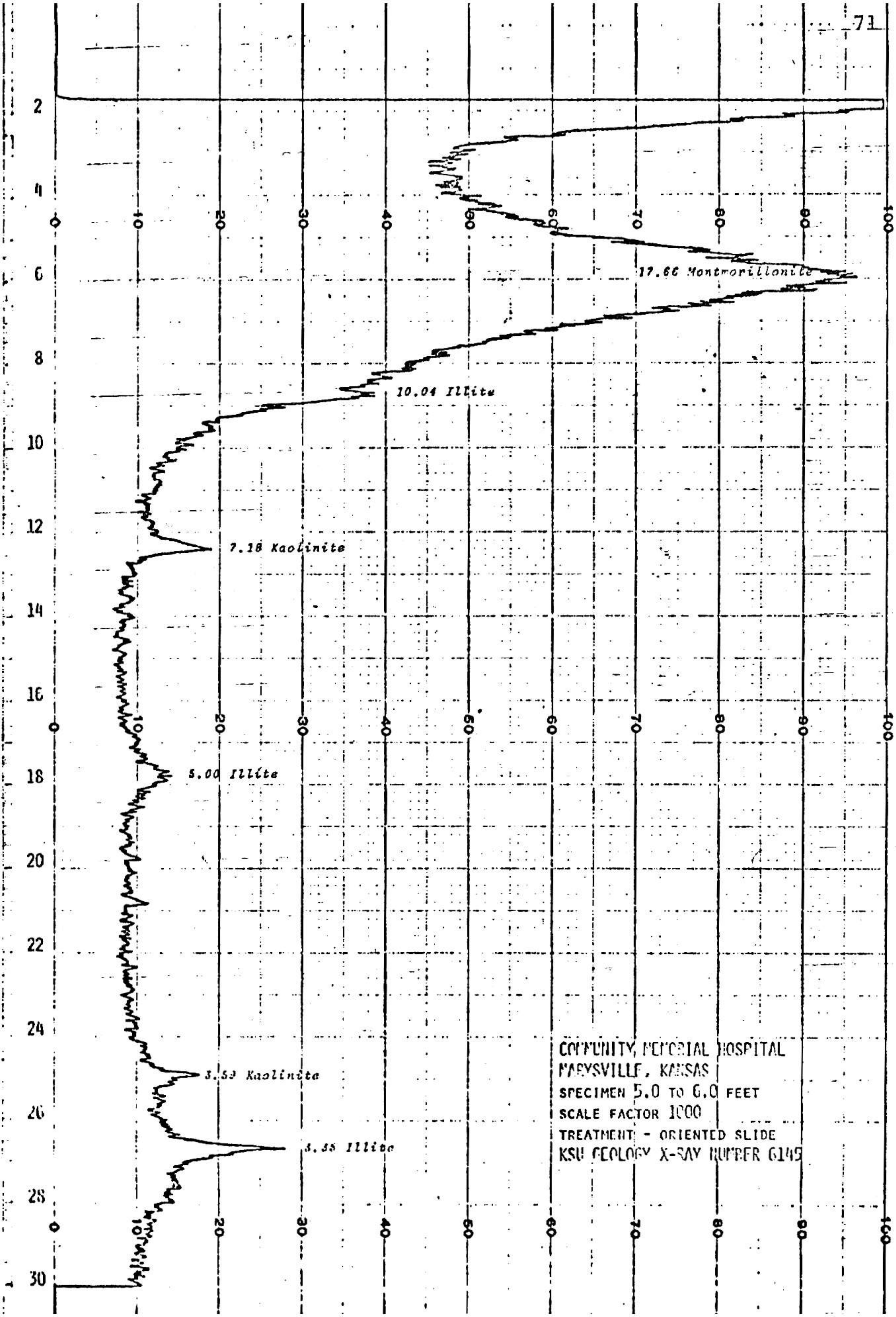


COMMUNITY MEMORIAL HOSPITAL
MARYSVILLE, KANSAS
SPECIMEN 4.0 TO 5.0 FEET
SCALE FACTOR 1000
TREATMENT - ORIENTED SLIDE
KSU GEOLOGY X-RAY NUMBER 6142

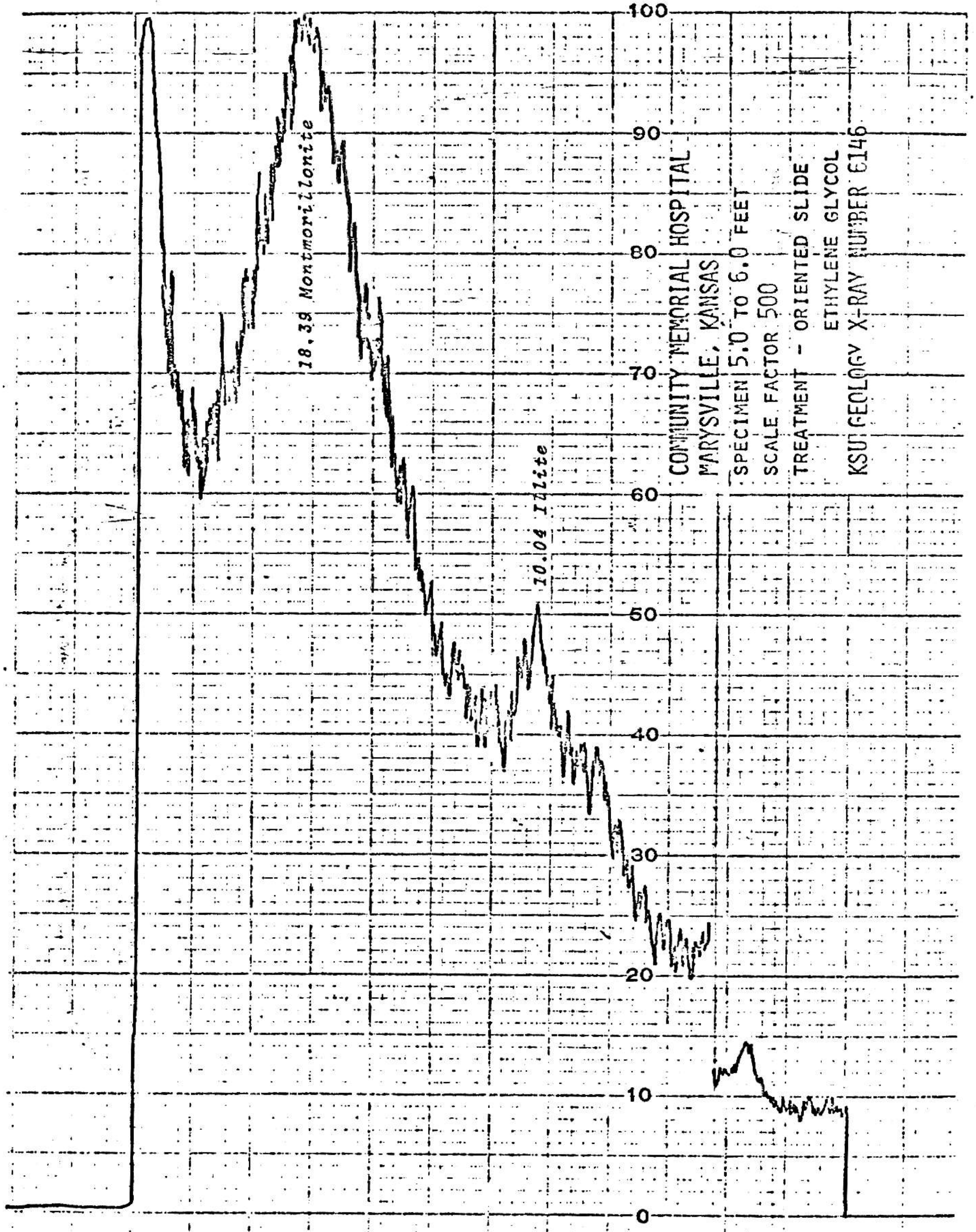

COMMUNITY MEMORIAL HOSPITAL
MARYSVILLE, KANSAS
SPECIMEN 4.0 TO 5.0 FEET
SCALE FACTOR 1000
TREATMENT - ORIENTED SLIDE
ETHYLENE GLYCOL
KSU GEOLOGY X-RAY NUMBER 6143
17.87 Montmorillonite
10.04 Illite
7.19 Kaolinite
0
10
20
30
40
50
60
70
80
90
100
2
4
6
8
10
12
14

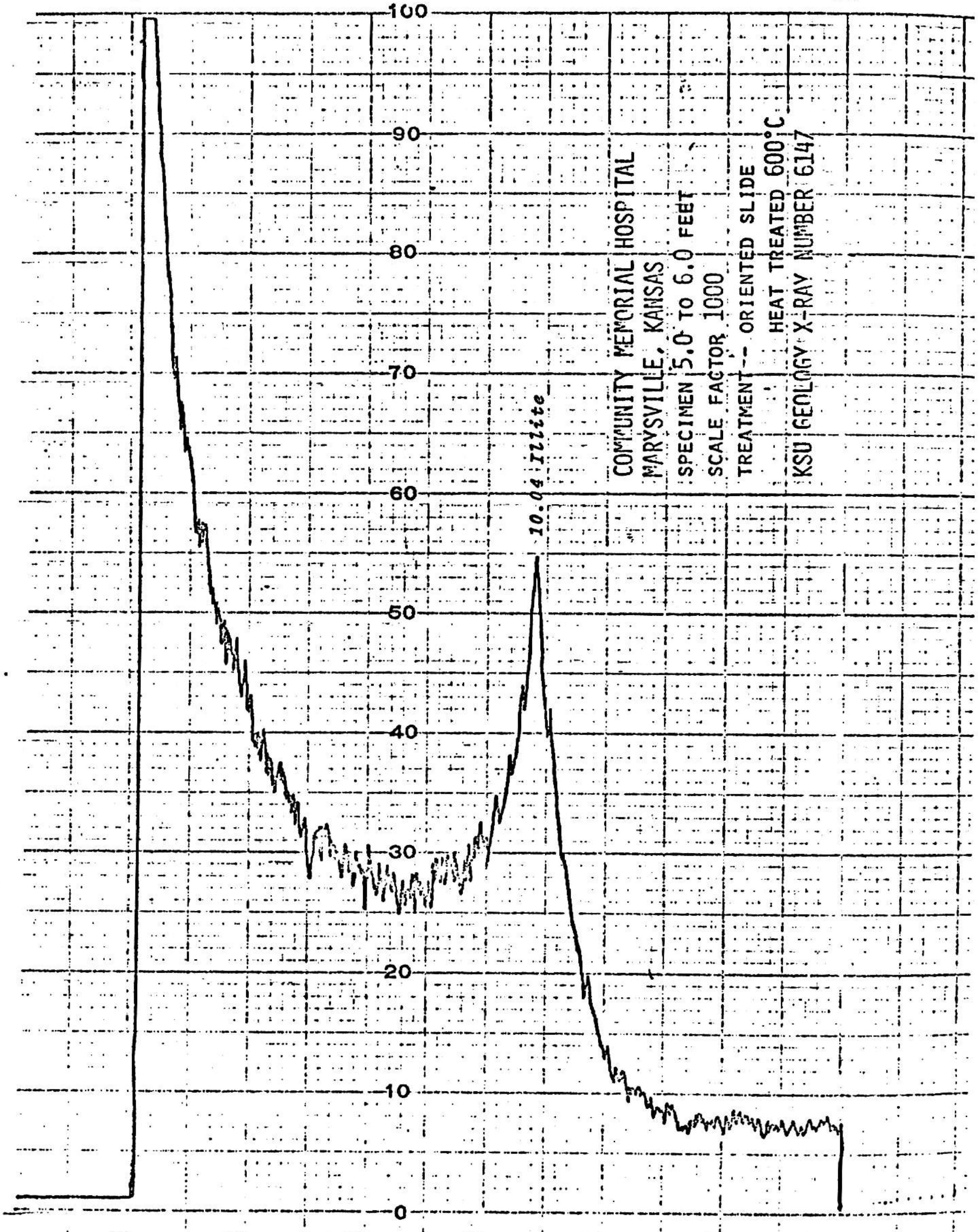


COMMUNITY MEMORIAL HOSPITAL
MARYSVILLE, KANSAS
SPECIMEN 4.0 TO 5.0 FEET
SCALE FACTOR 500
TREATMENT - ORIENTED
HEAT TREATED 600°C
KSU GEOLOGY X-RAY NUMBER 6144
10.04 Illite
7.16 Kaolinite
100
90
80
70
60
50
40
30
20
10
0
2
4
6
8
10
12
14
70



COMMUNITY MEMORIAL HOSPITAL
MARYSVILLE, KANSAS
SPECIMEN 5.0 TO 6.0 FEET
SCALE FACTOR 1000
TREATMENT - ORIENTED SLIDE
KSU GEOLOGY X-RAY NUMBER 6149


COMMUNITY MEMORIAL HOSPITAL
MARYSVILLE, KANSAS
SPECIMEN 5.0 TO 6.0 FEET
SCALE FACTOR 500
TREATMENT - ORIENTED SLIDE
ETHYLENE GLYCOL
KSU GEOLOGY X-RAY NUMBER 6146
18.39 Montmorillonite
10.04 Illite
100
90
80
70
60
50
40
30
20
10
0
2
4
6
8
10
12
14


COMMUNITY MEMORIAL HOSPITAL
MARYSVILLE, KANSAS
SPECIMEN 5.0 TO 6.0 FEET
SCALE FACTOR 1000
TREATMENT -- ORIENTED SLIDE
HEAT TREATED 600°C
KSU GEOLOGY X-RAY NUMBER 6147
10.04 Illite
100
90
80
70
60
50
40
30
20
10
0
2
4
6
8
10
12
14

measurement of the relative peaks for each of these minerals indicates the relative abundance of these minerals.

Thus, based upon examination of the X-ray data, the clay minerals were found to exist in approximately the following ratio:

Montmorillonite	15
Illite	3
Kaolinite	1

Thus, the Montmorillonite very greatly predominates the clay sized fraction of these tested layers.

Microscopic Examination

The glacial till from beneath the floor was studied by a scanning electron microscope at Iowa State University by John Hartwell, a graduate student in Soil Mechanics and Foundations. Photomicrographs are shown in Fig. 53 through Fig. 56.

These photographs indicate that the clay particles are concentrated at the contact points of the larger grains. This position allows the clay to cause the greatest volumetric expansion per unit volume of clay.

The transmission of electrons, as shown by the white areas in the photographs, shows the position of the clay minerals. The strength of the transmission indicates that the clay plates are oriented in a parallel direction. The lack of a specific shape of the clay minerals grains at the

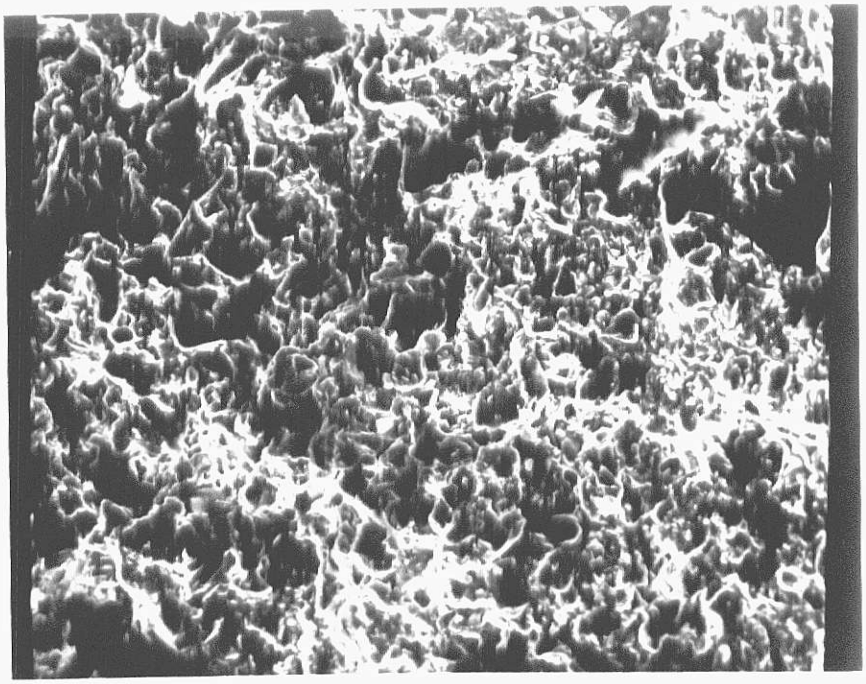


Fig. 53. Electron Microphotograph of Glacial Till X200

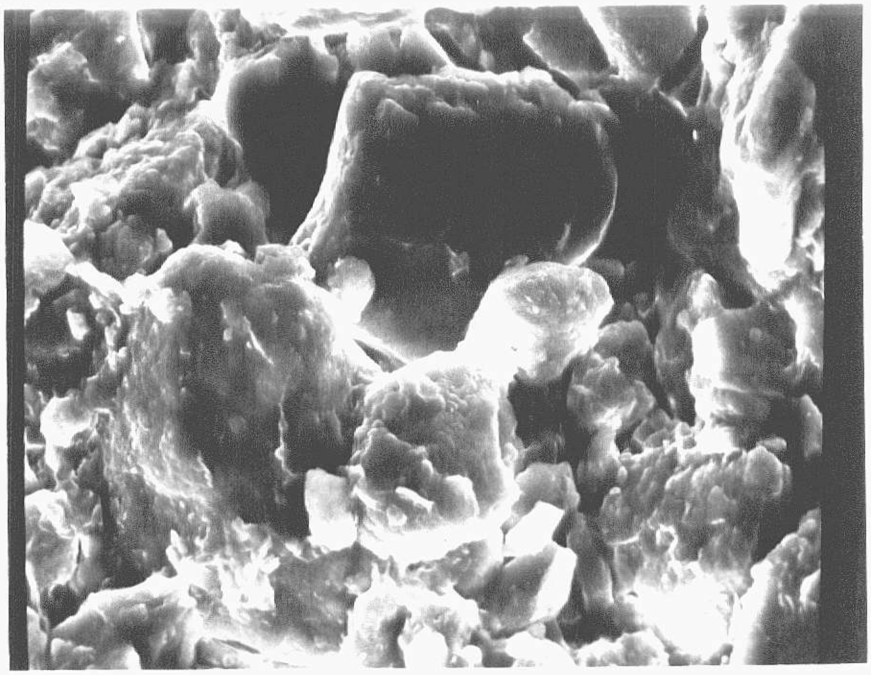


Fig. 54. Electron Microphotograph of Glacial Till X1000

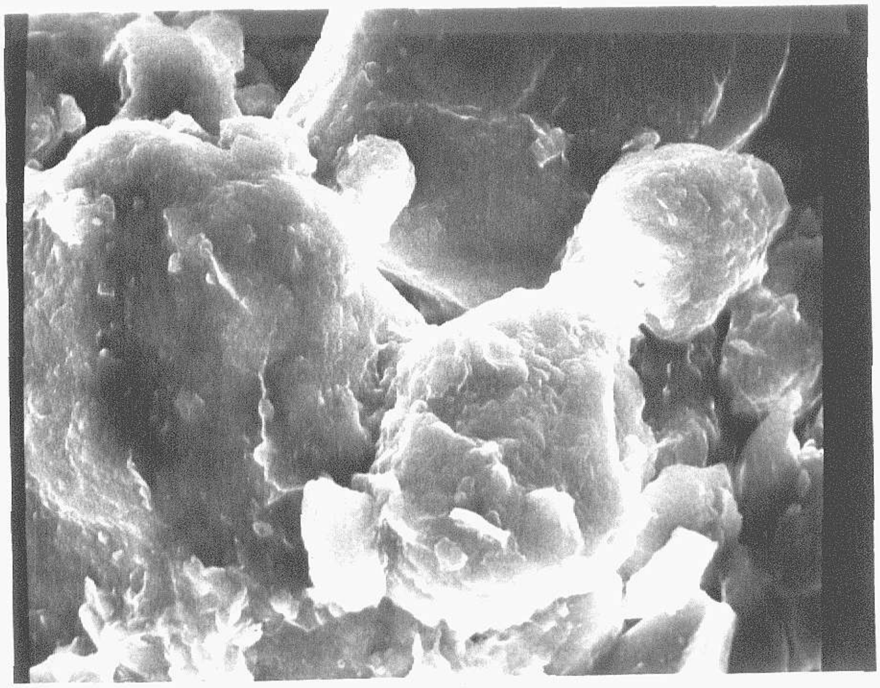


Fig. 55. Electron Microphotograph of Glacial Till X1600

Fig. 56. Electron Microphotograph of Glacial Till X3000

higher magnifications confirm that these are Montmorillonite and Illite.

These photographs confirm that the soil consists of a skeleton of large rounded mineral grains partially coated and bound to each other by an accumulation of oriented clay grains. The overall fabric of the soil shows a high porosity and large diameter pores.

These conditions preclude any theoretical computation of the amount of pressure developed by expansion due to wetting, since the clay will partially expand into the voids upon wetting. The large pores allow a maximum opportunity for the moisture content to fluctuate. It is expected that the soil would not increase in moisture appreciably by the forces of capillary water flow.

RESULTS AND CONCLUSIONS

Cause of Settlement

The settlement of the floor slab was clearly caused by shrinkage of the soil from drying. The typical soil boring logs indicate a natural moisture content (w) outside the hospital of some 25% while the soil inside to a depth of some 6 feet was found to contain less than 5% moisture. The cause of the drying was, however, not initially apparent, but it seemed to be related in some way to the air return system buried beneath the south corridor. Holes were broken through the floor over the air ducts and they were examined. An exploration through the pipes large enough to admit a man found that they were imperfectly sealed and the joints were, in some cases, misaligned. A current of air was found to exist under the floor when smoke was carried into holes drilled through the floor slab. At this point, it was assumed that all of the under floor air ducts were air returns, but a study of air flows at each duct showed clearly that the system serving the lobby area was the reverse of the others. Further study indicated an interchange of air from this system to the system under the south corridor, and the history of the failure indicated that the first distress was noted near their closest junction. An additional series of test holes showed the soil moisture to increase away from the closest junction of these air ducts, and the water content in the soil was found to be about 25% in all areas except the failed area. It was obvious that, as the soil dried in even wider areas, an increase in the air currents under the floor could be expected and that the settlement would extend gradually to all parts of the building and to a greater depth into the soil.

Suggested Corrective Measures

The following corrective measures were considered:

1. No corrective measures, with an annual repair of cracks, until settlement is complete.

2. Temporary shimming of walls not in contact with the floor, repair of existing cracks and an annual replacement of addition of shims until settlement is complete.

3. Rewetting of the dried soil under the floor to its original moisture content with periodic (probably bi-annual) addition of moisture to maintain a moisture content of some 25%.

4. Grouting with a sand-cement grout to fill existing voids and to lift the floor back near its original position.

Of these possibilities, listed in the order of least to highest immediate cost, the last would cure the problem quickly and effectively without continued future maintenance if rewetting of the soils would not occur. The rewetting of the soil under the floors represented a risky venture since no record of a similar full scale application could be found in the literature.

Corrective Procedure Adopted

The Board of Directors for the Community Memorial Hospital, on July 14, 1971, authorized funds for rewetting the soil under the floor, with the expectation that it would regain part or all of its original position.

The amount of water required to rewet the soil, and thus to re-expand it to its original volume, was calculated to be 9.0 gallons per square foot of floor area where the dehydration was most severe. The amount of water required would, of course, decrease to 0 gallons per square foot near the margins of the dry area. Based on the contours shown in Fig. 7, the average amount required in the dried area is 3.6 gallons per square foot, or some 20,000 gallons in total. Tests designed to show the time required for rewetting of the soil were inconclusive and the information was discarded.

Holes one inch in diameter were drilled at locations shown in Fig. 57, and the rewetting was started on July 19, 1971. Quite arbitrarily, it was decided that 100 gallons of water would be admitted to each hole by a hose connected to a water meter, as shown in Fig. 58. Water was added on successive Mondays, Wednesdays, and Fridays, until a total of 23,610 gallons had been added to the soil, as shown in Table 4. At this point, portions of the hospital showed a marked uplift, and holes in these areas ceased to take water. Along the air return in the south corridor, water was conducted

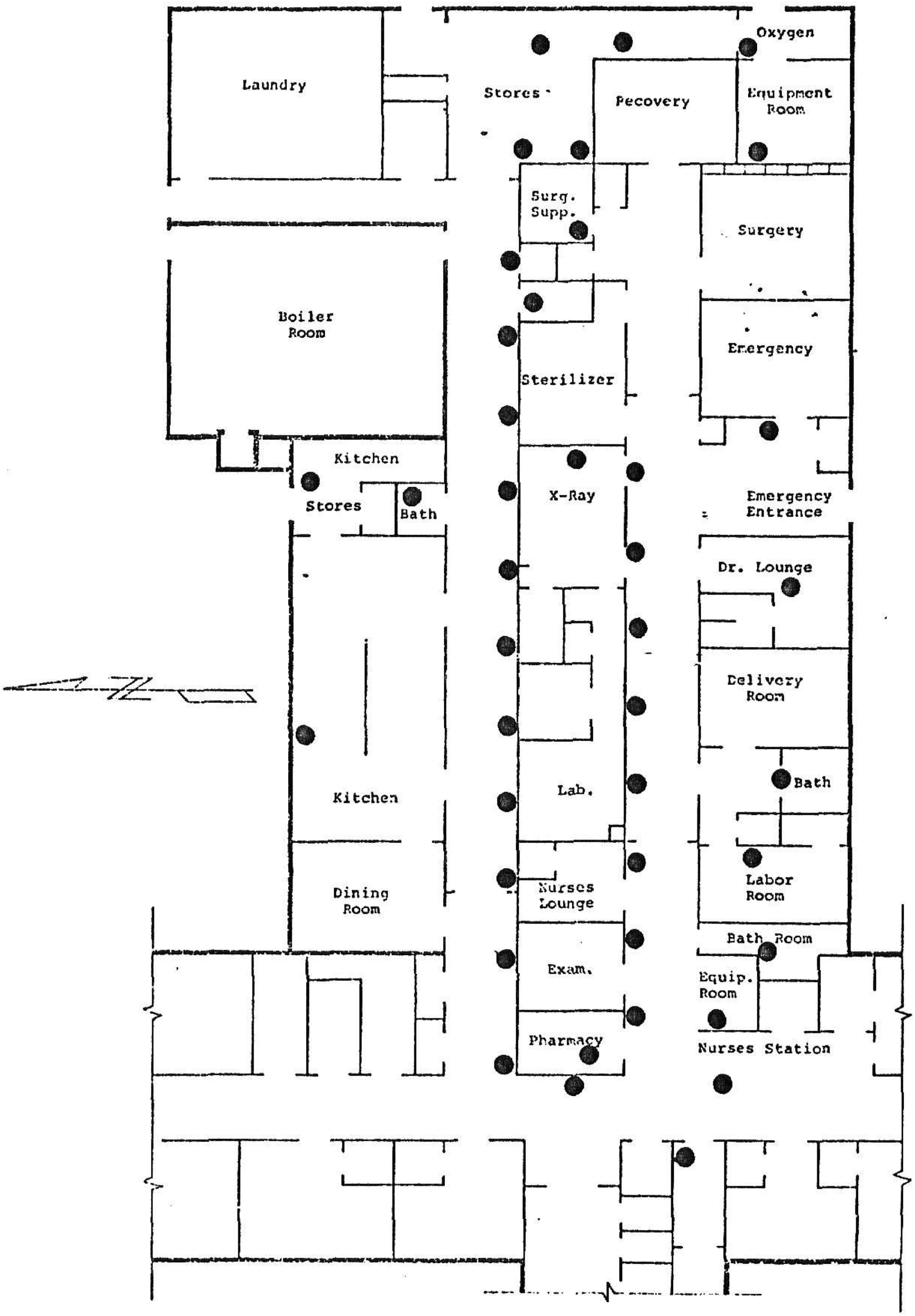


Figure 57 Location of the Watering Holes

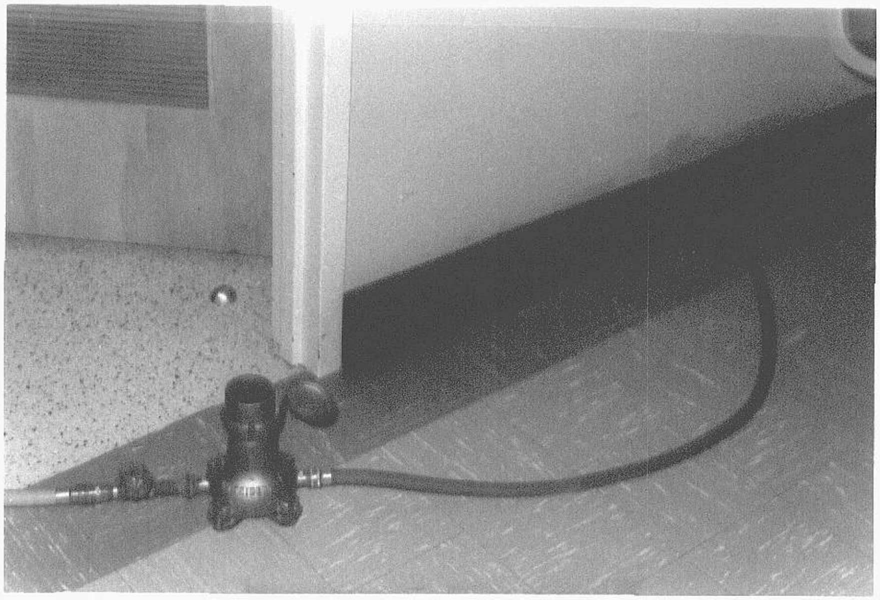


Fig. 58. Metering Water Into Soil

Hole No.	June	July, Aug., Sept.
1	550	300
2	400	200
3	400	100
4	590	200
5	400	100
6	700	365
7	400	---
8	400	60
9	320	---
10	1,120	100
11	500	100
12	1,000	---
13	700	---
14	1,300	100
15	500	100
16	1,600	100
17	280	---
18	400	100
19	400	100
20	500	100
21	1,775	100
22	510	100
23	490	100
24	Would	Not Take
25	500	100
26	Would	Not Take
27	250	20
28	500	100
29	750	200
30	600	200
31	700	300
32	700	100
33	600	100
34	675	100
35	1,900	250
36	300	480
37	300	400
38	300	300
39	300	---
	23,610	5,075

Grand Total 28,685

Table 4. Amount of Water Added to Each Location

directly into the air return, apparently through the shrinkage cracks in the soil without saturating the soil as expected. It was evident that the soil was now in contact with all areas of the floor, and that the floor had been uplifted. The lowest point in the floor was now one inch, as shown in Fig. 59.

Water Added to Each Watering Hole

Although the holes were not numbered on the drawing in Fig. 57, a careful metering of water into each hole was made, and Table 4 gives a summation of the water added.

Water in the amount of 5,075 gallons was added to the soil during July through September, and the floor elevations continued to rise until the lowest point was just slightly more than 0.5 inches, as shown in Fig. 60.

A summary of level readings is shown in Table 5.

Conclusions

This study has shown that the structural frame and foundation of the hospital are, and will remain, stable. The failure is limited to the settlement of the floor slab and non-load bearing walls. The settlement was caused by drying of the soil under the structure, which caused a collapse of Montmorillonite clay in the soil, thus causing a columetric reduction in both horizontal and vertical directions. The dehydration of the soil was caused, for the most part, by a circulation of air between the various underfloor air

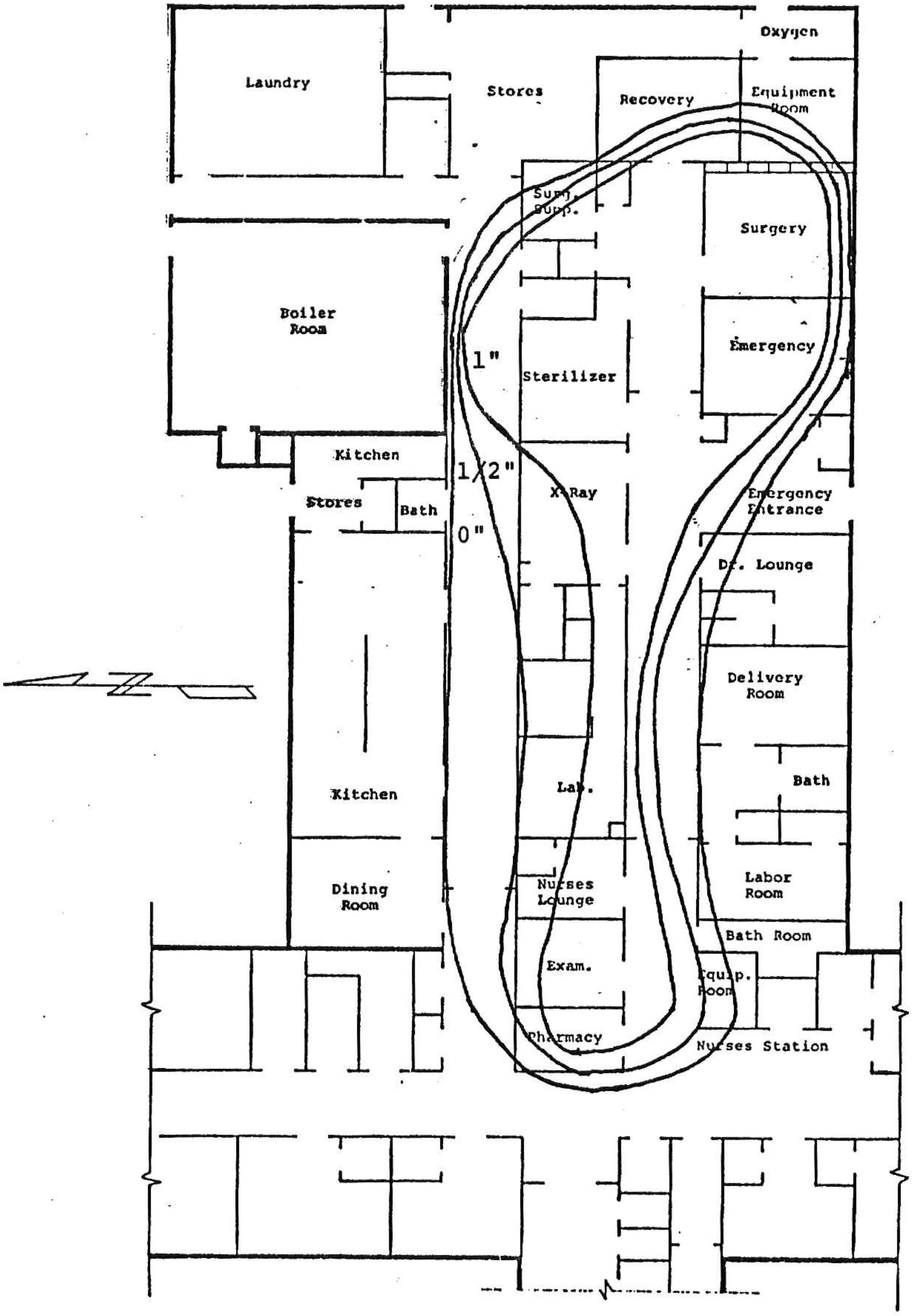


Figure 59 Relative elevation of the floor slab at the end of June, 1971.

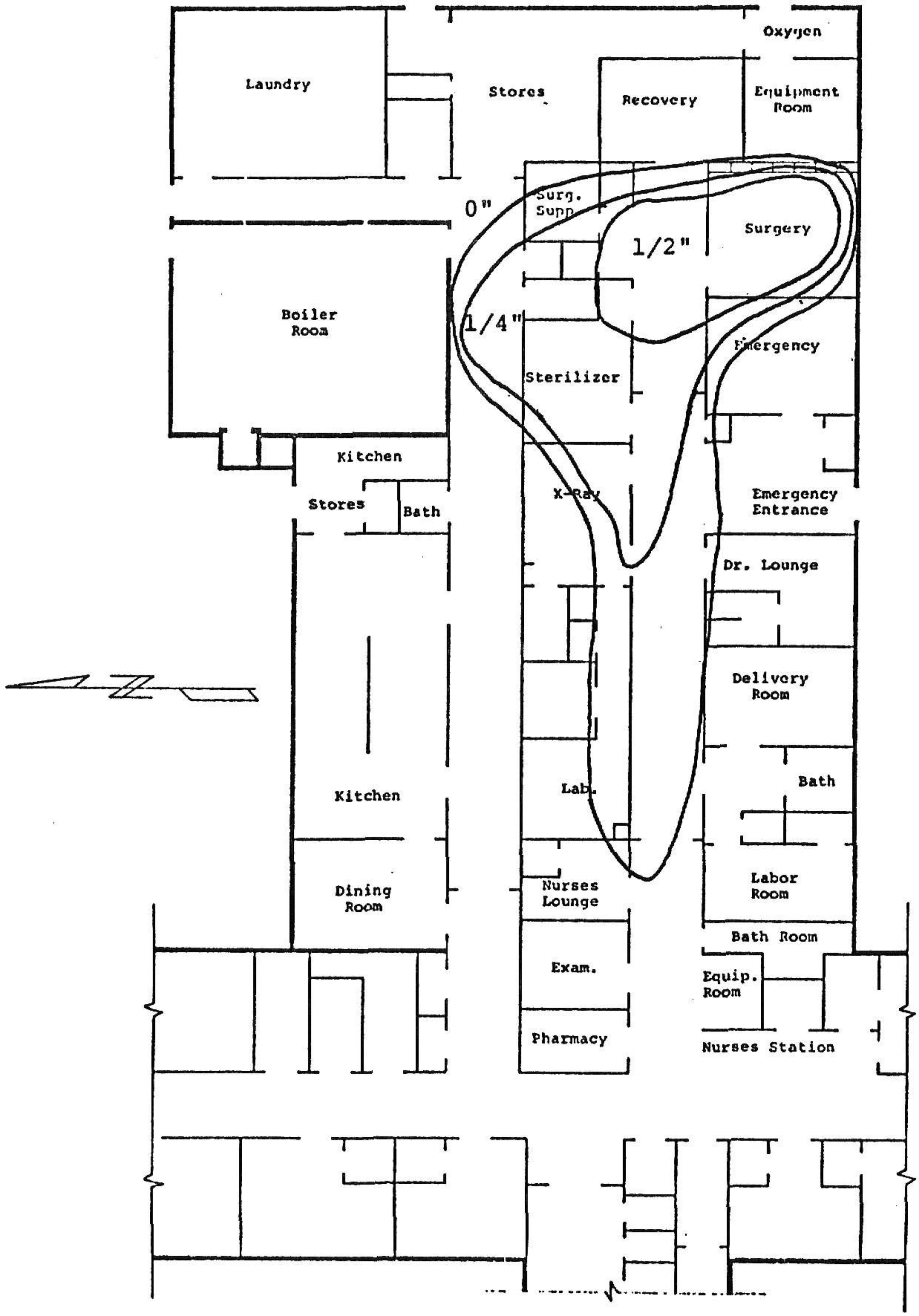


Figure 60 Relative elevation of the floor slab at the end of 1971.

Location	June 1971	July 1971	Aug. 1971	Sept. 1971	Nov. 1971	Dec. 1971	Feb. 1971
Intersection South Cor. and Emer.	0	0	0	0	0	0	0
Door Surgery	-2 1/2	-2 1/8	-7/8	7/8	-3/4	-7/8	-7/8
Door Recovery Room	-2 1/8	-2 1/8	-7/8	-3/4	-5/8	-1/2	-3/4
Door Surgical Supplies	-2.0	-1 3/8	-3/4	-1/2	-3/8	-1/2	-1/2
Door Doctor Lounge	-2 1/8	-2 1/8	-1/2	-3/8	-1/2	-1/4	-5/8
Door X-ray	-2 1/2	-1 1/2	-7/8	-7/8	-3/4	-5/8	-5/8
Nurses Station	-2 1/2	-2 1/8	-1.0	-1/2	-1/4	-1/4	-5/8
Pharmacy Cor.	-2 1/2	-2 1/8	-3/8	+3/8	+1/2	+1/2	+1/2
Entrance South Wing	0	0	0	0	0	-1/8	-1/8
Entrance Lobby	0	+3/8	+3/8	+3/8	+3/8	+1/4	+1/4
Entrance North Wing	0	0	0	0	-1/8	-1/8	-1/8
Comer. North and Main Corridors	-1 1/2	-1 1/4	-1/8	-1/8	-1/8	0	0
Door Dining Room	-1 1/4	-1.0	-1/4	-1/4	-1/8	-1/8	-1/4
Door Kitchen		-7/8	-1/2	-1/2	-3/8	-3/8	-1/2
East and North Cor.	-1 1/4	-1 1/4	-7/8	-3/8	-1/2	-1/2	-1/2
North Entrance	0	0	0	0	0	0	0

Table 5 Level Readings Summary

conduits. This interchange of air was increased greatly as the soil dried and cracked, thus permitting ever freer circulation.

The soil re-expanded by the addition of water to its original position, except in areas where sufficient water could not be introduced into the soil. It is expected that the moisture content of the soil will be equalized under the entire structure with time and that the soil will be able to retain the water for a long period of time if air circulation under the floor is prevented.

It is obvious that this method has proved to be the most efficient and economical method of repair. It is further concluded that redecoration can now be started since movements have ceased.

RECOMMENDATIONS OF FUTURE ACTION

It is recommended that all of the larger underfloor air conduits be sealed. The conduit to the surgical closet should be replaced by an overhead conduit, and the existing conduit effectively sealed by filling. The lobby air conduit that has now been sealed off should be filled to prevent future air flow.

The moisture content and elevation of the floor should be checked semi-annually for the next two or three years.

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Recognition is also extended to Dr. Page Twiss, Head of the Geology Department, for his cooperation and assistance in using the X-ray machine. Thanks is also extended to Dr. R. L. Handy, Head of the Soil Mechanics Department, Iowa State University, for the use of their scanning electron microscope.

Sincere thanks goes forth to Mr. Steve Kralik, Director, and the staff of the Community Memorial Hospital for their full cooperation and assistance.

Finally, thanks to my wife, Donna, for her many hours of help and assistance in helping make this thesis possible.

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A PRACTICAL APPLICATION OF THEORETICAL SOIL MECHANICS TO EXPANSIVE SOILS

by

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ABSTRACT

The properties of expansive clays have been recognized and studied for several years. These studies have generally been concerned with distress caused by the swelling of dry clays. The purpose of this thesis was to investigate the soil shrinkage, which caused severe distress to the Community Memorial Hospital in Marysville, Kansas.

The investigation showed that the failure was caused by severe drying of soil under the floor. Soil samples were taken and were subjected to Atterburg Limits, direct shear, grain size analysis, and consolidation tests in the laboratory. These tests showed that a large quantity of clay was present in the soil, which would account for the large amount of soil shrinkage. It is known that two types of clay, specifically Montmorillonite and Illite, expand upon wetting. X-ray diffraction and Electronmicroscope scanning tests were run on the samples to determine which type of clay material was present. These tests proved that the clay minerals present were Montmorillonite and Illite.

It was then decided to try a process, which has never been tried before, to correct the distress of the hospital. This process was simply adding water to the soil and letting it re-expand upon wetting, and, in the process, the distress was greatly corrected.