Report 74-6

REGIONAL CHEMISTRY AND WATER LEVEL DISTRIBUTION OF THE NEAR-SURFACE GROUNDWATERS OF THE EDMONTON AREA (NORTHWEST SEGMENT), ALBERTA

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REGIONAL CHEMISTRY AND WATER LEVEL DISTRIBUTION OF THE NEAR-SURFACE GROUNDWATERS OF THE EDMONTON AREA (NORTHWEST SEGMENT), ALBERTA

Abstract

The chemistry and water level distribution of the near-surface groundwaters are described and interpreted on a regional basis. To facilitate description and interpretation the available basic data were sorted into three groups. These groups were data from the drift, data from the upper 75 feet of bedrock and data from the bedrock from 75 to 250 feet. The data for each of these layers were then automatically contoured. These contour maps of chemistry and water levels for each layer are presented in the report. Interpretation of the contoured data led to the following major conclusions: the water level distribution closely resembles surface topography; over most of the area flow has a downward component relative to the water table; buried channel sands and gravels act as high permeability line-sinks and are a major influence on water level distribution; soils and drift lithology are the major influence on groundwater chemistry, flow direction is a minor influence; Stony Plain and Gladu Peak are major areas of infiltration to groundwater; ion exchange occurs from the drift to bedrock quickly and completely and some sulfate reduction takes place from drift to bedrock.

INTRODUCTION

This report comprises a description and interpretation of the regional chemistry and water level distribution of the near-surface groundwaters of the northwest segment of the Edmonton map area (NTS 83H). Three important features of the intent of the report should be noted.

In the sense that it is a description of the chemistry and water levels, it is meant to be a basic reference for the area. For this reason it contains a large number of contour maps of chemical constituents and water levels.

The adjective "regional" is used to restrict the applicability of the information and interpretation to large-scale phenomena: it is not meant to be valid for local, small-scale or detailed phenomena. This latter restriction arises primarily from the nature of the data available to the study. Whilst a large quantity of basic information was on hand, it was of generally poor quality. Such data can only be validly handled by some form of statistical averaging. This restricts its applicability to the regional scale.

The restriction of the scope of this report to near-surface groundwaters also results from the nature of the available basic data. The source of the data is almost entirely domestic water wells, most of which are completed in the upper 300 feet or so of sediments. For this reason the lower limit of investigation was taken as 250 feet below the bedrock surface.

Acknowledgments

The author has had many discussions with R. Stein about the hydrogeology of the northwest Edmonton area. They have been invaluable in writing this report. The author would like to thank D. A. Hackbarth, M. E. Holter, R. Stein and E. I. Wallick for reviewing this report, J. Gronlund for drafting the figures and D. Borneuf for typing the manuscript.

LOCATION

The northwest segment of the Edmonton map area is located in east-central Alberta and comprises an area of slightly over 1,000 square miles, being approximately 31 miles east-west by 34 miles north-south. It consists of all or part of townships 52 to 58 and ranges 22 to 28, west of the 4th meridian. More specifically the area lies between 53°30' and 54° north latitude and 113°15' and 114° west longitude (Fig. 1).

RELIEF

The area lies on the third prairie steppe and is, topographically, level to gently rolling.

Figure 2 is a contour map of surface topography. To facilitate interpretation of the groundwater chemistry and water level distribution, and for ease in specifying particular localities, the surface topography has been generalized as shown on figure 3. Three categories of topography are recognized and are termed Hills, Plains and Depressions. They refer respectively to regions of high, intermediate and low relief within the area.

Two types of Hills are recognized which are termed Peaks and Plateaus. A Peak is an area of high relief having an identifiable crest from which the ground slopes away in all directions. Gladu Peak, with a maximum elevation over 2,600 feet, and Sherwood Peak, with its highest point at 2,450 feet, are the Peaks in the area. A Plateau is a flat area of high relief. Busby Plateau at 2,350 feet is the only Plateau in the area.

A Plain is a flat area of intermediate relief. Morinville Plain, at 2,300 feet, Namao Plain, at 2,200 feet, Stony Plain, at 2,300 feet and Redwater Plain, at 2,150 feet, are the Plains within the area.

Two types of depressions are recognized and are termed Lows and Incisions. A Low is an area of low relief bounded by slopes of gentle gradient. Atim Low, at 2,300 to 2,150 feet, Sturgeon Low, at 2,250 to 2,150 feet, Big Lake Low, at 2,150 feet, Qui Barre Low, at 2,250 to 2,200 feet, and Legal Low, at 2,200 feet, are the Lows in the area. An Incision is an area of low relief bounded by slopes of very steep gradient. Sturgeon Incision, at 2,150 feet, Lily Incision, at 2,100 feet, and Saskatchewan Incision, at 2,050 feet, are the Incisions in the area.

Cross sections to illustrate these topographic features are shown on figures 4 and 5. The lines of section are located in figure 2.

An important feature to note is that the Depressions occupy a very small percentage of the total surface area. This feature is regarded as having a significant influence on flow directions.

CLIMATE

The climate of the area is continental, characterized by relatively warm summers and cold winters (Bowser *et al.*, 1962). The mean summer temperature, May to September inclusive, is 56°F. The mean winter temperature, November to March inclusive, is 16°F. The average frost-free period is about 100 days with an extreme variation from about 50 to 150 days. The growing season, calculated on a mean daily temperature of 42°F, is about 175 days.

The mean annual precipitation at Edmonton has averaged 17.5 inches over the past 75 years, with extremes of 9 and 30 inches. However, in 75 percent of the years the total precipitation was between 14 and 21 inches. June, July and August are the months of highest rainfall, totalling an average of just over 9 inches. The average water deficit for the growing season at Edmonton averages just under 5 inches for the past 30 years, assuming a 4-inch available storage capacity. However, the various soil types have different storage capacities and this causes greater variations in deficit than does the average climatic difference.

Approximately 70 percent of the precipitation falls as rain -- the remainder as snow, usually when the ground is frozen (on average about 150 days per year). The average annual snowfall at Edmonton is just over 50 inches, varying from 10 inches to 90 inches. From November to March precipitation is almost exclusively as snow. Summer rains are generally of the low intensity variety. The probability of over one inch of rain falling in less than one hour, in Edmonton, is only one year out of five. The maximum precipitation has not exceeded 5 inches in any one 24-hour period.

The foregoing climatic data have significant influence on recharge and discharge to groundwater systems. Only the qualitative aspects of this influence can be pointed out since no quantitative data are available. With a growing season of 175 days there are essentially no transpiration losses for about 190 days of the year. The 50 percent of rainfall occurring in the three summer months is probably lost, in the main, to evapotranspiration, especially as it is characteristically of low intensity. No recharge or discharge can occur for about 150 days of the year when the ground is frozen. In addition, snowmelt largely occurs before the ground is thawed out so that substantial losses to runoff will occur. At the same time, however, some of the runoff accumulates in depressions and will be available for infiltration. Wide variations in infiltration will also result from differences in soil type.

SURFICIAL GEOLOGY

The surficial geology is shown on figure 6, modified from Bayrock (1972). From a hydrogeological point of view the surficial geology can be considered to consist of two lithologic types: till, silt and clay, which are low permeability materials containing large amounts of soluble salts; and sand and pitted delta, which are high permeability materials containing small amounts of soluble salts. The first type covers most of the area. Pitted delta is found on Gladu Peak and the eastern edge of Morinville Plain, sand and pitted delta are found on Stony Plain, and sand is found on Redwater Plain, paralleling Sturgeon Incision, and on the north side of the eastern end of Saskatchewan Incision. Thus, in a general sense, the sand

and pitted delta are in the southwest and northeast, with till, silt and clay in the northwest, central and southeast. This same pattern will be seen in the chemistry maps.

An extremely important feature of the surficial geology is that all the Depressions of the area, with the exception of Lily Incision, are coincident with buried channels (Fig. 7), and, with the exception of Atim Low, are in hydraulic contact with the sands and gravels of these channels. This feature is considered to have a controlling influence on the potential distribution.

BEDROCK GEOLOGY

The near-surface bedrock formations are of Upper Cretaceous age. The typical sequence is Horseshoe Canyon Formation overlying Bearpaw Formation overlying Belly River Formation (Fig. 8). However, the Bearpaw Formation thins towards the northwest and is considered to be absent in the area north and west of the North Saskatchewan River. In this area Horseshoe Canyon and Belly River Formations are together called the Wapiti Formation. Thus, in nearly all of the study area the near-surface bedrock is Wapiti Formation.

The lithology of the formations is described as follows (Green, 1972):

Horseshoe Canyon Formation: grey, feldspathic, clayey sandstone; grey, bentonitic mudstone and carbonaceous shale; concretionary ironstone beds, scattered coal and bentonite beds of variable thickness, minor limestone beds; mainly nonmarine.

Bearpaw Formation: dark grey blocky shale and silty shale; greenish glauconitic and grey clayey sandstone; thin concretionary ironstone and bentonite beds; marine.

Belly River Formation: Grey and greenish grey, thick-bedded feldspathic sandstone; grey clayey siltstone, grey and green mudstone; concretionary ironstone beds; nonmarine.

SOILS

The soils of the area are shown on figure 9 which is simplified from Bowser *et al.*, (1972). The area has predominantly Chernozemic soils. Solonetzic soils occur on Namao Plain, Busby Plateau, the western part of Morinville Plain and in other smaller pockets. Gladu Peak has Podzolic soils. Gleysolic, Regosolic and Organic soils also are present in small areas.

The Chernozemic soils of the area have a medium permeability (0.2 to 2.0 inches per hour), medium to high water storage (2.0 to +5.0 inches of water per foot of soil) and a low salinity (less than 0.2% of soluble salt). With respect to the latter characteristic, calcium, magnesium, sodium and sulfate are usually between 1 and 3 epm,[1] chloride is absent and bicarbonate is 3 to 4 epm. In places sodium sulfate can be as high as 10 epm.

The Solonetzic soils of the area have a low permeability (less than 0.2 inches per hour), medium to high water storage (2.0 to +5.0 inches of water per foot of soil) and a high salinity (more than 0.8% soluble salts). The major soluble salt is Na_2SO_4 (12-140 epm) with lesser amounts of $MgSO_4$ (1-26 epm) and $CaSO_4$ (1-26 epm). Bicarbonate is 2 to 4 epm. Chlorides are absent.

The Podzolic soils of the area have a medium permeability (0.2 to 2.0 inches per hour), medium water storage (2.0 to 5.0 inches of water per foot

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[1]The measures of concentrations of chemical constituents used in this report are parts per million (ppm) and equivalent-weights per million (epm). By definition,

1 ppm = 1 milligram of solute in 1 kilogram of solution
1 epm = 1 ppm divided by the combining weight
Combining weight = atomic or molecular weight of ion divided by ionic charge.

The reciprocals of the combining weights (and hence the conversion factors from ppm to epm) of the ions referred to in this report are:

HCO_3^- (0.01639); Cl^- (0.02820); SO_4^{--} (0.02082); Ca^{++} (0.04990); Mg^{++} (0.08224); Na^+ (0.04350).

Further explanation is given by Hem (1965).

of soil) and a low salinity (less than 0.2% soluble salt). Ca, Mg, Na and SO_4 are from 0 to 2 epm, bicarbonate is 1 to 5 epm and chlorides are absent.

The permeability and water storage characteristics will, of course, be factors influencing recharge and discharge to groundwater, but other than the above data, no other quantitative information is available. It will be seen below that the salinity values influence groundwater chemistry.

BASIC DATA AND METHOD OF ANALYSIS

The basic data used in this study were obtained from the Central Data File of the Groundwater Division of Alberta Research.[2] Water level observations consisted almost exclusively of measurements reported by water well drillers. Such measurements are typically not made with accurate measuring devices and are not always taken at exactly static conditions. In reporting water level measurements, the driller usually also describes the completion of the well, so that the depth interval, to which the measurement refers, is known. This is not always the case, so that in many instances only the well depth and water level are known: 1,304 water level values were used in the study.

Chemical analyses of groundwater were primarily obtained from samples submitted by individuals to health authorities. In submitting the sample, the individual also reports the well depth. In some cases the chemical analysis can be matched to a driller's report so that completion details on the well are also known. There are two types of analyses with respect to the detail in which they are reported. In one, total dissolved solids, ignition loss, hardness, sulfates, chlorides, alkalinity, nitrates, iron and fluoride are reported. In the other, total dissolved solids, sulfates, chlorides, carbonate, bicarbonate, calcium, magnesium, sodium, potassium, nitrate, iron and fluoride are reported. Of the 1,040 chemical analyses used in the study, about 30 percent were of the latter type.

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[2]Formerly Research Council of Alberta

Both chemical and water level data are absent in the City of Edmonton so that no contouring was done within the city boundaries.

The water level and chemical data were sorted into three groups based on the depth at which the observation was made. The groups were:

(1) observations made in the drift, called the Drift Layer;
(2) observations made in the upper 75 feet of bedrock, called the Upper Layer;
(3) observations made in the bedrock from 75 to 250 feet below the bedrock surface, called the Lower Layer.

By sorting the data into groups according to depth of measurement it was possible to study the changes in chemistry and water levels in both horizontal and vertical directions. The particular depth intervals chosen segregated the drift and bedrock data and were also such as to divide the data into appproximately equal-sized groups. It is immediately apparent that the data have imposed a further restriction on the study, since it applies only to near-surface groundwaters. The density of data for each layer is shown on figures 46 to 48 for water levels and figures 10 to 12 for chemistry.

Within each layer the water level data and data for specific chemical constituents were automatically contoured. The contouring was done on the PDP-9 digital computer at Alberta Research using a program developed by Newton (1973). The main steps in the contouring program are:

(1) The randomly located observation data are read in.
(2) Using the input data, values of the parameter being contoured are interpolated to node points. The locations of the node points do not coincide with the locations of the input data but they are controlled by the density of the input data and by the specification of a radius of influence over which interpolation takes place. The actual value assigned to the node points by interpolation is determined by the input

data, the radius of influence and the specification of a further parameter which controls the degree of smoothing or averaging of the input data that takes place.

(3) The interpolated parameter values at node points are contoured.

The program has the capability to optimize the interpolation procedure in the sense that any input datum which shows large statistical difference from the other data in its vicinity has less weight assigned to it.

CHEMISTRY

The contour maps of the major chemical constituents for each of the layers are presented on figures 10 to 45. Potassium, iron and fluoride were not contoured because potassium is fairly constant in all analyses at 0 to 10 parts per million and the data on iron and fluoride are not accurate. It will be noted that for the Drift Layer the absence of data on most of Morinville Plain and Busby Plateau prevented contouring of these areas. In addition, the Depressions of the area do not show distinguishable chemical facies, probably because their area is so small that the "smoothing" process involved in contouring obliterates their small-scale effects. Also, data are usually scarce in the Depressions, particularly in the Incisions. Such data that are available are usually from the buried channels of the drift. Total dissolved solids are presented in ppm and the other constituents are presented in ppm, epm and percent of total anion or cation (epm%) with the exception of calcium and magnesium. For most of the analyses calcium and magnesium were not analyzed separately and had to be calculated from values for hardness. This can only give calcium plus magnesium in epm.

The main features of the contour maps for each of the constituents are given below.

Total Dissolved Solids (TDS) - Figures 10, 11, 12

(1) In all three layers the highest values of TDS are found on Namao Plain.

(2) In all three layers the lowest values of TDS are found on Stony Plain and Gladu Peak.

(3) In the Drift Layer low values also occur on Redwater Plain and the northeastern edge of Morinville Plain.

(4) In the Lower Layer high values also occur at the northern end of Morinville Plain and in the vicinity of the eastern end of Saskatchewan Incision.

(5) Of the Hill areas, Sherwood Peak and Busby Plateau always have higher TDS than Gladu Peak and are also always higher in TDS than Stony Plain.

(6) There is in general an increase in TDS from the Drift to Upper Layer and from the Upper to Lower Layer. The only exception to this is in the northeast part of the Namao Plain between Drift and Upper Layers.

(7) In the Upper and Lower Layers, Morinville Plain has moderately high TDS (not contoured in the Drift Layer).

Bicarbonate (HCO_3) - Figures 13 and 18

(1) In all three layers there is the same pattern of HCO_3 values: lowest in the southwest and northeast and highest in the northwest, center and southeast.

(2) There is a marked increase in HCO_3 from the Drift to Upper Layer but little change from the Upper to Lower Layer.

(3) In all three layers the areas of highest HCO_3 expressed in epm correspond to the lowest values of HCO_3 expressed in epm% and *vice versa*.

(4) The range of values in any layer is fairly narrow.

Sulphate (SO_4) - Figures 19 to 24

(1) In the southwest part of Namao Plain the epm value of SO_4 is very high in all three layers.

(2) There is, in general, a definite decrease in the epm value of SO_4 from the Drift to Upper to Lower Layer. An exception to this is the northern part of Morinville Plain which increases from Upper to Lower (not contoured in the Drift Layer).

(3) Stony Plain, Gladu Peak, Busby Plateau, Sherwood Peak and Redwater Plain have low epm values of SO_4 in all three layers.

(4) Morinville Plain has fairly high epm values in the Upper and Lower Layers (not contoured in the Drift).

(5) Epm% values of SO_4 vary directly as epm values.

Chloride (Cl) - Figures 25 to 30

(1) In almost all areas of the Drift and Upper Layers the epm value of Cl is less than 1, so in effect the only anions present in these two layers are HCO_3 and SO_4.

(2) In the Upper Layer epm values of 4 occur at the village of Riviere Qui Barre on the western edge of Morinville Plain, at Big Lake Low, and on the lower slopes of Sherwood Peak.

(3) In the Lower Layer most of the area has an epm value of 1 to 10. Gladu Peak, Stony Plain, part of Busby Plateau, southwest Namao Plain and northeast Morinville have epm values less than 1. The areas of the Upper Layer having 4 epm Cl, have over 10 epm Cl in the Lower Layer. In addition, in the Lower Layer the junction of the Sturgeon and Lily Incisions has over 10 epm Cl.

Calcium and Magnesium (Ca+Mg) - Figures 31 to 36

(1) There is a very large reduction in the epm value of Ca+Mg from the Drift to Upper Layer, but only a slight reduction from the Upper to Lower Layer. In the Drift Layer epm values range from 3 to 20 whilst in the Upper Layer the maximum value is 6, with much of the area less than 3. In the Lower Layer all of the area is less than 3 epm with about half the area less than 1 epm.

(2) In the Drift Layer the southwest and northeast corners of the area have lower epm values than the central and southeast regions. The southwest area has the highest epm% value and the northeast corner the lowest.

(3) Calcium is always present in larger amounts than magnesium in all three layers.

Sodium (Na) - Figures 34 to 39

(1) There is an increase in the epm value of Na from Drift to Upper to Lower Layers.

(2) In the Drift Layer the lowest epm values of Na are on Stony Plain and Gladu Peak; the highest values are on Namao Plain. The lowest epm% value is in the southwest corner whilst the highest value is in the northeast corner.

(3) In the Upper and Lower Layers Morinville and Namao Plains have higher epm values of Na than other areas.

(4) In the Lower Layer the epm% value is almost everywhere over 90 percent.

Sulfate-bicarbonate ratio (SO_4/HCO_3) - Figures 40, 41, 42

(1) In the Drift Layer the SO_4/HCO_3 ratio is less than one on Gladu Peak, Atim Low, Stony Plain, northeast Saskatchewan Incision, Redwater Plain and northeast Morinville Plain. It is from 1 to 4 in the rest of the area.

(2) In the Upper Layer all the area except southwest Namao Plain is less than 1. Therefore, in the area as a whole HCO_3 increases at the expense of SO_4 in going from the Drift to Upper Layer. Atim Low is an exception to this trend.

(3) In the Lower Layer all the area except southwest Namao Plain and north Morinville Plain have a ratio less than 1.

Chemical Facies Maps

Based on the foregoing maps of major chemical constituents, the chemical facies map for each layer is shown on figures 43, 44 and 45.

WATER LEVEL DISTRIBUTION

Figures 46, 47 and 48 give the water level contours for the Drift, Upper and Lower Layers, respectively. Figures 49 and 50 are contour maps of the differences between water levels in the Drift and Upper Layers and the Upper and Lower Layers, respectively.

Principles for the Interpretation of the Water Level Contour Maps

In interpreting the water level contour maps it should be borne in mind that there is intrinsically greater error in reading a water level contour map than a surface contour map, in that the latter contours are accurately located and the former are not. This means that with a water level contour map not only is it necessary to interpolate between contours but the contours are only approximately located.

To determine the resultant direction of flow from the contour maps, and hence define recharge and discharge areas, it is necessary to consider Darcy's Equation, in the form applicable to anisotropic media, the geometry of the layers relative to the water table and the definition of the terms recharge and discharge area.

Darcy's Law for anisotropic media can be written in tensor form as:

$$\begin{bmatrix} q_x \\ q_y \\ q_z \end{bmatrix} = - \begin{bmatrix} k_{xx} & k_{xy} & k_{xz} \\ k_{yx} & k_{yy} & k_{yz} \\ k_{zx} & k_{zy} & k_{zz} \end{bmatrix} \cdot \begin{bmatrix} \frac{\partial h}{\partial x} \\ \frac{\partial h}{\partial y} \\ \frac{\partial h}{\partial z} \end{bmatrix}$$

where, q_x, q_y, q_z, = components in the x-, y-, z-directions of the flow vector

k_{xx}, k_{xy}, etc = components of the permeability tensor

$\frac{\partial h}{\partial x}, \frac{\partial h}{\partial y}, \frac{\partial h}{\partial z}$ = components in the x-, y-, z-directions of the gradient of head vector.

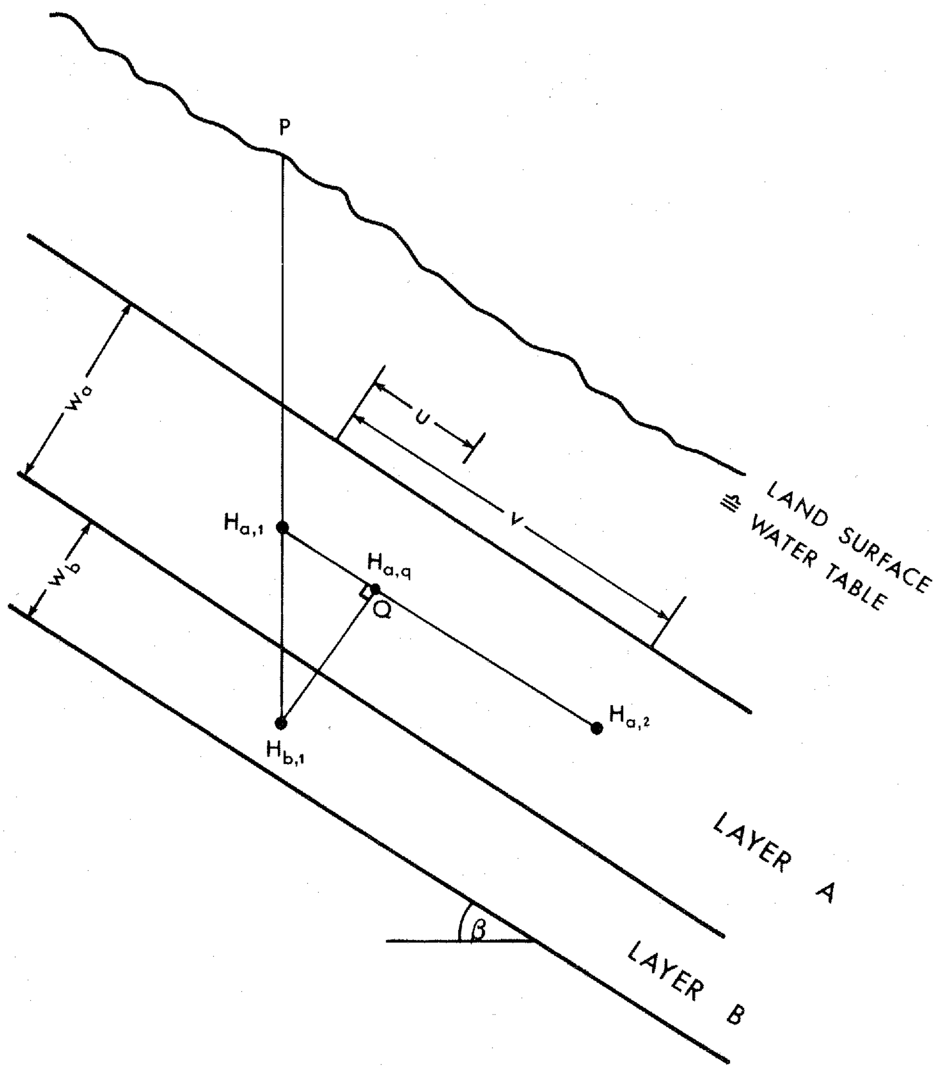
and the resultant flow vector is,

$$\underline{Q} = q_x \underline{i} + q_y \underline{j} + q_z \underline{k}$$

It will be noted from this equation that the direction of the resultant flow vector is not, in general, coincident with the direction of the resultant gradient of head vector.

If a coordinate system were to be established at some point in a horizontal layer such that the x-, y-directions were parallel to the layer and the z-direction was perpendicular, then the analysis of water level contours in the layer and between the layers would give the components the gradient of head vector $\frac{\partial h}{\partial x}, \frac{\partial h}{\partial y}, \frac{\partial h}{\partial z}$. If the values of the components of the permeability tensor are known, then the components of the flow vector, and hence the resultant magnitude and direction of flow, can be calculated by Darcy's Law. Since the permeability tensor is unknown such calculations cannot be made. However, the resultant direction of flow relative to the horizontal layer can be qualitatively determined and this is all that is necessary for the purposes of this study. Assuming the axes are orientated such that the components of the gradient of head vector are negative, then, because the off-diagonal components of the permeability tensor are greater than or equal to zero and the diagonal components are strictly positive, it follows that the components of the flow vector will be positive. Thus, the resultant flow vector will have an upward direction relative to the layer if there is a decrease in head in that direction, and a downward component if the head decreases downwards.

Considering the geometry of the layers, the Drift Layer has as its upper boundary the land surface and the Upper and Lower Layers are parallel to the bedrock surface, which is in most places approximately parallel to the land surface. In addition, the water table is approximately coincident with the land surface. This can be represented on the accompanying diagram. Here, two layers are considered, layer A having a thickness w_a and layer B having a thickness w_b. Both slope at an angle β to the horizontal and are approximately parallel to the land surface and water table. The layers have isotropic permeability.



Vertically beneath a point P, on the land surface, the water level in layer A is $H_{a,1}$ and in layer B is $H_{b,1}$. The component of water level gradient in layer A is given by

$$G_a = \frac{H_{a,1} - H_{a,2}}{v}$$

where $H_{a,2}$ is the water level in layer A at a distance v from $H_{a,1}$.

The component of water level gradient in the vertical direction between layers A and B is:

$$G_{ab} = \frac{H_{a,1} - H_{b,1}}{(w_a + w_b)/2} \cdot \cos\beta$$

At the point Q, the water level is:

$$H_{a,q} = H_{a,1} - (H_{a,1} - H_{a,2})\frac{u}{v} = H_{a,1} - G_a u$$

Now, $\tan\beta = \dfrac{u}{(w_a + w_b)/2}$

Therefore, $H_{a,q} = H_{a,1} - G_a \cdot \dfrac{w_a + w_b}{2} \cdot \tan\beta$ (1)

The resultant direction of flow in layer B at the point vertically beneath P will satisfy one of the following:

if $H_{a,q} < H_{b,1}$, the resultant flow direction is upward relative to the layer
if $H_{a,q} = H_{b,1}$, the resultant flow direction is lateral relative to the layer
if $H_{a,q} > H_{b,1}$, the resultant flow direction is downward relative to the layer.

Applying these three conditions to equation (1), gives:

$G_{ab} < G_a \sin\beta$ for upward flow
$G_{ab} = G_a \sin\beta$ for lateral flow
$G_{ab} > G_a \sin\beta$ for downward flow. (2)

The steepest land surface slopes in the area are, with the exceptions of the sides of the Incisions, on Gladu Peak, where there is a drop of about 300 feet in 4 miles. The sine of the angle of this slope is approximately 0.015, so that, for the purposes of determining resultant flow directions, the Drift, Upper and Lower Layers can be considered more or less horizontal. For the horizontal case equation (2) becomes:

$G_{ab} < 0$ for upward flow
$G_{ab} = 0$ for lateral flow
$G_{ab} > 0$ for downward flow.

This derivation was for an isotropic situation. However, the same result has already been shown to be valid for horizontal layers in the anisotropic case.

It can be concluded, therefore, on the regional scale under consideration, that the resultant flow direction relative to a layer will be in the direction of the component of decreasing head between layers. The steep slopes along the edges of the Incisions would be an exception to this. These areas are, however, very small and, as has already been pointed out, the contour maps do not accurately represent the flow conditions in the immediate vicinity of the Incisions.

With regard to the definition of recharge and discharge areas, Tóth (1963), in analyzing the groundwater flow system, defined a recharge area to be one in which flow was downward relative to the water table and a discharge area to be one in which flow was upward relative to the water table.

Combining the foregoing, the following argument is generally valid: if the contours of water level differences between layers indicate an upward component of gradient of head relative to the layer, then the resultant direction of flow is likewise upward relative to the layer, is therefore upward relative to the water table and consequently is in a discharge area. A similar argument holds for defining recharge areas.

It should be noted that by Tóth's definition (Tóth, 1966) a resultant flow direction can be downward relative to the horizontal plane in a discharge area. Also, water levels can increase or decrease with depth in a discharge area.

In analyzing the water level contour maps to define recharge and discharge areas, it should always be remembered that small-scale features controlled by local topography and geology will not be apparent. Such features are to be expected, particularly near the land surface.

Directions of Flow Components Within the Layers

In the Drift Layer the entire area cannot be contoured because data are only available for areas of fairly high permeability. In general, wells are not completed in areas of low permeability or thin surficial materials.

The outstanding feature of the water level contours in all three layers is that they show a very marked correlation with surface topography. On Gladu Peak only the lower slopes are contoured and they indicate that the component of groundwater movement within the layer is from the Peak towards Sturgeon and Atim Lows. On Stony Plain the contours show that the component of flow is in the direction of Atim Low. Sherwood Peak has contours indicating that the component of flow is from the high point of the Peak towards Saskatchewan Incision. The contours on Busby Plateau indicate that the component of flow is in the direction of Qui Barre Low.

On Morinville Plain there is very little data and contouring was not possible for much of the area. The contours indicate that components of flow within the layer leave the Plain to Legal Low, Lily Incision, Sturgeon Incision, Sturgeon Low and Qui Barre Low. On Namao Plain there is very little data. The contours show a maximum value, coincident with the high point of the Plain, from which flow components within the layer radiate in all directions, making Big Lake Low a closed water level depression.

Within the layer, flow components approaching Sturgeon Low and Atim Low are perpendicular to the thalweg, but on entering the Lows turn to become parallel to the thalwegs.

The flow pattern in the immediate vicinity of the Incisions is not clearly defined by the contouring. Along Sturgeon and Saskatchewan Incisions water levels are known to be at river level and along Lily Incision the bedrock outcrops so that there is no continuity in the Drift Layer across the Incision.

In the Upper and Lower Layers the same flow pattern is found but the more uniform data distribution gives better contours, particularly on Morinville Plain. Here, the flow components are shown entering the Plain from Busby Plateau, whilst on the Plain itself water level gradients within the layer are very low (about 5 feet a mile).

Direction of Flow Components Between the Layers

For the Drift and Upper Layers, differences between water level contours show that over most of the area the Drift Layer water levels are higher than the Upper Layer water levels. This indicates that the flow component is downward relative to the layer so that recharge is occurring. Areas of greatest difference between water levels are on Stony Plain, the lower slopes of the northeast side of Gladu Peak, Busby Plateau, the eastern side of Morinville Plain, Redwater Plain, southwest Namao Plain and Sherwood Peak. An upward component of flow relative to the layers is indicated on the southeast slope of Gladu Peak, in Atim Low and along Saskatchewan Incision. These are, therefore, discharge areas. The area along the southeast slope of Gladu Peak and in Atim Low corresponds to the only regionally significant area of flowing wells (Fig. 51) in the entire study area. Other small areas are indicated as having an upward component of flow, but of much smaller magnitude than those just described.

Between the Upper and Lower Layers differences in water level contours show a downward component of flow relative to the layers in essentially the entire area. In general, the topographically high areas show greater differences than the low areas. There are again small areas indicated as having upward components of small magnitude.

INTERPRETATION

Over most of the area and at all depths considered the water level distribution has two main characteristics. It closely resembles surface topography and it indicates that flow has a downward component. The former characteristic is typical of the Plains area of Alberta and the latter characteristic is to be expected for the following reasons.

(1) Only a small proportion of the total surface area has the Depression type of topography.

(2) Some of the Depression areas are deeply incised.

(3) All but one of the Depression areas coincide with a buried channel containing high permeability materials and, except for Atim Low, these high permeability materials are in hydraulic contact with rivers. It is significant that Atim Low is the only area of flowing wells in the study area, and most of these wells are completed in buried channel sand and gravel. These deposits act as high conductivity line-sinks causing distortions in the water level distribution that have the effect of increasing the area of downward flow at the expense of the area of upward flow. This is corroborated by the absence of surface discharge features on the slopes of the Depressions.

All these factors combine to restrict the zones of upward flow to narrow bands along Depressions, which, unfortunately, the data available to the study are unable to define.

The chemistry of the groundwater shows a definite relationship to lithology, soils and flow direction. The lithology and soils appear to have the dominant control, to the extent that in places the influence of the flow direction is masked. For instance, the distributions of TDS, SO_4, HCO_3, Ca+Mg, Na and the SO_4/HCO_3 ratio are markedly correlated with lithology and soils in the Drift Layer and, apart from the exchange of Ca and Mg for Na, retain the same pattern in the Upper and Lower Layers. In particular, the Hills and Plains which have a covering of sand and pitted delta, such as Gladu Peak, Stony Plain, Redwater Plain and east Morinville Plain, have lower TDS, SO_4, HCO_3, Ca+Mg and Na than the same topographic features, such as Sherwood Peak, Busby Plateau, Morinville Plain and Namao Plain which are covered by till, clay and silt. In fact, Namao Plain, which from topographic and potentiometric evidence is a recharge area, has the highest total dissolved solids of the entire study area in all layers. The main ions constituting this high value are Na, Ca and SO_4. The soils map shows that the Plain is mostly covered by Solonetzic soils which have high concentrations of soluble Na_2SO_4 and $CaSO_4$ and, in addition, that about half of the Plain has the Wetaskiwin class of Solonetzic soil which is abnormally high in soluble amounts of these salts.

The effect of flow direction on water chemistry is shown on Stony Plain, Gladu Peak and Busby Plateau, where TDS increases in the direction of flow. However, Morinville Plain and Namao Plain show a decrease in TDS with flow direction. Morinville and Namao Plains are both areas of high TDS associated with lithology and flat topography and show decreases in TDS at the edges of the Plains as flow exits to adjacent Depressions. It is thought that the cause for this is that more active, local flow systems are generated in the vicinity of the Plain-Depression boundary in contrast to the sluggish flow systems associated with the flat topography of the central areas of the Plains. These active, local systems bring water of low TDS into the layer.

A further effect of flow direction on water chemistry is the general increase in TDS and Cl with depth associated with the downward component of flow in most of the area.

Stony Plain and Gladu Peak appear to be the areas in which infiltration to groundwater is most important. Gladu Peak, with its high relief, sand and deltaic surficial materials and eluviated Podzolic soils, has an ideal combination of circumstances for significant infiltration. The low TDS and high epm% values of Ca+Mg and HCO_3 confirm this. Stony Plain has only intermediate relief and less permeable Chernozemic soils but is also covered by sand and pitted delta, and its similar water chemistry to Gladu Peak indicates that infiltration is pronounced.

Two major chemical processes are active in the area. Very definitely Ca and Mg are exchanged for Na as groundwater moves from the Drift to Upper Layer. The exchange would appear to be quite rapid since there is little change in epm% Na from the Upper and Lower Layer.

Sulfate reduction is also believed to be occurring as water moves from the Drift to the Upper Layer, but not in such a marked way as ion exchange. The organic material essential for sulfate reduction to occur is abundant in the bedrock materials. Values of SO_4 show, in all parts of the area, a decrease from the Drift to Upper Layer with a commensurate increase in HCO_3. This indicates that a form of the reaction:

$$SO_4^{--} + CH_4 \xrightarrow[\text{bacteria}]{} HS^- + H_2O + HCO_3^-$$

is taking place on a limited scale.

SUMMARY

The main feature of the regional chemistry and water level distribution of the area can be summarized as:

(1) The water level distribution closely resembles surface topography.

(2) Over most of the area flow has a downward component relative to the water table.

(3) Buried channel sands and gravels act as high permeability line-sinks and are a major influence on water level distribution.

(4) The major influences on groundwater chemistry are the lithology and soils of the Drift Layer. Flow direction is a minor influence.

(5) Stony Plain and Gladu Peak are major areas of infiltration to groundwater.

(6) Ion exchange occurs from Drift to Upper Layers quickly and completely.

(7) Some sulfate reduction takes place from drift to bedrock.

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FIGURES 1-51

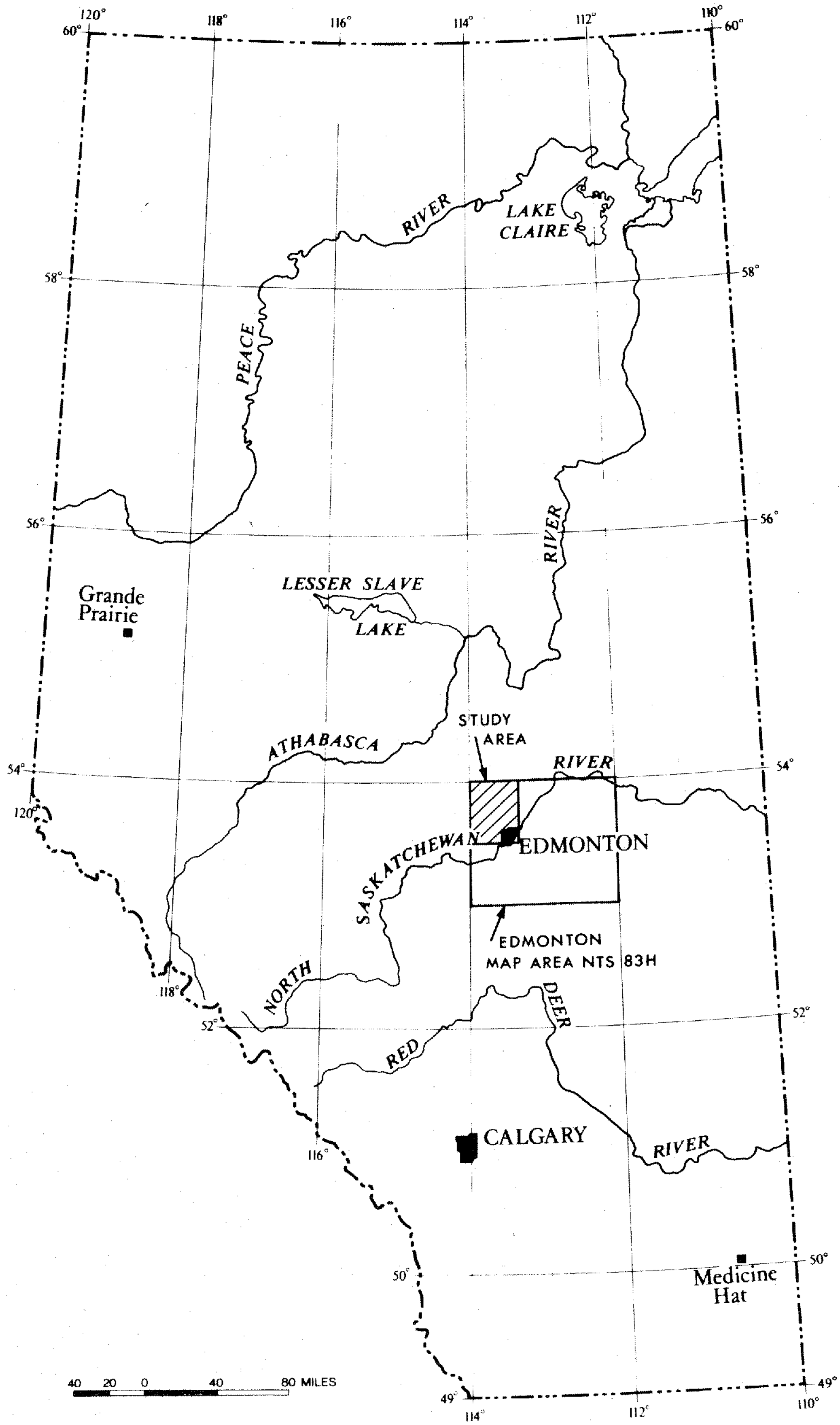


FIGURE 1. Location of study area.

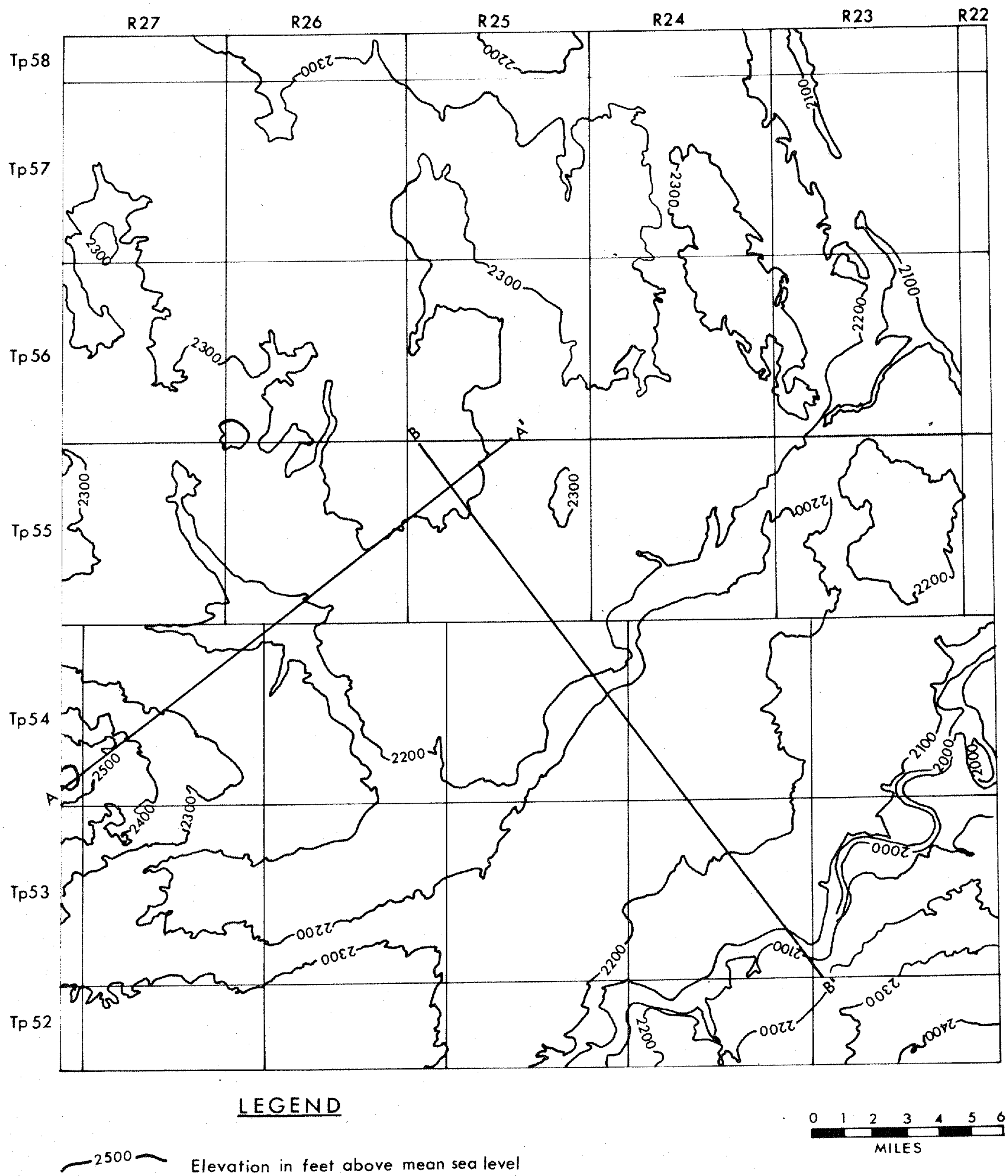


FIGURE 2. Surface topography.

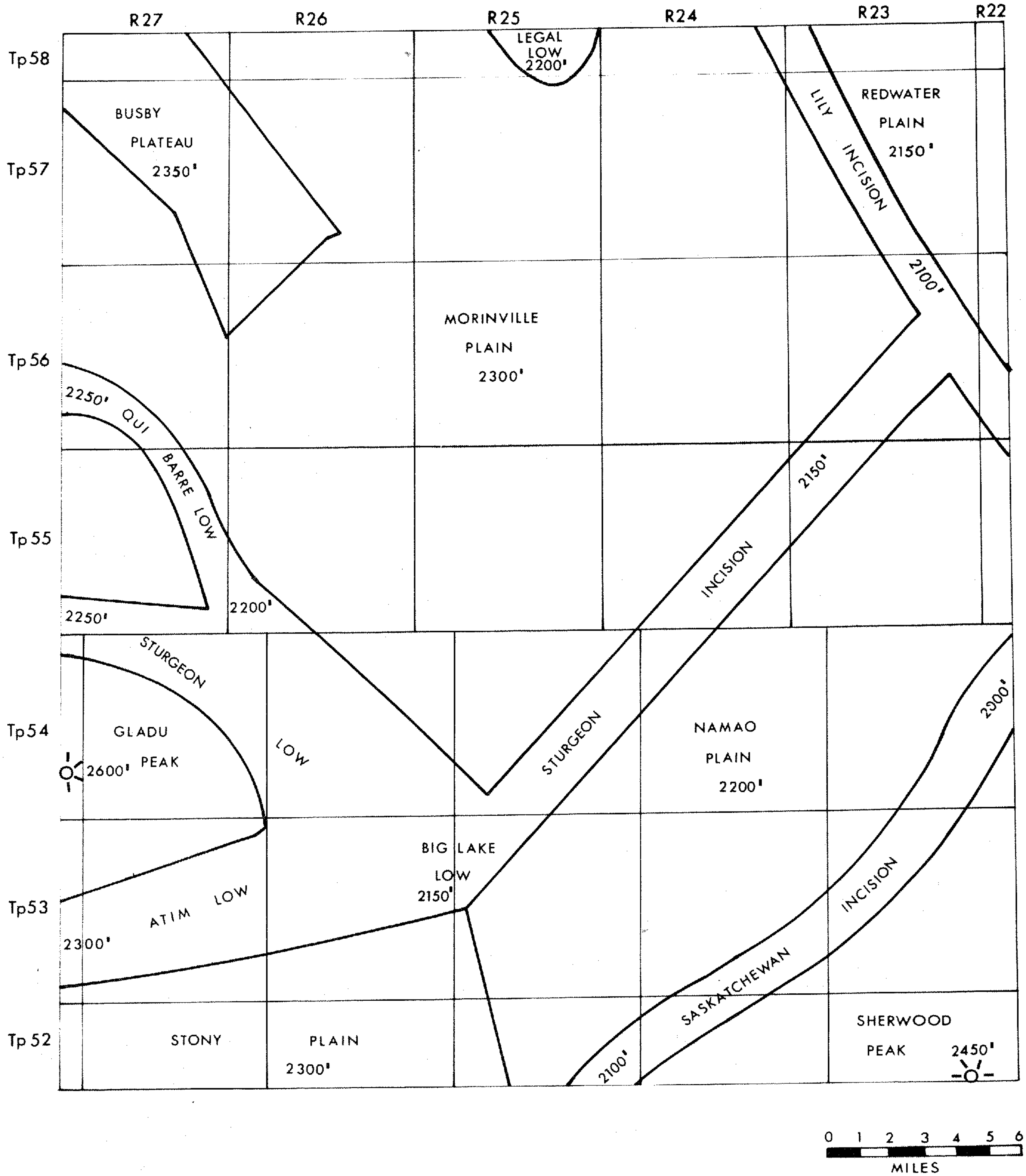


FIGURE 3. Generalized topography.

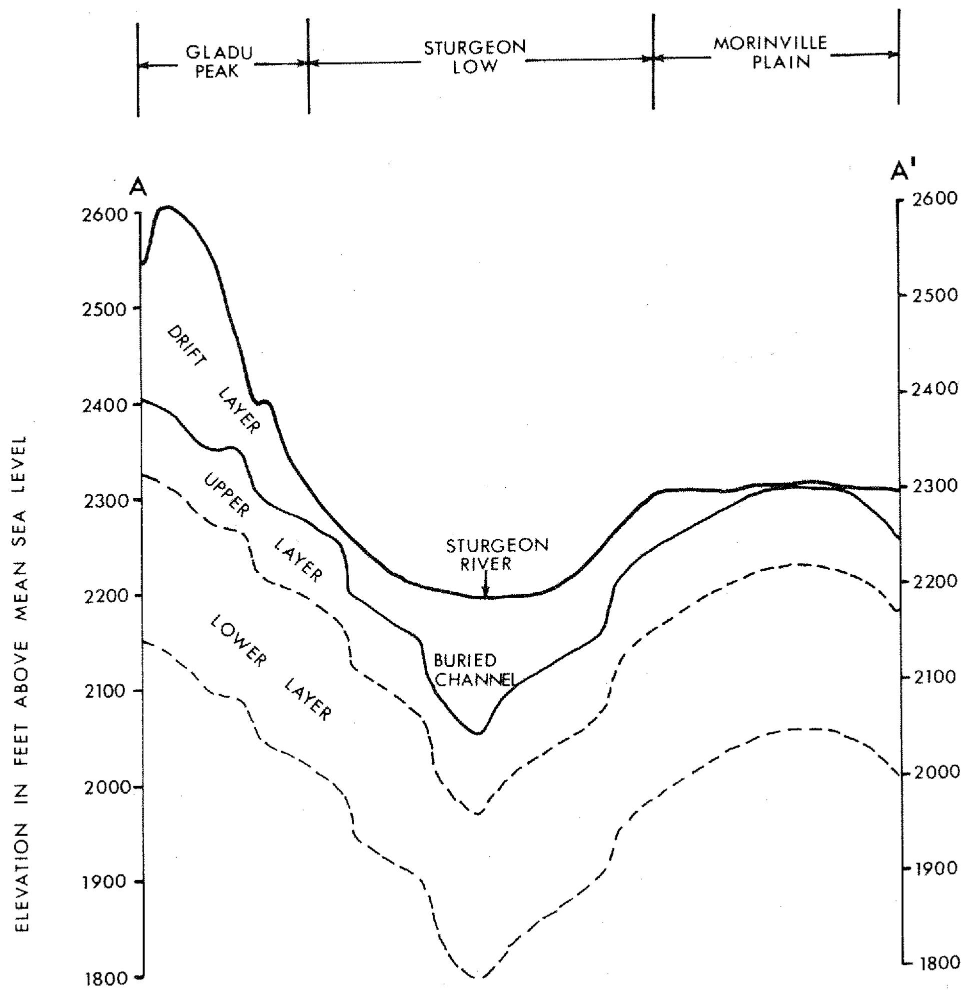


FIGURE 4. Cross section AA'.

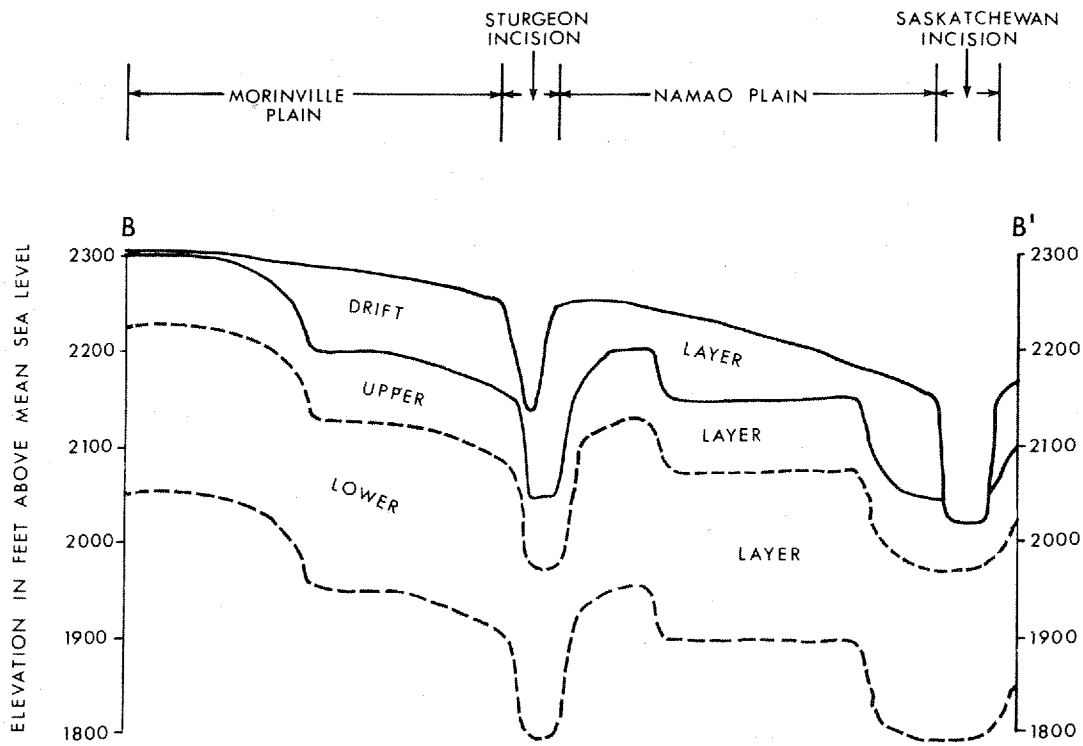


FIGURE 5. Cross section BB'.

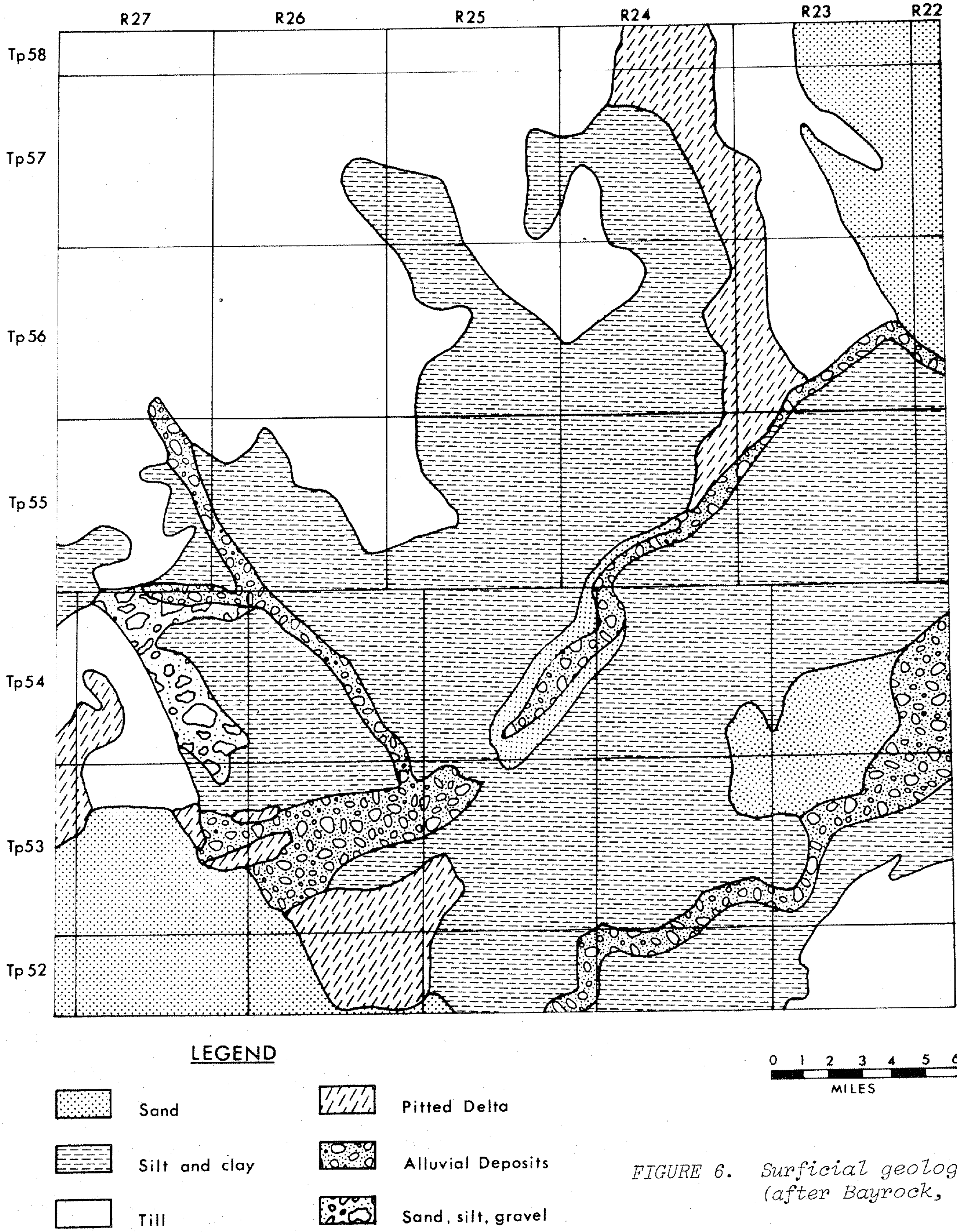


FIGURE 6. Surficial geology (after Bayrock, 1972).

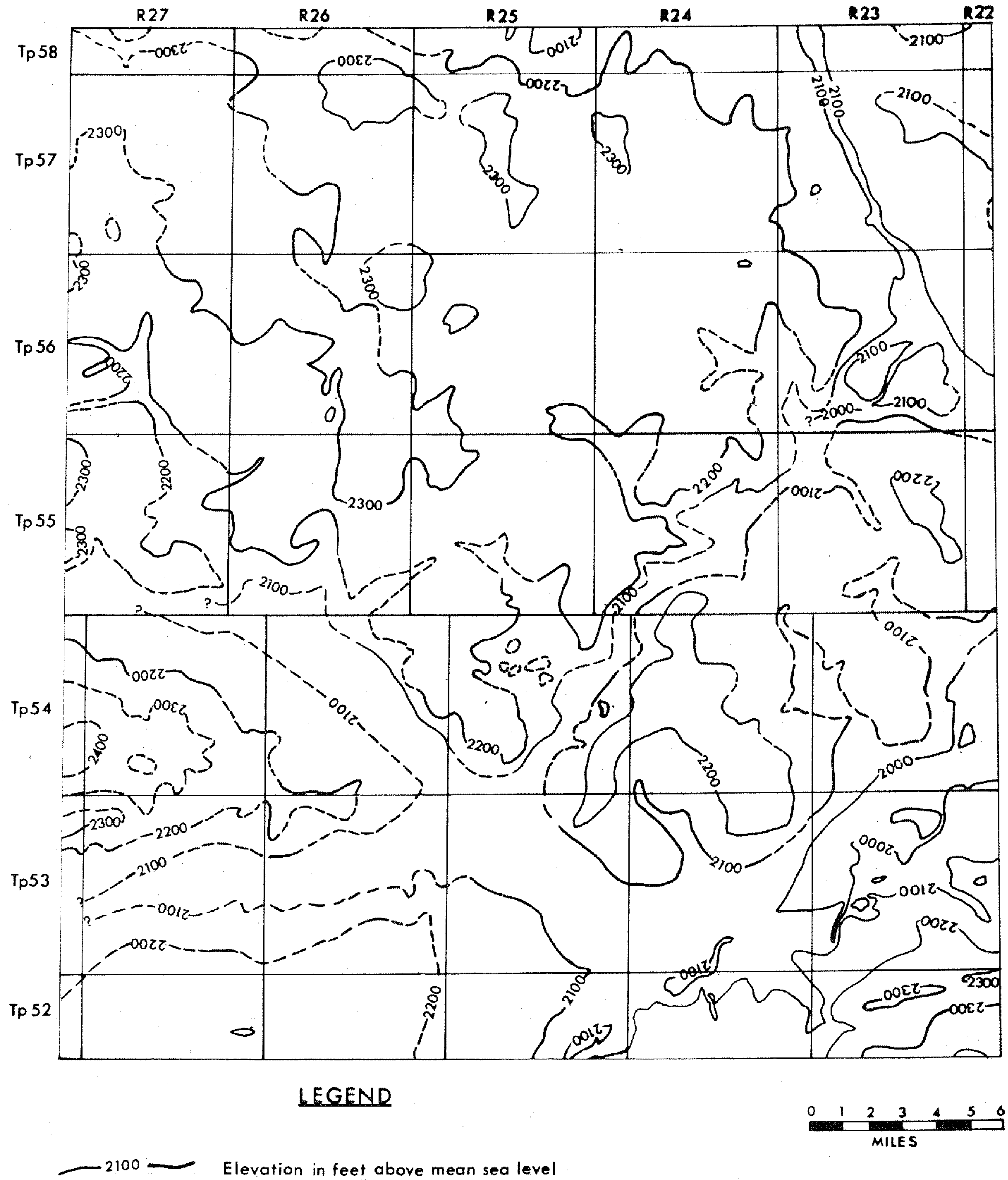


FIGURE 7. Bedrock topography (after Bibby, in preparation)

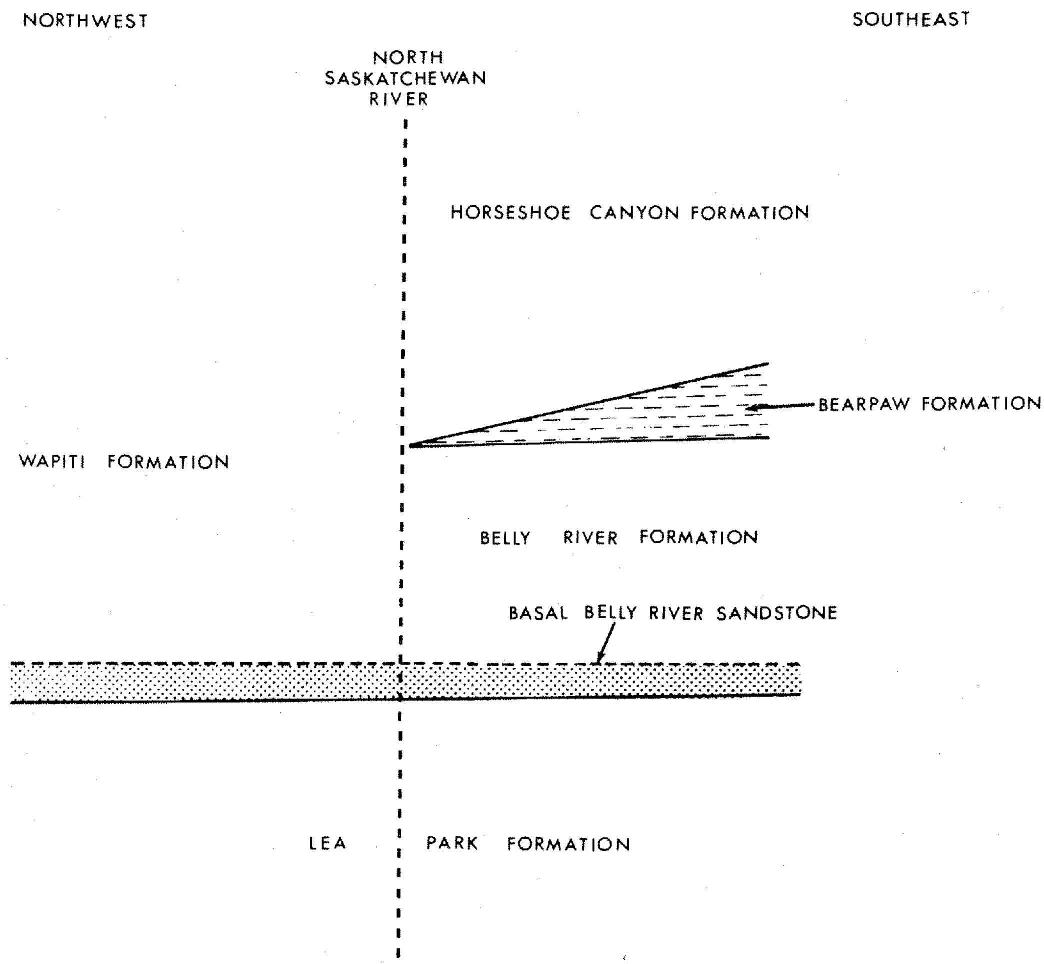


FIGURE 8. Idealized vertical section of bedrock geology.

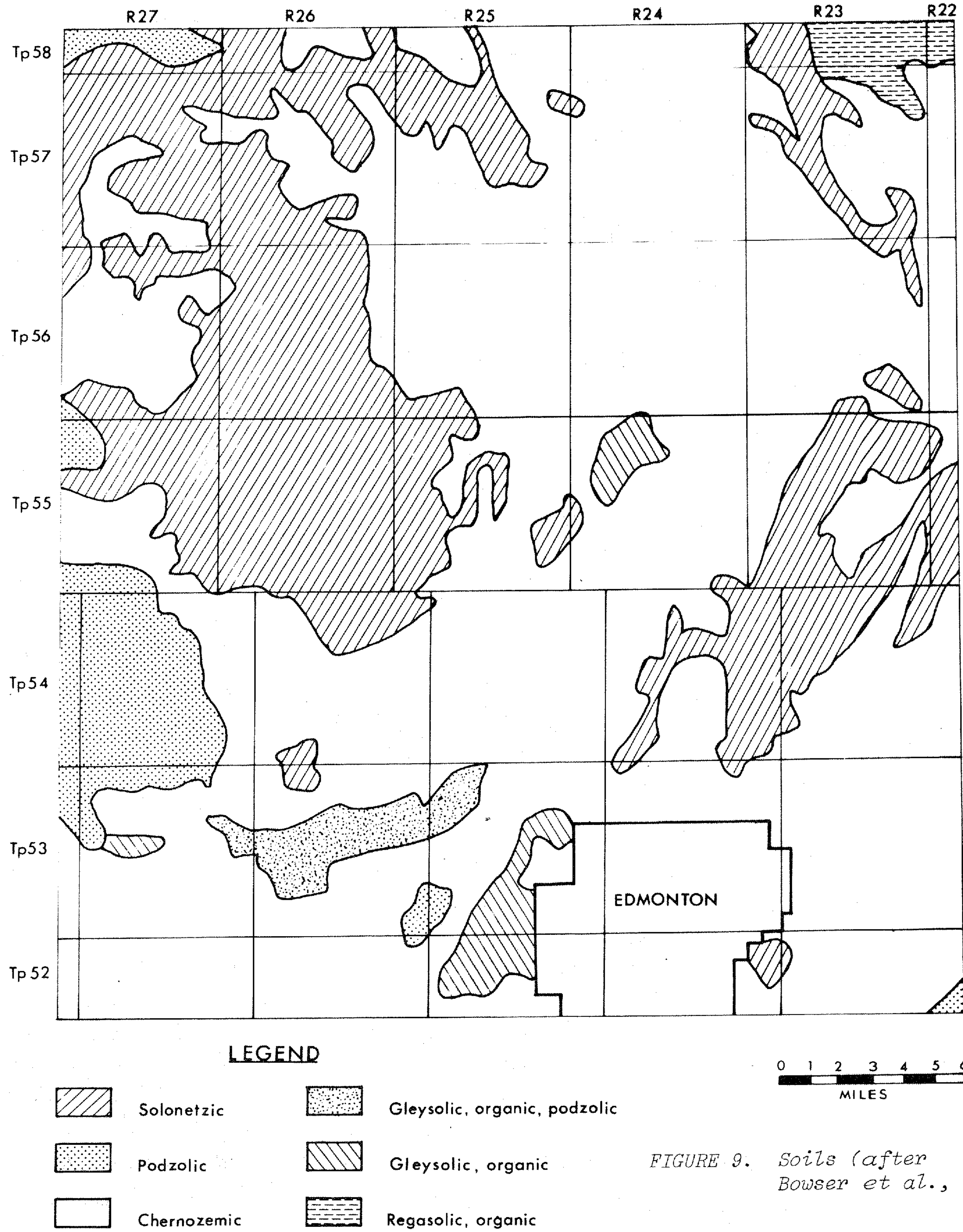
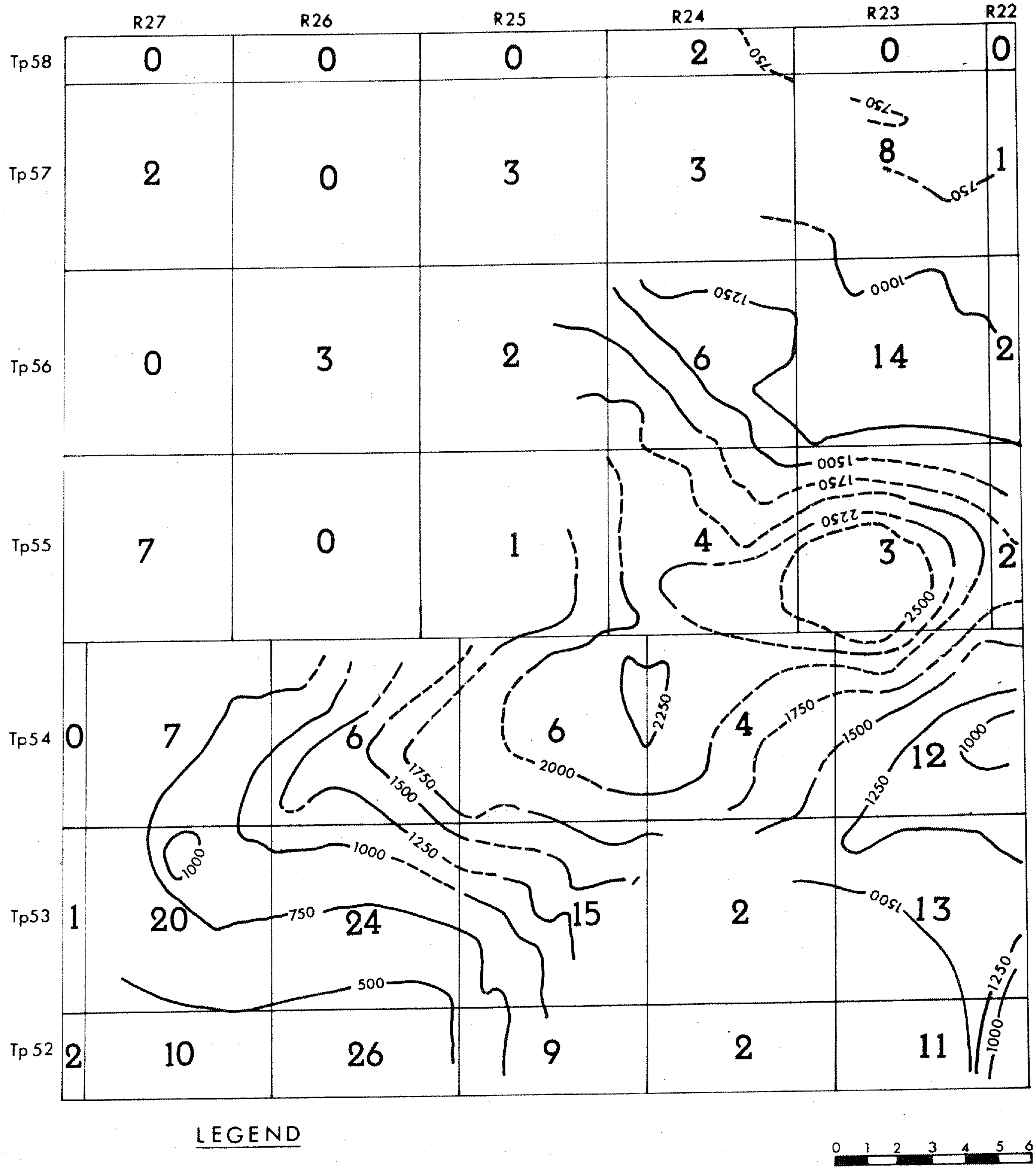


FIGURE 9. Soils (after Bowser et al., 1962)



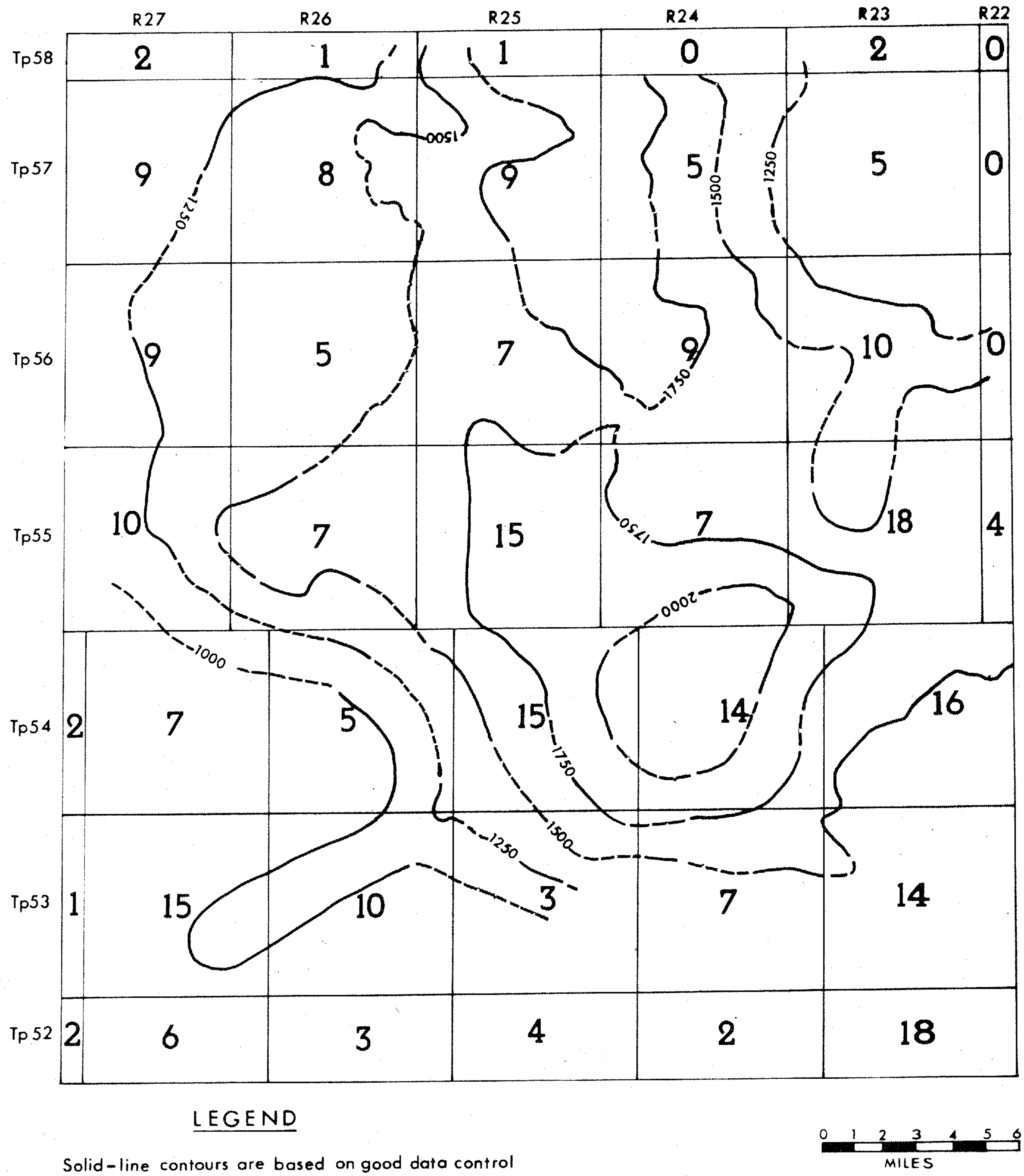
LEGEND

Solid-line contours are based on good data control

Dashed-line contours are based on poor data control

6 Number of data points in each township from which contours of all chemistry maps of Drift Layer were drawn.

FIGURE 10. TDS (ppm) and density of chemistry data of Drift Layer.



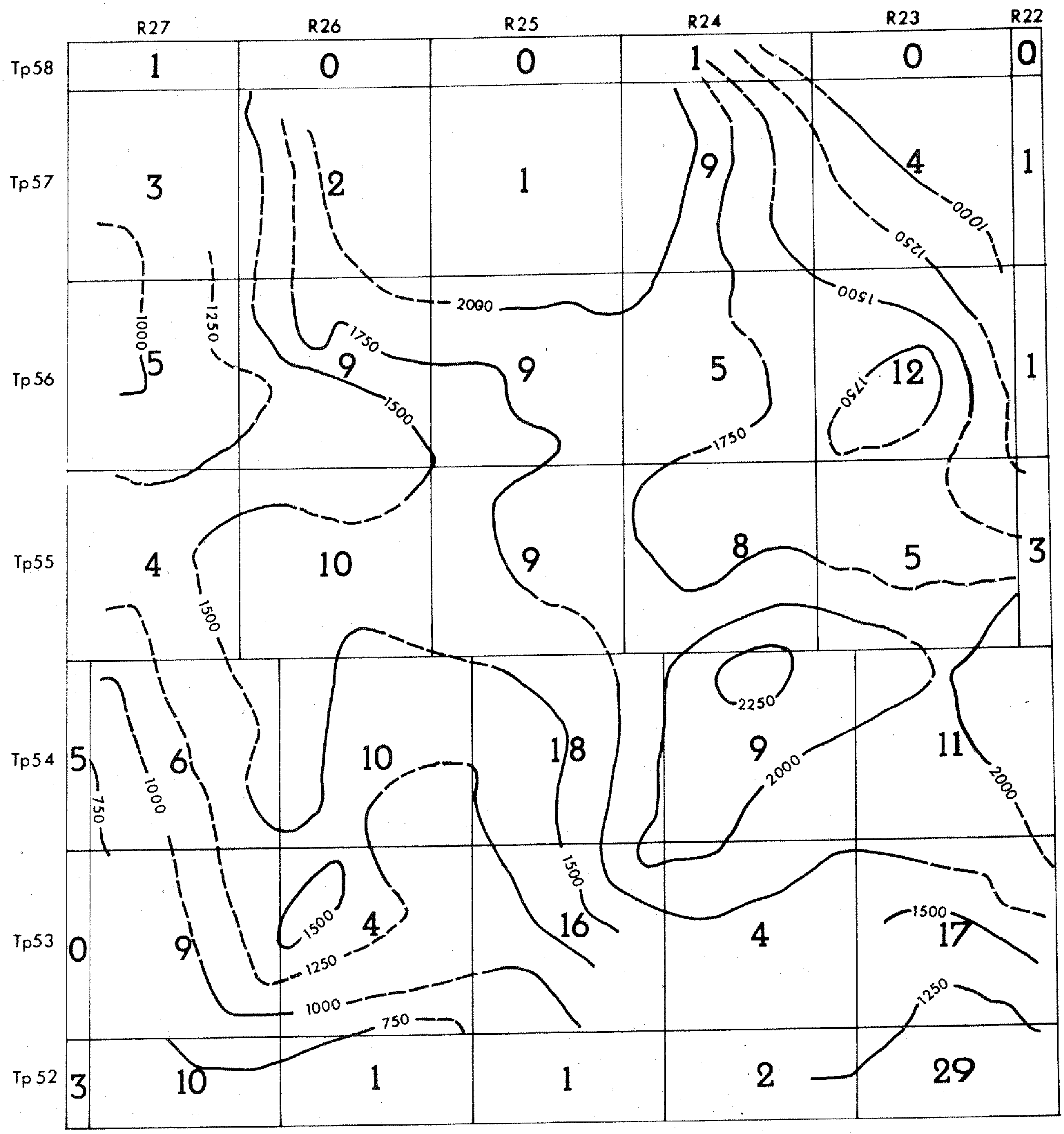
LEGEND

Solid-line contours are based on good data control

Dashed-line contours are based on poor data control

8 Number of data points in each township from which contours of all chemistry maps of Upper Layer were drawn.

FIGURE 11. TDS (ppm) and density of chemistry data of Upper Layer.



LEGEND

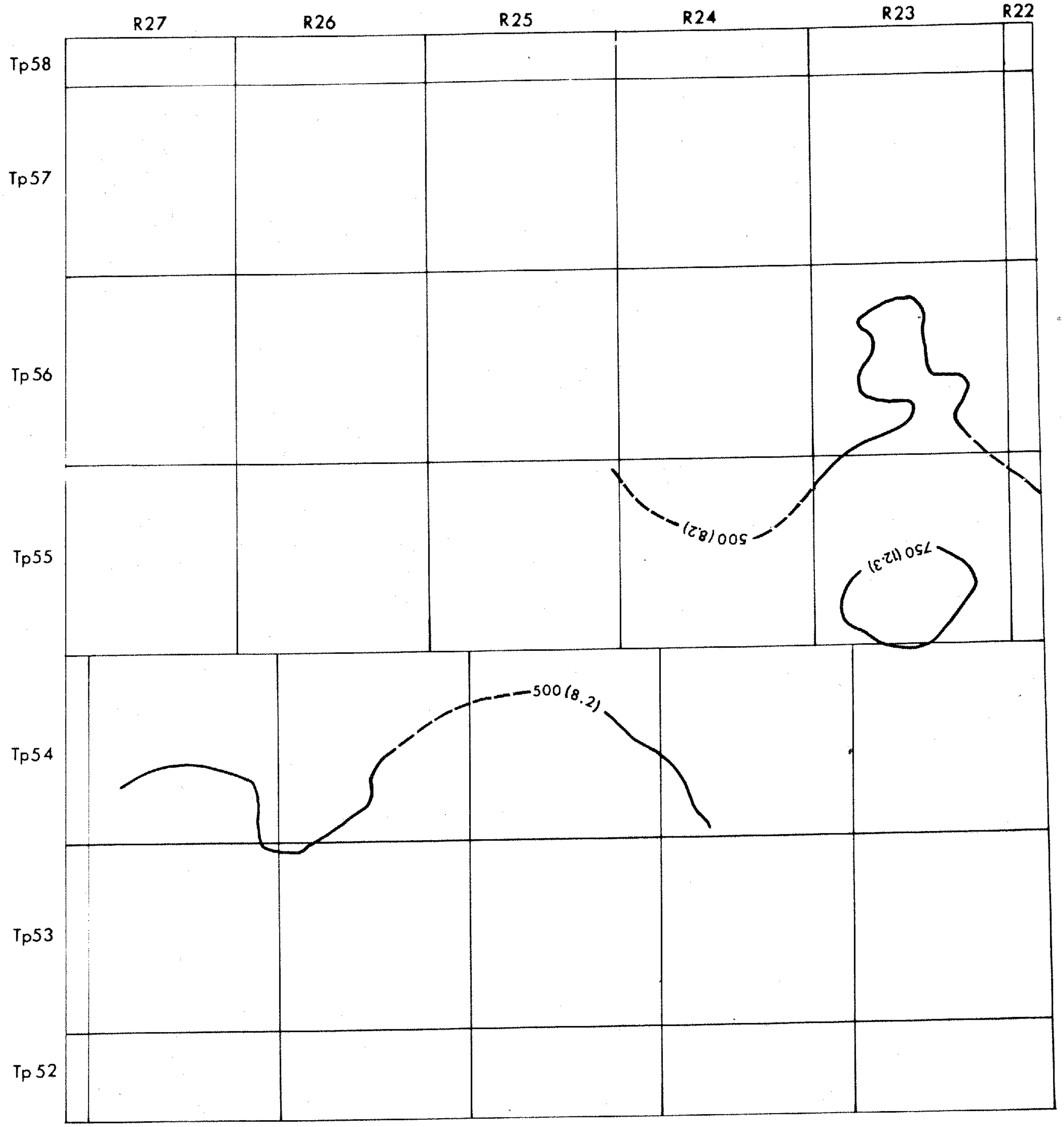
Solid-line contours are based on good data control

Dashed-line contours are based on poor data control

5 Number of data points in each township from which contours of all chemistry maps of Lower Layer were drawn.

0 1 2 3 4 5 6
MILES

FIGURE 12. TDS (ppm) and density of chemistry data of Lower Layer



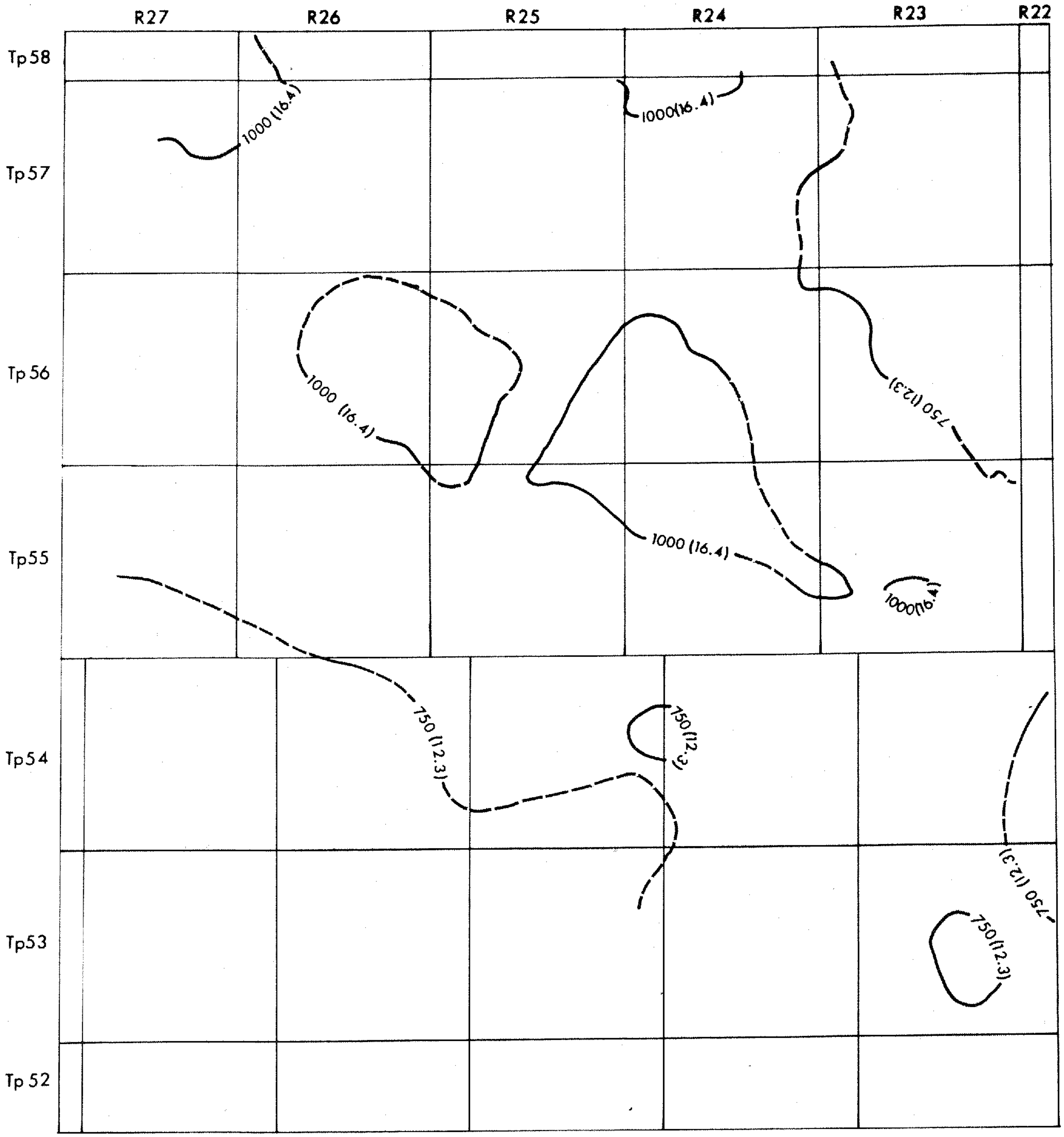
LEGEND

Solid-line contours are based on good data control

Dashed-line contours are based on poor data control

—500 (8.2)— ppm value with epm value in parentheses

FIGURE 13. HCO_3 (ppm and epm) of Drift Layer.



LEGEND

Solid-line contours are based on good data control

Dashed-line contours are based on poor data control

750 (12.3) ppm value with epm value in parentheses

0 1 2 3 4 5 6
MILES

FIGURE 14. HCO_3 (ppm and epm) of Upper Layer.

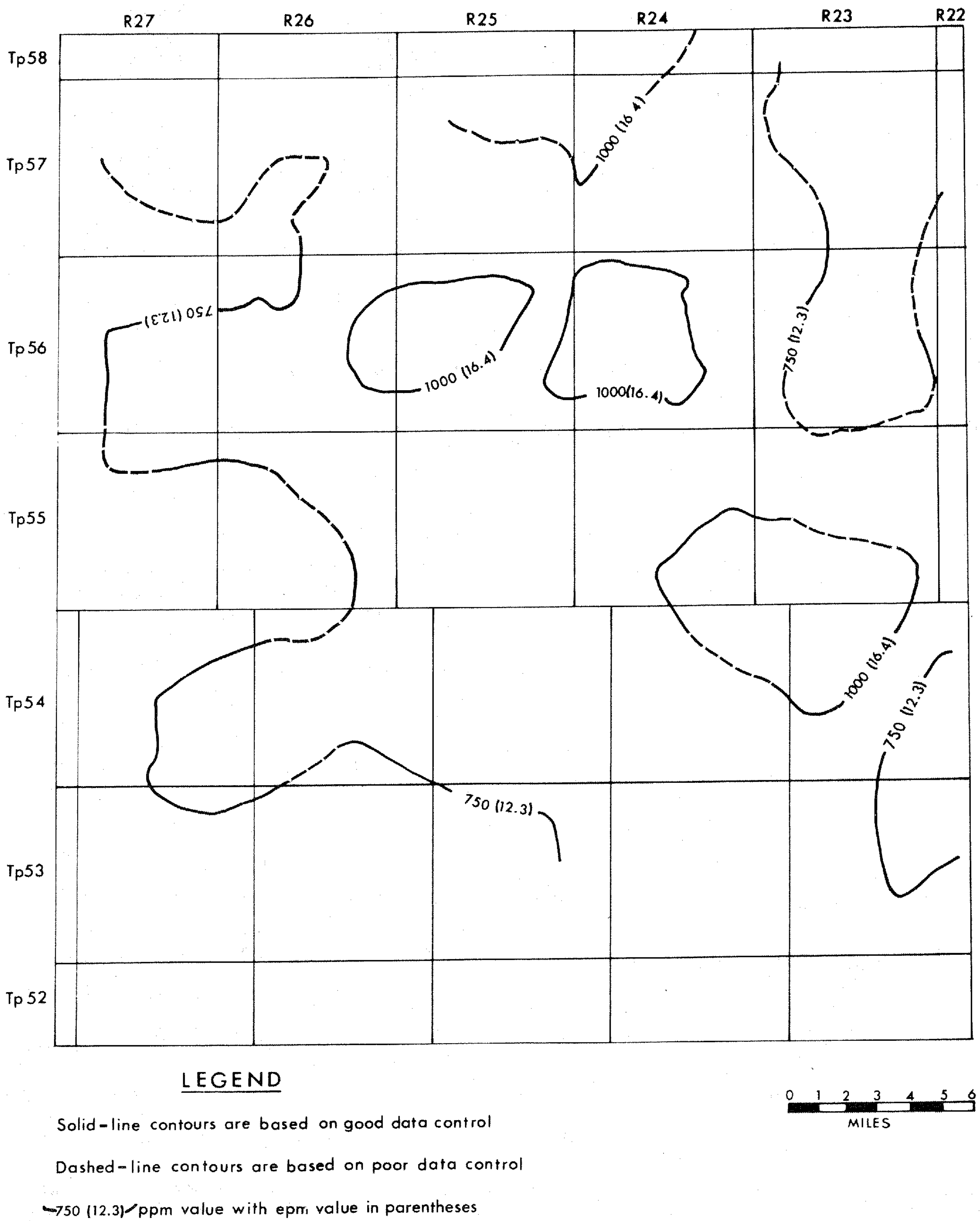
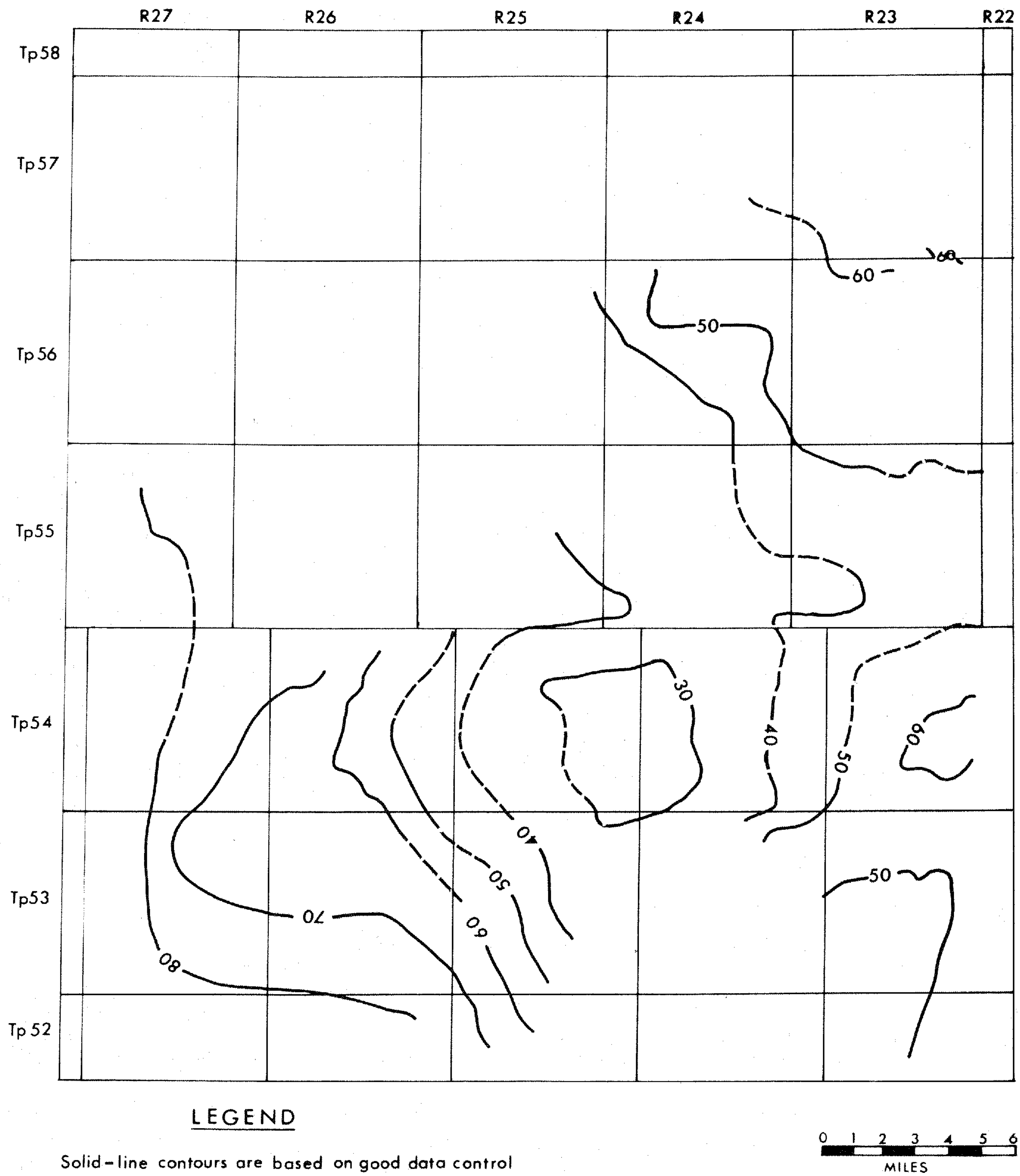


FIGURE 15. HCO_3 (ppm and epm) of Lower Layer.

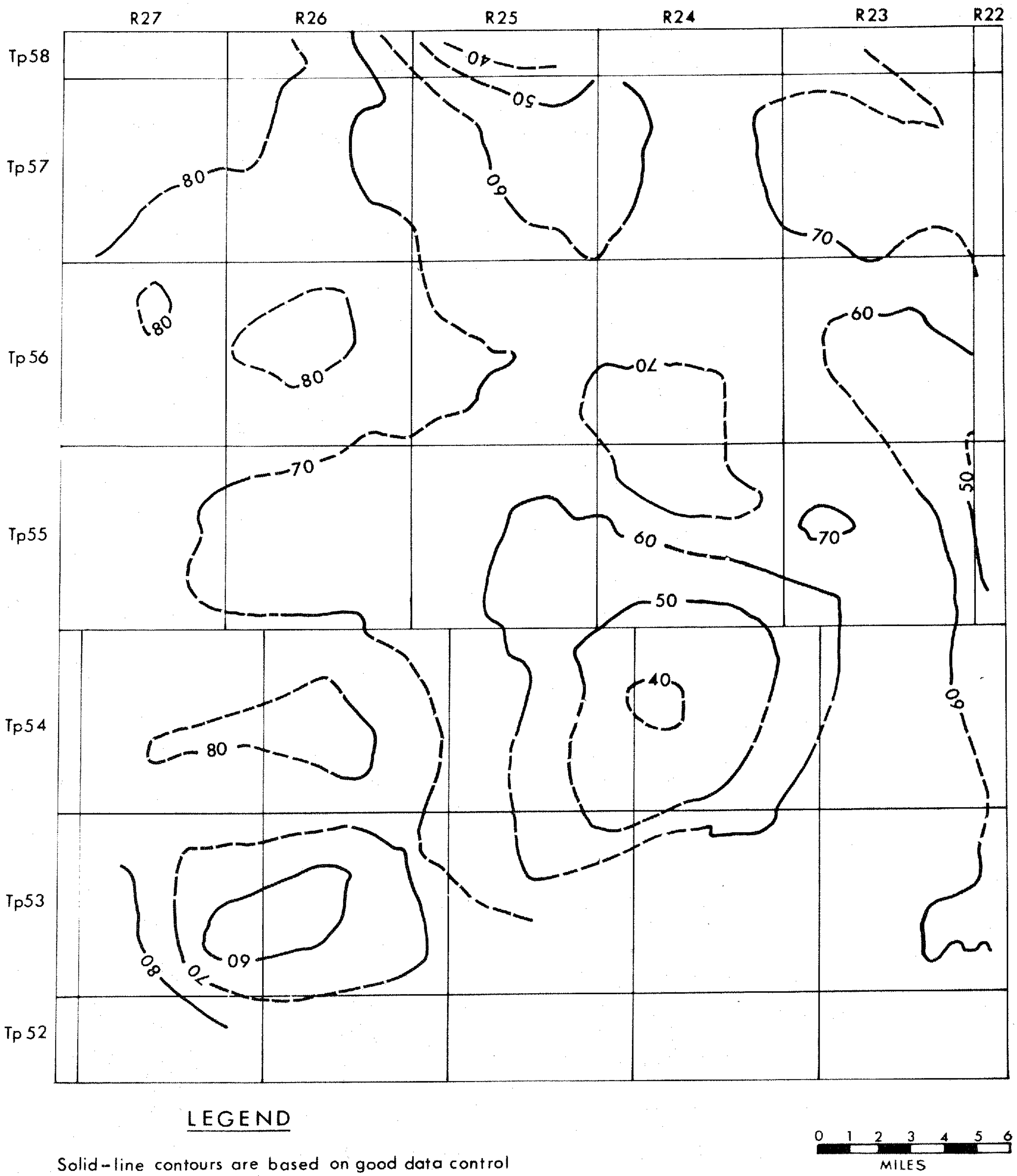


LEGEND

Solid-line contours are based on good data control

Dashed-line contours are based on poor data control

FIGURE 16. HCO_3 (epm%) of Drift Layer.



LEGEND

Solid-line contours are based on good data control

Dashed-line contours are based on poor data control

FIGURE 17. HCO_3 (epm%) of Upper Layer.

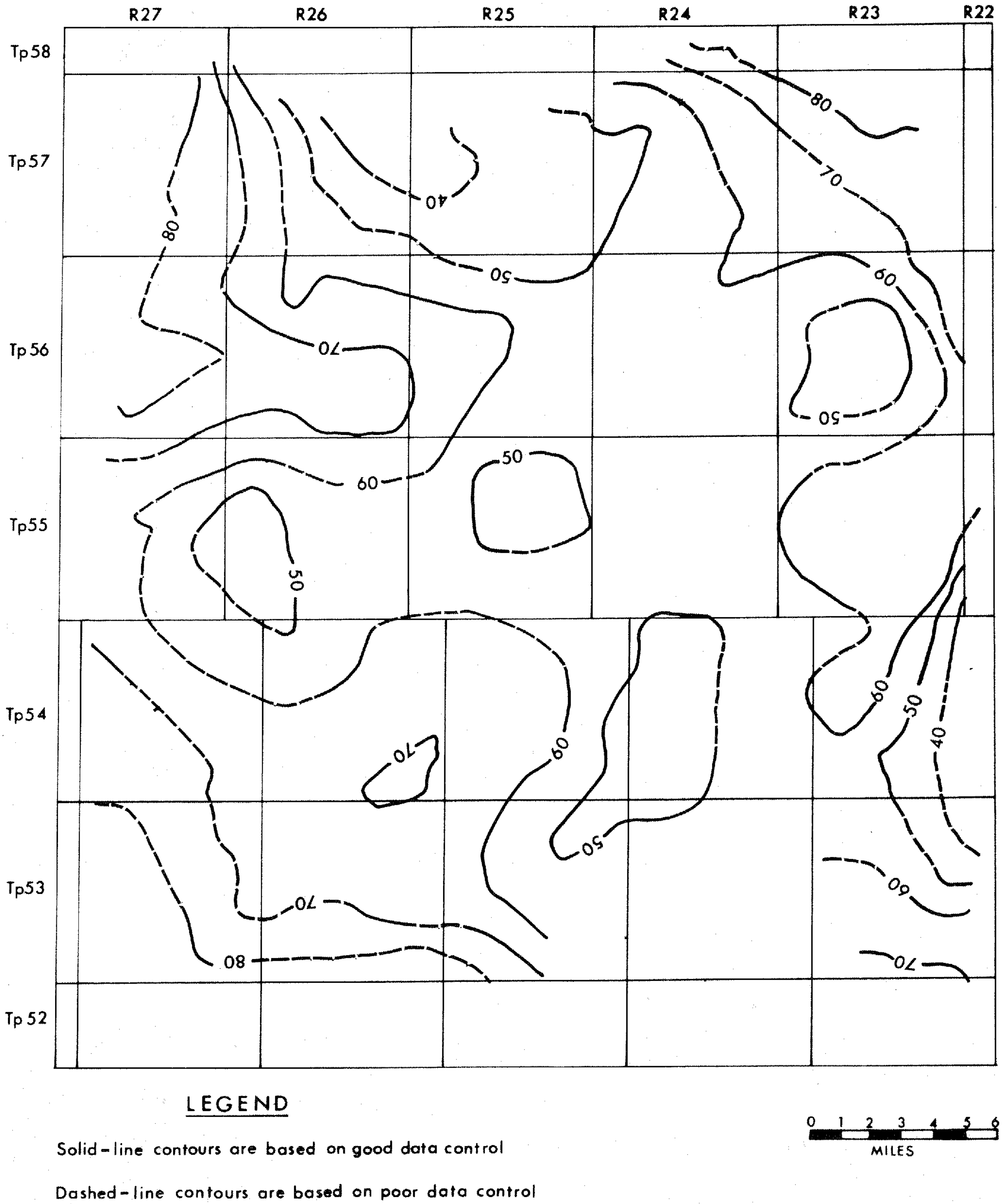


FIGURE 18. HCO_3 (epm%) of Lower Layer.

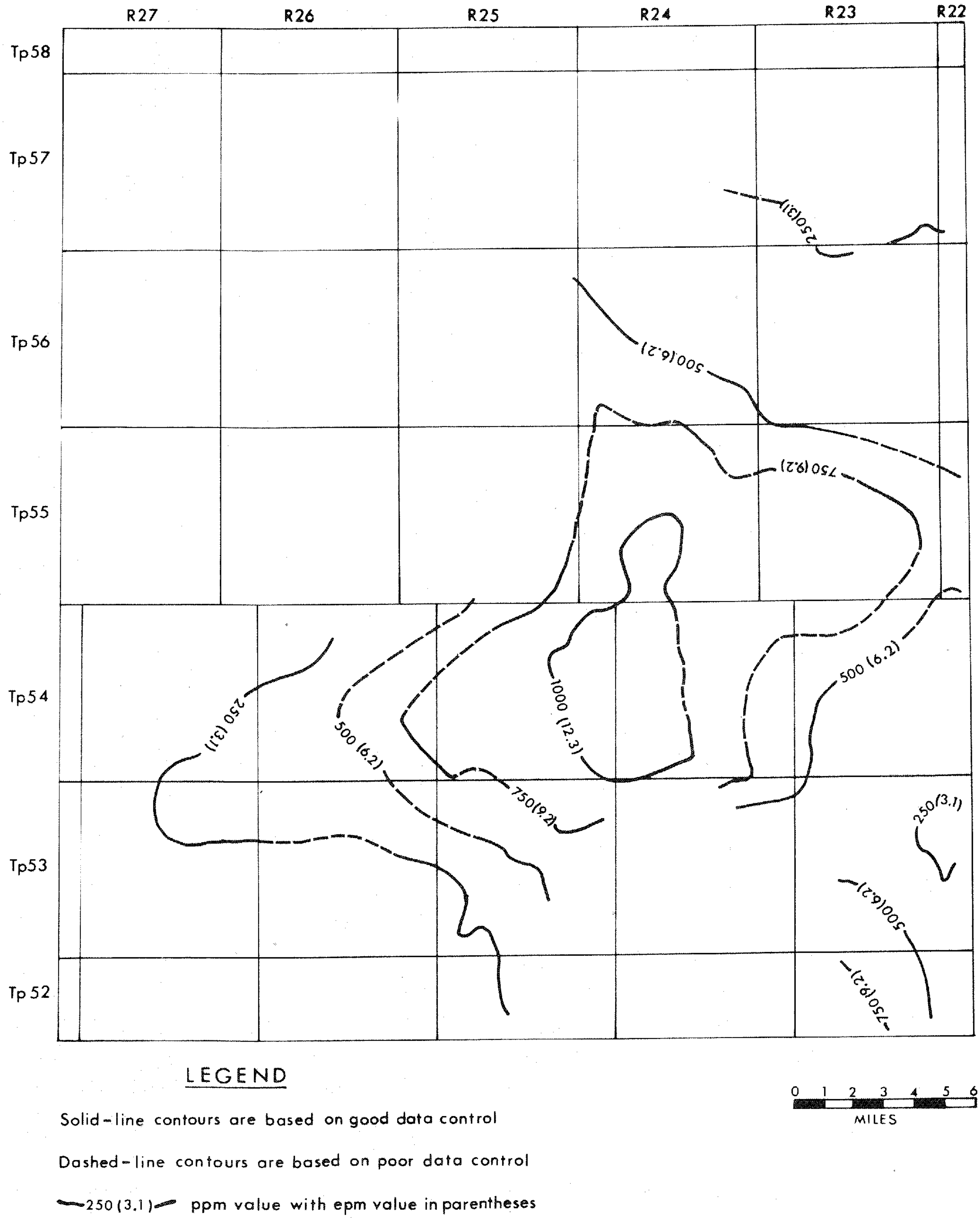
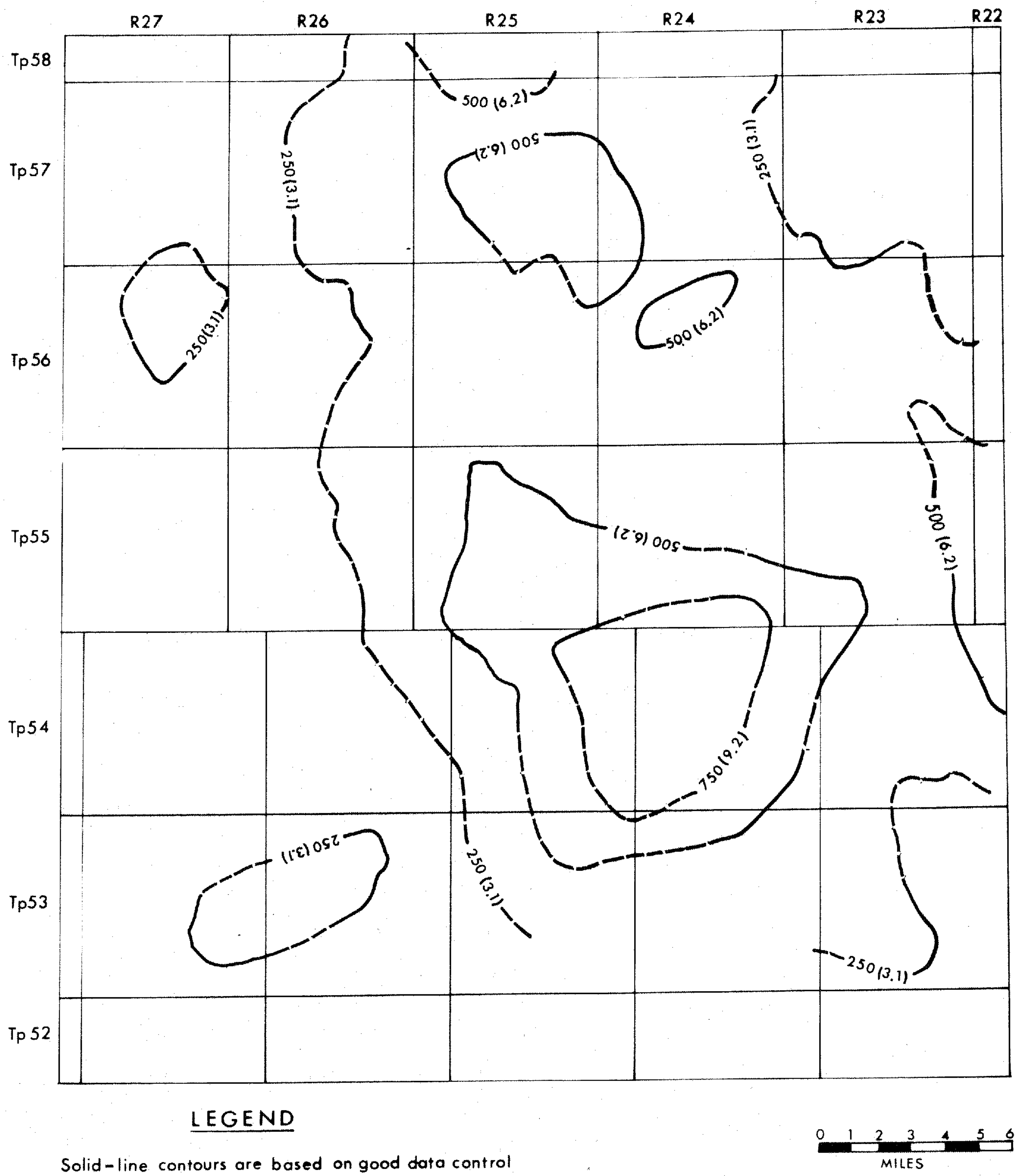


FIGURE 19. SO_4 (ppm and epm) of Drift Layer.



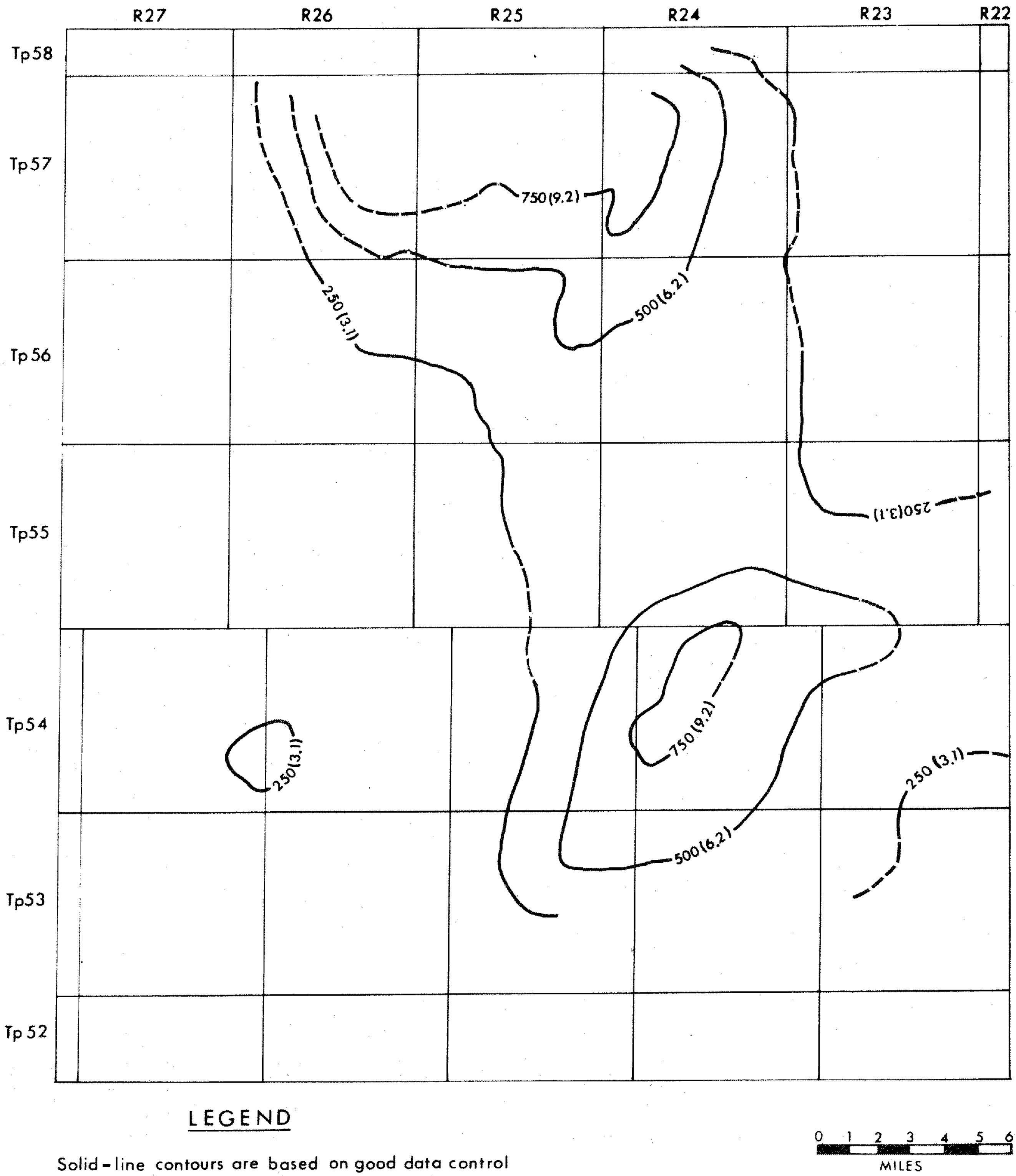
LEGEND

Solid-line contours are based on good data control

Dashed-line contours are based on poor data control

—500 (6.2)— ppm value with epm value in parentheses

FIGURE 20. SO_4 *(ppm and epm) of Upper Layer.*



LEGEND

Solid-line contours are based on good data control

Dashed-line contours are based on poor data control

—250 (3.1)— ppm value with epm value in parentheses

FIGURE 21. SO_4 (ppm and epm) of Lower Layer.

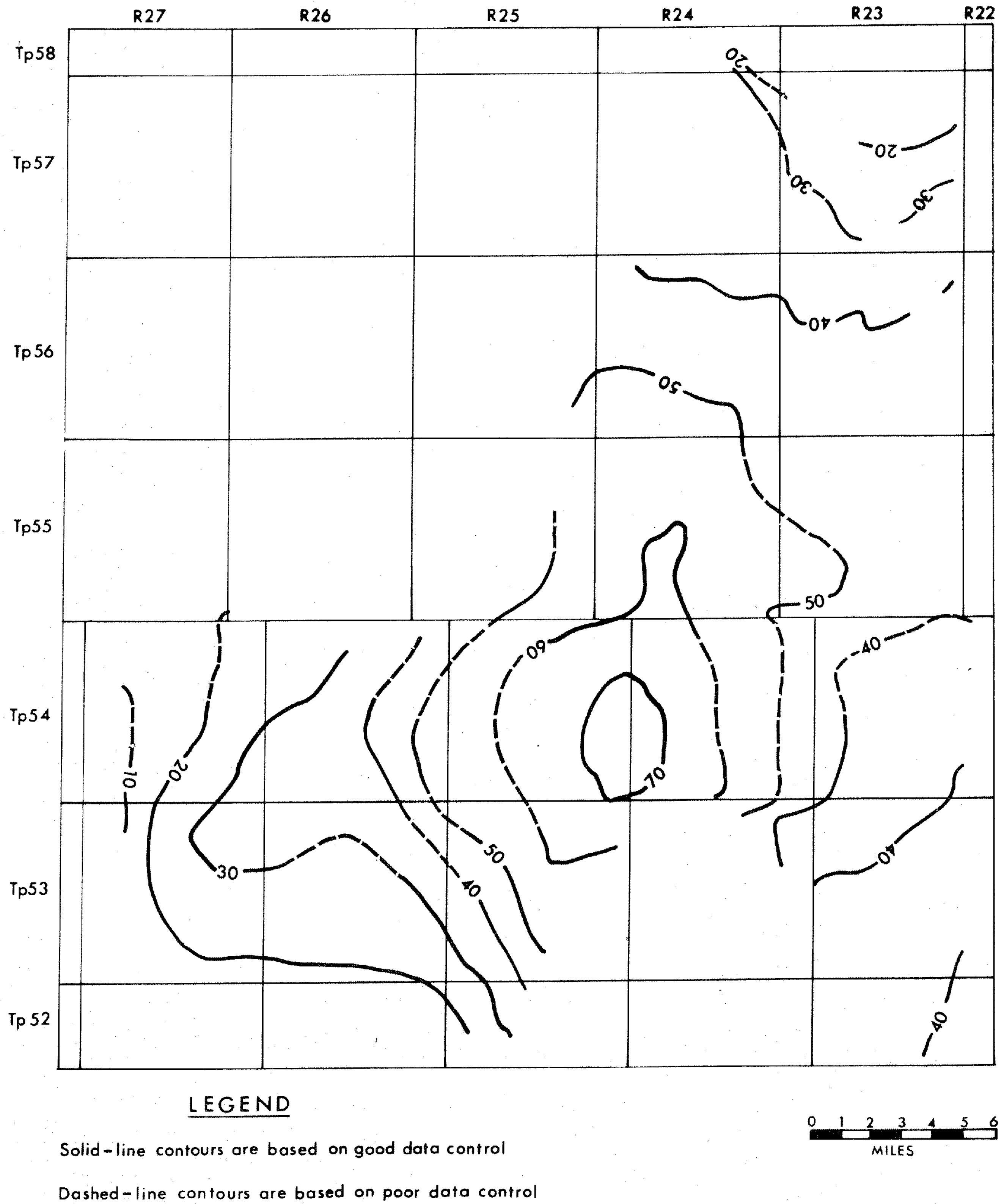
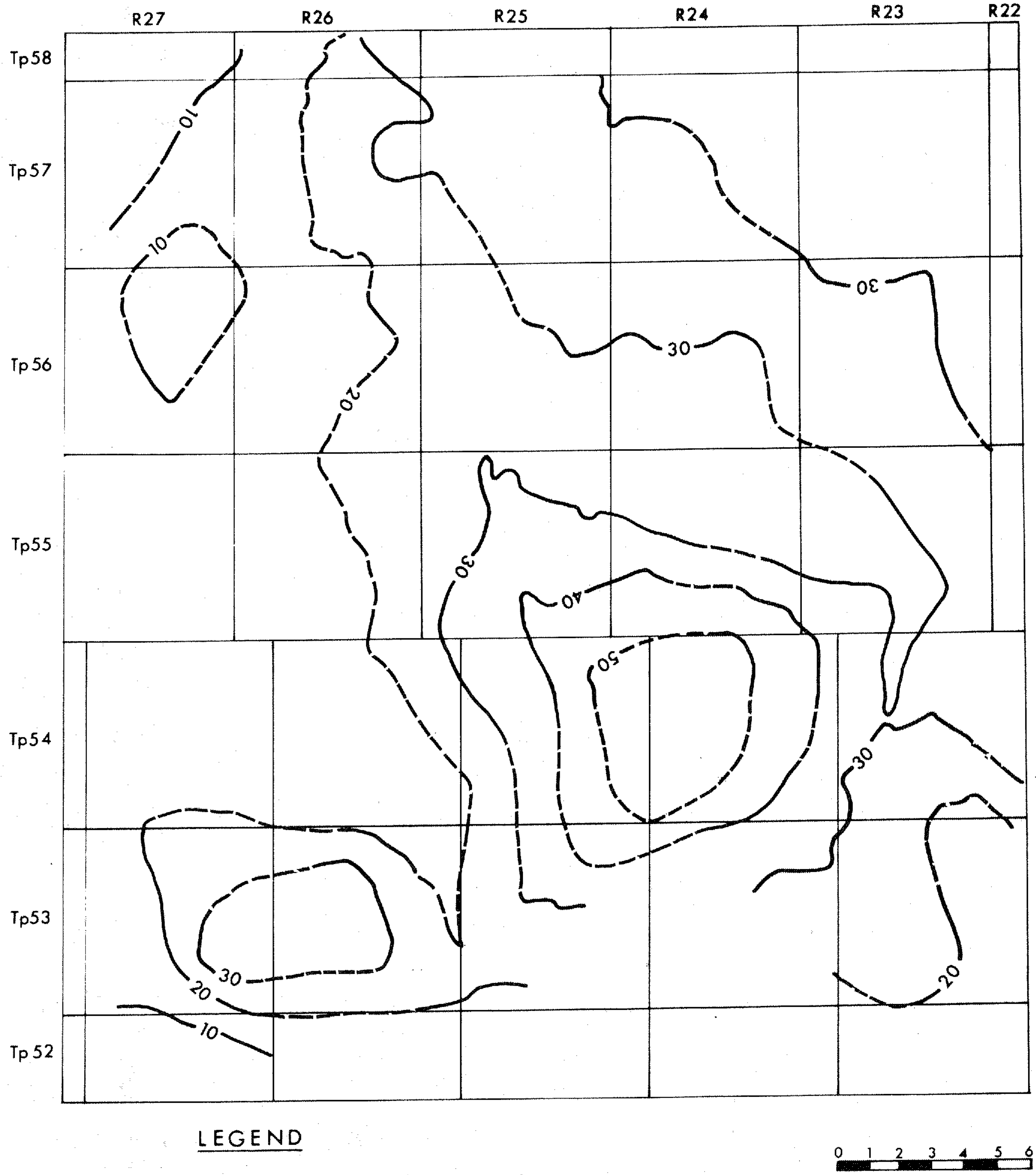


FIGURE 22. SO_4 (epm%) of Drift Layer.

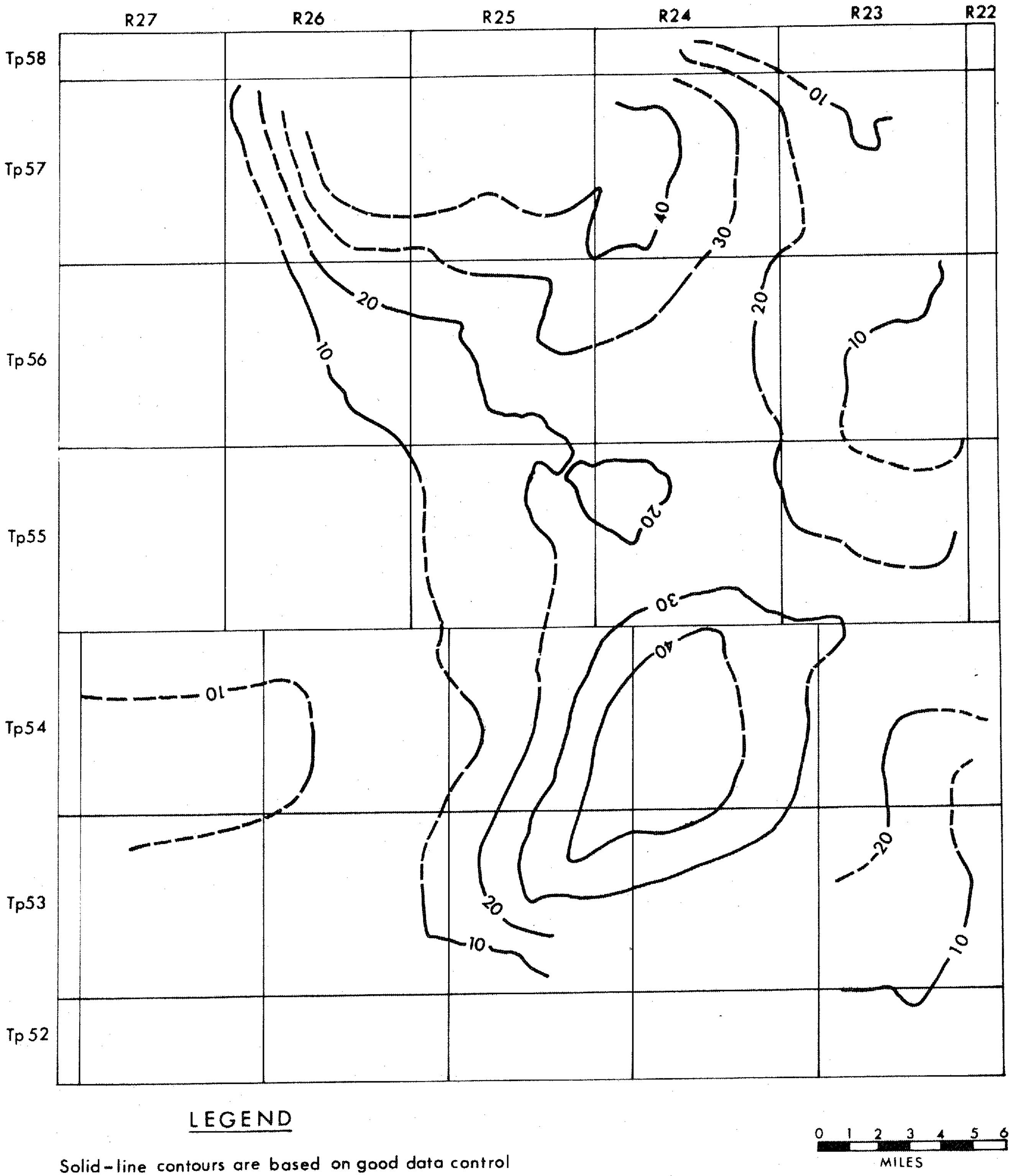


LEGEND

Solid-line contours are based on good data control

Dashed-line contours are based on poor data control

FIGURE 23. SO_4 (epm%) of Upper Layer.



LEGEND

Solid-line contours are based on good data control

Dashed-line contours are based on poor data control

FIGURE 24. SO_4 (epm%) of Lower Layer.

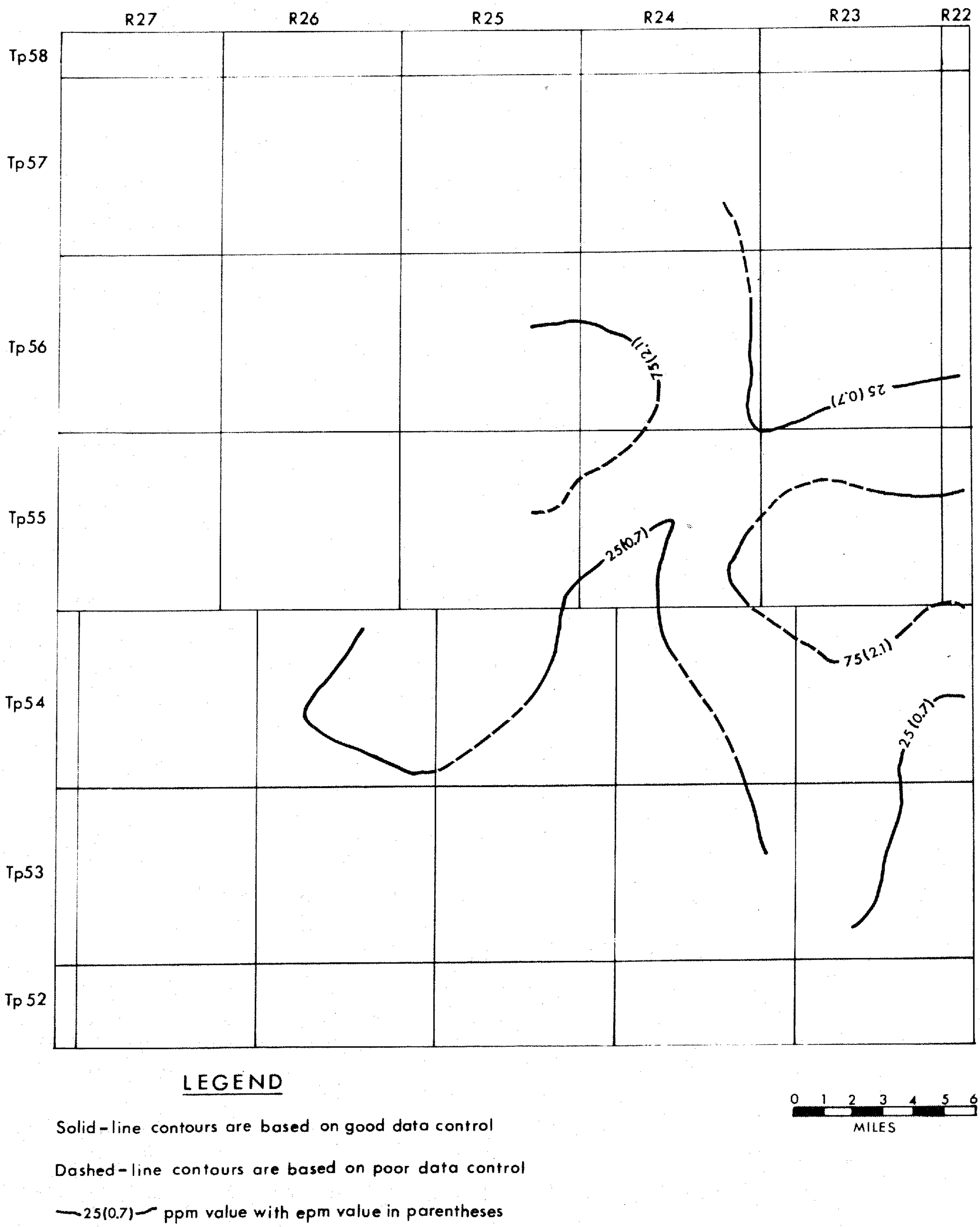
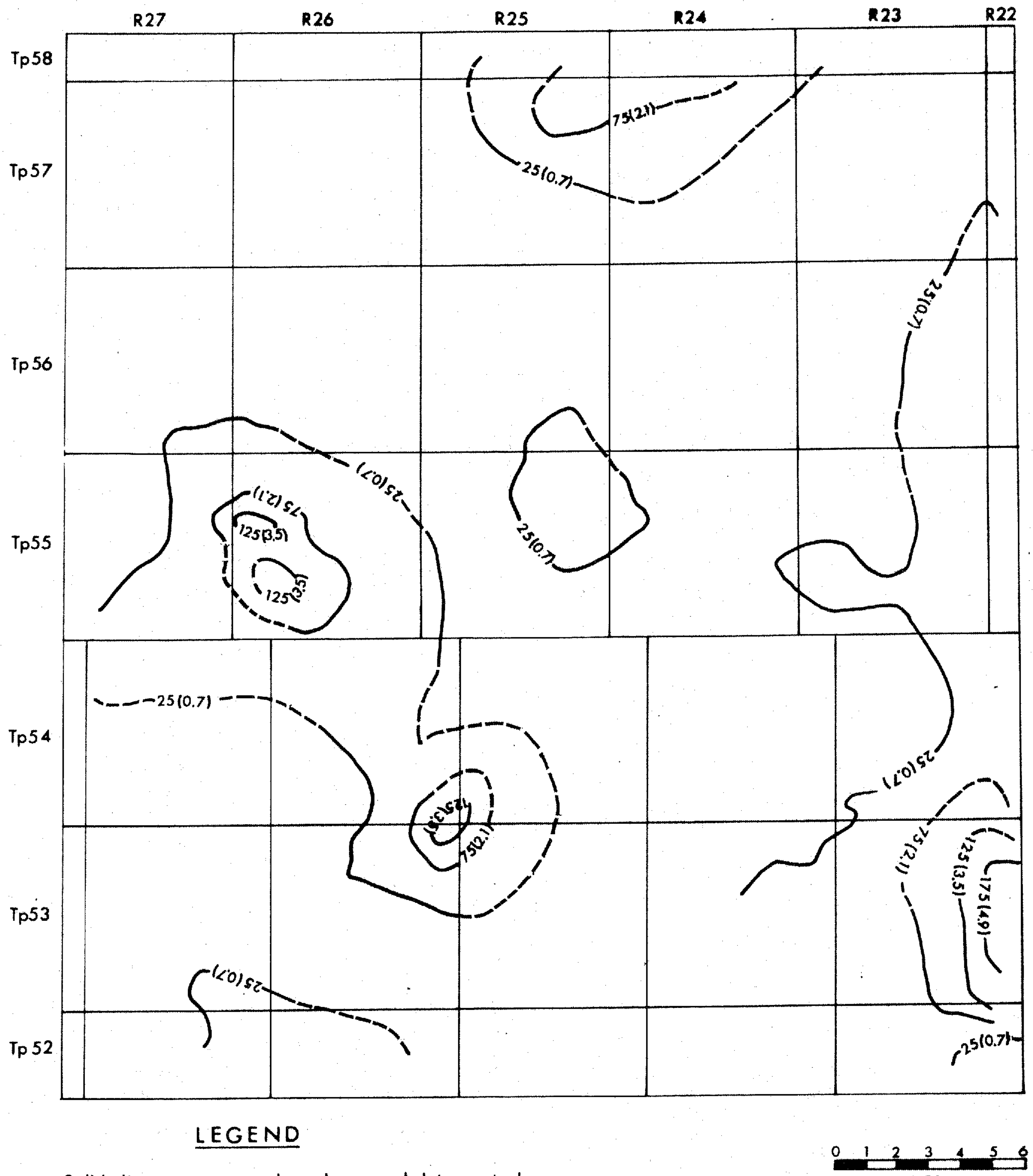


FIGURE 25. Cl (ppm and epm) of Drift Layer.



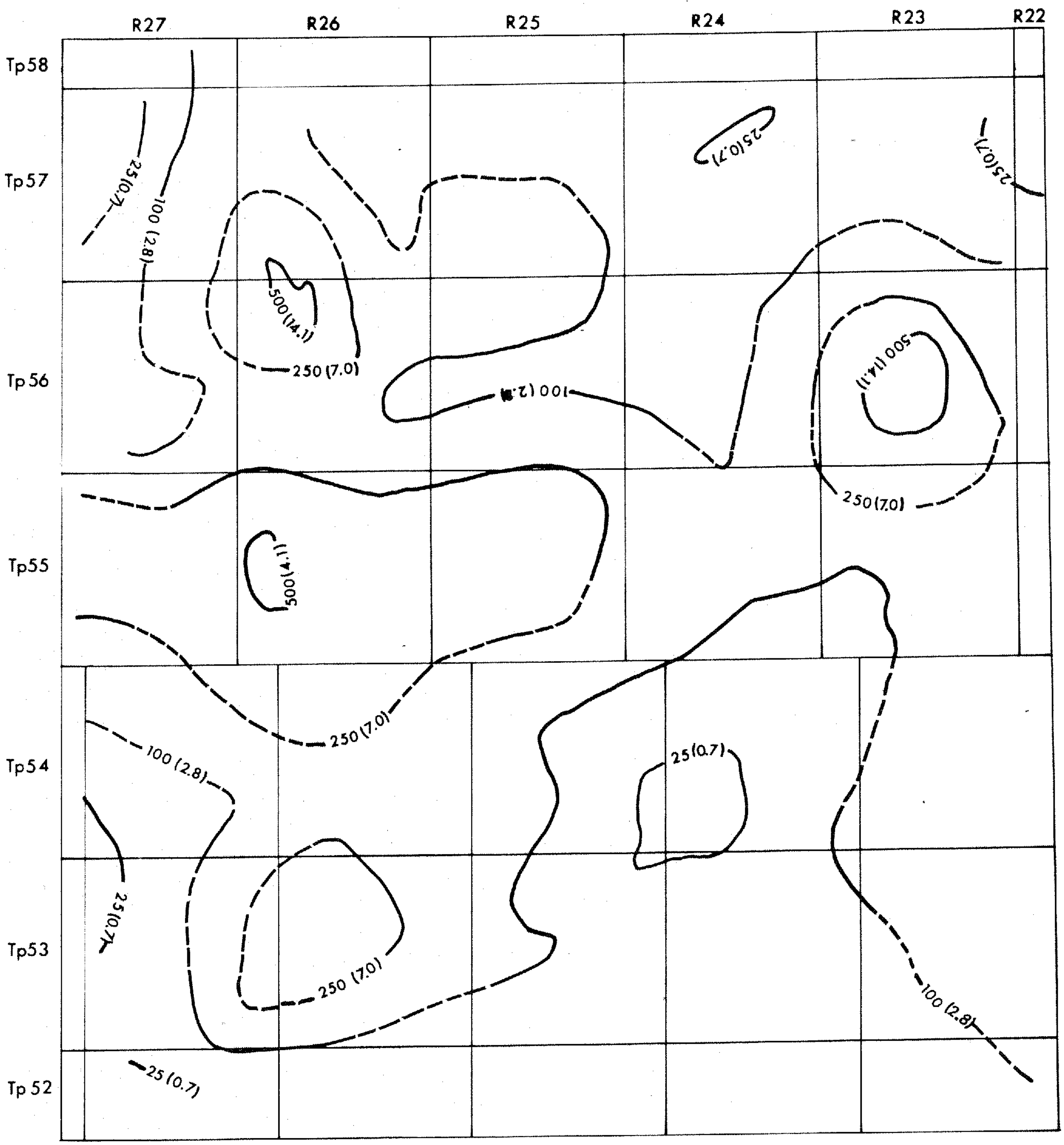
LEGEND

Solid-line contours are based on good data control

Dashed-line contours are based on poor data control

—25 (0.7)— ppm value with epm value in parentheses

FIGURE 26. Cl (ppm and epm) of Upper Layer.



LEGEND

Solid-line contours are based on good data control

Dashed-line contours are based on poor data control

25 (0.7) ppm value with epm value in parentheses

FIGURE 27. Cl (ppm and epm) of Lower Layer.

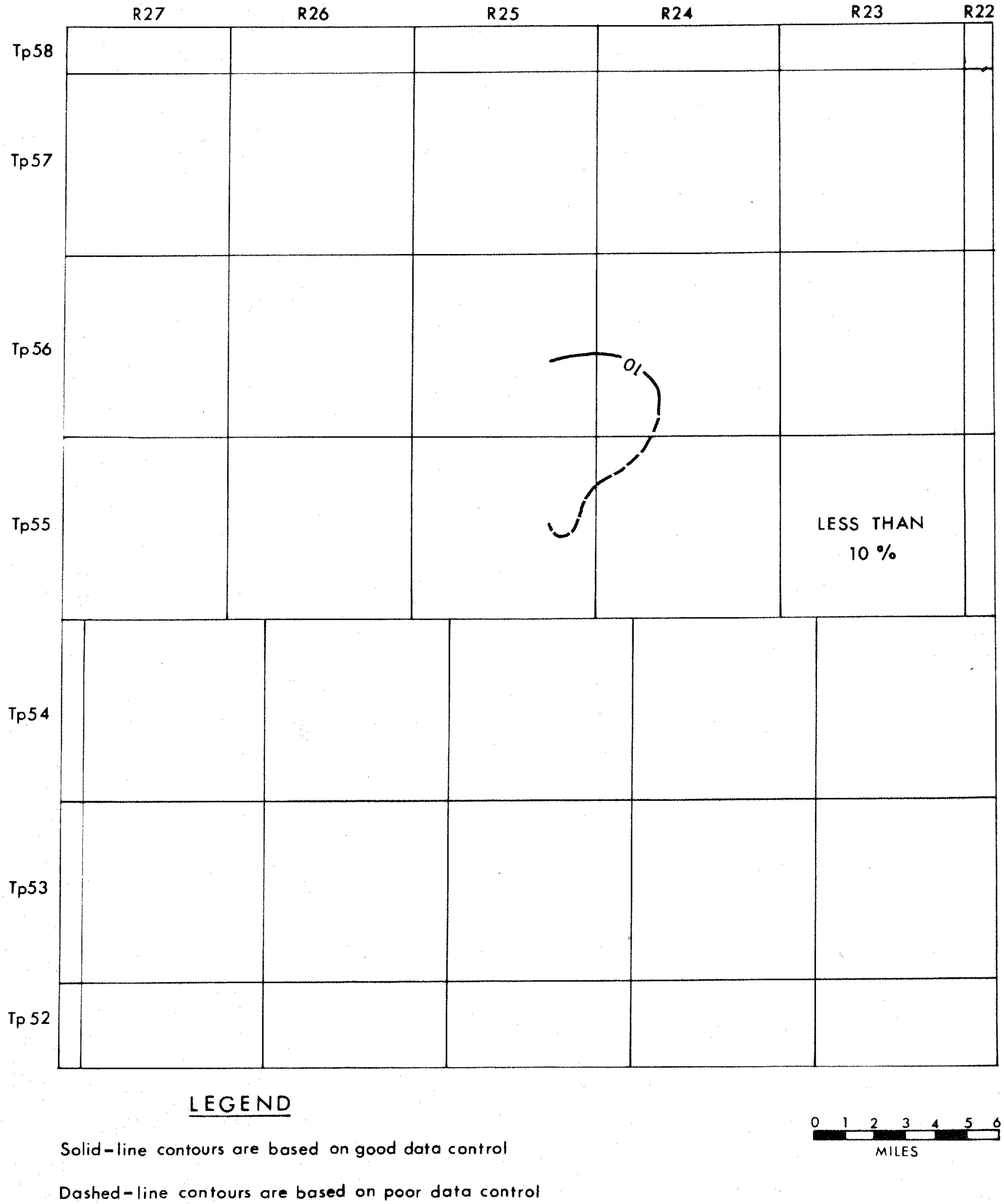


FIGURE 28. Cl (epm%) of Drift Layer.

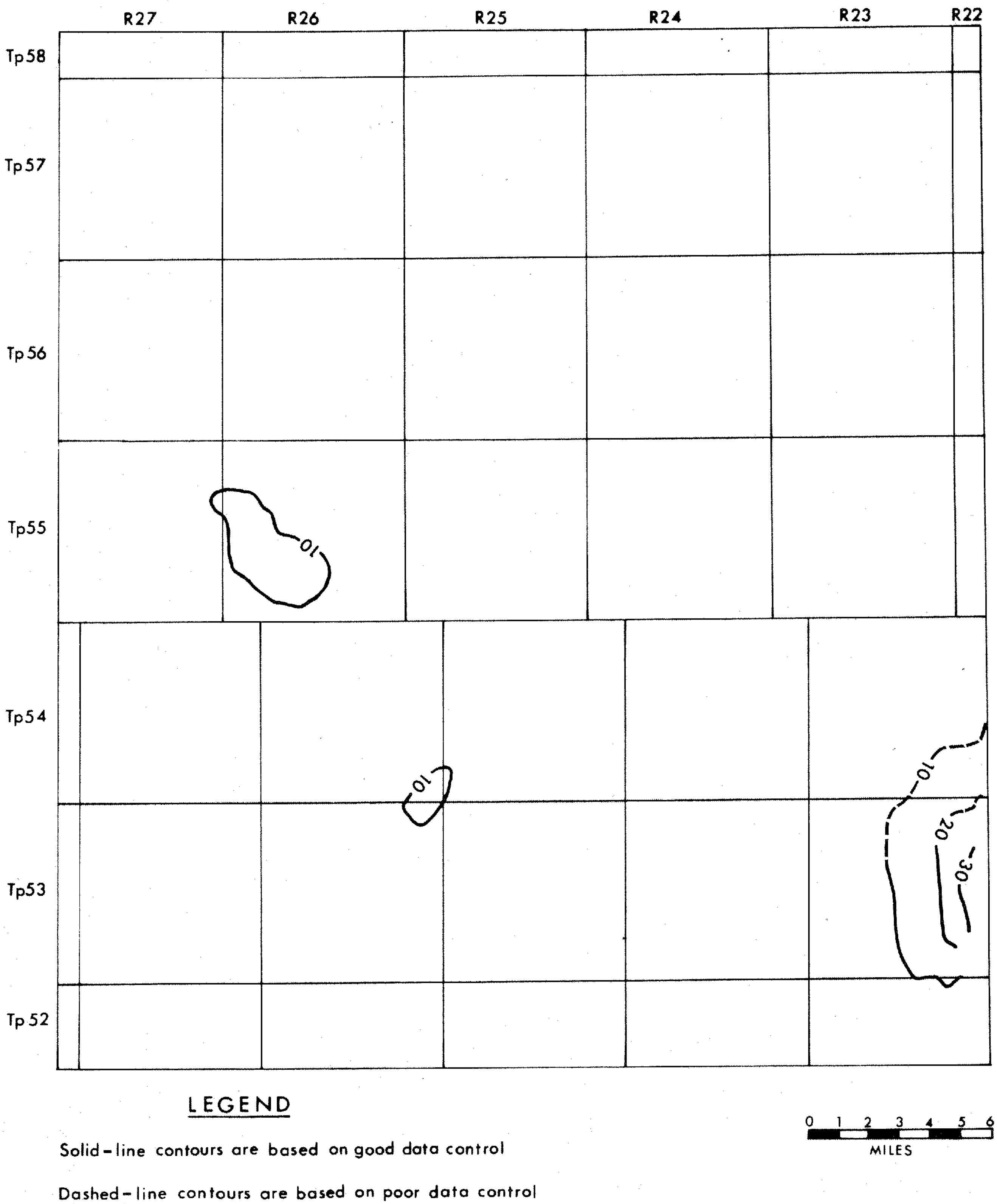
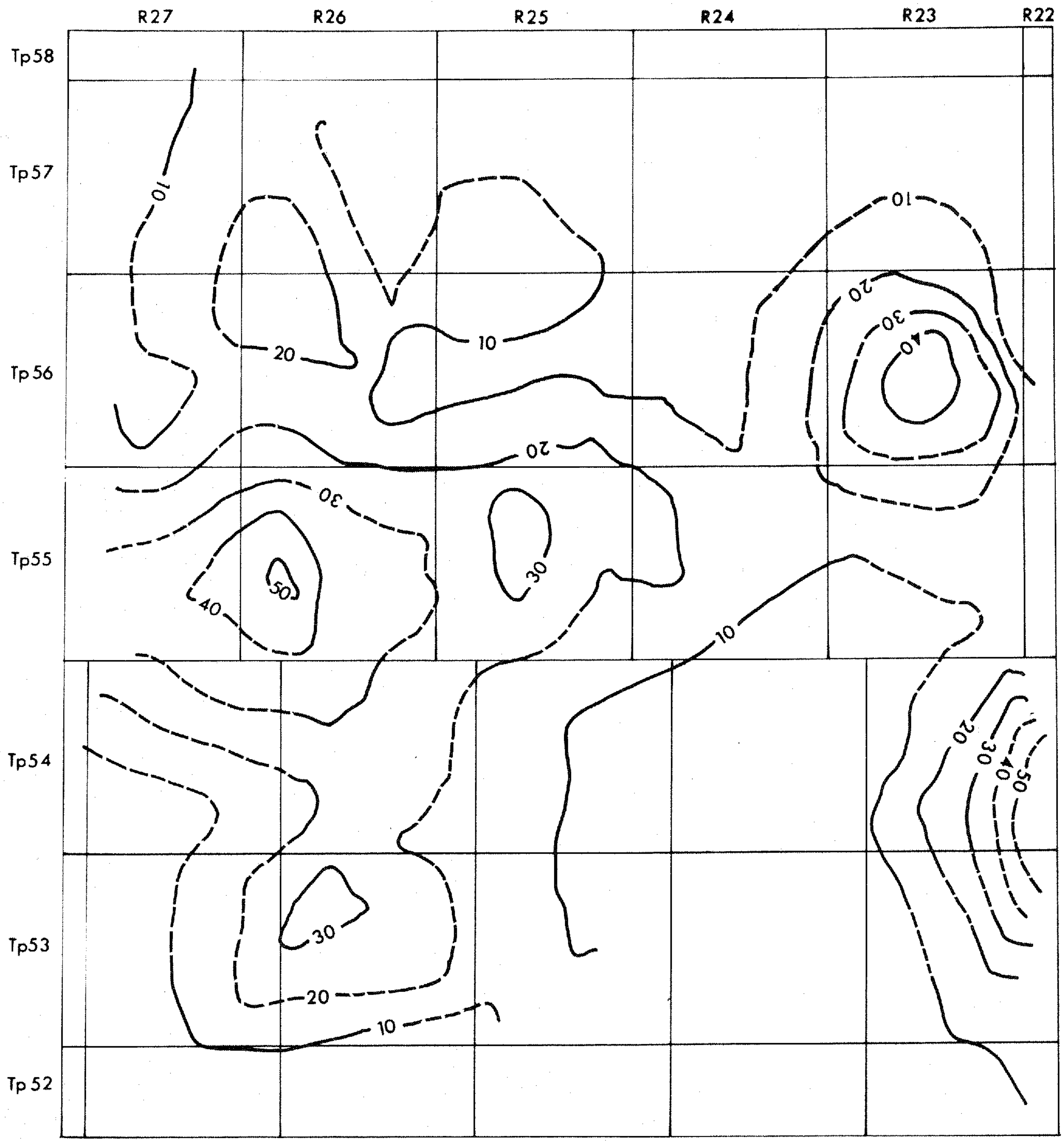


FIGURE 29. Cl (epm%) of Upper Layer.



LEGEND

Solid-line contours are based on good data control

Dashed-line contours are based on poor data control

FIGURE 30. Cl (epm%) of Lower Layer.

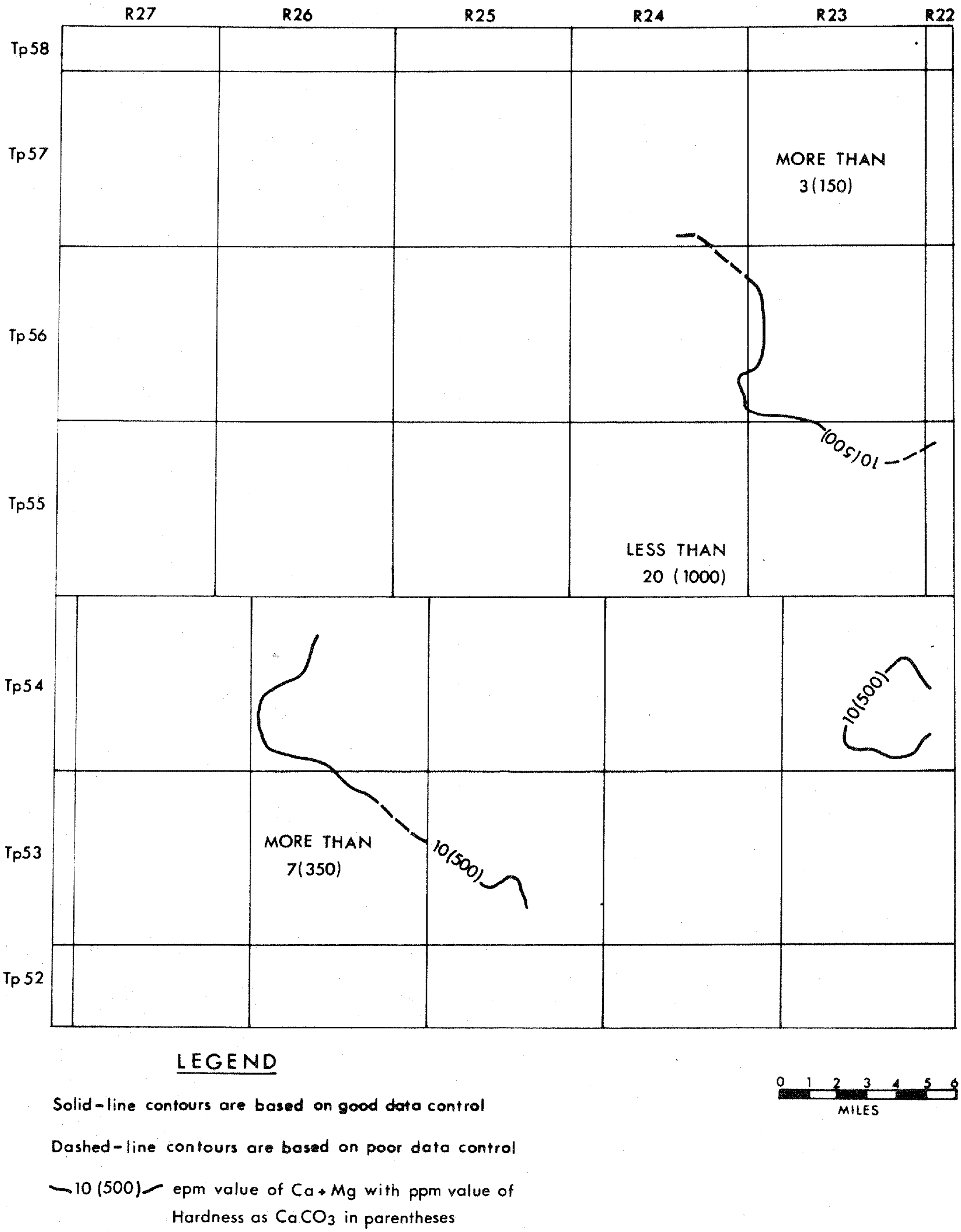
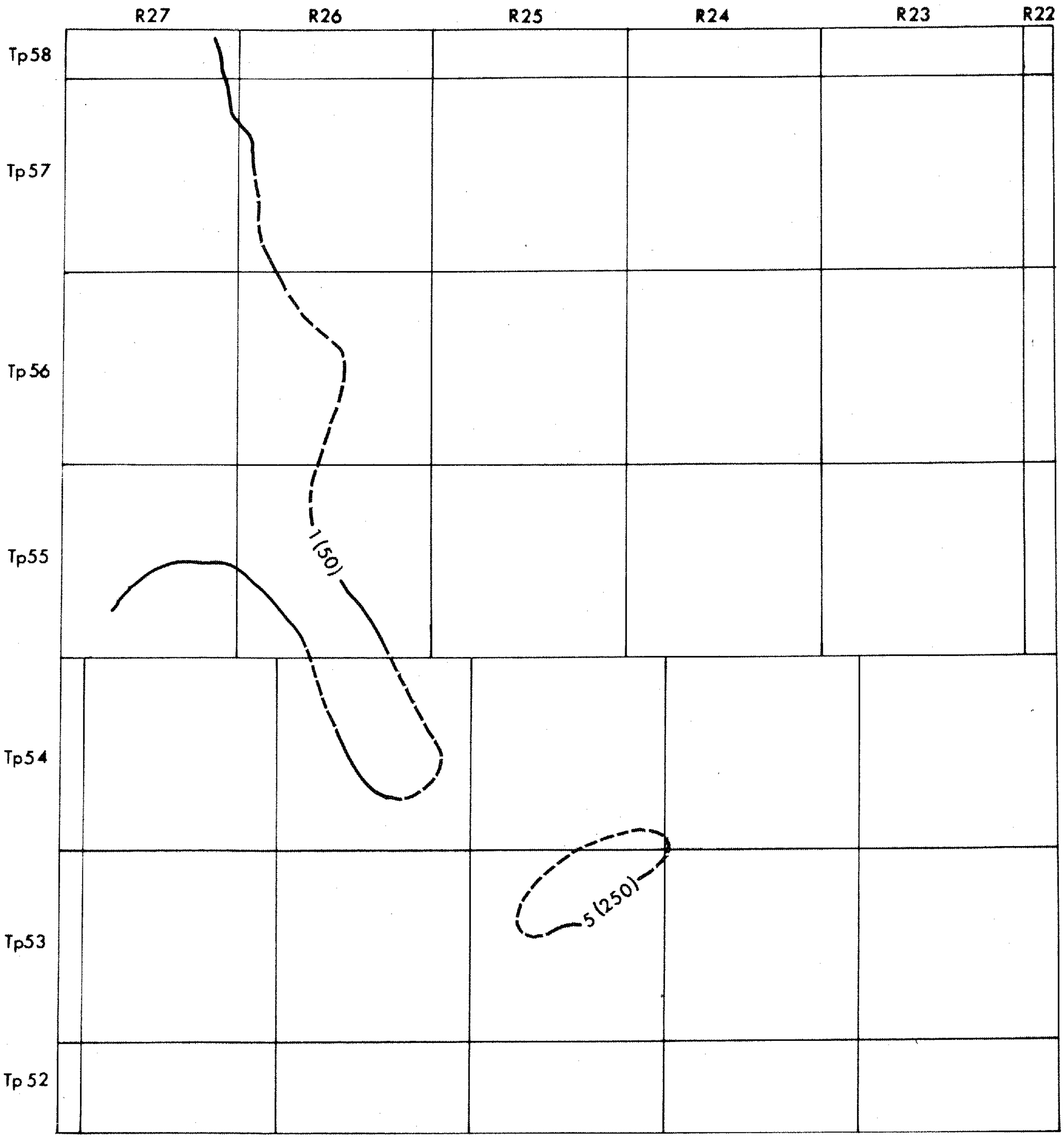


FIGURE 31. Ca+Mg (epm) and hardness (ppm as $CaCO_3$) of Drift Layer.



LEGEND

Solid-line contours are based on good data control

Dashed-line contours are based on poor data control

5(250) epm value of Ca+Mg with ppm value of Hardness as $CaCO_3$ in parentheses

0 1 2 3 4 5 6
MILES

FIGURE 32. Ca+Mg (epm) and hardness (ppm as $CaCO_3$) of Upper Layer.

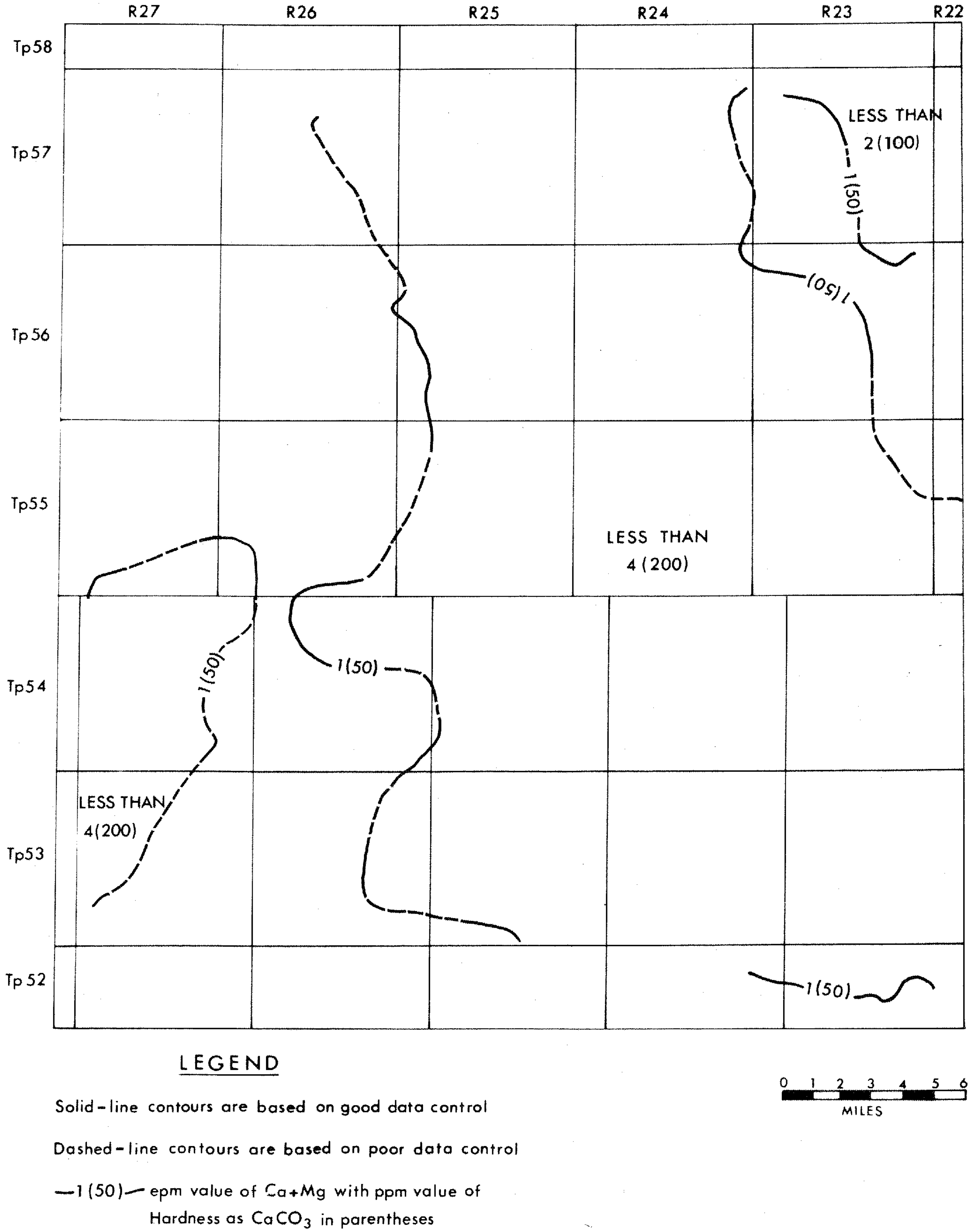
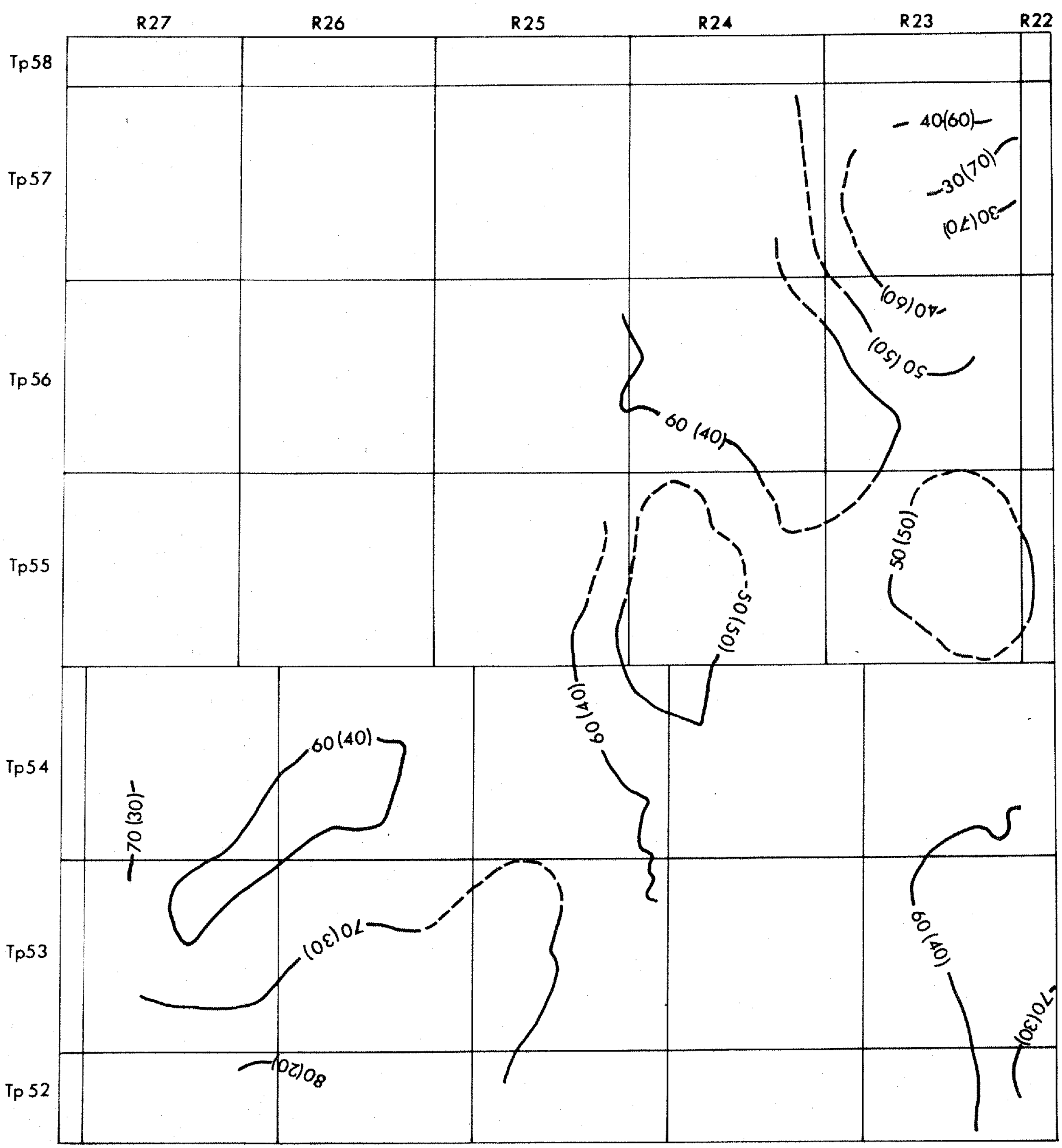


FIGURE 33. Ca+Mg (epm) and hardness (ppm as $CaCO_3$) of Lower Layer.



LEGEND

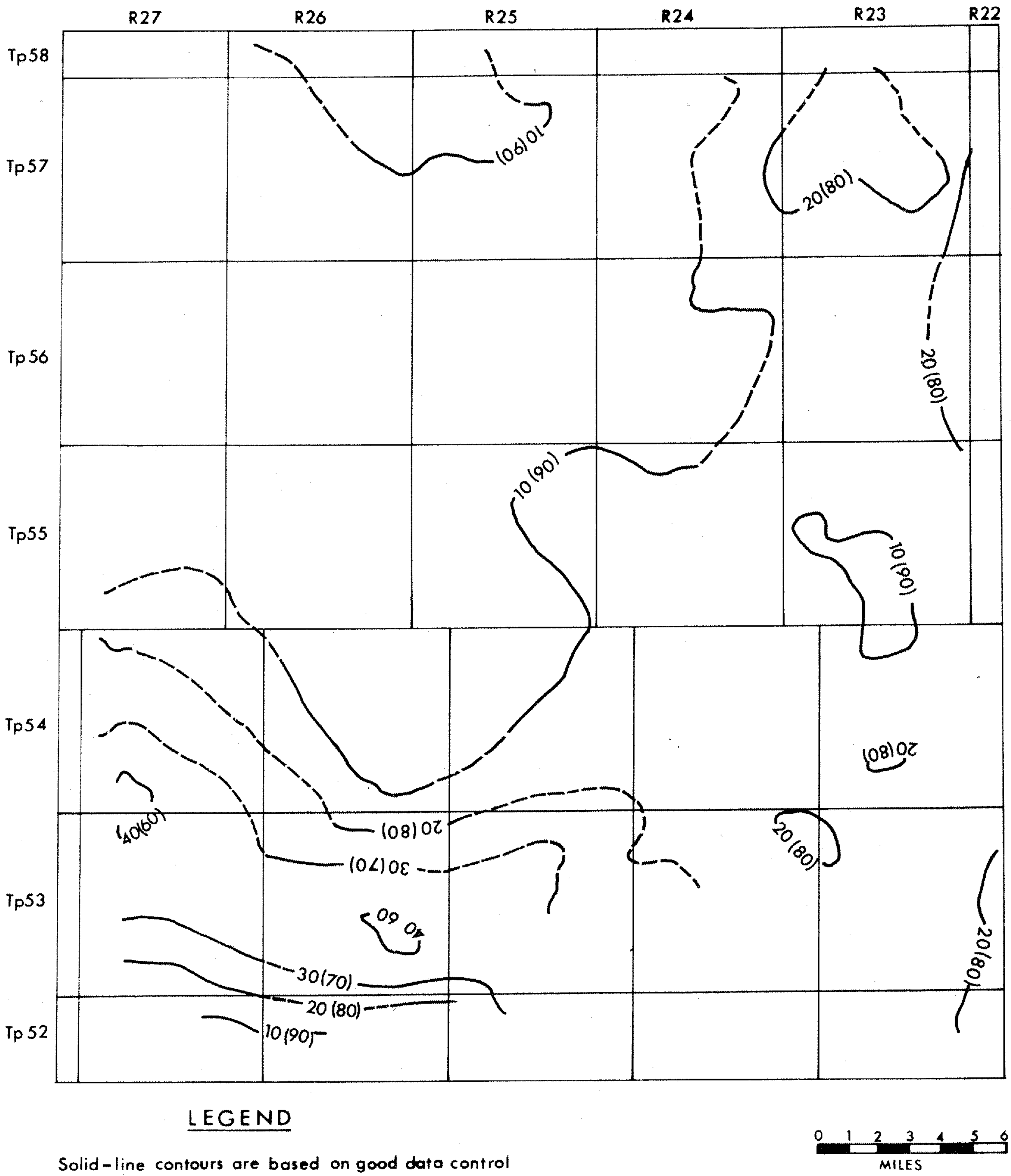
Solid-line contours are based on good data control

Dashed-line contours are based on poor data control

—60 (40)— epm % value of Ca+Mg with epm % value of Na in parentheses

0 1 2 3 4 5 6
MILES

FIGURE 34. Ca+Mg (epm%) and Na (epm%) of Drift Layer.



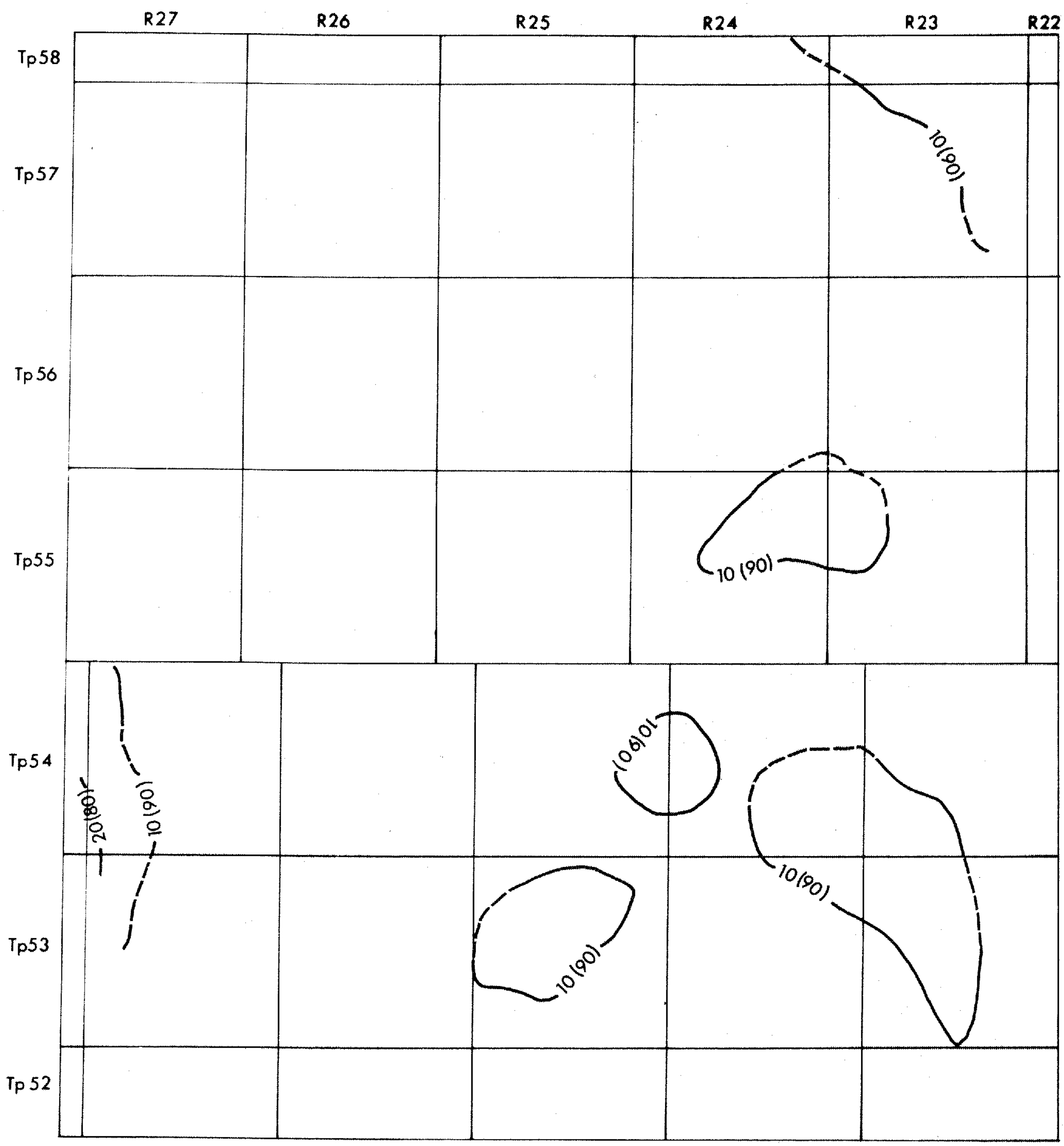
LEGEND

Solid-line contours are based on good data control

Dashed-line contours are based on poor data control

—10(90)— epm % value of Ca+Mg with epm % value of Na in parentheses

FIGURE 35. Ca+Mg (emp%) and Na (epm%) of Upper Layer.



LEGEND

Solid-line contours are based on good data control

Dashed-line contours are based on poor data control

—10 (90)— epm value of Ca+Mg with epm % value of Na in parentheses

FIGURE 36. Ca+Mg (epm%) and Na (epm%) of Lower Layer.

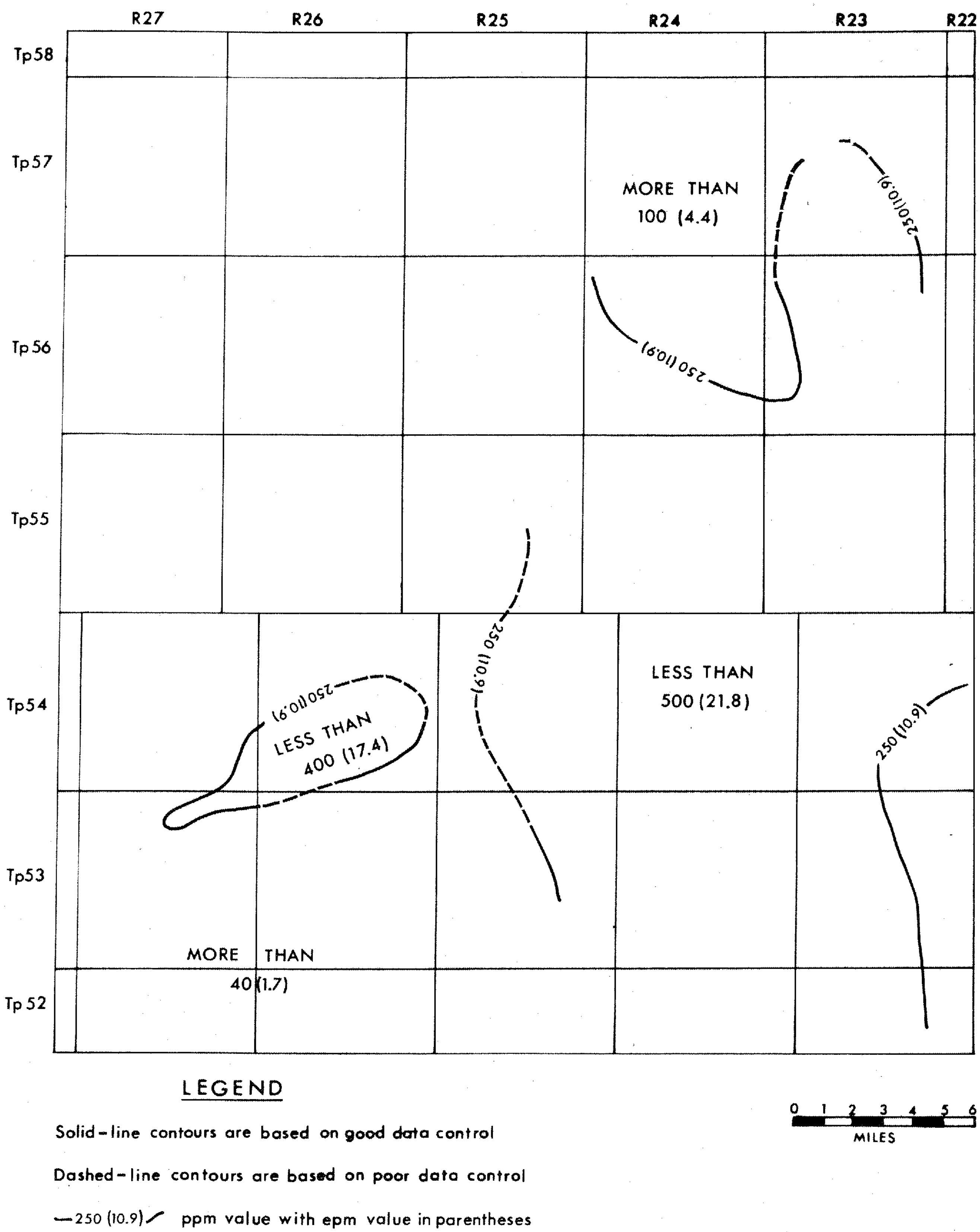
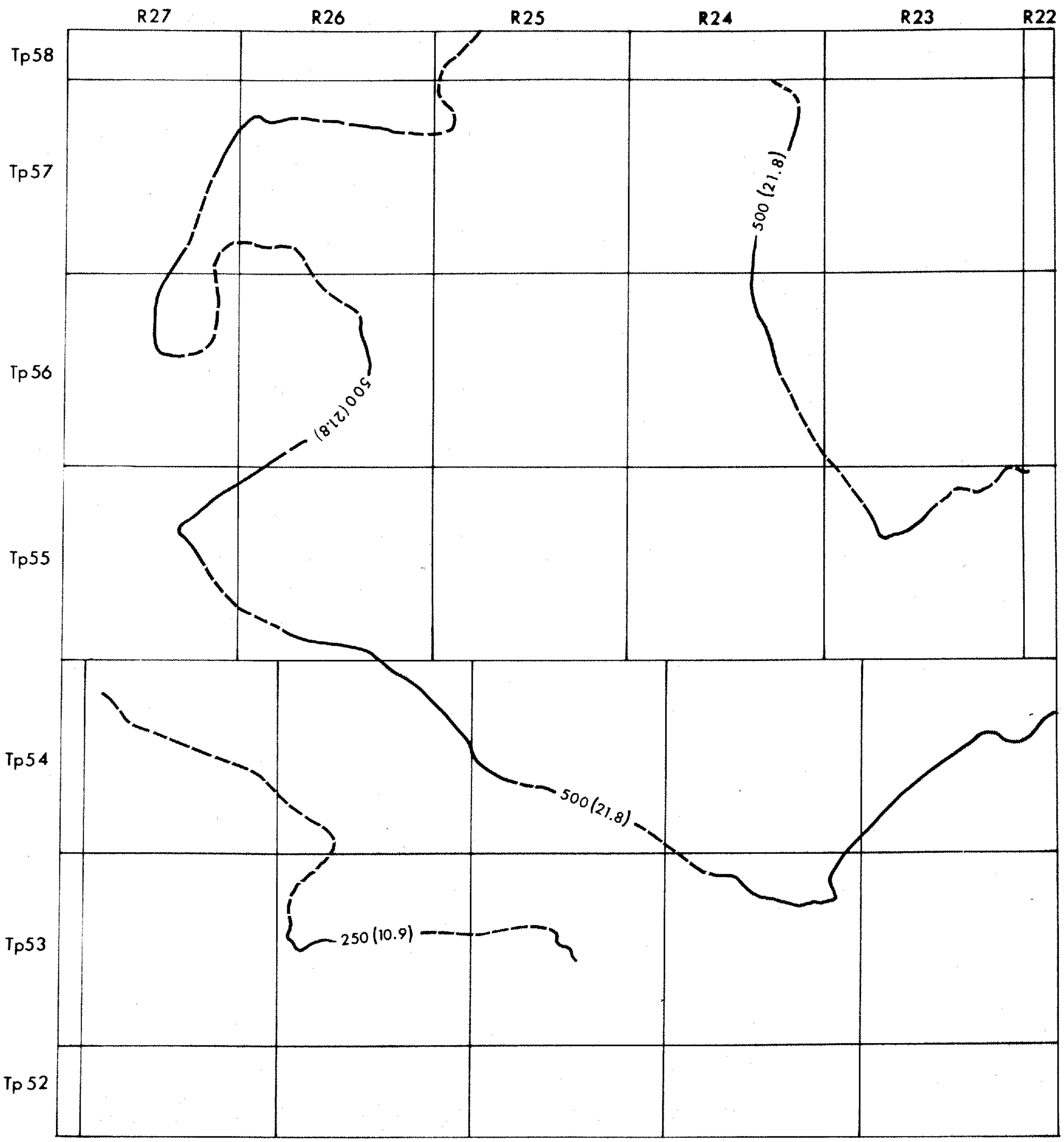


FIGURE 37. Na (ppm and epm) of Drift Layer.



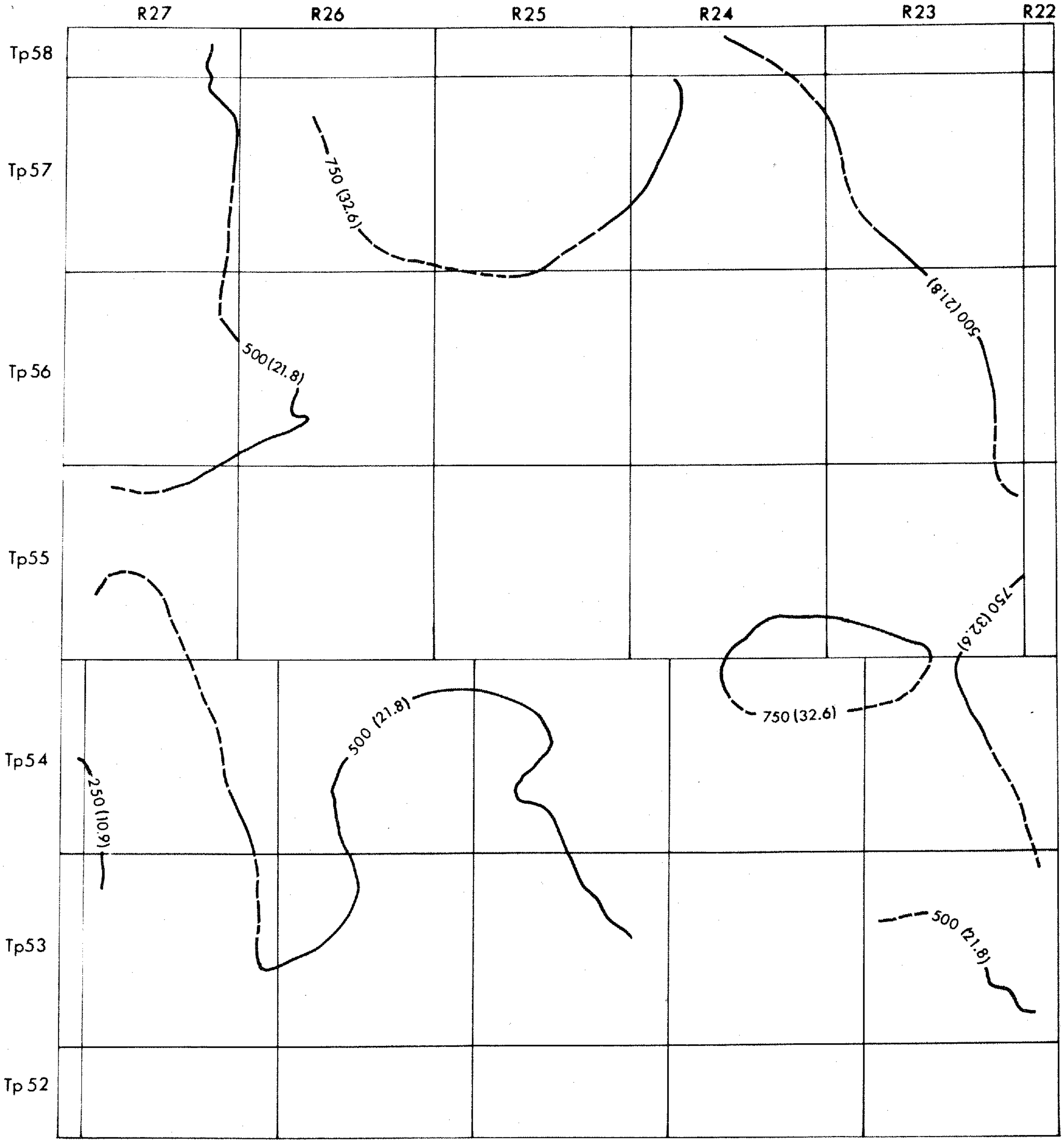
LEGEND

Solid-line contours are based on good data control

Dashed-line contours are based on poor data control

—500 (21.8)— ppm value with epm value in parentheses

FIGURE 38. Na (ppm and epm) of Upper Layer.



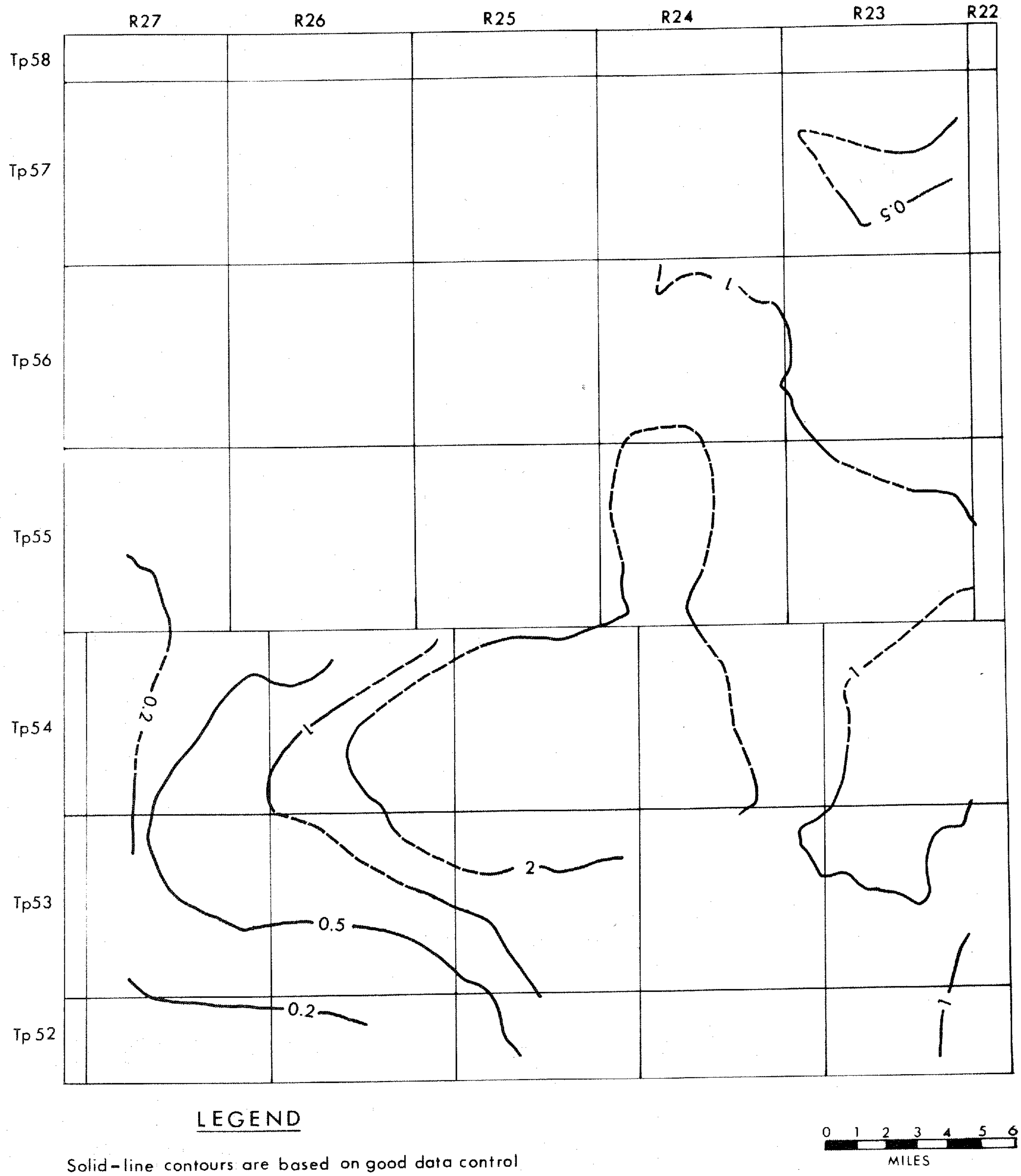
LEGEND

Solid-line contours are based on good data control

Dashed-line contours are based on poor data control

500 (21.8) ppm value with epm value in parentheses

FIGURE 39. Na (ppm and epm) of Lower Layer.



LEGEND

Solid-line contours are based on good data control

Dashed-line contours are based on poor data control

FIGURE 40. SO_4/HCO_3 (epm/epm) of Drift Layer.

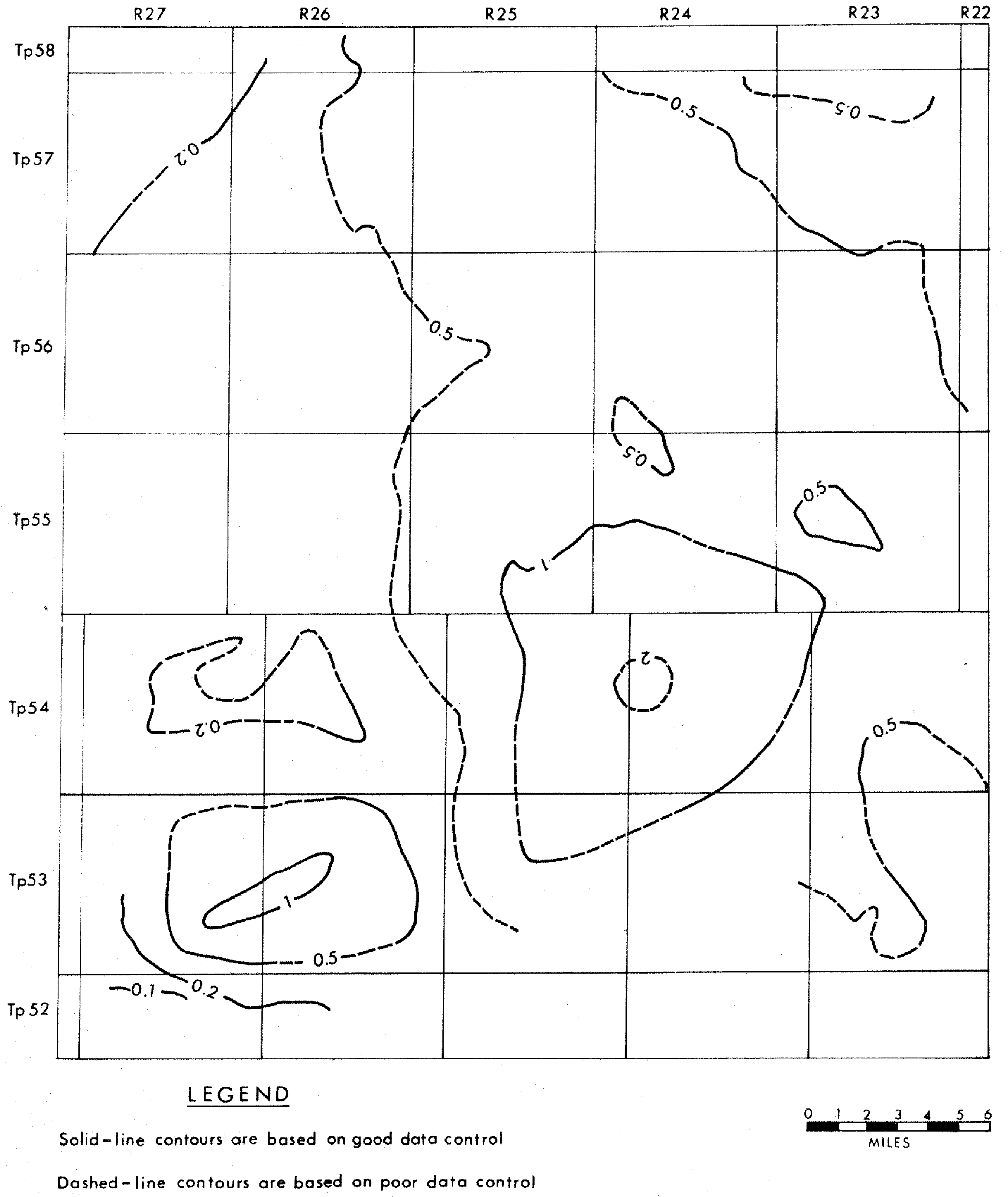
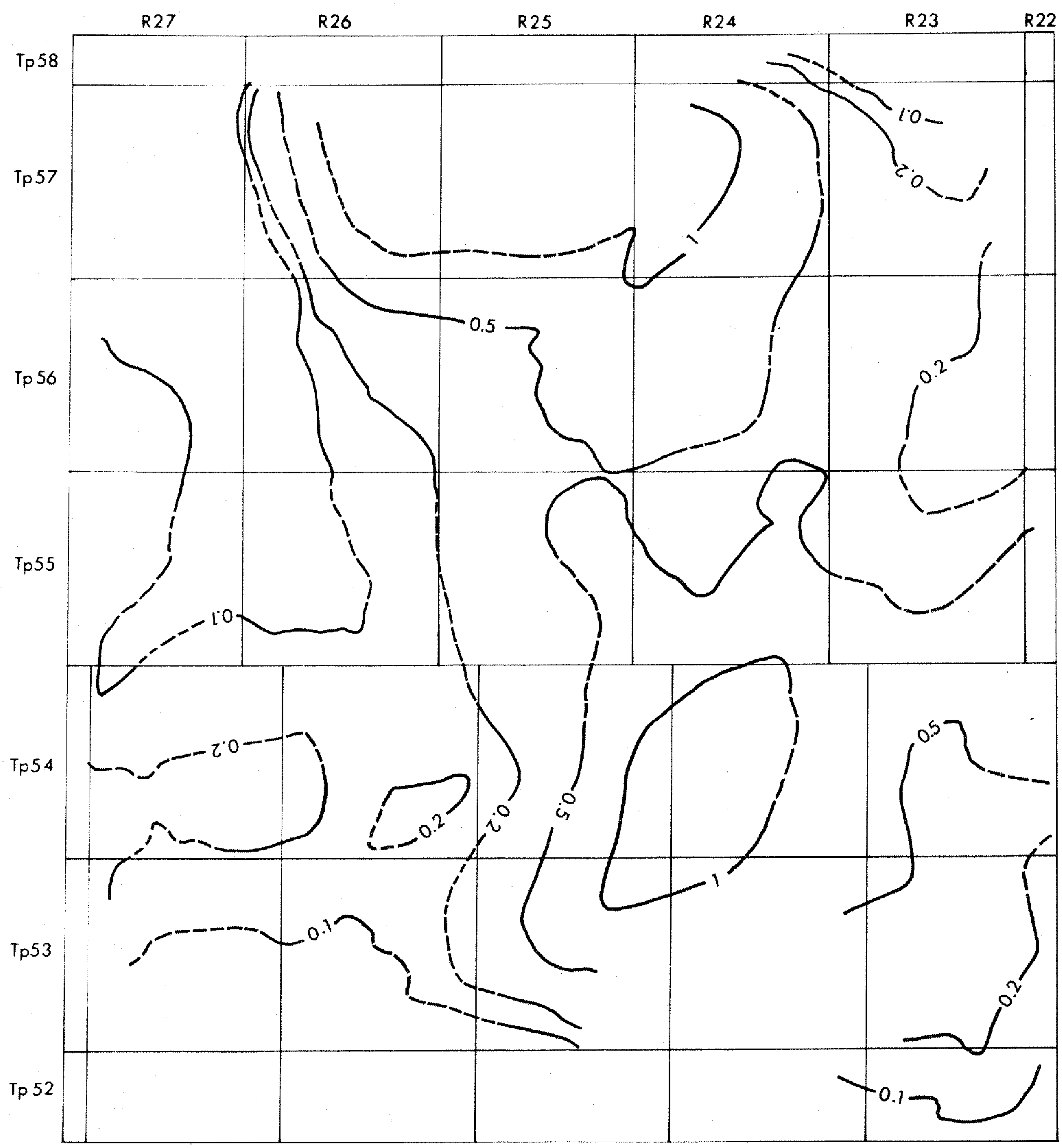


FIGURE 41. SO_4/HCO_3 (epm/epm) of Upper Layer.



LEGEND

Solid-line contours are based on good data control

Dashed-line contours are based on poor data control

FIGURE 42. SO_4/HCO_3 (epm/epm) of Lower Layer.

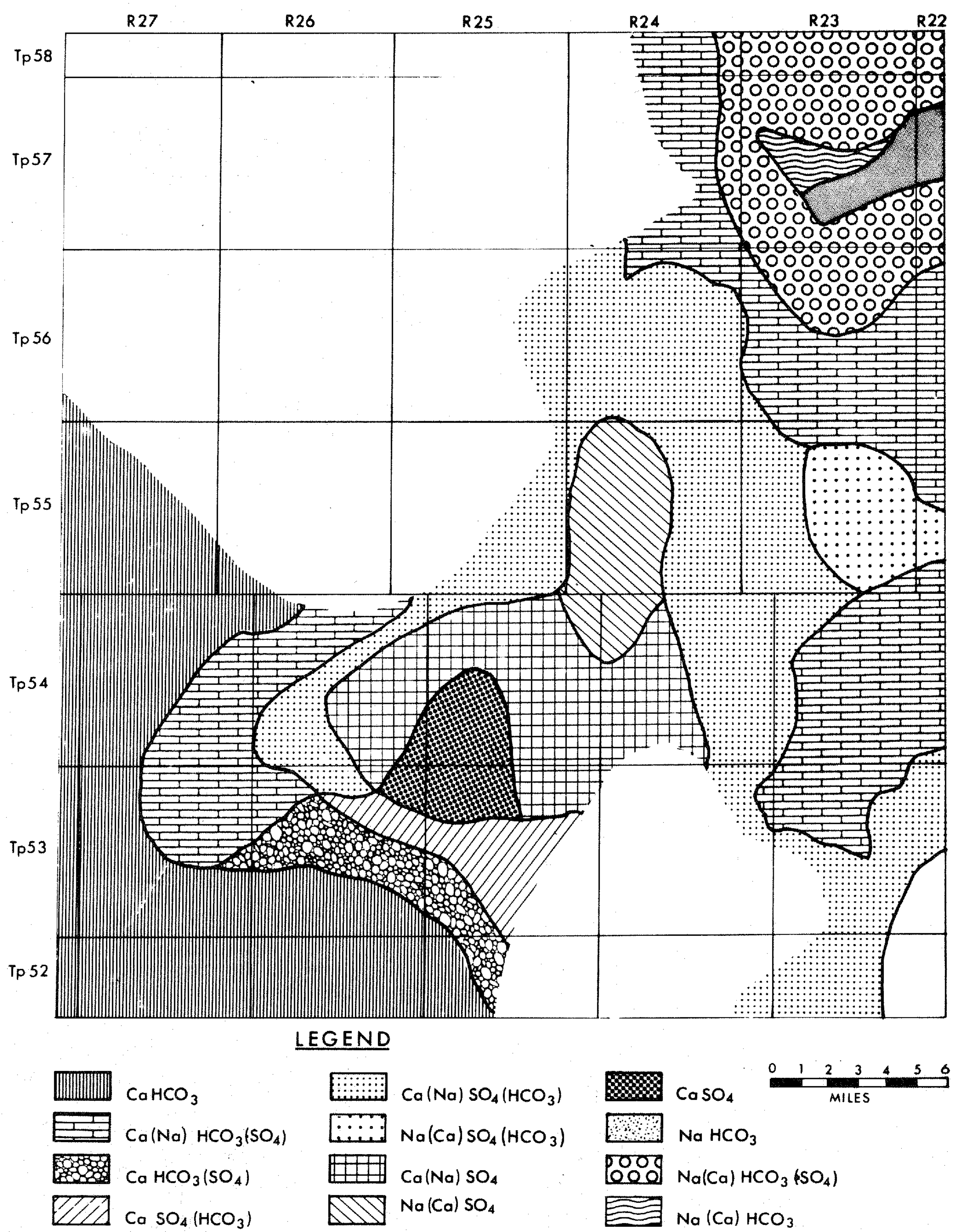


FIGURE 43. Chemical facies map of Drift Layer.

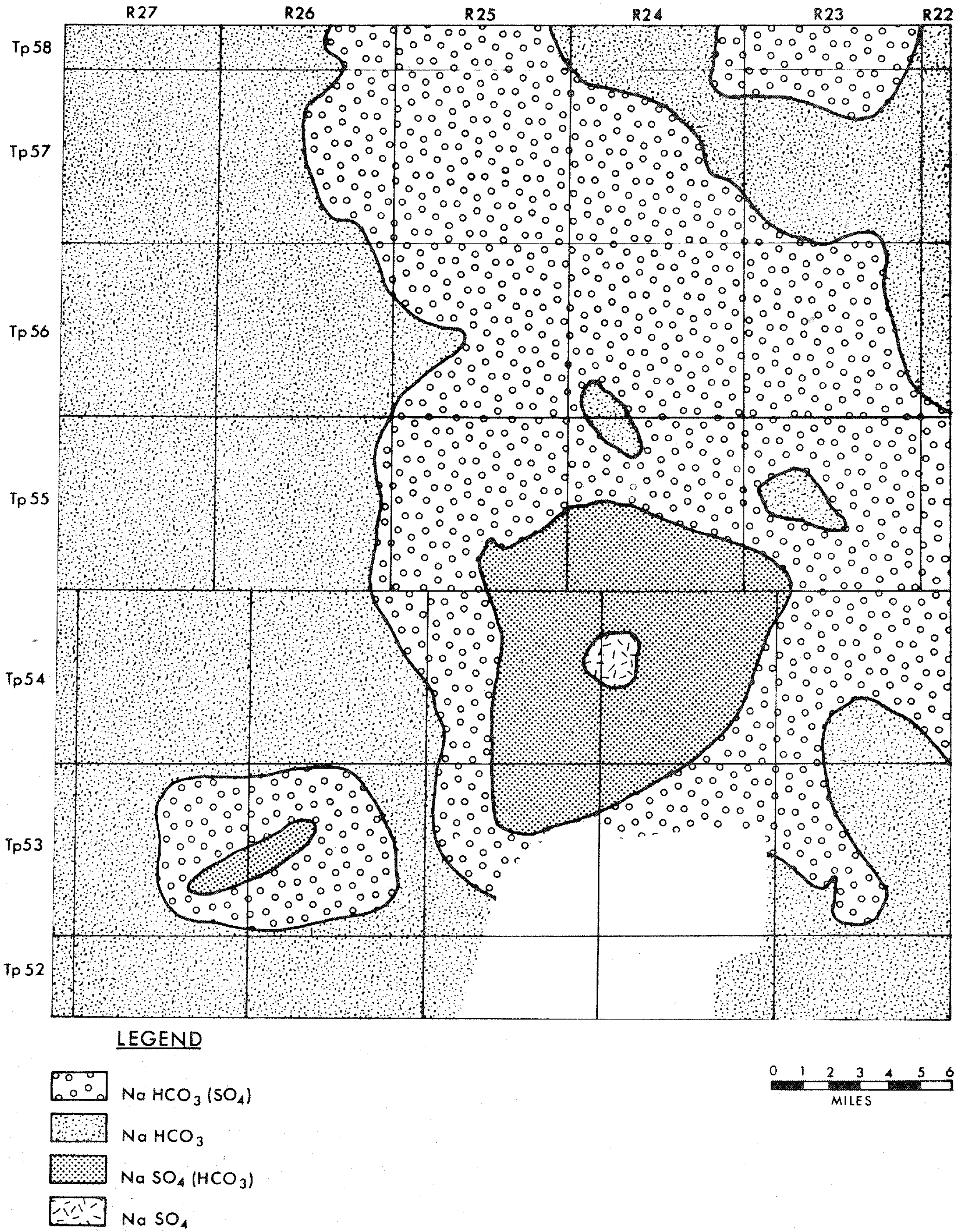


FIGURE 44. Chemical facies map of Upper Layer.

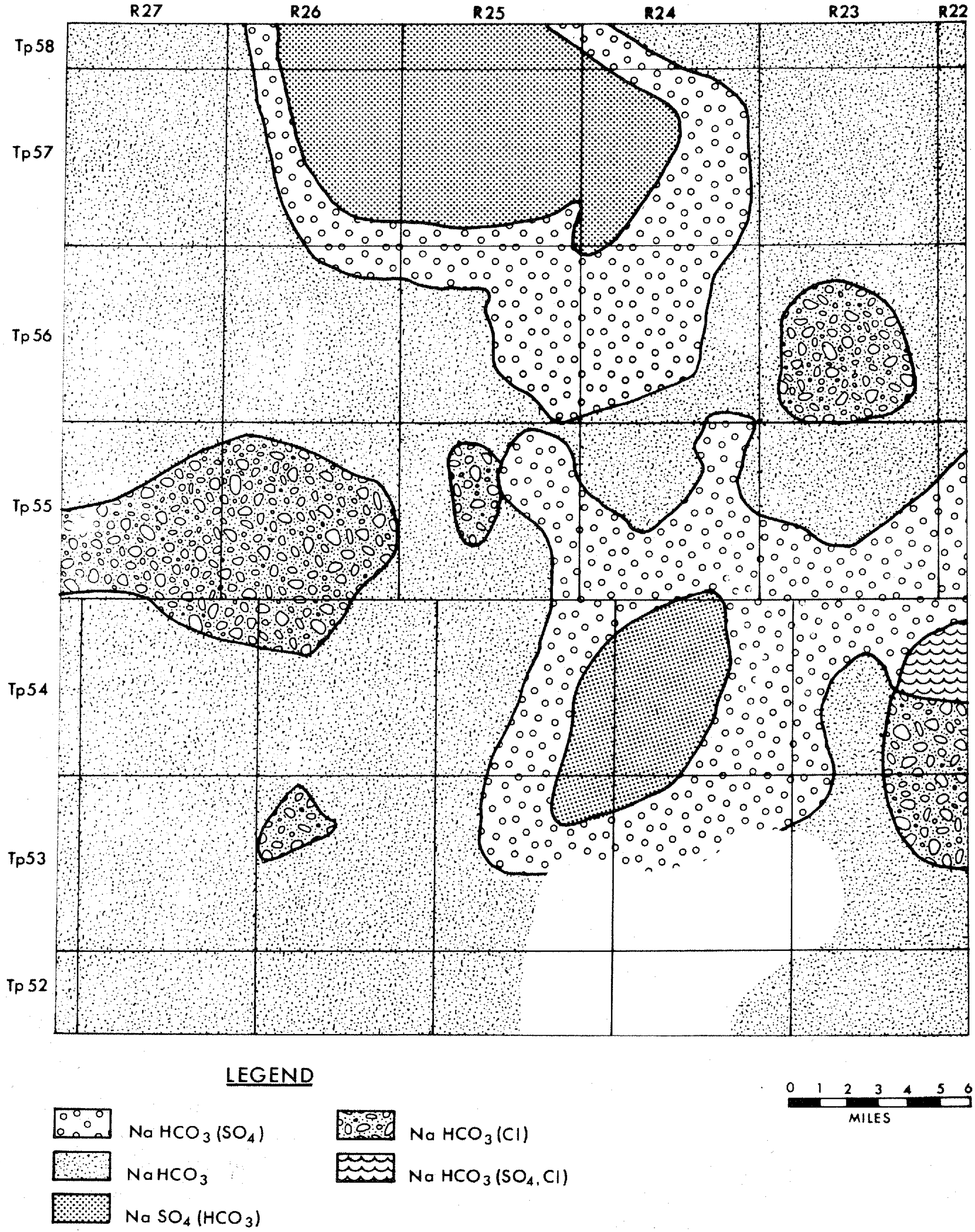
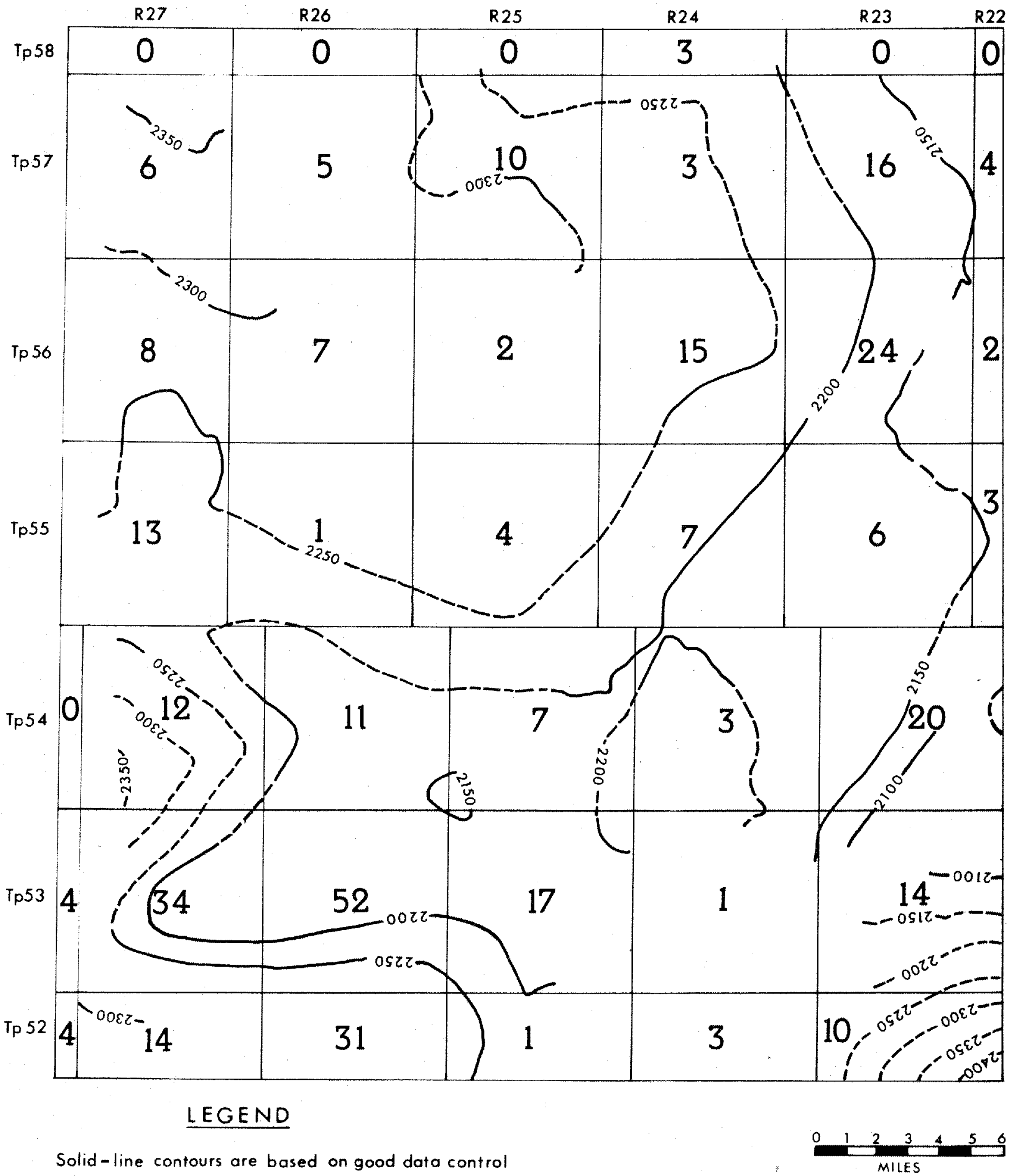


FIGURE 45. Chemical facies map of Lower Layer.



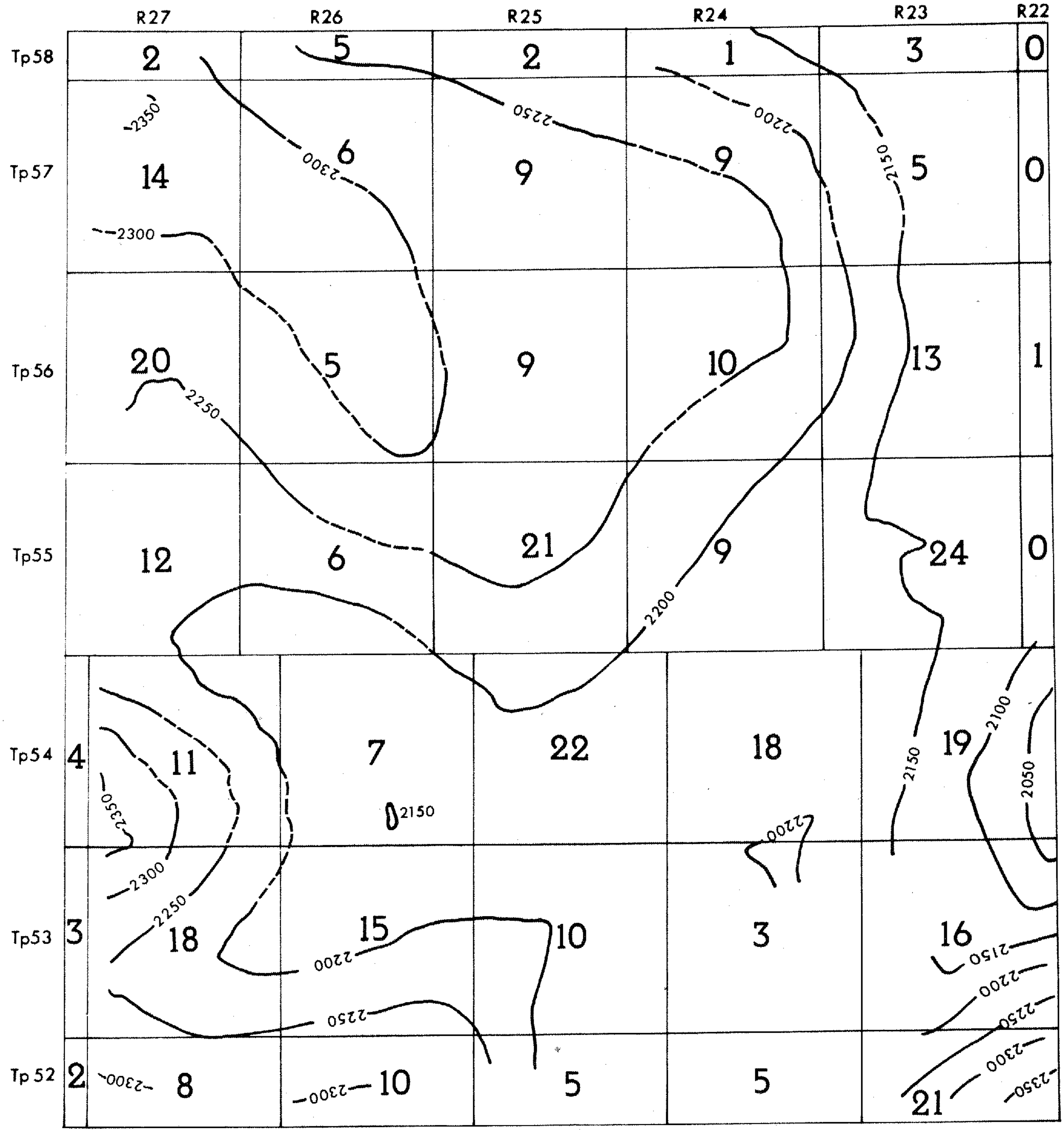
LEGEND

Solid-line contours are based on good data control

Dashed-line contours are based on poor data control

6 Number of data points in each township from which contours were drawn.

FIGURE 46. Water levels, in feet above mean sea level, and density of data of Drift Layer.



LEGEND

Solid-line contours are based on good data control

Dashed-line contours are based on poor data control

9 Number of data points in each township from which contours were drawn.

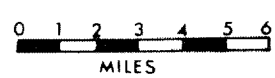
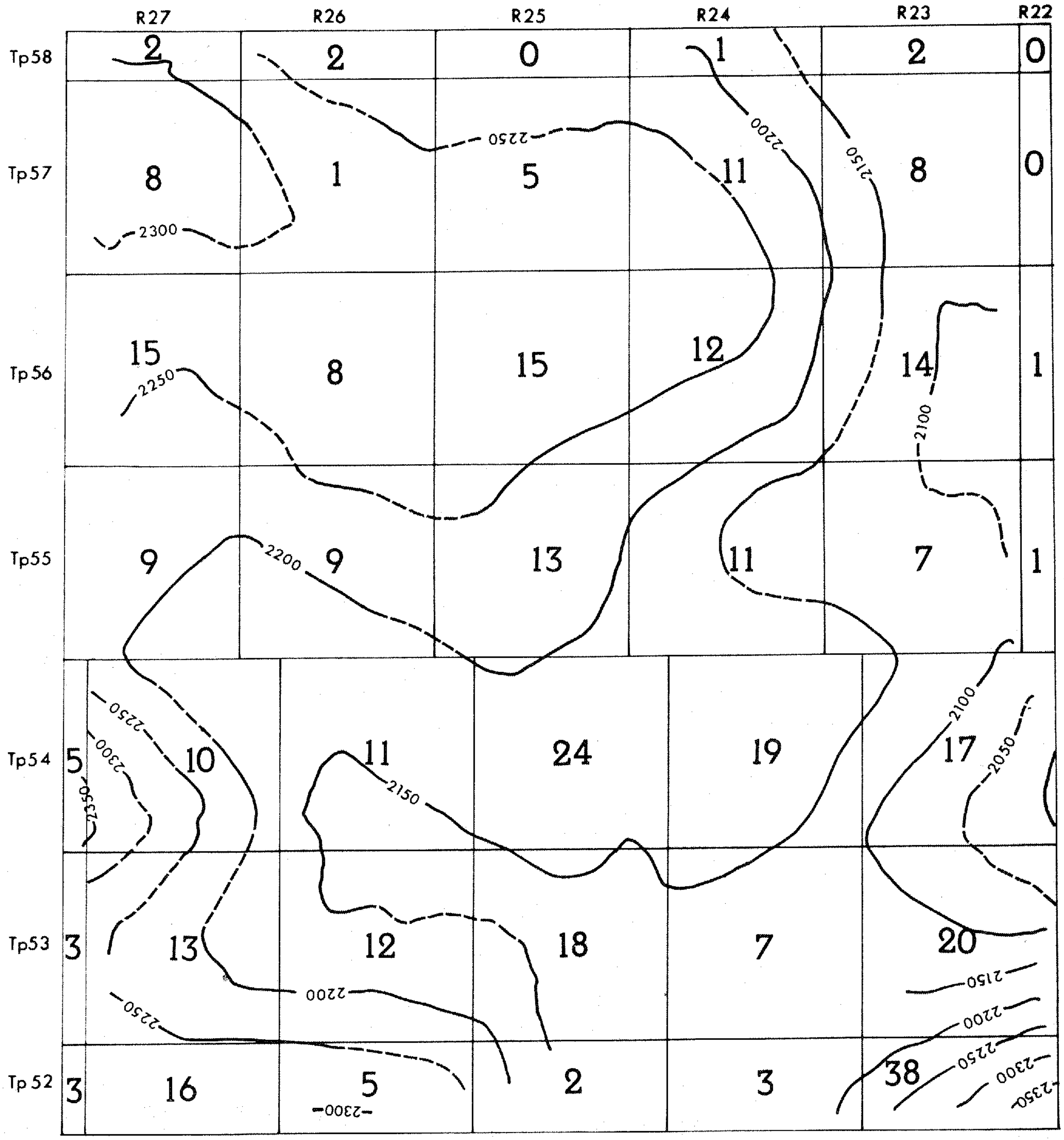


FIGURE 47. Water levels, in feet above mean sea level, and density of data of Upper Layer.



LEGEND

Solid-line contours are based on good data control

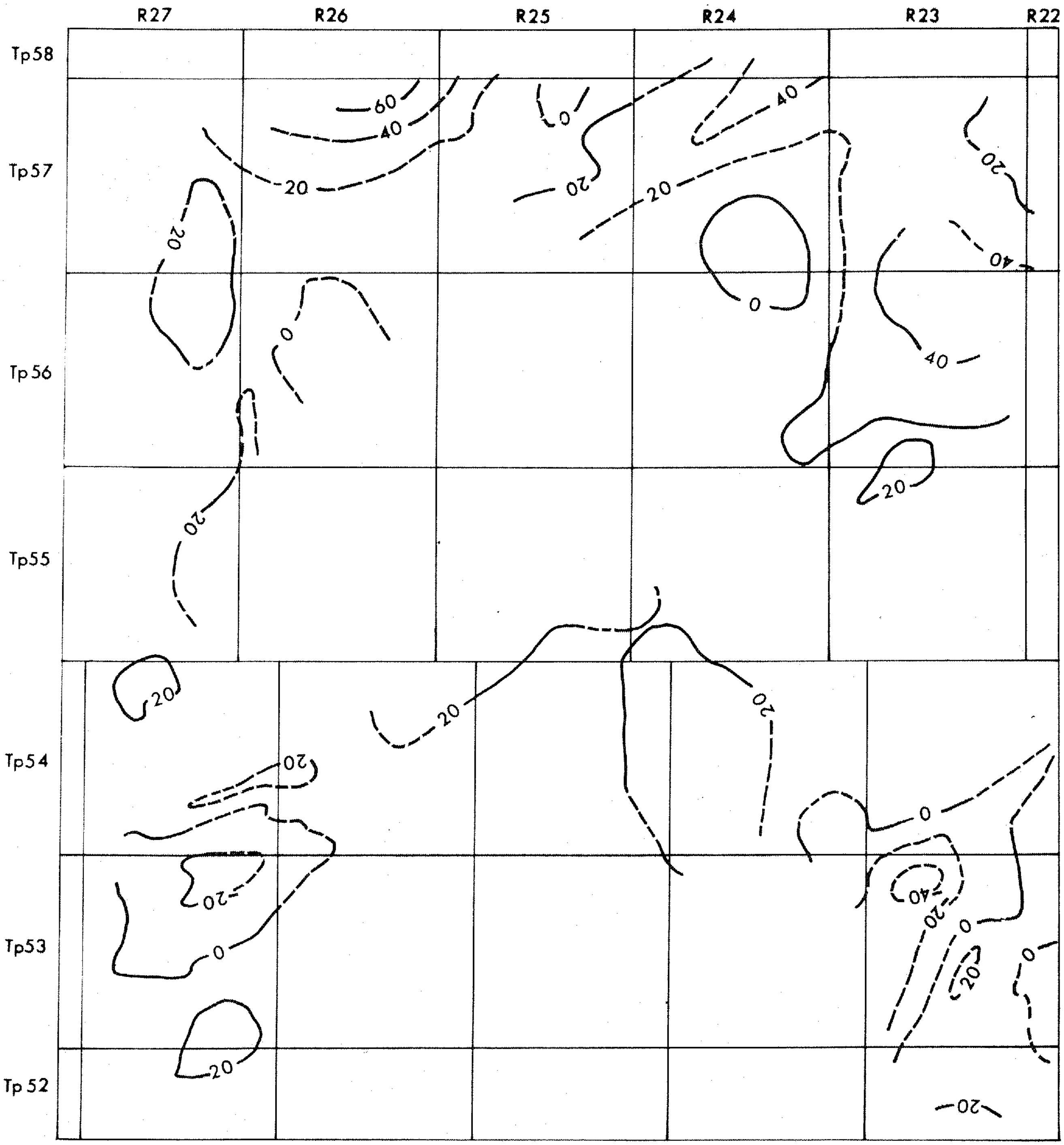
Dashed-line contours are based on poor data control

3 Number of data points in each township from which contours were drawn.

0 1 2 3 4 5 6

MILES

FIGURE 48. Water levels, in feet above mean sea level, and density of data of Lower Layer.



LEGEND

Solid-line contours are based on good data control

Dashed-line contours are based on poor data control

—20— Drift Layer water level 20 feet lower than Upper Layer water level

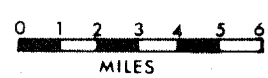
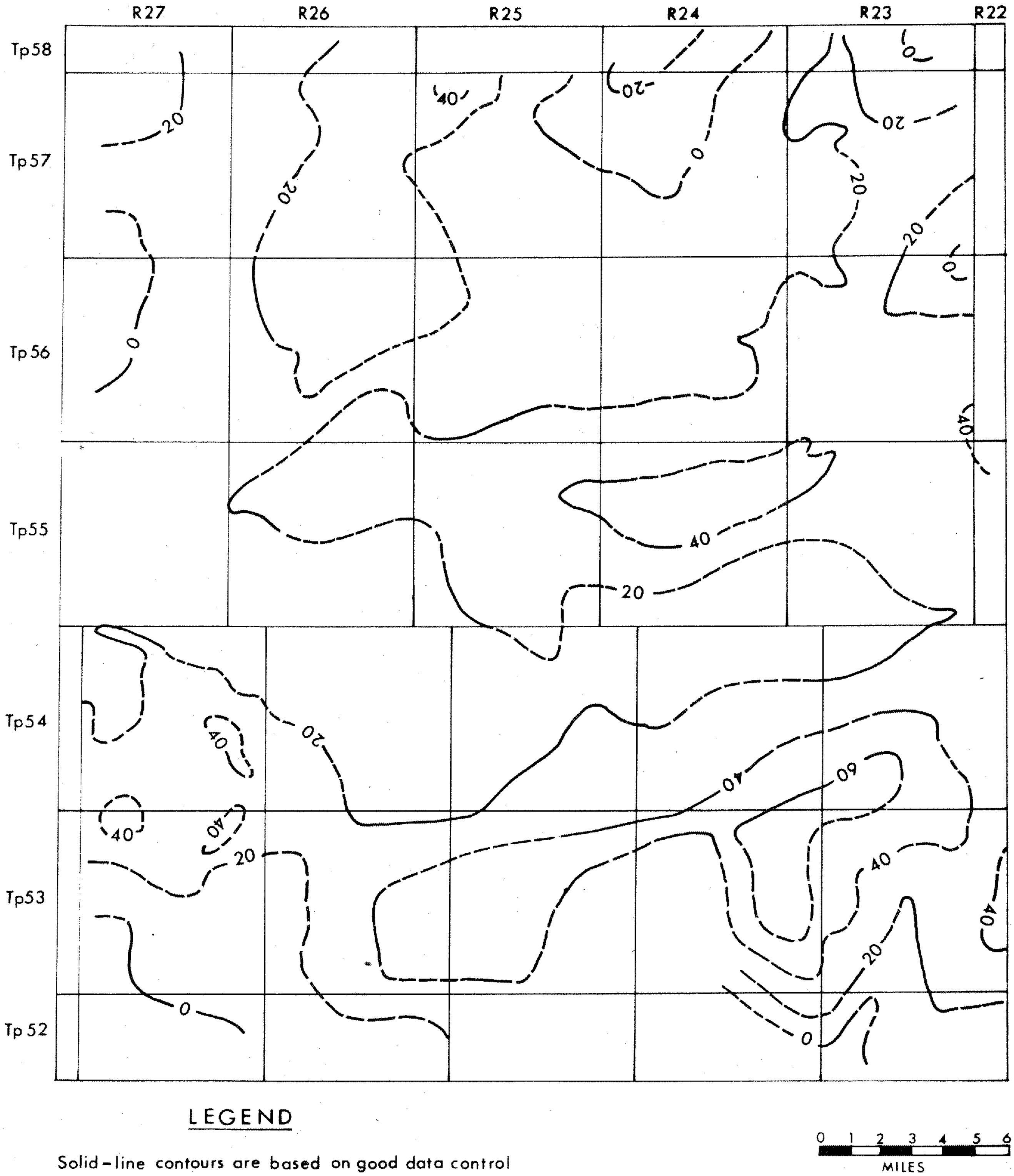


FIGURE 49. Water level differences (Drift minus Upper Layer).



LEGEND

Solid-line contours are based on good data control

Dashed-line contours are based on poor data control

—20— Upper Layer water level 20 feet higher than Lower Layer water level

FIGURE 50. Water level differences (Upper minus Lower Layer).

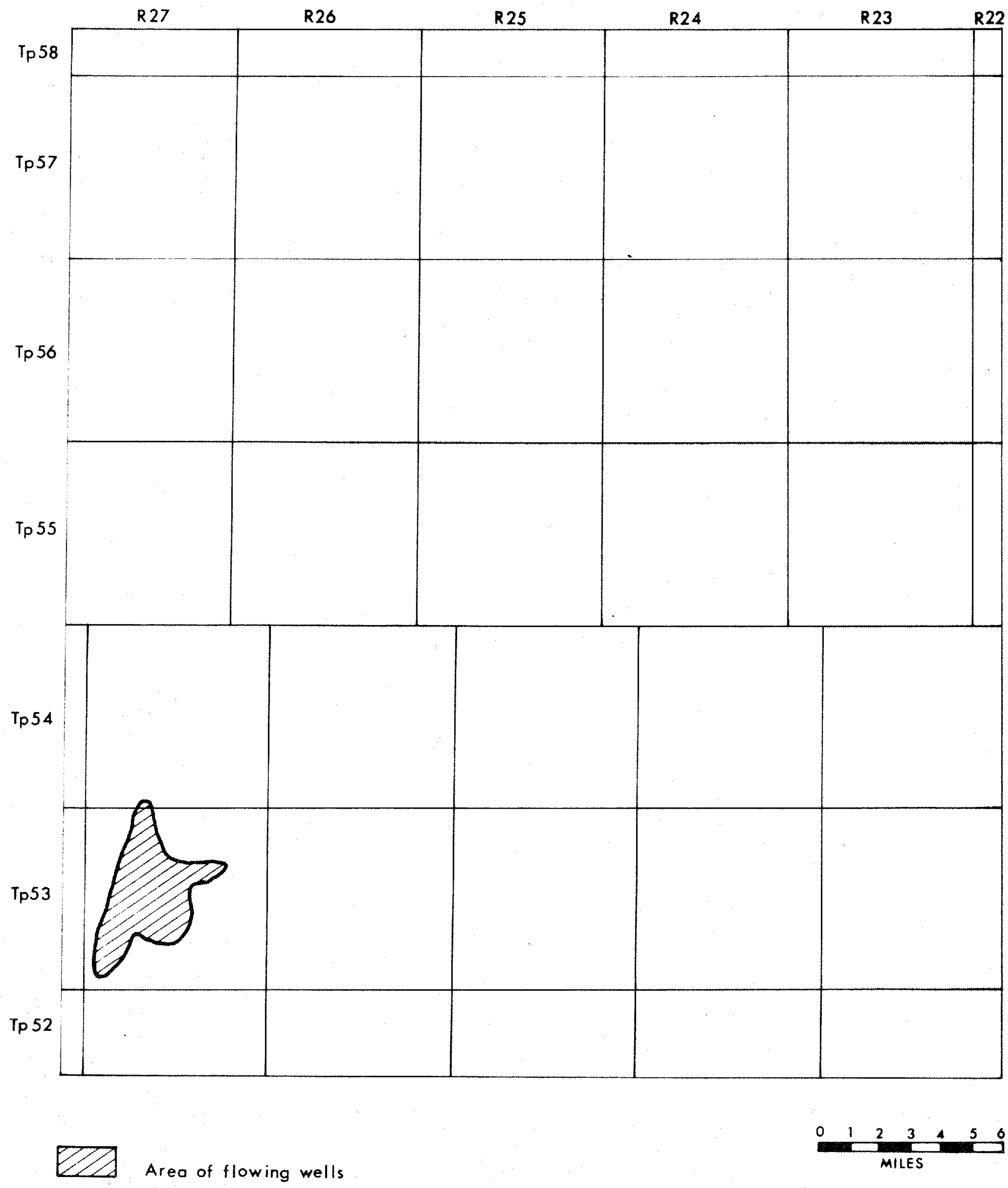


FIGURE 51. Area of flowing wells.