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Report 75-6

REGIONAL CHEMISTRY OF GROUNDWATER IN THE WAINWRIGHT AREA, ALBERTA

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CONTENTS

	Page
Abstract	1
Introduction	2
Acknowledgments	3
Physiography	3
Climate	3
Geology	5
Surficial geology	5
Bedrock geology	5
Hydrogeology	5
Groundwater flow	5
Groundwater chemistry	9
Groundwater from glacial drift from 0 to 150 feet (0 to 46 m) below the land surface	10
Groundwater from glacial drift from depths greater than 150 feet (46 m) below the land surface	12
Groundwater from the bedrock from 0 to 150 feet (0 to 46 m) below the land surface	12
Groundwater from the bedrock from 150 to 350 feet (46 to 107 m) below the land surface	14
Health aspects	16
Summary	18
References	19
Appendix A	21

ILLUSTRATIONS

Figure 1.	Topography and drainage	24
Figure 2.	Geology and glacial drift thickness	25
Figure 3.	Structural contour on top of Lea Park Formation	26
Figure 4.	Water levels in wells 0 to 150 feet (0 to 46 m) deep	27
Figure 5.	Water levels in wells 150 to 350 feet (46 to 107 m) deep	28

		Page
Figure 6.	Water levels in wells 350 to 500 feet (107 to 152 m) deep	29
Figure 7.	Total dissolved solids; glacial drift, 0 to 150 feet (0 to 46 m)	30
Figure 8.	Hardness; glacial drift, 0 to 150 feet (0 to 46 m) ...	31
Figure 9.	Sodium plus potassium; glacial drift, 0 to 150 feet (0 to 46 m)	32
Figure 10.	Alkalinity; glacial drift, 0 to 150 feet (0 to 46 m)	33
Figure 11.	Sulfate; glacial drift, 0 to 150 feet (0 to 46 m)	34
Figure 12.	Chloride; glacial drift, 0 to 150 feet (0 to 46 m) ...	35
Figure 13.	Total dissolved solids; bedrock, 0 to 150 feet (0 to 46 m)	36
Figure 14.	Hardness; bedrock, 0 to 150 feet (0 to 46 m)	37
Figure 15.	Sodium plus potassium; bedrock, 0 to 150 feet (0 to 46 m)	38
Figure 16.	Alkalinity; bedrock, 0 to 150 feet (0 to 46 m)	39
Figure 17.	Sulfate; bedrock, 0 to 150 feet (0 to 46 m)	40
Figure 18.	Chloride; bedrock, 0 to 150 feet (0 to 46 m)	41
Figure 19.	Fluoride; bedrock, 0 to 150 feet (0 to 46 m)	42
Figure 20.	Total dissolved solids; bedrock, 150 to 350 feet (46 to 107 m)	43
Figure 21.	Hardness; bedrock, 150 to 350 feet (46 to 107 m)	44
Figure 22.	Sodium plus potassium; bedrock, 150 to 350 feet (46 to 107 m)	45
Figure 23.	Alkalinity; bedrock, 150 to 350 feet (46 to 107 m) ...	46
Figure 24.	Sulfate; bedrock, 150 to 350 feet (46 to 107 m)	47
Figure 25.	Chloride; bedrock, 150 to 350 feet (46 to 107 m)	48
Figure 26.	Fluoride; bedrock, 150 to 350 feet (46 to 107 m)	49

TABLES

Table 1.	Mean annual stream flows	4
Table 2.	Geological and hydrogeological properties of bedrock units	6

REGIONAL CHEMISTRY OF GROUNDWATERS
OF THE WAINWRIGHT AREA, ALBERTA

Abstract

The Wainwright map area is located southeast of Edmonton between longitudes 110° and 112° west and latitudes 52° and 53° north. It covers about 6,000 square miles (15,500 km^2), lying mostly in the aspen parkland vegetational assemblage. Average precipitation is about 14 inches (36 cm) annually, while potential evapotranspiration is about 21 inches (54 cm) annually.

Geological units of hydrogeological interest include glacial drift, preglacial sands and gravels, Horseshoe Canyon Formation, Bearpaw Formation, Belly River Formation and Lea Park Formation.

Contour maps of the following hydrochemical parameters for various depth intervals are presented:

1) total dissolved solids
2) hardness
3) sodium plus potassium
4) alkalinity
5) sulfate
6) chloride
7) fluoride.

Groundwater quality is related to the thickness and nature of the glacial drift and to the character of the underlying bedrock. Areas where the water quality is comparatively good for depths up to 500 feet (152 m) are usually overlain by 50 to 400 feet (15 to 122 m) of coarse-grained glacial drift. Rapid movement of water downward is hypothesized to account

for this good quality. Groundwater of poorer quality is commonly found in areas of thin, fine-grained drift and is apparently the result of slow downward movement of water. The marine Bearpaw Formation accentuates this situation.

Considered regionally, the area acts as a recharge area for groundwater flowing to the northwest. However, much water is probably discharged locally in sloughs.

INTRODUCTION

The area covered by this study is located between longitudes 110° and 112° west and latitudes 52° and 53° north. It covers townships 35 through 46, ranges 1 through 14, west of the fourth meridian. Under the National Topographic System, the area is designated as 73D, and is covered by the 1:250,000 map: Wainwright, Alberta.

The area is dominantly utilized for mixed farming with certain portions suitable only for stock raising due to relatively great local relief and poorly arable soils. The numerous farms result in relatively abundant groundwater information for depths less than 500 feet (152 m).

Petroleum production is a major industry of the area, and about half of the area contains established petroleum fields.

This publication is intended to supplement Alberta Research Council Report 75-1, Hydrogeology of the Wainwright area, Alberta (Hackbarth, 1975). Therefore, it will not deal with the availability of groundwater, a subject which is discussed at length in the above publication. Detailed discussion of groundwater flow and more particularly groundwater chemistry is presented in this report.

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PHYSIOGRAPHY

The general trend of the topography of the area is shown in figure 1. High areas, exceeding 2,800 feet (850 m) above mean sea level, occur in the Neutral Hills which are located in the south-central portion of the area. Much of the rest of the southern one third of the study area varies between 2,400 and 2,700 feet (730 to 820 m) above sea level while most of the northern half is below an elevation of 2,200 feet (670 m).

The central and northern portions of the area are typically hummocky and contain many undrained depressions. An internal drainage system is characteristic of this area.

The Battle River is incised several hundred feet throughout the area. The valley is fairly narrow in the upper reaches but widens downstream. There are no gauging stations on the Battle River within the map area. However, there are stations at Forestburg, Alberta just west of the map boundary and at Unwin, Saskatchewan, just downstream from the eastern map boundary. Table 1 presents mean annual flows for the Battle River at these stations, as well as for Ribstone Creek at Edgerton, Alberta. It is seen from the table that the Battle River gains about two- to three-fold in flow while passing through the area.

CLIMATE

Mean annual precipitation varies from about 13 inches (33 cm) in the southeast to slightly over 15 inches (38 cm) in the northwest. Calculated potential evapotranspiration (Thornthwaite and Mather, 1957) is about 21 inches (54 cm) per year while evaporation (Bruce and Weisman, 1967) is slightly less than 35 inches (90 cm) per year. The average annual temperature is about 36°F (2°C).

Table 1. Mean annual streamflows

River or creek (location)	Year						Mean for period of record 1970
	1972	1971	1970	1969	1968	1967	
Battle (Forestburg, Alberta)	165	274	196	156	23.6	-	125
Battle (Unwin, Sask.)	-	431	406	368	118	171	302
Ribstone (Edgerton, Alberta)	12.2	31.4	22.7	40.2	15.5	11.5	22.9
Iron (Hardisty, Alberta)	12.9	39.4	25.1	40.4	20.3	8.4	26.3

STATION LOCATIONS:

Forestburg, Alberta - NW ¼, Sec. 35, Tp. 41, R. 17, W. 4th Mer.

Unwin, Saskatchewan - NW ¼, Sec. 4, Tp. 46, R. 27, W. 3rd Mer.

Edgerton, Alberta - NW ¼, Sec. 35, Tp. 43, R. 4, W. 4th Mer.

Hardisty, Alberta - NE ¼, Sec. 13, Tp. 43, R. 10, W. 4th Mer.

SOURCE:

Canada Department of the Environment (1971, 1972a, 1972b, 1972c, 1972d, 1972e, 1973a, 1973b).

Canada Department of Energy, Mines and Resources (1971, 1970).

GEOLOGY

Surficial Geology

Surficial deposits in the entire area have been mapped by Bayrock (1958a, 1958b, 1967), Gravenor (1956), Gravenor and Bayrock (1955), and Gravenor and Ellwood (1957). Moraine, outwash and lacustrine deposits are the most prevalent glacial deposits. Ground moraine and hummocky moraine predominate in the western half of the area, while outwash and lacustrine deposits are more prevalent in the eastern half.

About one half of the area is covered with glacial drift less than 50 feet (15 m) thick (see Fig. 2). A major preglacial buried channel, the Battleford Valley (Christiansen, 1965) has deposits composed mostly of sand and gravel which are up to 450 feet (137 m) thick. This valley has also been referred to as the Red Deer Bedrock Channel by Farvolden (1963) and as the Wainwright Valley by Carlson and Topp (1971).

Bedrock Geology

The Horseshoe Canyon, Bearpaw, Belly River and Lea Park Formations are the bedrock units of hydrogeological interest. Table 2 presents geological and hydrogeological information concerning these units. Figure 3 presents structural contours on the top of the Lea Park Formation and shows that regionally the dip on this surface is towards the southwest.

HYDROGEOLOGY

Groundwater Flow

Groundwater level elevations in wells 0 to 150 feet (0 to 46 m) deep, 150 to 350 feet (46 to 107 m) deep and 350 to 500 feet (107 to 152 m) deep are presented in figures 4, 5 and 6, respectively. Areas in which groundwater level elevations in an interval are less than in the immediately underlying interval are indicated in figures 4 and 5. These should not be confused with areas of flowing wells since upward flow of groundwater does not

Table 2. Geological and hydrogeological properties of bedrock units

	Formation and geological description*	Usual Safe Yield	Comments
UPPER CRETACEOUS	*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.	0-5 igpm	Basal sandstone unit utilized for water supply. Coal is locally a good producer.
	Bearpaw Formation: dark grey blocky shale and silty shale; greenish glauconitic and grey clayey sandstone; thin concretionary ironstone and bentonitic beds; marine.	0-25 igpm	Three major sandstone members (Bulwark Sands) used for water supply. Potentially useful for domestic supplies in subcrop area.
	Belly River Formation: grey to greenish grey, thick-bedded, feldspathic sandstone; grey clayey siltstone, grey and green mudstone; concretionary ironstone beds; nonmarine.	5-25 igpm	Usually provides a good supply of potable water.
	Lea Park Formation: dark grey shale; pale grey glauconitic, silty shale with ironstone concretions; marine	Less than 1 igpm	Poor source of supply. Not worth drilling into for water supply.

*from Green (1972)

necessarily mean flowing wells will occur. However, in figure 4, because it represents the surficial layer, such areas should be coincident with flowing conditions for wells completed in the 150-350 foot (46 to 107 m) layer.

The reader is cautioned that this study is of a regional nature. Evaluation of groundwater flow for this report did not consider the local flow systems, and local flow systems are undeniably important in areas of hummocky moraine. However, the volumes of water entering local, intermediate and regional flow systems are open to question because estimates vary (Meyboom, 1966, 1967), so this study did not attempt to evaluate these volumes.

Locally water moves toward and discharges into the Battle River Valley; however, major groundwater discharge does not appear to take place in this valley as surficial evidence is not present. The area of upward flow into the 0 to 150 foot (0 to 46 m) depth interval in Tps. 41, 42 and 43, R. 1 and 2 roughly coincides with an area of observed groundwater discharge phenomena (springs, salt deposits and flowing wells). The extremely saline Reflex Lake (total dissolved solids approximately 35,000 ppm) lies in this area.

The discharge area in Tp. 36, R. 4 and 5 also exhibits some surficial expression of its existence. Surficial salt deposits are observed in the vicinity of Sounding Lake which is moderately saline. As will be seen in another section, however, there is no reflection of this area in the hydrochemical maps of the drift.

The basic control on groundwater flow in this shallow interval appears to be the surface topography. However, the regional nature of this study does not permit presentation of the local aspects of groundwater flow in the hummocky moraine in the area. On a larger scale, a multitude of local flow systems could be shown representing the movement of groundwater adjacent to each local depression.

Figure 5 shows the distribution of water levels in wells 150 to 350 feet (46 to 107 m) deep. The pattern is very similar to topography but slightly subdued. Flow is basically from southwest to northeast. Upward flow into the layer is indicated in the vicinity of Tp. 42, R. 2 and 3. This is, as indicated before, an area where surficial expressions of groundwater discharge are observed. These phenomena can be related, at this location, to upward flow of groundwater from depths up to 350 feet (107 m).

Upward flow of groundwater into this interval appears to be taking place over a much greater area than upward flow out of this interval. This probably can be attributed to the presence of relatively permeable zones within this interval which act as receivers of upward moving water and transmit it laterally. There is no correspondence of upward flow areas between this interval and the overlying one except for the area near Tp. 42, R. 2 and 3 that was mentioned previously.

Flow towards the Battle River occurs locally as indicated in figure 5 but does not appear to be widely prevalent.

Figure 6 depicts the pattern of groundwater flow as discerned from wells 350 to 500 feet (107 to 152 m) deep. The contours continue to mirror the topographic surface in a subdued manner. Flow continues to be basically from southwest to northeast. The presence of the Battle River Valley appears to have some influence at this depth, as flow does appear to be taking place towards it. Consideration of a larger map area would present more definitive results on this point.

Viewed on a regional basis, it may generally be said that groundwater flow:

1) is from southwest to northeast
2) is dominantly downward from the water table
3) may be influenced somewhat by the Battle River Valley.

That is, the region is a recharge area for regional groundwater flow systems whose size is larger than the study area.

Groundwater Chemistry

Hydrochemical data from the area were separated into several groups based on certain criteria related to well depth and bedrock surface elevation. Initially, the data were separated into two groups based on whether the well from which the sample was obtained terminated within the glacial drift or the bedrock. Then these groups were subdivided on the basis of depth of the well. Thus five groupings of the data were formed:

1) groundwater from glacial drift from 0 to 150 feet (0 to 46 m)
2) groundwater from glacial drift from depths below the land surface greater than 150 feet (>46 m)
3) groundwater from the bedrock from 0 to 150 feet (0 to 46 m) below the land surface
4) groundwater from the bedrock from 150 to 350 feet (46 to 107 m) below the land surface
5) groundwater from the bedrock from 350 to 500 feet (107 to 152 m) below the land surface.

The division of samples into groups derived from glacial drift and from bedrock is intended to show the difference in water quality in these two lithologically different units. The further division of samples by depth of well allows examination for changes with depth. The reader should make use of the drift thickness map (Fig. 2) to determine whether a well of a certain depth at a particular location will be completed in drift or bedrock.

The calculation of epm (equivalent per million) was based on procedures outlined by Le Breton and Vanden Berg (1965). Analysis of the data was done according to a procedure developed by Newton (1973) and employed by Hackbarth (1974). Appendix A presents a synopsis of values of the chemical parameters for the various intervals.

Iron in solution in groundwater is usually in the ferrous (Fe^{++}) state. Once the water is aerated, as during pumping and distribution, the iron oxidizes to the ferric (Fe^{+++}) state, a form which readily reacts with hydroxide ions. Iron thus precipitates to the bottom of any water sample container and may not be included in an analysis. This condition can be accounted for by proper handling of the sample; however, most of the water analyses available for and used in this report resulted from samples which received no special handling. Thus the concentrations reported for iron are very questionable values, and are not included in this report as they would be misleading.

Groundwater from glacial drift from 0 to 150 feet (0 to 46 m) below the land surface

Figure 7 shows the pattern of total dissolved solids for this interval. The pattern is very similar to the pattern of drift thickness shown in figure 2. Generally the areas of thick drift tend to have lower total dissolved solids. This is probably due to the fact that in this area the drift tends to become coarser as it thickens and to have less local bedrock material contained in it. This results in rapid movement of water through the thick glacial material with the consequent reduction in time for dissolution of mineral material. The average total dissolved solids value for this interval is 935 ppm.

The pattern of hardness in this interval is presented in figure 8. An area of relatively high hardness values roughly coincides with the subcrop of the Bearpaw Formation. This may be due to incorporation of gypsum from the Bearpaw into the glacial drift. The average value of hardness from samples in this interval is 410 ppm.

The distribution of the concentration of sodium plus potassium in equivalents per million is shown in figure 9. Lower values are seen in areas where drift is comparatively thick. The area in the south and west where values exceed 16 epm roughly coincides with the subcrop of the Bearpaw and Horseshoe Canyon Formations. Areas of low hardness roughly correspond to areas of relatively high sodium plus potassium. This is due to higher cation exchange capacity in the areas of finer-grained, thinner drift into which a large amount of sodium-rich Bearpaw Formation has been incorporated. The average value of sodium plus potassium in this interval is 7.7 epm.

Alkalinity is also distributed in a manner similar to total dissolved solids and sodium plus potassium. Values of this parameter seem to relate inversely to the drift thickness: areas of thick drift have low alkalinity, areas of thin drift have higher values. Alkalinity is the summation of carbonate and bicarbonate anions expressed as calcium carbonate, and since there is virtually no carbonate species present, the map (Fig. 10) represents bicarbonate ion. The average value of alkalinity in this interval is 362 ppm.

Figure 11 presents the pattern of sulfate distribution in this interval. Again, the concentrations tend to be inversely related to the thickness of the drift. Somewhat higher values are observed in the southwest where the drift is thin and the Bearpaw Formation subcrops. The average sulfate value is 335 ppm.

The concentration of chloride ion tends to be quite low in this interval, the average value being 30 ppm. Figure 12 shows that the lower values of chloride tend to occur in the central portion of the area, where the drift is thickest.

The small areas of high chloride values in Tp. 42, R. 3 and Tp. 43, R. 10 are also the location of surficial expressions of groundwater discharge; however, not all of the areas can be correlated with those type of features.

The distribution of fluoride ion in the drift is not presented. The average value is 0.3 ppm.

Groundwater from the glacial drift from depths greater than 150 feet (46 m) below the land surface

Only a small portion of the area has glacial drift thicker than 150 feet (46 m) (Fig. 2). Data on the quality of water in the deep portions of buried valleys are not abundant. In the western portions of the buried valley systems, calcium and magnesium appear to be the dominant cations while sodium and potassium are more abundant in the east. The dominant anion is bicarbonate. Total dissolved solids content tends to be low, usually less than 1,000 ppm with some areas having less than 500 ppm. The fact that the quality is quite good even to depths of 300 feet (91 m) reflects the rapid movement of water in the coarse-grained deposits of the buried valleys.

Groundwater from the bedrock from 0 to 150 feet (0 to 46 m) below the land surface

The chemical maps of this interval note those areas where the glacial drift thickness is more than 150 feet. Within these areas no bedrock would be encountered in a borehole less than 150 feet (46 m) deep so the mapped parameters are undefined.

Values of total dissolved solids remain comparatively low in the central portion of the map area (Fig. 13) where the overlying glacial drift is thick. Generally, areas where the overlying drift is thin tend to have much higher concentrations of dissolved solids. The rapid downward movement of water through the thick drift is reflected in the total dissolved solids content of this bedrock interval. The area of Bearpaw subcrop coincides quite well with areas where total dissolved solids content is higher. The average total dissolved solids content of samples from this interval is 1,180 ppm which is about 200 ppm greater than the average for the overlying drift.

The distribution of hardness in this interval is shown in figure 14. Values are somewhat lower than in the drift as cation exchange has been taking place reducing the relative amount of calcium present. The average value of hardness is 326 ppm (as $CaCO_3$).

There does not appear to be any obvious relationship between hardness and drift thickness or bedrock geology. The higher values in the south central area are probably due to recharge of water in the Neutral Hills. Very low values of hardness appear in the west central and northwest areas where chloride concentration tends to rise.

The distribution of sodium plus potassium (Fig. 15) reflects quite strongly the existence of the marine Bearpaw Formation. Where wells of this depth encounter Bearpaw in the subsurface the concentration of sodium plus potassium rises markedly. This pattern is modified to some extent by groundwater flow patterns. In the northwest corner of the area high concentrations of sodium plus potassium extend significantly east beyond the subcrop limit of the Bearpaw; this is probably due to eastward movement of water as seen in figures 4, 5 and 6. The average value of sodium plus potassium for this interval is 12 epm.

The pattern of distribution of alkalinity (Fig. 16) does not seem to follow any readily identifiable pattern. Concentrations are usually between 400 and 600 ppm, and the average for this interval is 445 ppm.

The distribution of sulfates (Fig. 17) in this interval very distinctly reflects the bedrock geology. In areas where Bearpaw Formation is encountered in this interval the concentration of sulfates is markedly higher than in those areas where Horseshoe Canyon or Belly River underlies the drift. The abundance of sulfate minerals in the Bearpaw is the probable reason for this condition. The central area, where the glacial drift is thick, shows comparatively low values of sulfate. Bedrock in this area is the Belly River Formation which contains little sulfate material. The average sulfate value in this interval is just over 400 ppm.

The pattern of chloride distribution (Fig. 18) seems to be influenced by local discharge areas. The relatively high values occurring in Tp. 43, R. 9 and 10 correlate with observations of surficial features related to groundwater discharge. This location is in the valley of Iron Creek.

The area of relatively high chloride values in Tp. 42, R. 11 and 12 was not investigated extensively for surficial expressions of groundwater discharge. However, the area does correspond roughly with a relative high of chloride concentration in the overlying drift as seen in figure 12. At very low elevations in this particular area a few flowing wells do occur. Bellshill Lake, however, is not saline. The two areas of higher chlorides coincide with the lowest hardness values observed in the area. The average value of 32 ppm for chloride concentration is slightly greater than in the comparable drift interval where the value is 30 ppm.

The concentration of fluorides remain generally quite low (Fig. 19) although higher concentrations occur in the northwest area. The average value is 0.4 ppm.

Groundwater from the bedrock from 150 to 350 feet (46 to 107 m) below the land surface

The chemical maps for this interval indicate the area where the glacial drift is thicker than 350 feet (107 m). In this area no bedrock will be encountered at depths up to 350 feet (107 m).

The distribution of total dissolved solids in this bedrock interval (Fig. 20) is still related to the thickness of the glacial drift. In the central portions of the area, where drift tends to be thicker, the total dissolved solids content tends to be low. The rapid movement of water downward through the thick, coarse-grained drift keeps the total dissolved solids content low. Those areas which have less than 50 feet (15 m) of drift cover tend to have groundwater with dissolved solids content in excess of 1,000 ppm.

The influence of the Bearpaw Formation on total dissolved solids content does not seem to be as great as in the overlying interval. There is still a tendency for higher values in the area where water in this interval comes from the Bearpaw but the influence of topography, particularly near the Neutral Hills, may also play an important role.

It is of interest to note that the average value of total dissolved solids has not changed from the overlying interval to this interval.

Figure 21 presents the distribution of hardness in this depth interval. Hardness values continue to decline with depth into the bedrock as cation exchange takes place between the sodium-rich shales and the calcium-rich water moving downward. The average value for hardness in this interval is 273 ppm. There appears to be no consistent relationship between either drift thickness or bedrock geology and the hardness of the groundwater in this interval.

The concentration of sodium plus potassium continues to increase with depth into the bedrock. The average value of this parameter is 16 epm in this interval. The influence of the areas of thick drift is shown in figure 22. In the central portions of the map area the concentration of sodium plus potassium is quite low compared with those areas where the glacial drift is thicker.

Alkalinity values are higher in this interval than in the overlying one. The average alkalinity value in the interval is 535 ppm. Figure 23 presents the distribution of alkalinity values and shows the well established strong correlation between relatively low concentrations and thick drift.

The average sulfate value in this interval is 273 ppm, much lower than in the overlying interval. This suggests that the sulfates are undergoing reduction to sulfides. Figure 24 shows that even at these depths there is still some local influence of the Bearpaw Formation on the sulfate concentration in the south central portion of this area. Relatively high sulfate values are observed here and probably represent water derived from the Bearpaw Formation.

Figure 25 shows that higher chloride concentrations are observed in the western portion of the map area. This represents quite a drastic modification in the chloride distribution pattern observed in the overlying interval (Fig. 18). Not only are observed values greatly increased but there is also a northwestward shift.

Comparison of the distribution of chloride ions with the areas of upward flow in figure 5 reveals that several of the areas of high concentration coincide quite well with upward moving groundwater. Apparently, chloride ions are being moved upward in these areas. The area of upward flow in Tps. 42 and 43, R. 2, 3 and 4 continues into the overlying 0 to 150 foot (0 to 46 m) depth interval (Fig. 4); however, the relative highs of chloride do not appear in either the overlying bedrock or drift intervals (Figs. 12 and 18). A possible explanation is that the chloride-rich water moves laterally eastward along the highly permeable deposits of the Battleford Buried Valley.

The distribution of fluoride ion is presented in figure 26. The average fluoride concentration for samples from this interval is 0.9 ppm. Lower values tend to occur in the central and northeast portions of the area where the glacial drift is thickest. This again indicates the relatively rapid downward movement of water to this depth.

Health Aspects

Compared to current water quality standards for Alberta (see Appendix A) groundwater in the area is not exceptionally good. Average total dissolved solids content tends to be very close to or greater than the standard in water from many wells at depths less than 500 feet (152 m). Average sulfates tend to exceed standards at depths less than about 350 feet (107 m). Alkalinity values average in excess of 500 ppm in wells deeper than 150 feet

(46 m). The average value of iron concentrations is much greater than health standards but because of previously stated reasons may not be a valid representation. Sodium (plus potassium) tends to be in excess of health standards at depths greater than 150 feet (46 m).

Nitrate pollution is another, perhaps more pressing, problem for the area. This problem can be discussed from two aspects: rural nitrate pollution and urban nitrate pollution.

Rural nitrate pollution results mostly from a combination of animal wastes and poor well completion techniques. Shallow wells in this area exhibit a strong tendency to have high nitrate levels. (For purposes of this discussion "high nitrate" will be defined as concentrations in excess of 20 ppm (as NO_3^-). Although the health standard is 45 ppm, a value of 20 ppm indicates a strong degree of contamination.) About 28 percent of all analyses from wells less than 75 feet (23 m) deep located outside of towns and villages had nitrate in excess of 20 ppm. Better site location with respect to sources of nitrate pollution and much greater attention to details of completion of shallow wells could eliminate much of this problem. Drilling of deeper wells would also tend to produce lower nitrate levels.

Nitrate pollution in shallow wells in towns and villages is quite prevalent. About 60 percent of the water analyses from shallow wells in the towns of Czar, Hayter, Killam, Metiskow and Sedgewick reported over 20 ppm nitrate. Sources of nitrate in towns include privies, stockyards, fertilizer storage areas and leaking sewage lines, all of which are often concentrated in a relatively small area. It is possible that these high nitrate levels are the result of pollution in the past and that the installation of public sewerage in some of these centers will ameliorate the problem. In any event the shallow groundwater at these centers contains significant amounts of nitrate and should not be used for infants.

SUMMARY

Groundwater flow within 500 feet (152 m) of the land surface is predominantly from southwest to northeast, which is up the regional dip and parallel to topographic gradients. Viewed regionally, movement of groundwater is downward throughout most of the area. Local discharge takes place in the Battle River Valley and in the sloughs of the hummocky moraine.

Groundwater quality is linked to the thickness and nature of the glacial drift as well as to the character of the underlying bedrock unit. In general, the central portion of the area contains thicker and coarser-grained glacial deposits than peripheral areas. The resulting higher permeability allows recharging groundwater to move rapidly to depths of at least 500 feet (152 m). This rapid downward movement of water is reflected in the quality of groundwater both in the bedrock and in the drift. Areas having thinner and fine-grained glacial drift tend to show a rapid decline in water quality with depth. This is because the low permeability results in longer contact time between the water and the minerals in the glacial drift.

Those areas where the Bearpaw Formation subcrops also happen to coincide with areas of thin drift. In these locations, the incorporation of a large proportion of the Bearpaw in the drift results in poor water quality.

The Belly River Formation is of generally sandy lithology, and in many areas subcrops beneath relatively thick and coarse-grained drift. This situation facilitates rapid downward movement of water and results in good water quality in both the drift and the bedrock formation.

The basic pattern of groundwater chemistry at depths up to 500 feet (152 m) shows low values of all parameters in the central portion of the area where thick glacial drift overlies the Belly River Formation. The peripheral parts of the map area exhibit relatively higher values of dissolved constituents, a condition related to the thin nature of the drift and, in some cases, to the existence of the Bearpaw Formation.

Nitrate pollution is a common problem in wells less than 75 feet deep (23 m). Better water well location and construction techniques as well as control of sources of nitrates can lessen this problem.

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APPENDIX A

Geologic unit and interval	Number of points	Minimum value (ppm)	Maximum value (ppm)	Average value (ppm)	Health standard (ppm)
TOTAL DISSOLVED SOLIDS					
Drift					
0 to 150 foot depth	526	86	8788	935	
Bedrock					1000
0 to 150 foot depth	342	86	6278	1179	
150 to 350 foot depth	519	222	6896	1173	
350 to 500 foot depth	114	99	3512	1216	
HARDNESS (as $CaCO_3$)					
Drift					
0 to 150 foot depth	526	0	5525	410	
Bedrock					500
0 to 150 foot depth	342	0	1758	326	
150 to 350 foot depth	519	0	4092	273	
350 to 500 foot depth	114	0	719	70	
SODIUM PLUS POTASSIUM					
		(epm)*	(epm)*	(epm)*	
Drift					
0 to 150 foot depth	507	0	187	7.7	
Bedrock					
0 to 150 foot depth	332	0.2	103	12	300 (13 epm Na)
150 to 350 foot depth	519	0	100	16	
350 to 500 foot depth	114	0.9	51	19	

*If considered to be all sodium then one epm is about 23 ppm.

Geologic unit and interval	Number of points	Minimum value (ppm)	Maximum value (ppm)	Average value (ppm)	Health standard (ppm)
ALKALINITY (as $CaCO_3$)					
Drift					
0 to 150 foot depth	526	0	1920	362	
Bedrock					
0 to 150 foot depth	342	0	1920	445	500
150 to 350 foot depth	519	0	1010	535	
350 to 500 foot depth	114	0	720	525	
SULFATE					
Drift					
0 to 150 foot depth	526	0	9511	335	
Bedrock					
0 to 150 foot depth	342	0	4954	404	250
150 to 350 foot depth	519	0	4092	273	
350 to 500 foot depth	114	0	1241	148	
CHLORIDE					
Drift					
0 to 150 foot depth	526	0	648	30	
Bedrock					
0 to 150 foot depth	342	0	695	32	250
150 to 350 foot depth	519	0	1892	81	
350 to 500 foot depth	114	0	1650	244	

Geologic unit and interval	Number of points	Minimum value (ppm)	Maximum value (ppm)	Average value (ppm)	Health standard (ppm)
FLUORIDE					
Drift					
0 to 150 foot depth	222	0	3.4	0.3	
Bedrock					1.5
0 to 150 foot depth	156	0	3.2	0.4	
150 to 350 foot depth	218	0	3.0	0.6	
350 to 500 foot depth	66	0	2.6	0.9	
NITRATE (as NO_3)					
Drift					
0 to 150 foot depth	509	0	828	34	
Bedrock					45
0 to 150 foot depth	336	0	648	20	
150 to 350 foot depth	507	0	695	5.9	
350 to 500 foot depth	110	0	68	2.1	

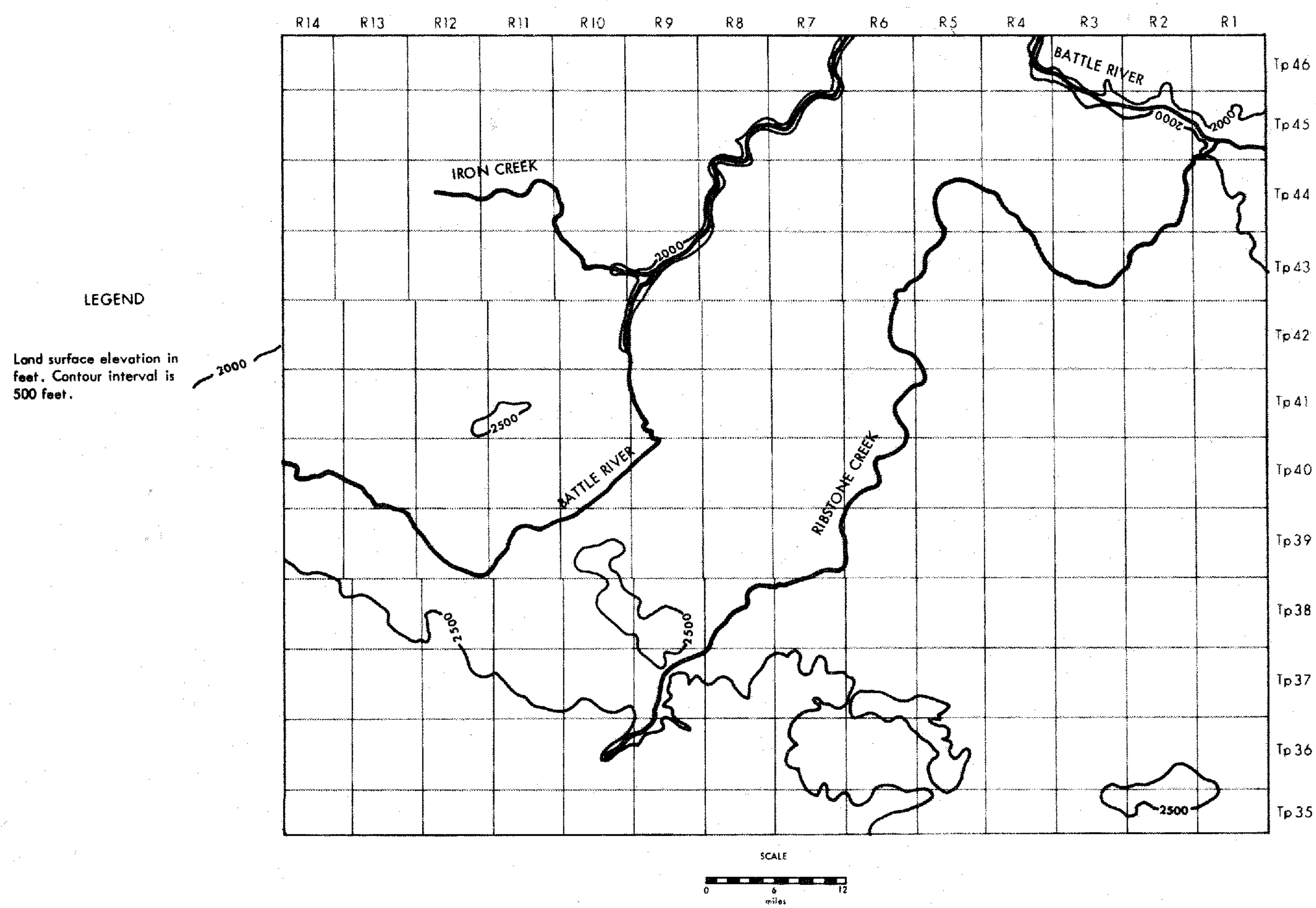

FIGURE 1. Topography and drainage.

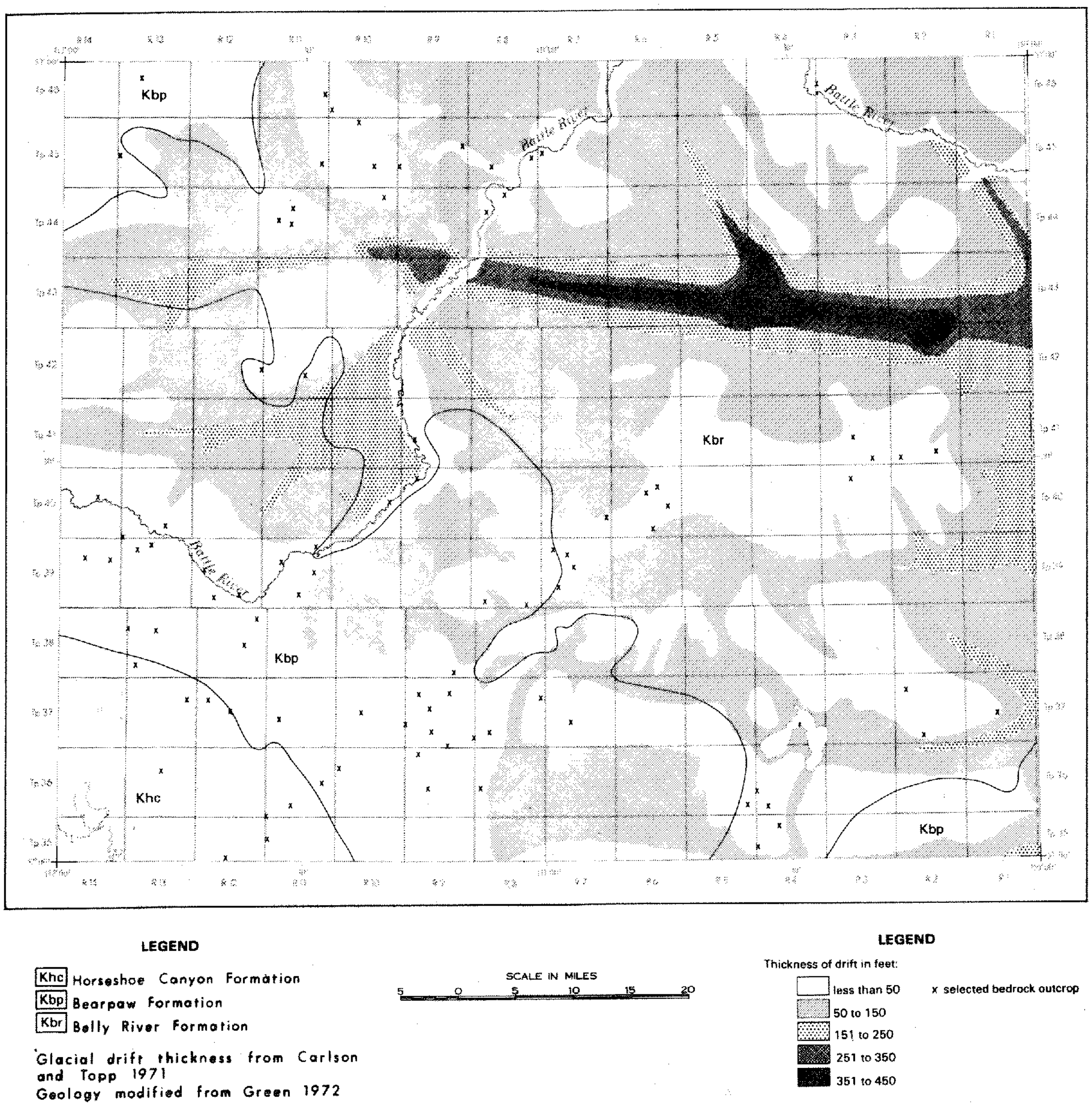

FIGURE 2. Geology and glacial drift thickness.

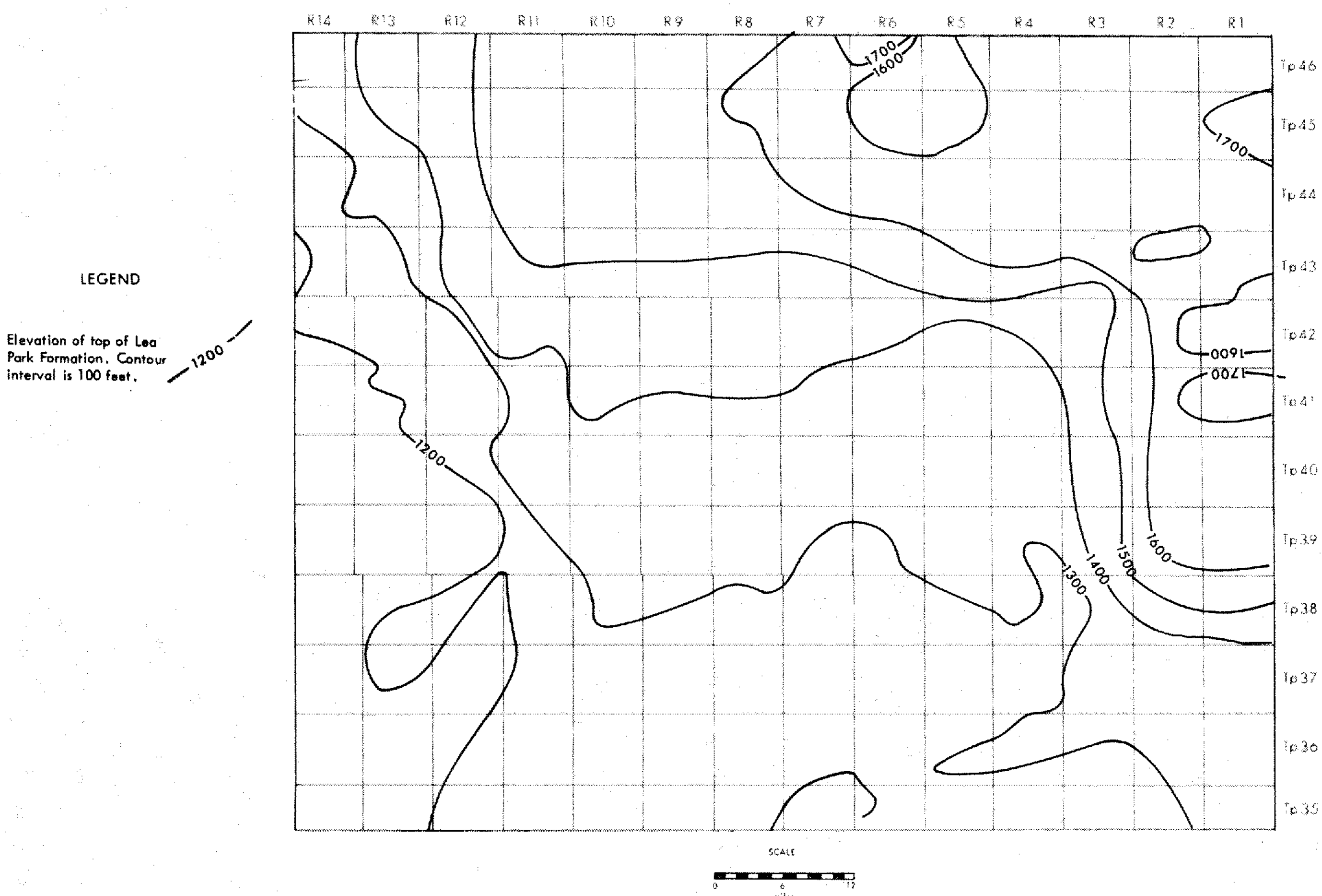

FIGURE 3. Structural contour on top of Lea Park Formation.

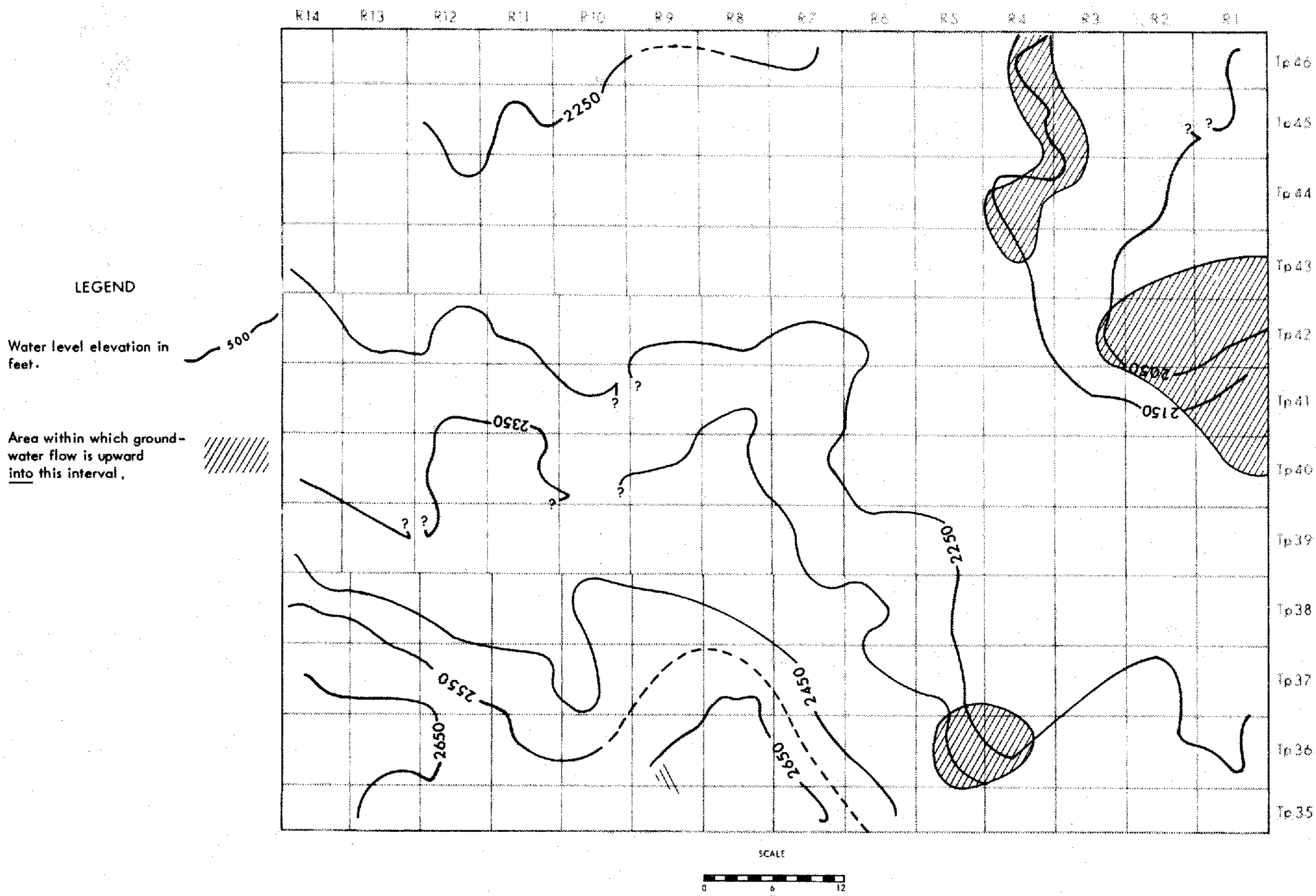

FIGURE 4. *Water levels in wells 0 to 150 feet (0 to 46 m) deep.*

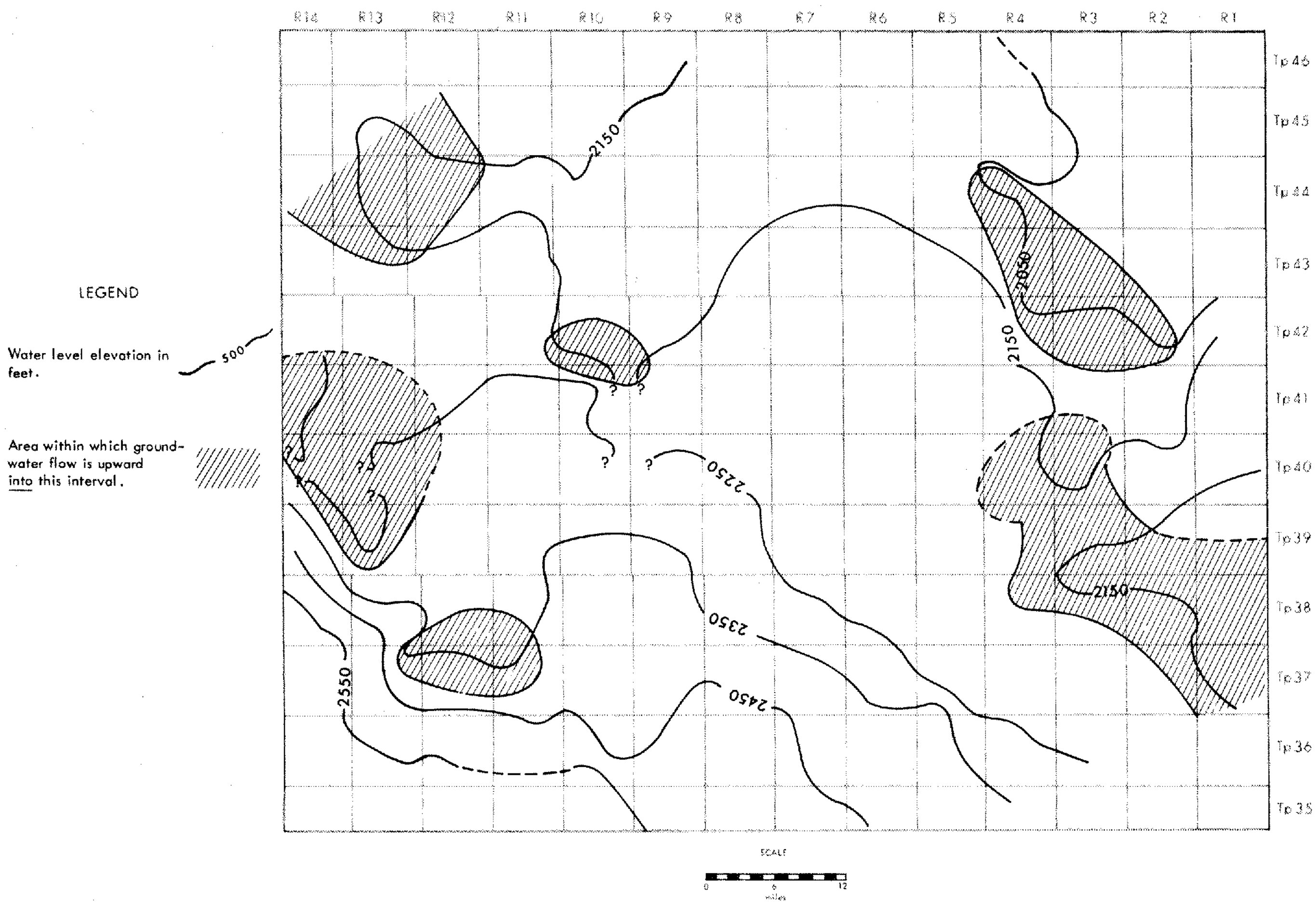

FIGURE 5. Water levels in wells 150 to 350 feet (46 to 107 m) deep.

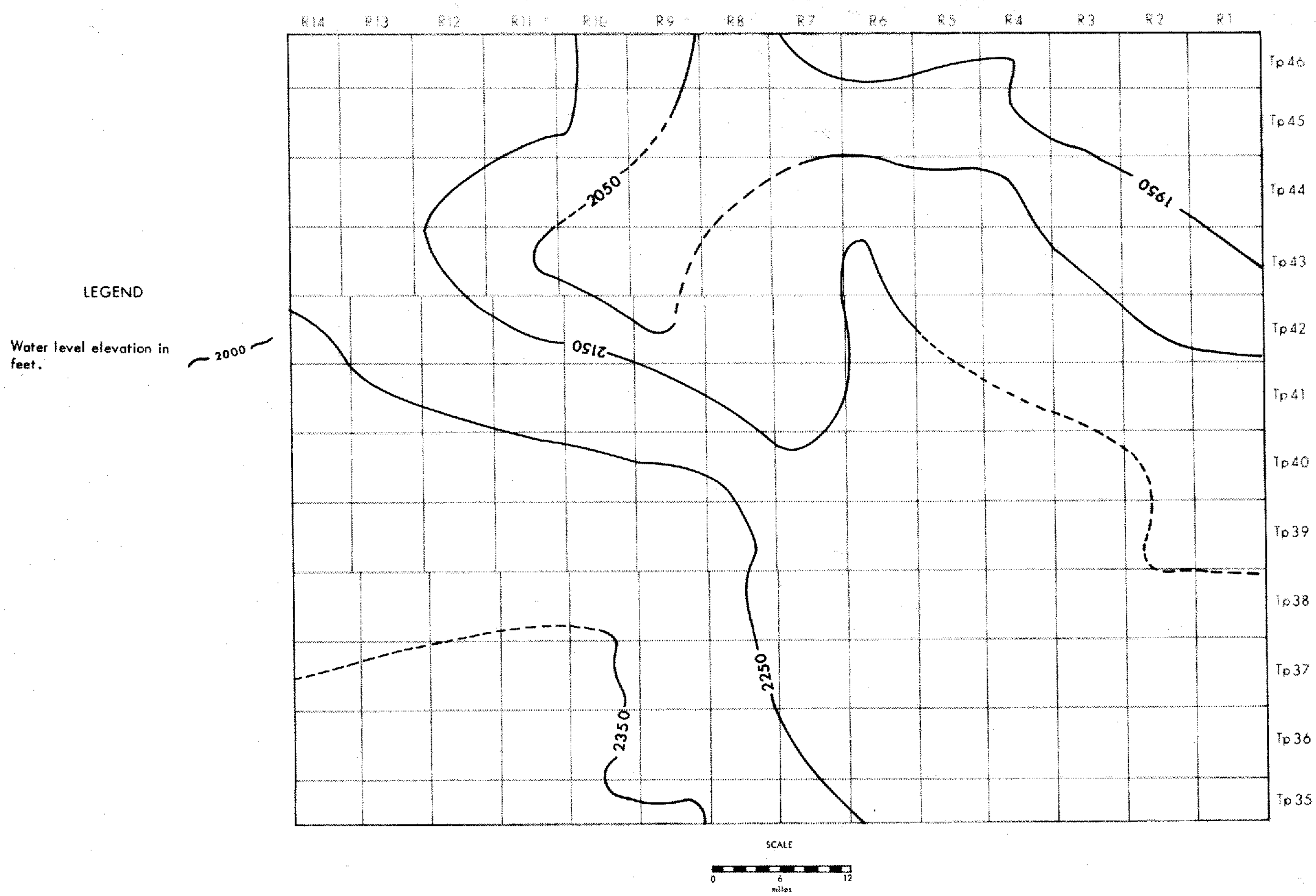

FIGURE 6. Water levels in wells 350 to 500 feet (107 to 152 m) deep.

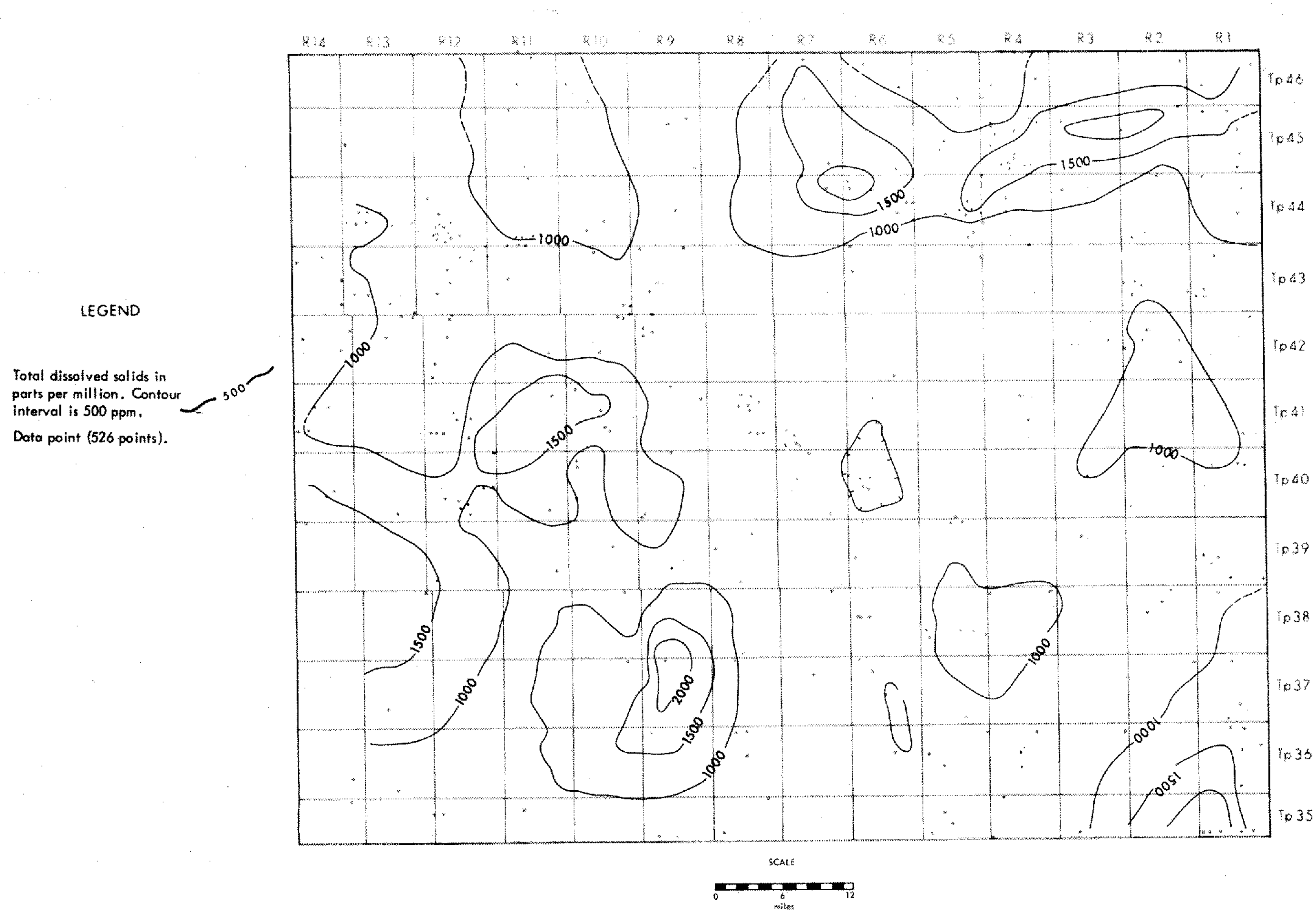

FIGURE 7. Total dissolved solids; glacial drift, 0 to 150 feet (0 to 46 m).

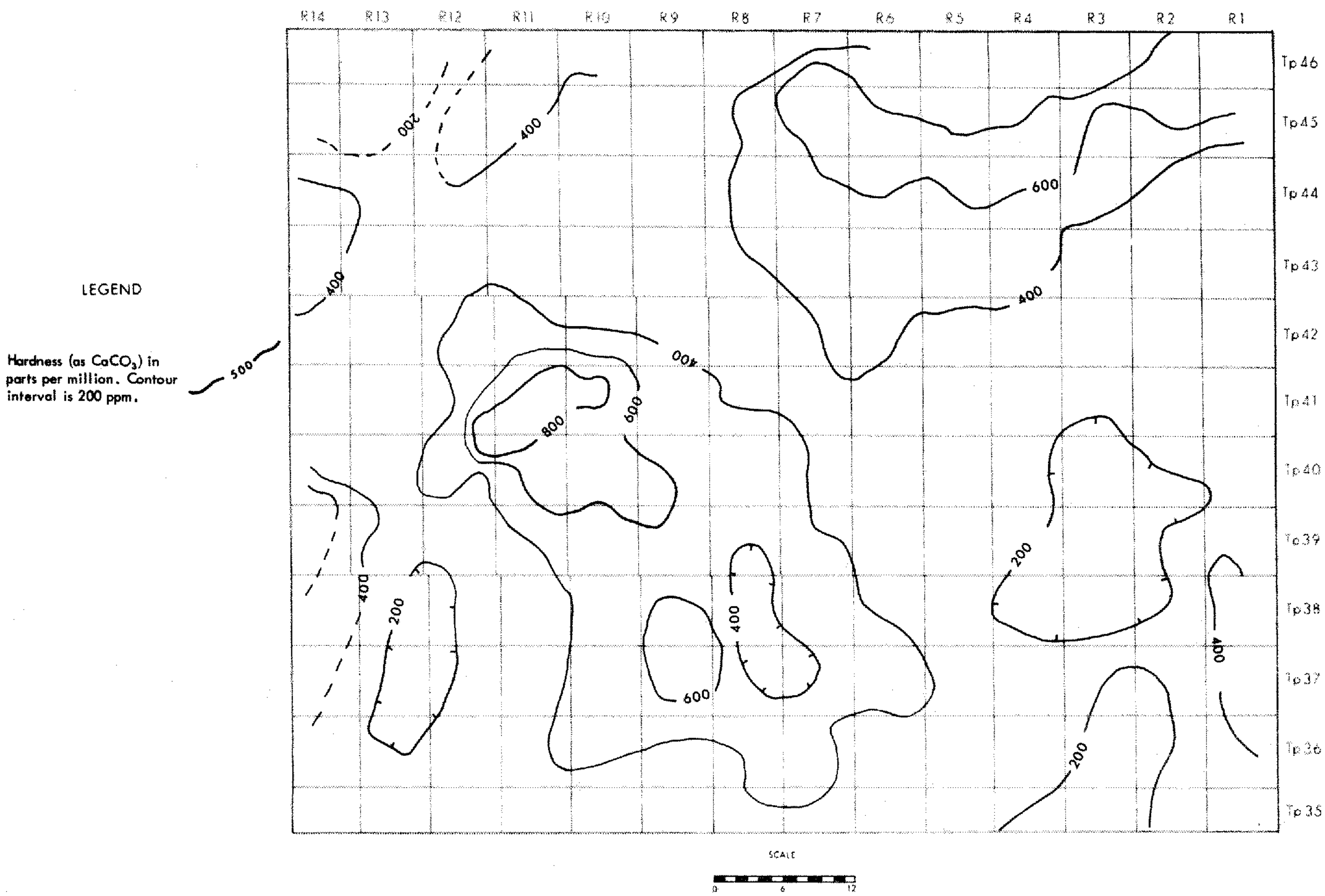

FIGURE 8. Hardness; glacial drift, 0 to 150 feet (0 to 46 m).

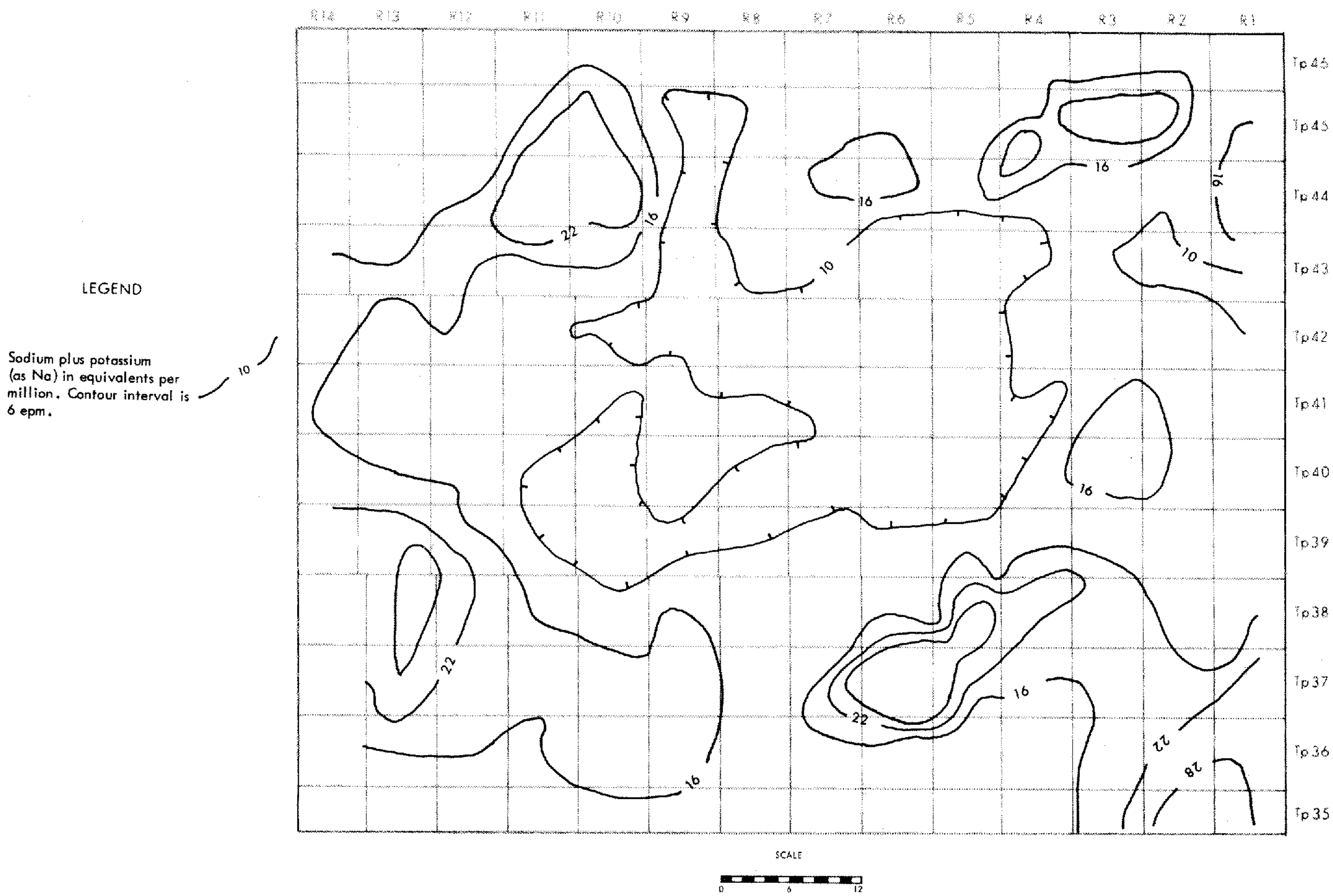

FIGURE 9. Sodium plus potassium; glacial drift, 0 to 150 feet (0 to 46 m).

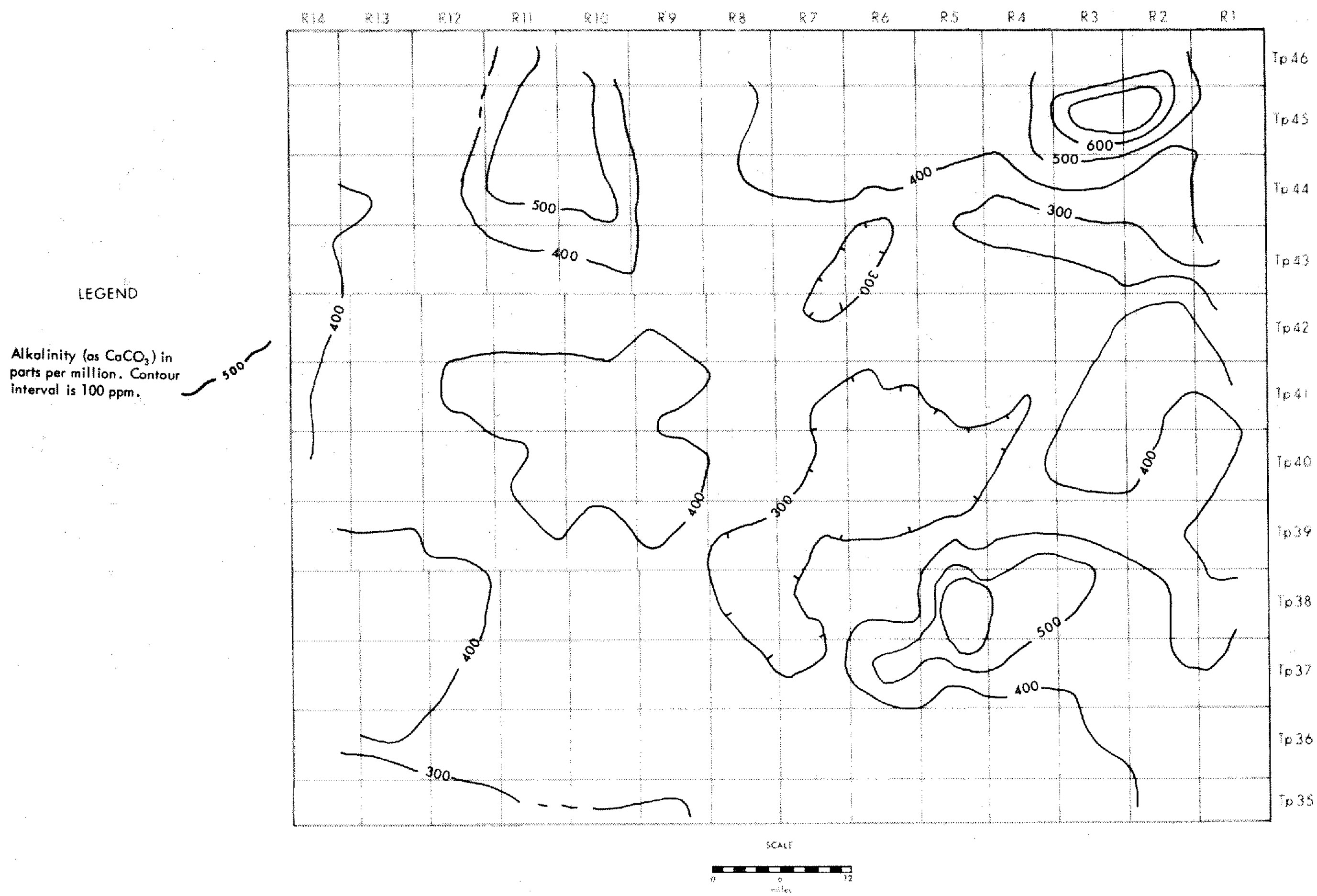

FIGURE 10. Alkalinity; glacial drift, 0 to 150 feet (0 to 46 m).

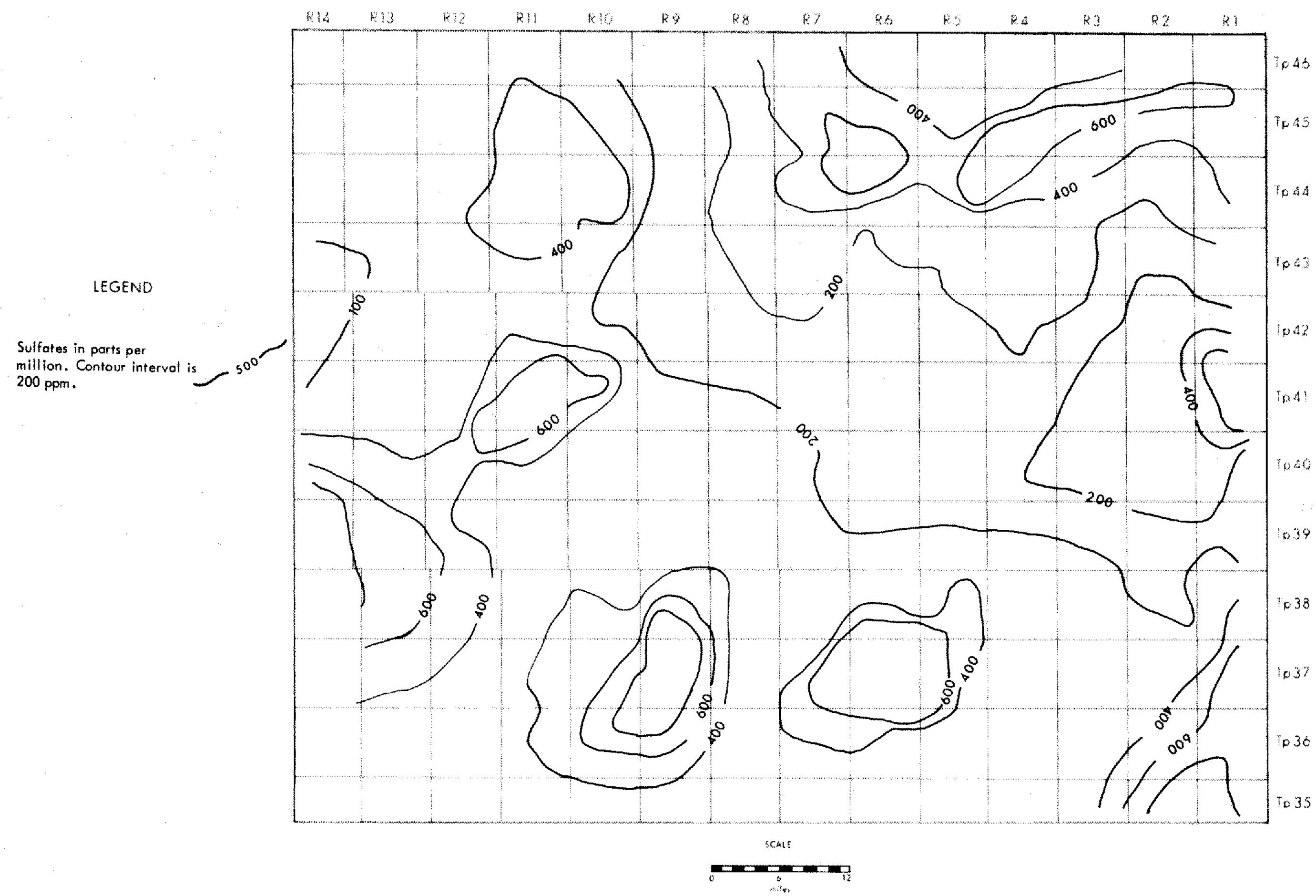

FIGURE 11. Sulfate; glacial drift, 0 to 150 feet (0 to 46 m).

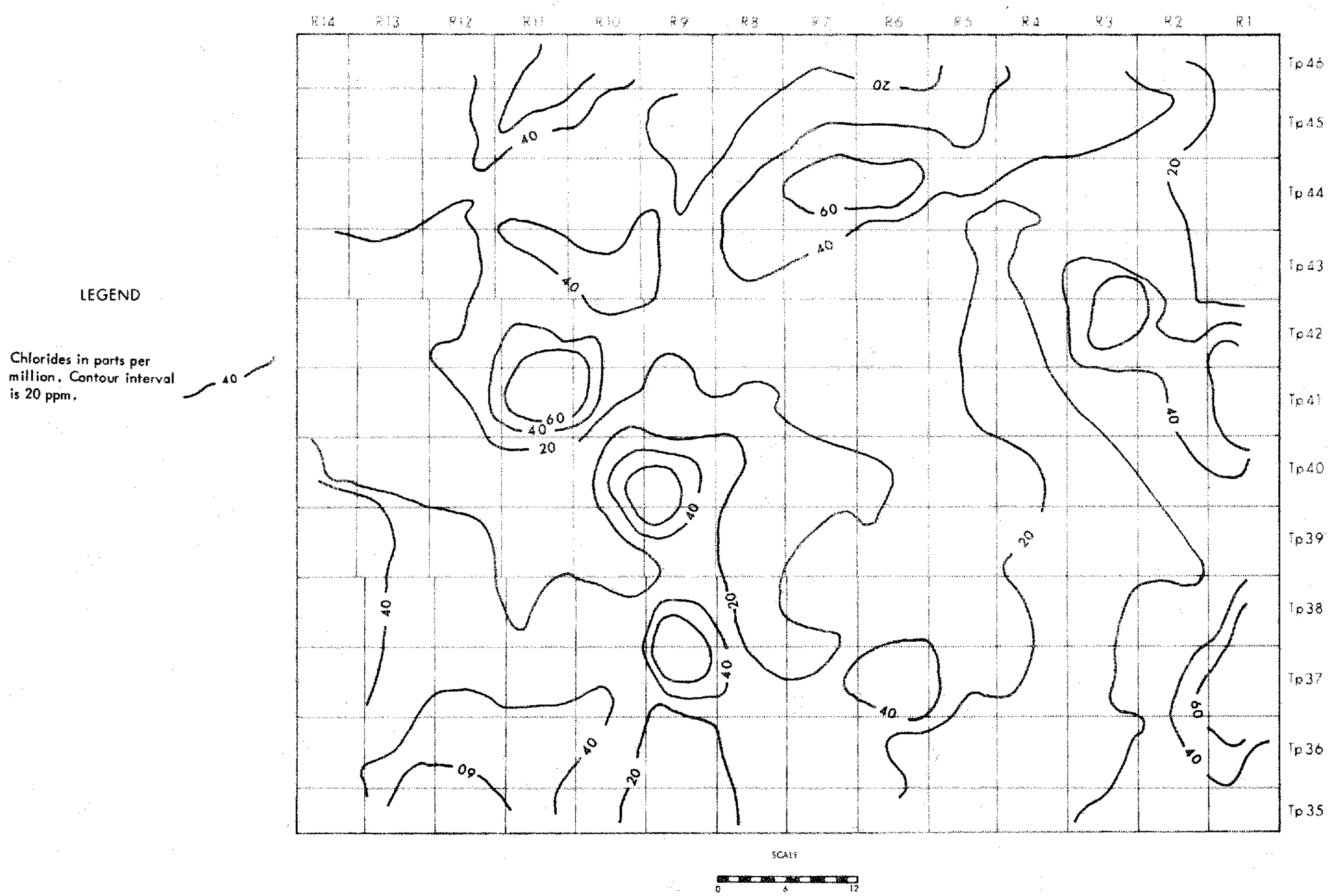

FIGURE 12. Chloride; glacial drift, 0 to 150 feet (0 to 46 m).

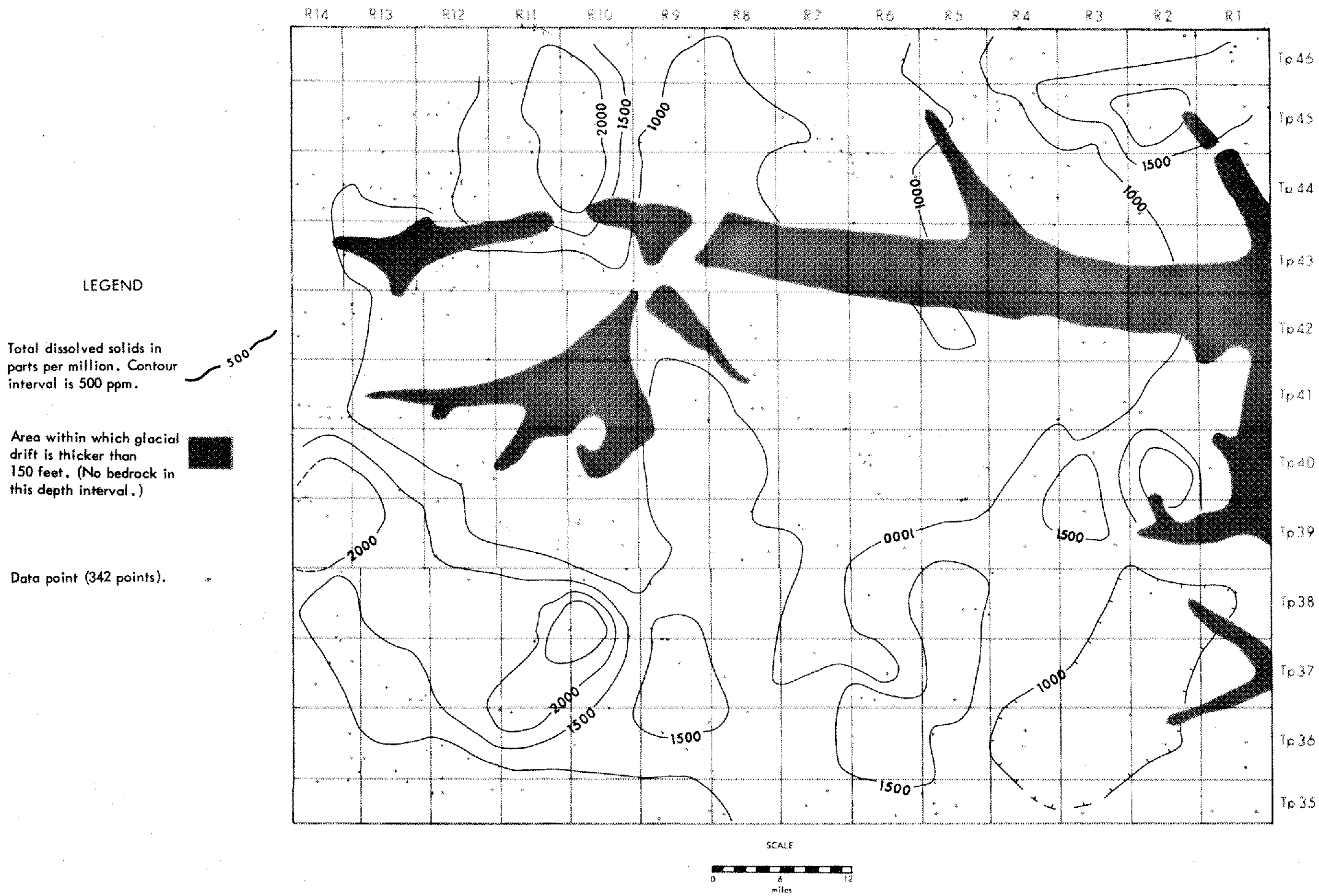

FIGURE 13. Total dissolved solids; bedrock, 0 to 150 feet (0 to 46 m).

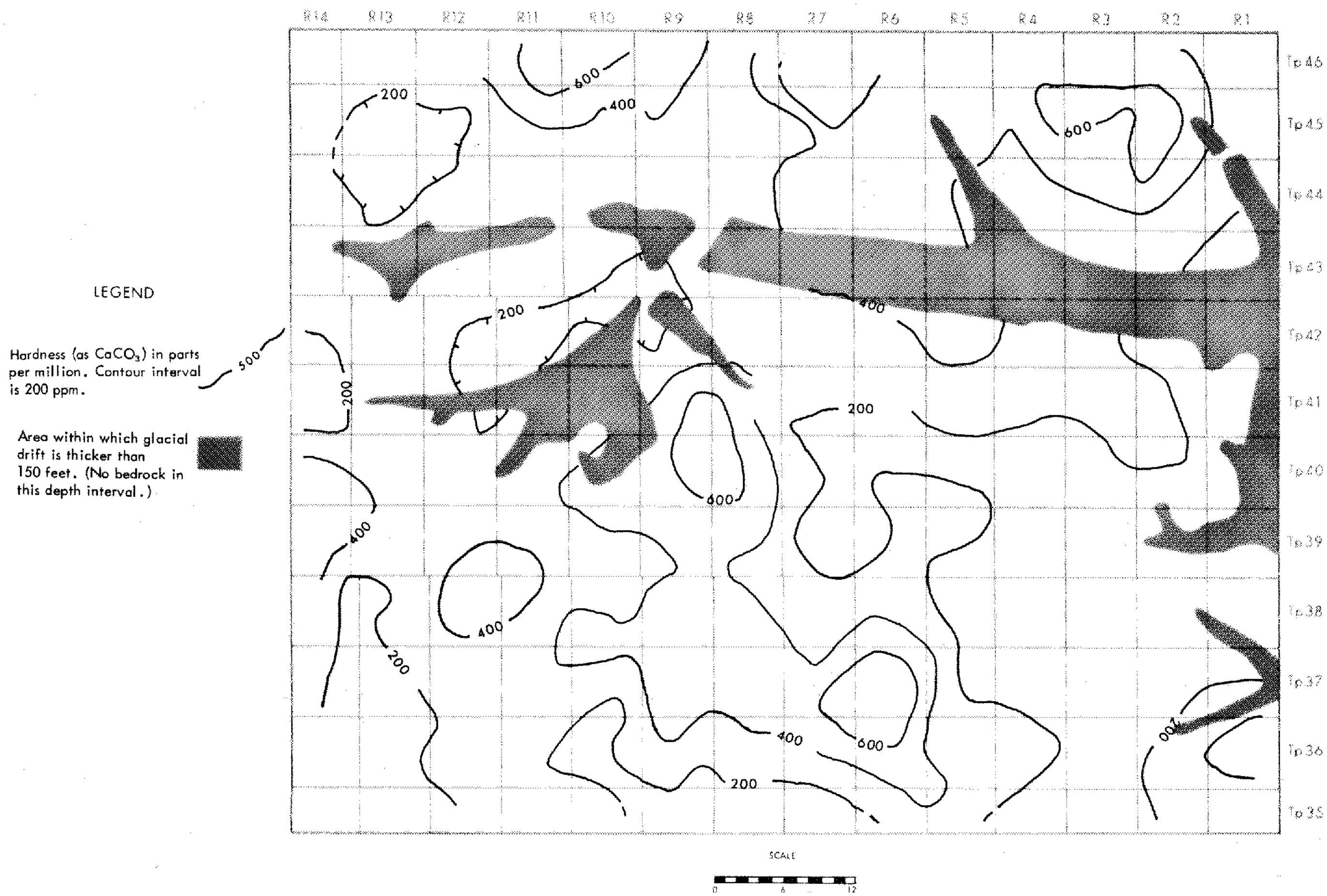

FIGURE 14. *Hardness; bedrock, 0 to 150 feet (0 to 46 m).*

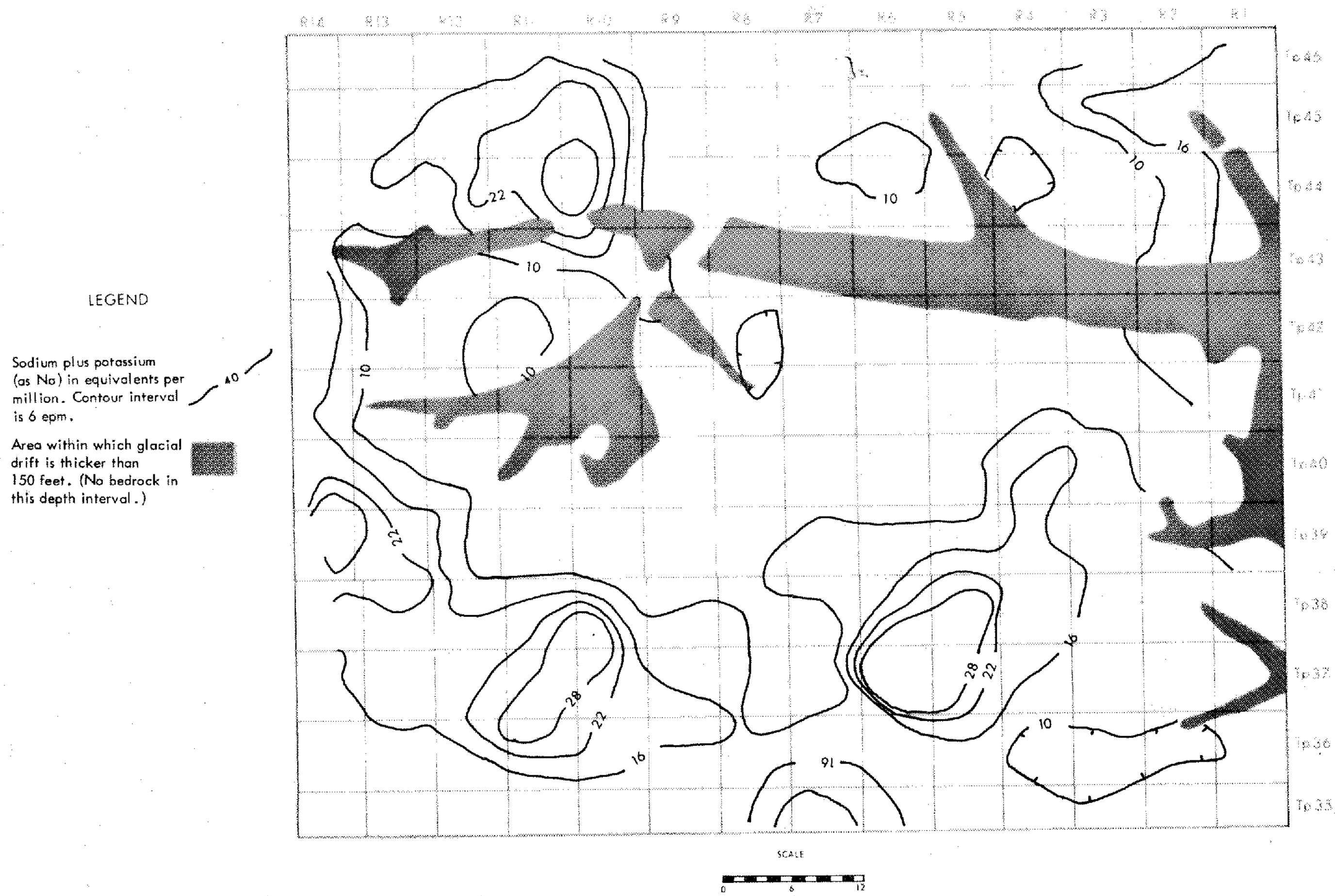

FIGURE 15. Sodium plus potassium; bedrock, 0 to 150 feet (0 to 46 m).

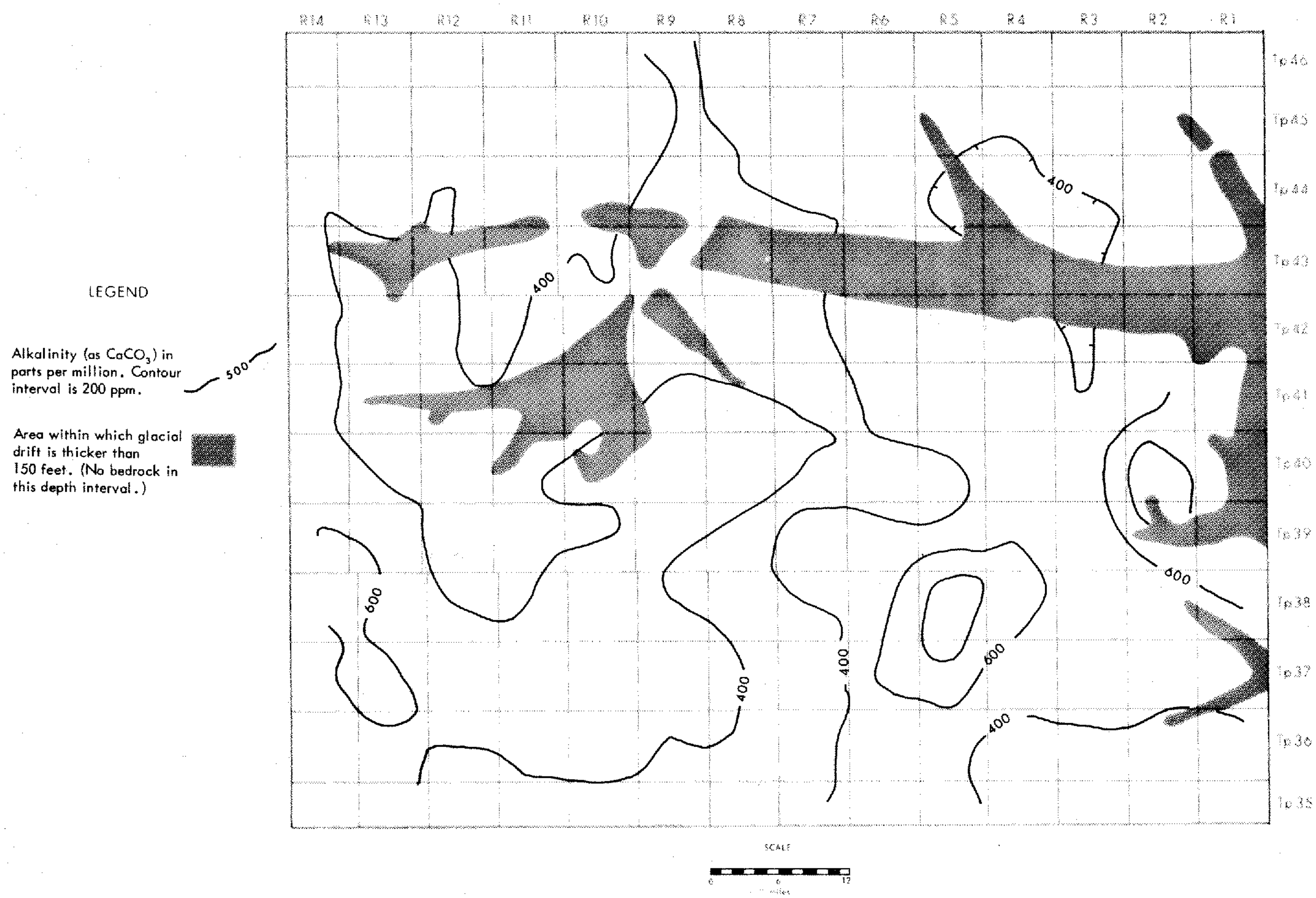

FIGURE 16. Alkalinity; bedrock, 0 to 150 feet (0 to 46 m).

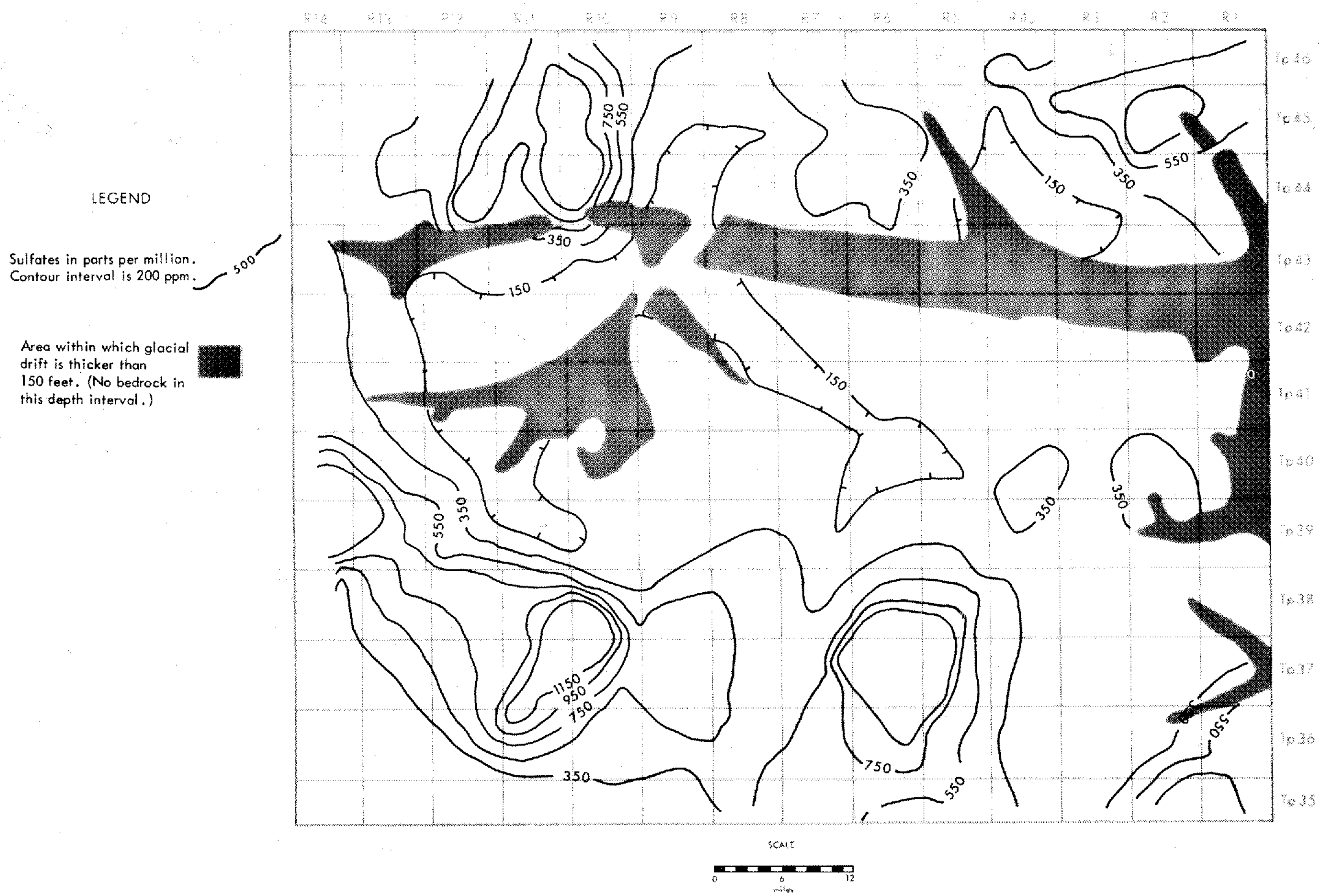

FIGURE 17. Sulfate; bedrock, 0 to 150 feet (0 to 46 m).

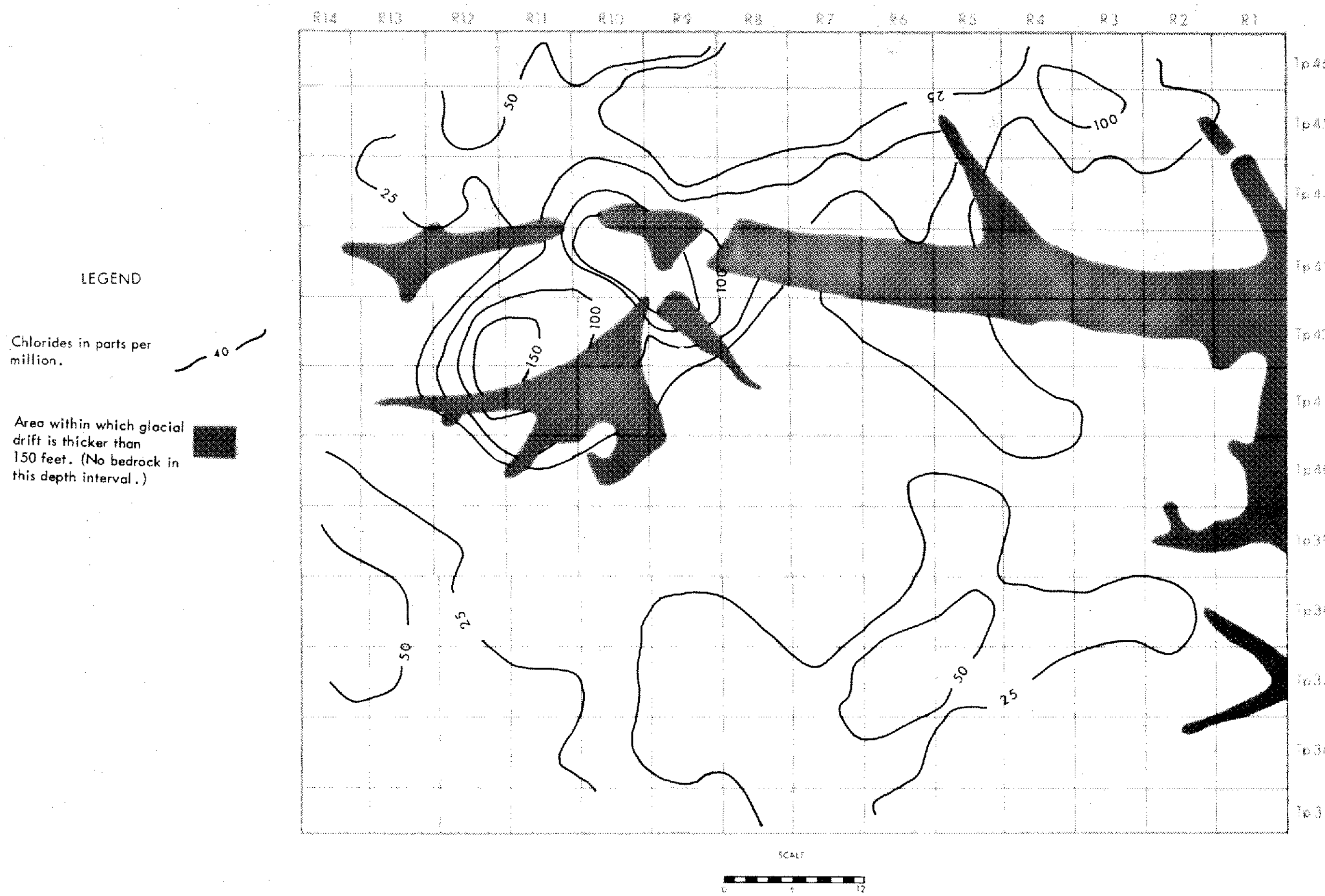

FIGURE 18. Chloride; bedrock, 0 to 150 feet (0 to 46 m).

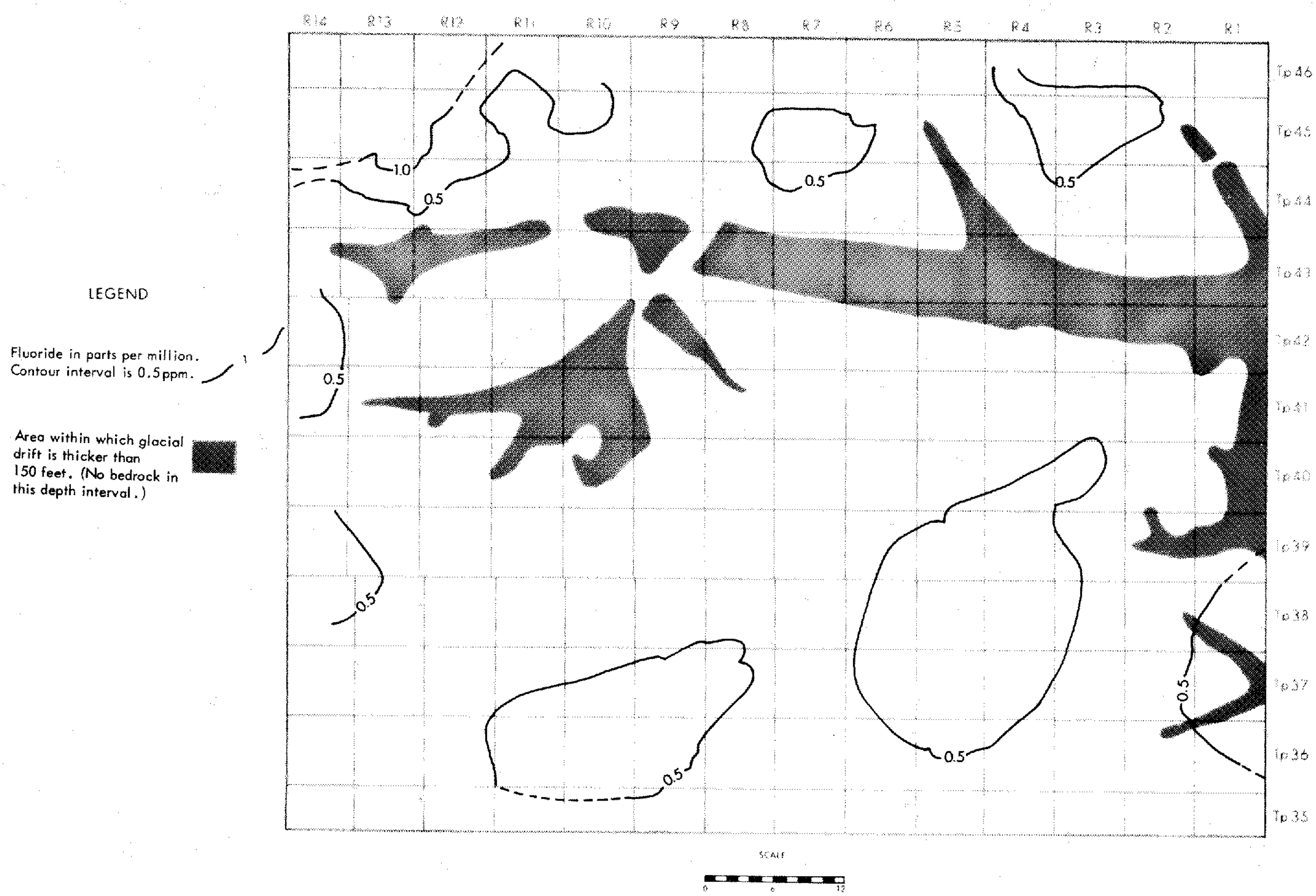

FIGURE 19. *Fluoride; bedrock, 0 to 150 feet (0 to 46 m).*

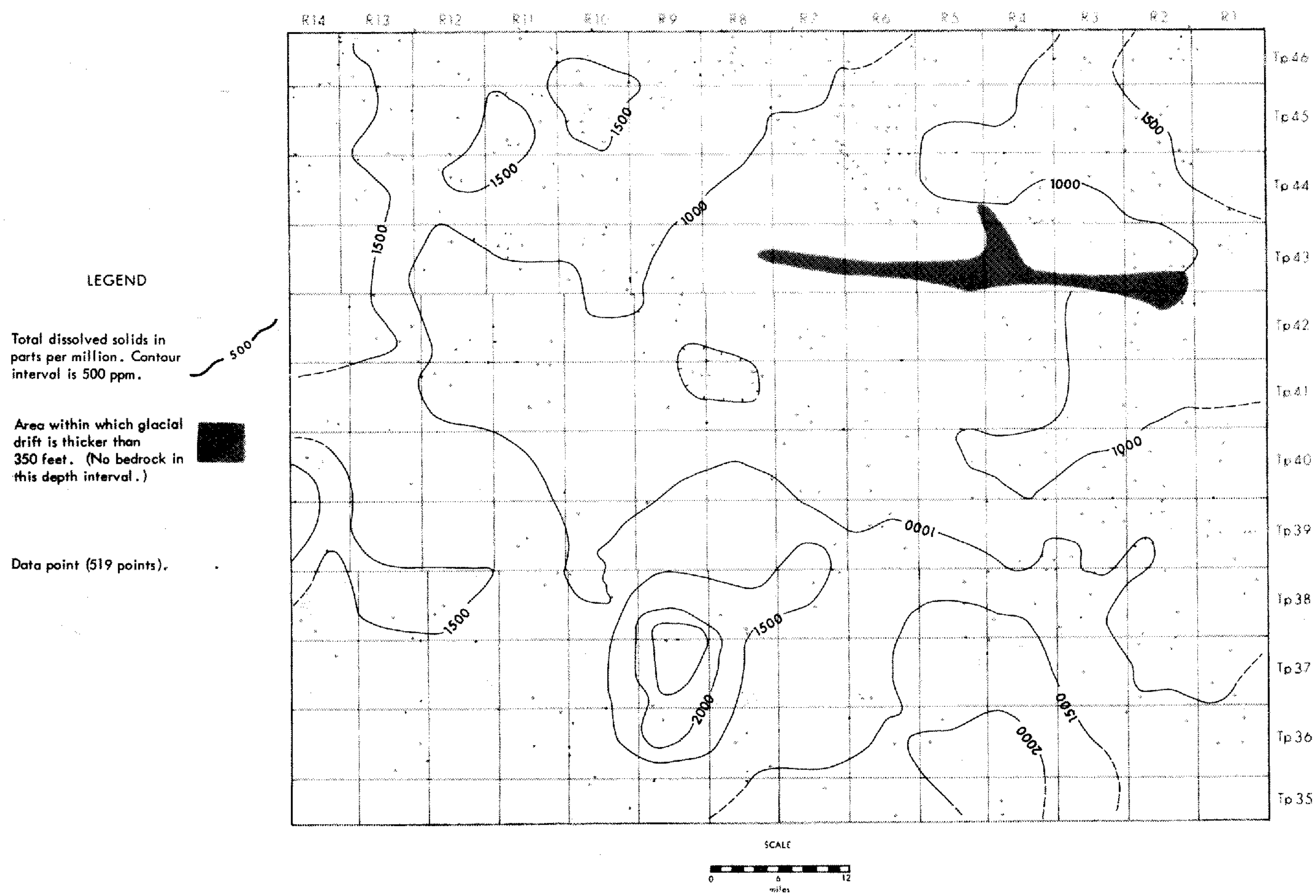

FIGURE 20. *Total dissolved solids; bedrock, 150 to 350 feet (46 to 107 m).*

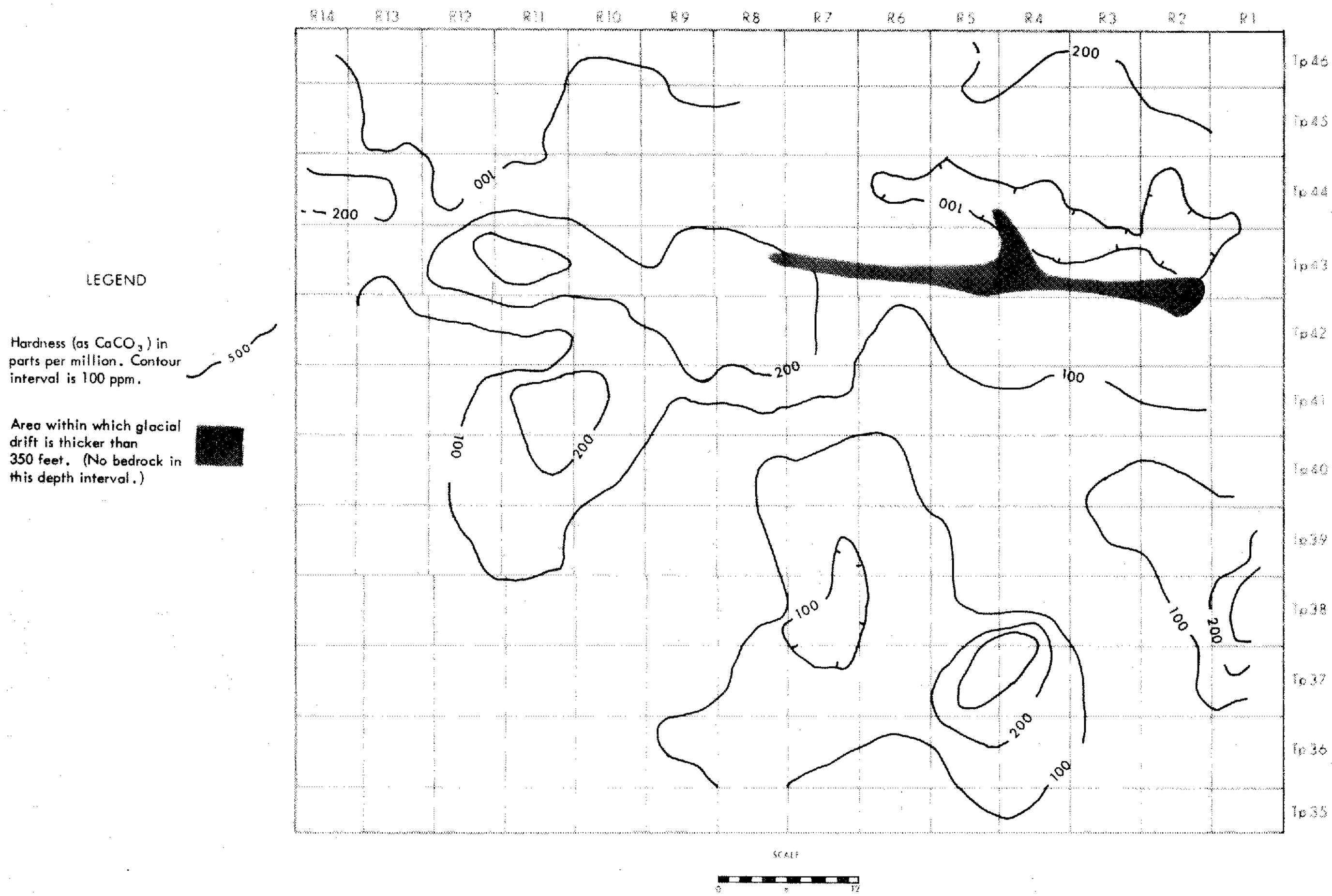

FIGURE 21. Hardness; bedrock, 150 to 350 feet (46 to 107 m).

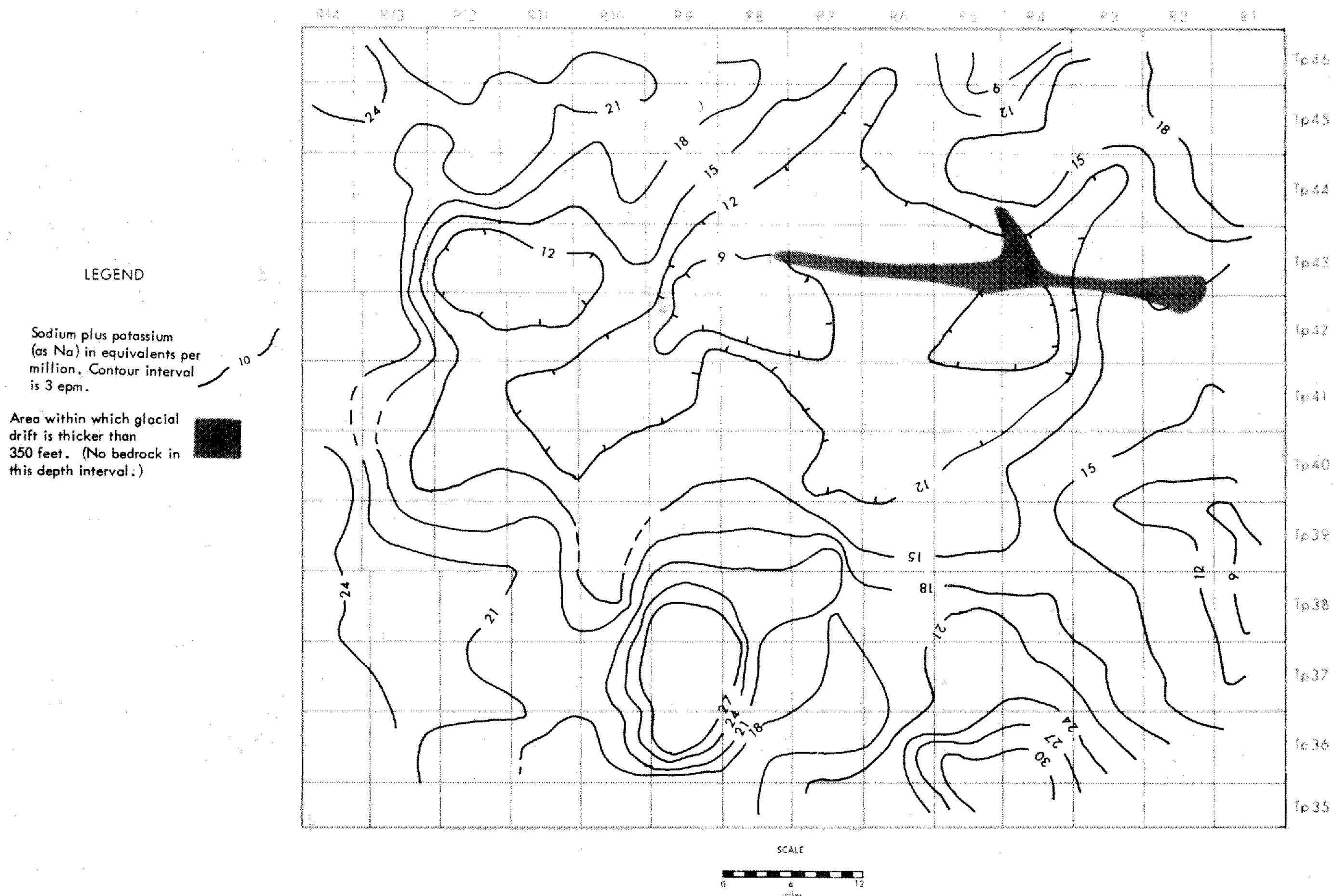

FIGURE 22. Sodium plus potassium; bedrock, 150 to 350 feet (46 to 107 m).

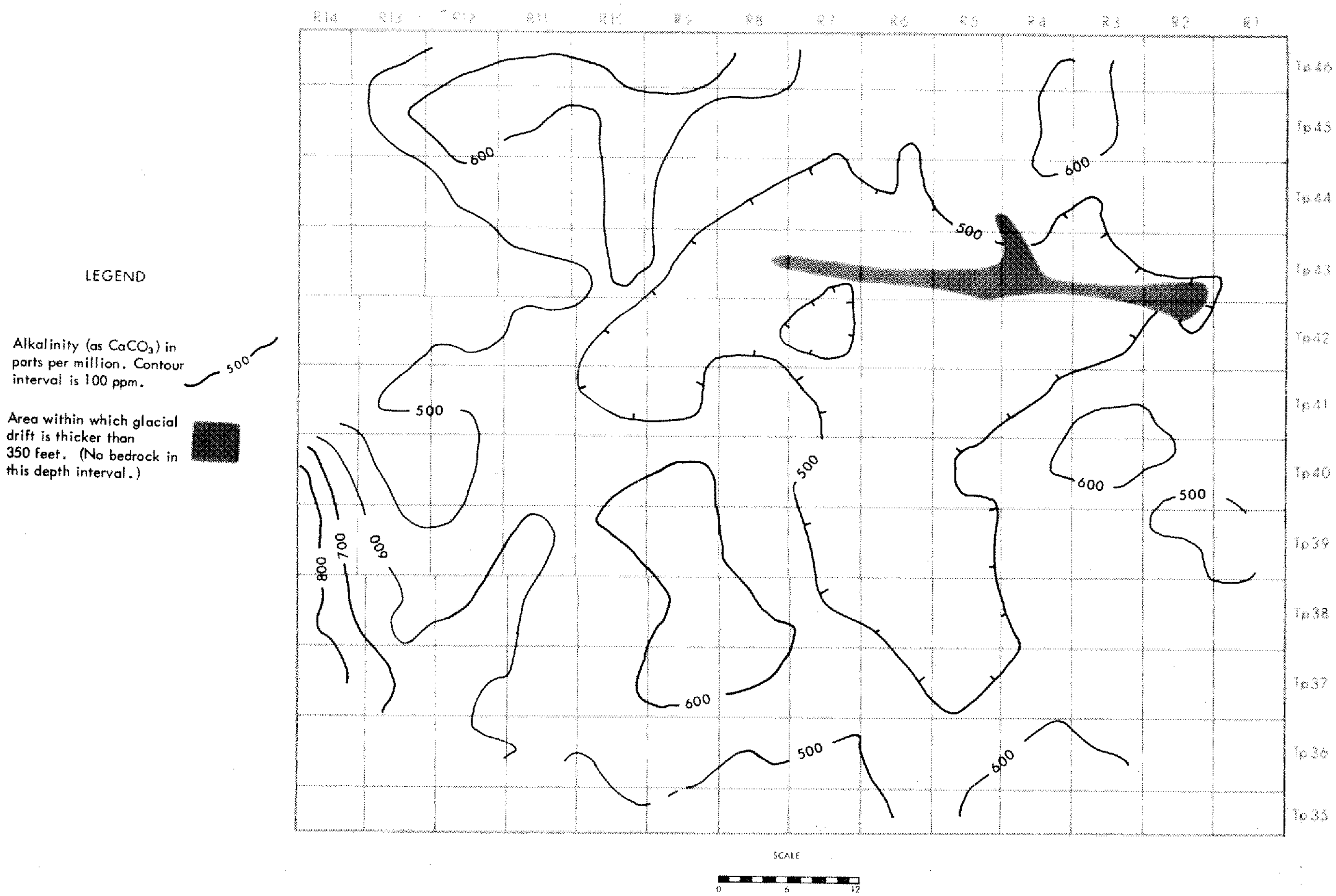

FIGURE 23. Alkalinity; bedrock, 150 to 350 feet (46 to 107 m).

LEGEND

Sulfates in parts per million. Contour interval is 200 ppm.

Area within which glacial drift is thicker than 350 feet. (No bedrock in this depth interval.)

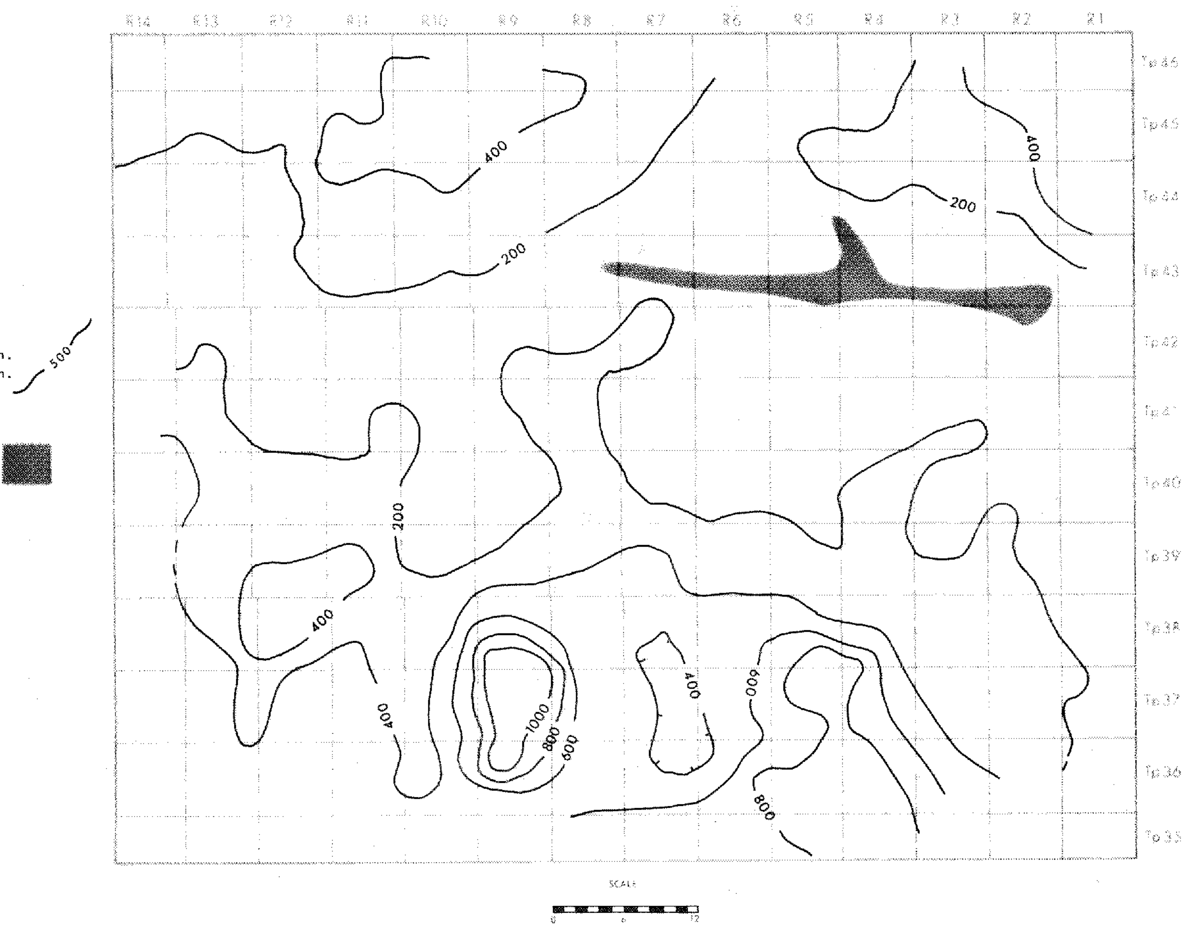

FIGURE 24. *Sulfate; bedrock, 150 to 350 feet (46 to 107 m).*

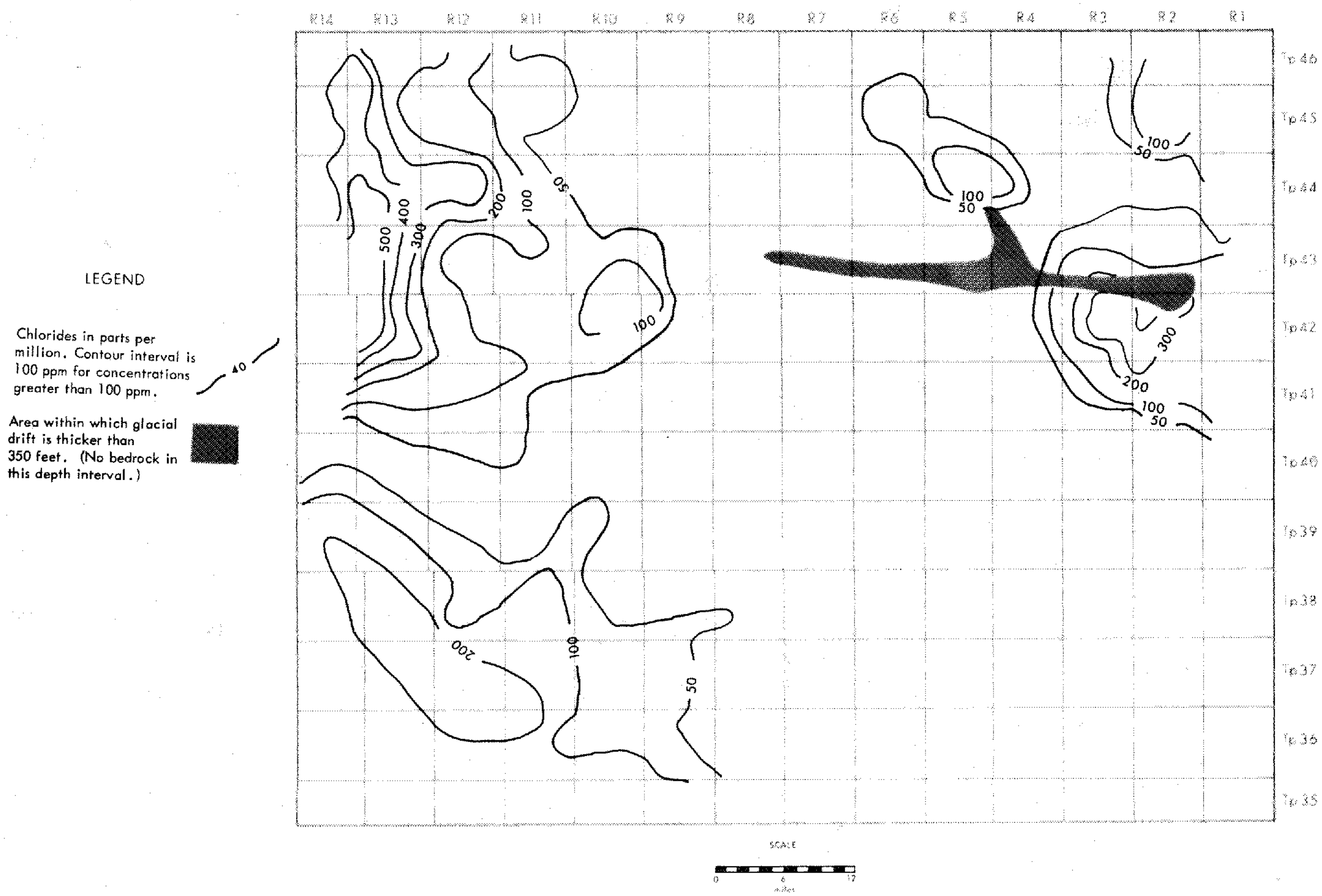

FIGURE 25. Chloride; bedrock, 150 to 350 feet (46 to 107 m).

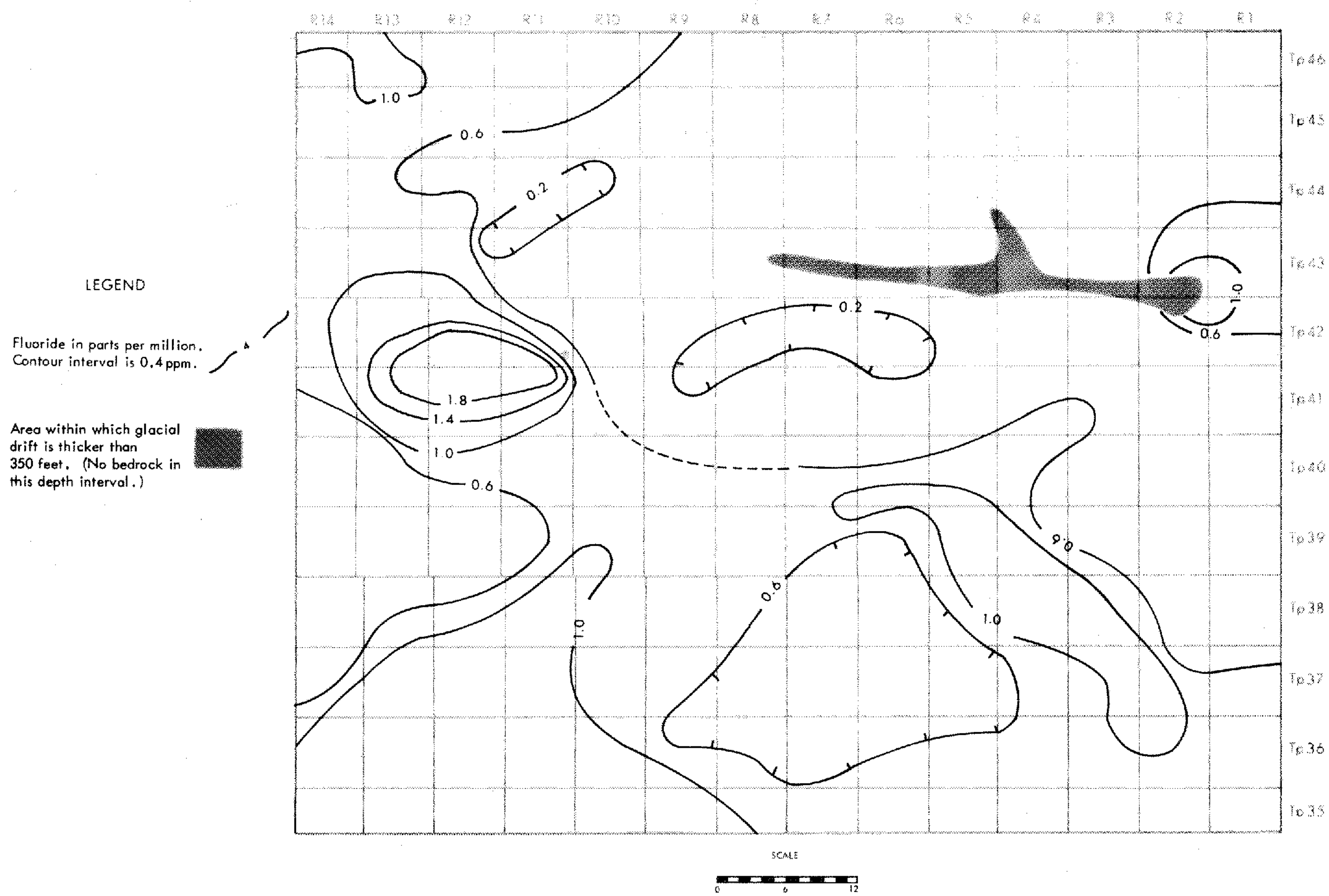

FIGURE 26. Fluoride; bedrock, 150 to 350 feet (46 to 107 m).