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# HYDROGEOCHEMICAL INVESTIGATIONS OF THE CYPRESS HILLS AREA, SASKATCHEWAN



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## ABSTRACT

In order to assess the U potential and the hydrogeochemical character of the Cypress Hills area, Saskatchewan, a regional groundwater survey was carried out during the summer of 1976 covering 18,000 $km^2$ of the southwest corner of Saskatchewan. Approximately 865 wells and 75 springs were sampled at a sample density of 1 sample per 13 $km^2$, where possible, and up to 30 variables were determined on each sample. In addition to the regional groundwater survey 20 lakes and three main streams in the area were also sampled.

Analytical results show that a great contrast exists between the geochemistry of natural and man-made lakes. Natural lakes, essentially salt pans, are highly concentrated in dissolved salts, whereas the man-made lakes (i.e., dammed-up streams) exhibit element contents similar to that of the streams. Detailed seasonal studies of a section of the Frenchman River near Eastend revealed several Rn and U rich groundwater sources which were not visible in the stream sediment patterns.

Numerous field observations, sampling and analytical error, and precision tests indicate that the methodology employed needs simplification and improvement. In particular, procedures are required which minimize sample contamination, errors in sample data coding and recording, and analytical errors, particularly in the misreading of instrumental analog displays. The mass production of high quality data requires more foolproof procedures than those adequate for small batches of samples.

The results from the well survey clearly reveal that regional topographic and hydrological features have a strong effect on the distribution of the dissolved salts. Waters from the more highly elevated areas (the Cypress Hills), where rainfall is more abundant, contained significantly lower concentrations of dissolved salts and trace elements than did the water from the lower flatter regions to the south and

north of the hills. This dominant trend in the element patterns is believed to be due in part to the mechanism of evapotransportation. The distribution of U followed this same regional pattern, however, elevated Rn levels are confined primarily to the Cypress Hills, viz., the radioactive conglomerates of the Cypress Hills Formation, and the underlying radioactive lignites.

Coincident He and $CH_4$ anomaly patterns, with weaker but similar F, Na, Cl, and depth patterns, are believed to be structurally controlled and give an indication of the brine- and natural oil and gas pools at depth in the region.

Anomalous As and Se concentrations in the well waters, with individual concentrations markedly in excess of the maximum acceptable levels of 50 ppb and 10 ppb respectively, may pose a health problem for humans and livestock in the area.

## INTRODUCTION

The encouraging results of a regional well water survey in eastern maritime Canada (Dyck et al., 1976a, 1976b) and the high demand for U resources in 1976 prompted a similar survey in the Cypress Hills area of southwestern Saskatchewan. In addition to its U potential the area also provided a climatic contrast to the Maritimes. The location of the area is shown in Figure 1.

The geological similarities between the Cypress Hills of Saskatchewan and the Gas Hills of Wyoming have long been used to posulate the existence of uranium deposits in the Cypress Hills similar to those in the Gas Hills (Harshman, 1968). Uranium enriched coal and lignite seems (Cameron and Birmingham, 1970), not unlike those in the Dakotas (Densen, 1959; Denson and Gill, 1965), and radioactive fossil bones (Bell et al., 1976) in the Cypress Hills have lent further support to this hypothesis. However, extensive overburden has made it difficult or impossible to detect uranium mineralization in bedrock by conventional scintillometer tests of outcrops. Water wells penetrate the overburden cover in many places and therefore can serve as windows to the underlying geology and geochemistry. The well water orientation survey carried out in the Carboniferous basin of eastern Canada proved useful in detecting U and other mineralization, and it was hoped the current survey would prove of similar benefit to the Cypress Hills area.

The surveys described in this report were a joint venture between the Geological Survey of Canada, the Saskatchewan Geological Survey, and the Saskatchewan Research Council, and were funded by the then newly established Federal-Provincial Uranium Reconnaissance Program (Darnley et al., 1975). The main purpose of the surveys was to determine regional trends in the U content of ground water, and by relating these trends to known mineral occurrences, determine whether such surveys are useful for prospecting. While this well water survey showed that it could be used to trace uraniferous ground waters and point to radioactive sources, the preliminary assessment of the results did not indicate economic mineralization in the area (Dyck et al., 1976c)

By the time all analyses were completed, the U boom of the seventies was waning and other work had demanded greater attention, thus delaying this final report. The surveys produced a vast amount of data useful for well water survey methodology, exploration and environmental groundwater studies, but only U, Rn, He and $CH_4$ in wells have been summarized elsewhere (Dyck, 1979; 1981). The raw data are also available on magnetic tape and as computer listings (Dyck, 1980b). This report attempts to point out common sampling and analytical errors made in high speed hydrogeochemical well water surveys and mass-produced analytical data and summarizes the main hydrogeochemical features of the area. An attempt is also being made to relate the chemistry of the waters to the climate and the geology of the area.

## TOPOGRAPHY, CLIMATE, AND VEGETATION

The topography of Southwestern Saskatchewan is dominated by the Cypress Hills Plateau, maximum elevation 1,402 m (4,600 ft), surrounded by the flat treeless plains, elevation between 518 m (1,700 ft) and 762 m (2,500 ft). The Cypress Hills have been referred to as "the hills that shouldn't be" because they are a small erosional remnant of a large depositional plateau which once existed in the region about 40 million years ago. The hills rise steeply from the surrounding plains on the west and north, forming a plateau with an east-west length of 160 km (100 mi) and a width of 24 to 30 km (15 - 20 mi). The plateau dips slightly to the south-east causing the elevation to decrease to 1,158 m (3,800 ft) just west of the town of Eastend, and falls away gradually to the level of the plains. Along the northern and southern boundaries of the Cypress Hills deep coulees have been cut. Between these coulees transitional areas exist where soil and grass covered spurs and badlands without soil or vegetation cover can be found.

Outcrops are scarcer on the plains than within the Cypress Hills. On the plains outcrops are generally confined to exposures along river valleys, while on the Cypress Hills Plateau the slopes (particularly the southern slopes) of deeply cut streams offer a good amount of outcrop exposure.

Because of the relatively high elevation of the Cypress Hills, a divide has formed separating two major water-sheds; north of the divide the South Saskatchewan River drains into Hudson's Bay and in the south the Missouri River drains into the Gulf of Mexico. Most of the northward flowing creeks within the Cypress Hills Plateau contribute to an interior drainage pattern that flows into a series of alkaline lakes situated north of the study area. On the southern slopes of the plateau most of the creeks flow into an east-west drainage channel consisting of Cypress Lake and the Frenchman River. West of Cypress Lake, Battle Creek and Middle Creek drain southeastward into the United States.

Three major streams, all originating in the hills, Frenchman River, Battle Creek and Swiftcurrent Creek, flow through the study area. The Frenchman River flows southeastward into Montana, and the Battle Creek has its origin in Alberta and flows southward into the Milk River in Montana. The third stream, the Swiftcurrent Creek, originates on Anxiety Butt, northeast of Eastend, and flows into the South Saskatchewan River north of Swiftcurrent.

The climate in the plains areas surrounding the Cypress Hills can be referred to as semi-arid. This area has the lowest precipitation, less than 30 cm, and the highest temperatures found anywhere on the Canadian Prairies. In the Cypress Hills the climatic conditions are like those found in the valleys and slopes of the

Rockies. Here there is a greater amount of precipitation, cooler temperatures, and less evaporation than in the surrounding plains. A third climatic regime, a mixture of the other two, occurs on the slopes and lower regions of the Cypress Hills.

The hills are also subject to Chinook winds (Chinook coming from an Indian word meaning snow eater). These are warm southwesterlies which blow occasionally during the winter months and cause short periods of thawing.

One of the unique features of the Cypress Hills plateau is its vegetation. It is a mixture of prairie vegetation and mountain vegetation characteristic of the Rocky Mountain foothills located 300 km to the west. Desert grasses, sprinkled with cacti, gradually give way to grasslands and grainfields, which yield to bushland, full fledged Aspen woodland, and spruce and pine forests on the plateau. The Lodgepole pine is the dominant forest species, so named as its long straight trunk was used for tepee poles by the Indians. It is said that the hills derived their name from this pine when voyageurs in the early 1800's mistook them for jackpine or "cypress" of eastern Canada (Morrison, et al., 1973).

## GENERAL GEOLOGY

Sedments washed from the mountains to the west during periods of uplift, and marine sediments deposited during periods of stability, form the rock sequence of the present day Cypress Hills.

In southwestern Saskatchewan the geological structure is limited to slightly dipping strata, slumping and localized faulting. Because southwestern Saskatchewan is situated on the east limb of the Sweetgrass Arch, the strata dip slightly in a southeast direction. Slumping is widespread in the formations exposed along the valleys of the major rivers and creeks. Few faults have been found except for localized faults with very small displacements.

The sediments exposed within the survey area are those of the Judith River, Bearpaw, Eastend, Whitemud, Battle, Frenchman, Ravenscrag, Cypress Hills and reworked Cypress Hills formations and glacial drift (See Fig. 1). These sediments range in age from Upper Cretaceous (Judith River to Frenchman Formations) through Paleocene (Ravenscrag Formation) and Oligocene-Eocene (Cypress Hills Formation).

The oldest, Judith River Formation, rocks are found in small areas in the extreme western part of the survey area. The Judith River Formation ranges in thickness from 73 to 235 m (240 - 770 ft) and consists of interbedded marine sand, silt, and clay shales which are both carbonaceous and non calcareous.

Furniwal (1946) concluded that all the marine beds between the Judith and Eastend Formations should be defined as the Bearpaw Formation. The Bearpaw Formation is made up of grey noncalcareous clay, silty clay, sandy clay, bentonite and fine-medium grained sandstone beds. A maximum thickness of 405 m (1,330 ft) has been found for the Bearpaw Formation within the survey area. This formation is the most exposed in southwestern Saskatchewan, covering 60% of survey area. The contact between the Bearpaw and the Judith River Formations is sharp while the upper contact with the Eastend Formation is transitional, grading from marine to non-marine beds.

The lithology of the Eastend Formation is that of very fine-grained buff-yellowish non-marine sand and silty shale. Near the gradational contact with the Bearpaw Formation numerous carbonaceous shales, coal and calcareous zones have been found. A maximum thickness of 35 m (116 ft) has been measured for the Eastend Formation in an area at the west end of the Cypress Hills.

The upper boundary of the Eastend Formation is transitional, gradually changing from the light buff Eastend sand to the light grey sand of the basal

Whitemud Formation (Russell, 1948). The beds of the Whitemud Formation consist of non-marine white-grey clay, kaolinitic sandstone, silt and carbonaceous zones. These beds have a total thickness of 7 m (35 ft) with each separate bed ranging from a few centimeters to 2 m in thickness.

The Battle Formation conformably overlies the Whitemud Formation, with a well defined contact, over most of the survey area. The Battle Formation is fairly uniform in composition, consisting of dark shales, benonitic shale, bentonite tuff, grey and brown siltstone, fine grained sand and local carbonaceous zones. Furniwal (1946) considered this formation to be non-marine.

The conformable sequence is interrupted by an erosional unconformity at the base of the Frenchman Formation, which may overlay the Whitemud or Battle Formations. The Frenchman Formation is composed of greenish brown, well sorted, non-marine sand, silt and clay beds and local bentonities, carbonaceous, calcareous and concretionary zones. Within the survey area thickness range from 3 - 52 m (10 - 170 ft). The age of the Frenchman Formation is considered to be uppermost Upper Cretaceous, but is may contain some Tertiary sediments.

The Ravenscrag Formation is Tertiary (Paleocene) in age and is conformable with the Underlying Frenchman Formation but is overlain unconformably by the Cypress Hills Formation. The interbedded sand, silt, clay and lignite of the Ravenscrag Formation contain local carbonaceous, concretionary and calcareous zones. Certain Tertiary lignite beds in the Ravenscrag Formation have been found by Cameron and Birmingham (1970) to be radioactive. The local thickness of the Ravenscrag Formation reaches 98 m (320 ft).

The erosional unconformity at the base of the Cypress Hills Formation is highly irregular and represents a long period of widespread erosion. A good example of this unconformity can be seen on the flanks of the Cypress Hills where the Cypress Hills Formation lies directly on the Bearpaw Formation. The Cypress Hills Formation varies in thickness from 0 - 76 m (0 - 250 ft) and covers an area of 1,105 $km^2$ (425 $mi^2$) in the survey area. This non-marine formation is Oligocene in age and consists of quartzite and chert gravel interbedded with sand, silt and clay zones, with bentonitic beds and conglomerate zones ocurring locally.

Some deposits found in the survey appear to be lithologically similar to the sands and gravels of the Cypress Hills Formation and it is believed that these deposits represent reworked material derived from the Cypress Hills Formation. This redeposited Cypress Hills Formation rests unconformably on the underlying strata and ranges in age from Middle Oligocene to Late Pliocene or Early Pleistocene. The distribution of the reworked Cypress Hills Formation is variable, ranging from a minimum of a few meters to a maximum of 30 m (100 ft) in thickness.

The glacial geology of the study area consists of Pleistocene undifferentiated glacial drift. This drift is mainly comprised of brown-grey calcaresous till but also includes calcareous gravel, sand, silt and clay. The thickness of the glacial drift is extremely variable (0 - 100 m) and its distribution is highly irregular.

Since the non-marine formations of the Upper Cretaceous and Tertiary periods are permeable and the marine Eastend, Bearpaw and Judith River formations contain numerous sand layers, these formations are waterbearing. Thus, regional aquifer formation is likely, favouring the movement of groundwater over relatively large areas. For more detailed accounts of the geology of the area the reader is referred to Russell (1948) and Kupsch (1956).

## MINERALOGY

Oil pumps, wheat fields, and cattle herds are the surficial indicators of the economic wealth of the area. The extent of gas and oil exploraion in the area is evident from the large number of holes sunk into the ground. By 1976 over 1,700 holes had been completed with an average depth of 1,500 m and range of 280 - 2,700 m (Buller, 1972, C.E. Dunn, Saskatchewan Geological Survey, 1978 personnal communication). The oil and gas fields of the area are part of the Williston Basin, which covers southern Saskatchewan and parts of Montana, North Dakota, and South Dakota (Gerhard, et al., 1982; Kent, 1969; Gallup and Hamilton, 1953). These fields, and possibly the large number of holes, are responsible for the strong $CH_4$ and He anomalies in the well waters discussed below.

Ultimately the source of He is the decay of U and Th in basement rocks (Hitchon, 1963). Burwash and Cumming (1974, 1976) have postulated uranium-rich porphyritic granites along the Precambrian-Cambrian unconformity and circulating formation fluids for the He anomaly in a natural gas well nine miles north of Swift Current; hole B.A. Wilhelm 1-9 produced an inert gas mixture composed of 97% $N_2$, 2% He, and 1% $CO_2$ (Sawatzky et al., 1960).

Uraniferous lignite coal seams similar to those in the Dakotas (Denson and Gill, 1965) have been found and investigated in the Cypress Hills area from time to time (Cameron and Birmingham, 1970; Little and Ruzicka, 1970). They occur in the Ravenscrag Formation in narrow bands usually less than 25 cm thick, but thicknesses of 30 m have been encountered (Little and Ruzicka, 1970). However, thickness and grades encountered have not warranted commercial exploitation of the U.

## HYDROGEOCHEMISTRY

The semi-arid Cypress Hills area experiences average annual precipitation ranging from 25 cm north and south of the hills to 45 cm over the hills. This shift in the water balance has a marked effect on the chemical composition of the well waters. Fresh weakly mineralized waters on the hills evolve into highly mineralized waters through evaportransportation and mixing with older waters in the surrounding plains areas. Evaporation is a significant factor in concentrating trace elements in the ground waters of the area. As these waters become more mineralized their composition tends towards that of seawater. Sinking groundwaters tend to change from Ca and Mg-rich (hard) to Na-rich (soft) waters as a result of base exchange with clays. Because of the nature of the rocks and the $CO_2$ cycle the waters in the area are predominantly alkaline. The presence of coal and gaseous hydrocarbons in the Ravenscrag and Frenchman formations favour sulphate reduction and generally poorly oxygenated waters. For a more detailed description of Saskatchewan groundwaters the reader is referred to the report by Rutherford (1966) and Whitaker (1977).

## SAMPLING PROCEDURES AND FIELD OBSERVATIONS

The 1976 field work in southwestern Saskatchewan commenced June 1 and closed at the end of August. During this field season, well, spring, lake and stream waters were collected in pre-designated areas. The extent of these areas is indicated in Figure 1. Stream sediments were also collected in areas of geochemical interest. The observations recorded in the field are given in Table 1.

Approximately 940 wells and springs were sampled in an area of 18,000 $km^2$ (7,000 $mi^2$) in southwestern Saskatchewan. A sample density of 1 sample every 13 $km^2$ (5 $mi^2$) was maintained where possible, but because wells were scarce in the south, the overall sample density was lower than $1/13\ km^2$. The survey also included the collection of stream waters at 8 km (5 mi) intervals along the three major rivers, and detailed stream water and sediment sampling along a short section of the Frenchman River near the Town of Eastend.

The well and spring water survey area included the areas covered by NTS map sheets 72F /(72KO1 and 72KO2. This area is bounded in the west and east by longitudes 110° 00' and 108° 00' respectively. The southern extremity is the Saskatchewan-Montana border, latitude 49° 00', while the northern boundary is latitude 50° 00' between longitudes 110° oo' and 109° 00' and latitude 50° 15' between longitudes 109 00' and 108° 00'.

The wells sampled were either domestic wells or pasture stock wells and in some areas springs were used instead of wells. Routinely, at each site, three bottles were filled and at every tenth site three additional bottles were filled. The three bottles filled at every site consisted of one 250 mL polyethylene bottle and two glass bottles, one holding 310 mL and the other 320 mL. The three additional bottles filled at every tenth site were a 250 mL polyethylene bottle and two 2,500 mL polyethylene bottles. To minimize confusion and contamination in the field, all bottles were prelabelled and capped in the field laboratory prior to sample collection. the 310 mL glass bottle filled at each site and the 250 mL polyethylene bottle filled at every tenth site received, in the laboratory prior to the collection of the samples, 2 mL of 8 M $HNO_3$ and 2.5 mL of 18 m $H_2SO_4$, respectively. The glass bottles were completely filled at each site with the water sample. The untreated routine sample from the 320 mL glass bottle was analysed in the field laboratory for radon gas, uranium, fluorine, Eh, pH, dissolved oxygen content, total alkalinity, and $HCO_3^-$. The acidified sample in the glass bottle was shipped to Ottawa where the water was analysed for methane, helium, hydrogen and heavy metals. The 250 mL untreated polyethylene bottle of water was also sent to Ottawa where it was kept in case any re-analysis was necessary. The water in one of the 2,500 mL polyethylene bottles was filtered in the field laboratory, analysed for uranium and fluorine, and 310 mL was acidifed with 2 mL of 8 M $HNO_3$ and shipped to Ottawa for analyses. The other 2,500 mL and 250 mL acidified water samples in plastic bottles were sent to the Saskatchewan Research Council in Saskatoon where they were analysed for various major, minor and trace elements.

In addition to the routine samples, one blank, containing distilled deionized water, and one control reference sample, containing a certain volume of a multi-element standard, were bottled and placed in each group of twenty samples. Also, in each group of twenty samples, one set of duplicate samples was collected. In addition, two seasonal sites were chosen in the early stages of the field season. One was a tap in the field laboratory providing Eastend town water originating in the Frenchman River, and the other was a well, 10 m deep, situated less than 1 km east of Eastend.

Finally, to check for seasonal fluctuations, sites with more than 60 ppb U and/or 1,200 pCi/L Rn in the water were resampled and analysed at the end of the field season.

The stream waters were collected in one 310 mL glass bottle and in one 2,500 mL polyethylene bottle upstream from bridges and roads and away from the banks in order to avoid contamination and turbulence. The sample in the glass bottle was analysed in the field laboratory in a similar fashion to the well waters as outlined previously. About 600 mL of the 2,500 mL of water collected in the polyethylene bottle was filtered, divided and placed in two 250 mL polyethylene bottles, one acidified with 2 mL of 8 M $HNO_3$ and the other untreated. Two additional 250 mL polyethylene bottles were filled with unfiltered water from that remaining in the 2,500 mL polyethylene bottle. One of the bottles was acidified as outlined before and the other left untreated and both were shipped to Ottawa for analysis. In the field laboratory the unfiltered and filtered unacidified samples were analysed for uranium and fluorine.

In the area of geochemical interest along the Frenchman River the detailed stream samples were collected three times from the same sites at intervals of about two weeks. Only one 310 mL glass bottle was filled at these sites and the water was analysed in the field labotatory in a similar manner to the well waters.

Stream sediments were collected at these detailed sites along the Frenchman River during the last week of the field season. About 0.5 kg (1 lb) of the sand-silt sediment was collected by hand at each site and placed in a prelabelled paper bag. These samples were then air dried and shipped to Ottawa for analysis.

Information such as NTS map number, UTM location, sample type, water type, flow rate, colour, suspended matter, rock type, rock formation, replicate status, and the date sampled were added to the appropriate field cards. The type of pressure system, tank and pipe, depth of well, owners name, address, and municipal land location were also recorded on the well water cards. On the stream cards, contamination, width and depth of the stream, and temperature were recorded.

At each site the time and date of sample collection was recorded on the bottles when they were filled with water, the field cards were completed, and the sample site plotted directly onto the appropriate 1:50,000 NTS map. Back at the field camp, well sample locations were plotted onto 1:250,000 NTS maps and the stream sites onto a 1:500,000 NTS map.

## ANALYTICAL PROCEDURES

### 1. WATER SAMPLES

#### a) Field Laboratory Procedures

The procedures for this survey were similar to those used in the 1975 Maritime well water survey (Dyck et al., 1976a). Names, units, abbreviations, and detection limits of variables determined on water samples are given in Table 2 and on stream sediment samples in Table 3. Abbreviations used in tables are defined in Table 4.

In the field laboratory, which was set up in the skating arena in the town of Eastend, the samples were analysed for U, Rn, F, $O_2$, Eh, pH, alkalinity, and conductivity. U was analysed by the fluorometric method without removal of U quenching components (Smith and Lynch, 1969). Rn was determined by degassing a 120 mL aliquot into a ZnS (silver activated) cell and measuring the alpha particle emanation rate with a Rn counter (Dyck, 1969). Alkalinity was determined by titrating a 25 mL aliquot to a pH of 4.65 with 0.01 $H_2SO_4$ (Thomas and Lynch, 1960). F, $O_2$, Eh, pH, and conductivity were measured with appropriate electrodes. To determine the sampling and analytical precision of the results control samples were inserted in every group of 17 field samples, one blank (distilled water), one reference (home-made trace element standard mixture) and on unknown duplicate sample.

#### b) Analytical Methods Unsed in the Resource Geochemistry Subdivision Laboratories, Geological survey of Canada

##### i) Hydrogen, Methane, Helium, and Argon

Hydrogen, methane, helium and argon were analysed by a mass spectrometer technique developed by Dyck et al. (1976d). In this method a 25 mL aliquot from a completely filled, tightly sealed, acidified sample in a glass bottle was admitted to an inlet system under high vacuum, the gases were extracted by boiling for a few minutes, dried by passage through dry ice - acetone traps, and admitted to the analyser of the mas spectrometer. The observed ion currents were converted to partial pressures by comparison with standard samples in the case of $H_2$ and $CH_4$ and atmospheric air in the case of He and Ar. The routine precision varied from ± 10% to ± 30% depending upon levels of concentration.

ii) **Zn, Cu, Pb, Mn, Fe, Ni, Na, K, Ca, and Mg**

These elements were analysed by atomic absorption spectrophotometry using a Perkin Elmer 306 analyser and an automated data acquisition facility devised by Bristow (1975). Aliquots were taken from the acidified samples in the glass bottles and analysed directly for Zn, Mn, and Fe with deuterium background correction for Zn. Cu and Pb were determined on the extract from a 80 mL sample using a mixture of 5 mL sodium acetate buffer (at a pH of 4.75), 2.5 mL 1% APDC, and 6 mL MIBK.

iii) **As and Se**

Arsenic and Se were determined by hydride generation with $NaBH_4$ using a 5 mL aliquot in an automated flow system (Aslin, 1976). The hydrides were atomized in a silica tube and their absorbance measured with a Perkin Elmer 306 atomic absorption spectrophotometer. EDTA was used to complex interferring ions such as iron.

iv) **Cl**

Chloride determinations were carried out colorimetrically by the thiocyanate method (Environment Canada, Inland Waters Directorate, 1974).

v) **$SO_4$**

The sulfate ion was determined spectrophotometrically using a modified 2-aminoperimidine method described by Jones and Stephen (1973).

## 2. STREAM SEDIMENT SAMPLES

The variables determined in stream sediments and their abbreviations and detection limits are listed in Table 3.

Arsenic and Se were determined by leaching 1 g samples with aqua-regia, forming the hydride of the element with $NaBH_4$, atomizing the hydrides in a silica tube, measuring the infra-red absorbance with a Perkin-Elmer 306 atomic absorption spectrometer.

Fluoride was determined by sintering a 250 mg sampel with 1 g of flux consisting of two parts $Na_2CO_3$ and one part $KNO_3$, dissolving the pellets in water, adjusting the pH of this solution to 6, and measuring the F ion activity with an ion selective electrode.

Uranium was determined under contract by AECL as described by Boulanger et al. (1975). It involved the irradiation of 1 g samples in the Slo-Poke reactor with slow neutrons and counting the delayed neutron emission.

Radium was determined by Rn emanometry. One g samples were dissolved in aqua-regia, the solutions bottled for a specified time, degassed and the Rn emanations counted in an alpha counter using ZnS (Ag activated) cells (Dyck, 1969).

The remaining elements in Table 3 were determined by direct reading d.c. arc emission spectrometry (Timperley, 1974).

## SAMPLING AND ANALYTICAL CONTROLS AND ERROR ESTIMATION

As described under sampling procedures, each set of 20 samples contained one distilled deionized (blank) water sample, one reference solution, and one field duplicate. The blank was obtained by distilling Eastend tap water, which was obtained from the Frenchman River via the town's filtration plant, and passing the distilate through a Barnstead mixed bed, ion exchange resin cartridge. Concentrated reference solutions were prepared from reagent grade salts and acids and diluted with the deionized water for reference samples. Three different strength solutions were prepared by adding 5 mL, 10 mL and 15 mL of concentrated reference solution to empty prelabelled bottles, filling the bottles to the top with deionized water, and sealing them before the rest of the bottles were filled with well water samples. The analytical results from these blank and reference samples are given in Table 5. Nominal concentrations of dissolved gases were calculated assuming 20°C water in eqiulibrium with atmospheric air at an altitude of 900 m (average estimated temperature and altitude at Eastend where samples were prepared). For ionic species, nominal concentrations were derived by dissolving weighed amounts of salts in acidic solutions.

Generally, the results in Table 5 show that analytical errors for acidified samples, the concentrations well above the detection limits, were small compared to data variability of unknown samples (Table 16). However, five variables He, pH, Cl, cond. and Na show larger variations than the other variables. Examination of the raw data reveals that the high He values resulted from a memory effect in the analytical procedure. Each He high in the control sample suits was preceeded by a well water sample with anomalous He content. Below equilibrium concentrations of dissolved gases may be due in part to unsaturated freshly deionized water. Low pH-high conductivity results for the blanks occur together and suggest that some bottles were not rinsed well enough after the routine acid wash of the bottles. The Cl and Na scatter may be due to the same cause, i.e., inadequate rinsing; HCl was used for the acid wash and the Na could have come from the sodium benzoate that is used to preserve soft drinks - soft drink bottles were purchased full, then emptied and rinsed just prior to use to ensure "clean" bottles. However, there still remain a few inexplicable anomalous values for which we have to invoke contamination or operator error. It should also be pointed out that 12 analytical results from the blank reference solutions were in error by a factor of 10 as a result of misread dials or transcription errors, and 3 samples had been given the wrong replicate status code or the wrong aliquot of concentrated reference solution. Thus, transcription errors were more troublesome than was expected and the procedures used in the introduction of elaborate controls in itself caused errors.

The analytical results of 51 field duplicate pairs are listed in Table 6. These pairs were collected in separate bottles, one immediately after another, from the same tap or well. The paired Student's t values and other statistical paremeters in Tables 6, 7, 9, and 10 were calculated using a computer program called BREAKDOWN and T-TEST found in the Statistical Package for Social Sciences (Nie et al., 1975). For paired samples:

$$t = \left(\sum_{i=1}^{n} (X_{1i} - X_{2i})/n\right)/S_d \quad \text{and}$$

$$S_d^2 = \frac{1}{n}\left(S_1^2 + S_2^2 - \frac{2\Sigma X_1 X_2}{n-1}\right)$$

where n = no. of pairs

$X_1$ and $X_2$ = the 1st and 2nd values of a pair

$S_1$ and $S_2$ are respectively the standard deviations of the first and second of the duplicate pairs

$S_d$ = standard deviation of the differences

The results in Table 6 indicate that at the 95% probability level there were no significant differences between the duplicates except for Rn and Se which were found to be significantly different at the 97% level. In geochemical terms the higher Se levels in the first of the duplicate pairs is not significant. The higher Rn values in the first of duplicates may indicate a Ra accumulation in the water line and that the water was not let to run long enough before the sample was collected.

As could be expected, the probability of a significant difference between pairs collected at different times is somewhat greater than for pairs collected at the same time. The results in Table 7 give the paired t test results of 41 pairs in which the first sample was collected routinely and the second at the end of the field season to check on anomalous Rn and/or U sites as indicated by the first sample. Student's t values are somewhat greater and p values smaller in this set of pairs, but the pairs on the whole show no significant difference between routine and resampling. Where significant differences occur, K and Cl were low during routine sampling and Cu and Pb were high during routine sampling. From this it is inferred that there are no systematic seasonal factors effecting the anomalous sites. Most of the significant differences reside in the related pH-$CO_2$-$HCO_3$, conductivity system, suggesting that perhaps the acid wash and rinse procedure introduced some imprecision in the data.

A more rigorous seasonal test than the one described above was conducted on two sites during the course of the survey; the town water supply and a shallow well

(10 m) just outside of Eastend. The town water supply comes from the Frenchman River just below the reservoir dam and had passed through a sand and gravel filter bed before pressurization. The actual samples were taken from a tap in the laboratory. The water was a consistent beige colour due to a fine clay suspension which could only be removed with difficulty by filtering under vacuum with 0.45 micron filters. The results from these two sample sites are simmarized in Table 8. The change in concentration with time of a few variables is also shown in Figure 3. Evidently, variables with concentrations well above the detection limit do not vary by more than ±30% during the two month period of the test. Variables near the detection limit exhibit larger ranges. Fe, as usual, exhibits a rather large range which, no doubt, is the result of a variable amounts of hydrous iron oxides in the waters.

The duplicate and seasonal results indicate that sampling and analytical errors and seasonal variations account for about 30% fo the data variability. Figures 4 and 5 indicate that there is an evapotransport mechanism operative in the Cypress Hills region which has a much larger effect on some surface and near surface water element contents than 30%. The existence of the evapotransport effect is evidenced by the smooth rise in conductivity and U in a downstream direction from the source of the three streams. The seasonal perturbations in the results from the repeated detailed sampling of the Frenchman River are shown in Figure 5.

The question as to what is the best sample treatment, once a sample has been collected, has occupied researchers for a long time. The answer depends on the purpose of a survey. Obviously, filtering and acidification with proper precautions will give the best value of the true ionic concentration of dissolved salts. However, filtering may also distort the element concentrations at very low concentrations becuase of adsorption on walls of the filtering apparatus and on the filter itself. Earlier ground water surveys have shown that some samples would form precipitates on standing - mostly hydrous iron oxides, but sometimes also carbonates (Dyck et al., 1976a; Dyck, 1980a). Hence, in the Cypress Hills survey, as outlined in the sampling procedures above, the heavy metals, the major elements, and the dissolved gases, except Rn and $O_2$, were determined on unfiltered acidified samples. However, to determine the effect filtering and acidification had on the samples, two comparison tests were carried out. One involved the comparison of analytical results from 62 well water triplicates, one untreated, one filtered and acidified, and one acidified only. The second test involved 65 stream water samples plus 6 man-made lake waters and 4 distilled water samples, and additionally included a fourth, filtered only sample. The analytical and statistical results of these two comparison tests are summarized in Tables 9 and 10. The effect of filtering and/or acidification on the heavy metals is quite obvious, with Fe and Mn showing the largest effect, followed by Zn, Cu, Pb, and Ni. For these heavy metals, acidified samples yield the highest concentrations, filtered acidified the second highest, and untreated samples the lowest concentrations. It is reasonable to expect that unacidified filtered well waters would yield even lower results. Filtering would remove particulate matter, such as pipe scale and oxides, coming from pipe walls during sampling. The Ca and Mg results do not warrant such a conclusion with respect to pipe scale, but the large Fe increase between the acidified and the filtered acidified samples suggests iron oxide particles are causing some of this increase. Filtering and acidification has little or no effect on the contents of Na, K, Mg, Cl, F, and U in either the well or the stream water samples. Statistically, however, the differences in the means, as indicated by the paired t-tests, are significant at the 95% probability level for most pairs. Some of these differences are probably due to systematic and transcription errors as explained in the section on blanks and reference solutions above. Such errors would not necessarily be visible from a comparison of means but would show up in the t-test.

The random insertion of pure water and reference solutions into sample suits of hydrogeochemical surveys proved to be valuable in determining the accuracy of the results and the practical detection limits of techniques. In this survey, these solutions revealed a memory effect in the He determination method and insufficient care in washing bottles. Insufficient rinsing appears to have affected the accuracy of Na, Cl, pH alkalinity and conductivity results. The results of these control samples also suggest that, the methods used in preparing the reference solutions, the recording of data, and coding of sample records require simplification and errorproofing.

The analyses of replicate sample suites show that, for samples with element contents well above the detection limits, maximum variation of concentrations in field duplicates and seasonal duplicates was about ±30% relative to the geometric mean.

On the average one year old samples acidified with 2 mL of 8 M $HNO_3$ contained about twice as much Cu, Pb, Ni, and Ca, 4 times as much Zn, 10 times as much Mn, and 30 times as much Fe as unacidified samples. Filtered and acidified samples contained heavy metal concentrations between those of acidified and untreated samples. These findings are in agreement with observations that some fresh samples contained hydrous oxides of Fe and Mn, and formed more on standing. Filtering and acidification had little or no effect on the concentrations of Na, K, Mg, Cl, F and U.

## LAKE AND STREAM WATER RESULTS

Although the main thrust of the Cypress Hills hydrogeochemical survey was directed at groundwaters, it was thought only fitting that at least an indication of the chemical composition of surface waters should be obtained. The survey area was only sparingly dotted with natural lakes, augmented with a few man-made lakes or reservoirs (dammed-up streams).

The analytical results of the lake water samples are summarized in Table 11. Average element concentrations of these lake waters are somewhat lower than those of the main streams in the area (Table 12), illustrating the purifying effect (i.e., flocculation and precipitation) still open waters have on dissolved constituents in natural environments. The natural lakes, located in the dryer flatter regions of the survey area, naturally contained much higher element concentrations; no doubt as a result of evaporation of water from what are essentially catchment basins. Unfortunately, for reasons unknown, the samples from these lakes did not reach the Ottawa laboratories for trace and other element analysis.

The few streams in the area all originate in the Cypress Hills and flow either northerly or southerly. When the three main streams, Battle Creek, Swiftcurrent Creek, and Frenchman River were samples at about 8 km intervals from their origins to the boundaries of the survey area, an unusually large rise in the U content and conductivity in the Frenchman River water samples between Eastend and Val Marie was noted (see Fig. 4). On the surface, these highs are closely associated with the Ravescrag Formation, in which radioactive Tertiary lignites are found. Between Mule Creek and Val Marie the river recedes from this formation and the U and conductivity values decrease. Two reservoirs and an increased number of tributaries in this section of the Frenchman River may also explain the decreased values brought on by dilution.

The section of the river with the sharp rise in the U content and conductivity was resampled in more detail (1 km) intervals shortly after the first sampling, only to find that the concentrations of these elements had decreased markedly from the first sampling. This prompted two more resamplings, the results of which indicated that the river was slowly returning to its original (July 13 - 15) composition (see Fig. 5). The arithmetic means of the three streams sampled on a regional scale are compared in Table 13. Table 14 presents the results of three successive samplings of a 15 km section of the Frenchman River between the Eastend Reservoir and Eastbrook Coulee. The foul smell of the air in Eastend, particularly when the wind was calm, between the first and second sampling of the river, eventually helped to solve the riddle of the dilution of the river water immediately downstream from the town. The unusally high rainfall in July (18 cm) prompted the opening of the sluices at the Eastend Reservoir, about 1 km upstream from the town to lower the water level in the reservoir. This extra water diluted the normal run-off with a significant portion of oxygen deficient bottom reservoir water, causing the foul smell in the air as well as the dilution of trace elements in the Frenchman River. In spite of this disturbance of the stream, careful inspection of the data reveals three to four areas where more mineralized groundwater enters the river. The weak, but reproduceable, Rn peaks help define these entry points (Fig. 5), suggesting a weak or distant radioactive source. One is tempted to conclude that the domestic well that was used for the seasonal study just southeast of the town tapped the same aquifer as the one that is discharging into the river farther downstream. This well gave anomalous Rn and U values of up to 1,100 pCi/L and 100 ppb (Fig. 3) compared to the stream maximums 56 pCi/L and 11 ppb, respectively.

## STREAM SEDIMENT RESULTS

To obtain more information in this interesting section of the Frenchman River, sediments were also collected when the waters were sampled for the last time. But, as the results in Table 15 indicate, there is little contrast in the data, and plotting the U and Ra results does not give indentifiable patterns like those evident in the U and Rn in water data plots. Even though most of the Ra values are close to the detection limit of the analytical technique, the correlation coefficient between it and U is highly significant ($r = .8$).

## WELL AND SPRING WATER RESULTS

### FACTORS RESPONSIBLE FOR VARIATIONS IN ELEMENT CONTENT

The reader is reminded to review and keep in mind the conclusions of the sampling and analytical precision tests and the effect of filtering and or acidification of samples on the measured trace element concentrations when evaluating the weighing the analytical results of the hydrogeochemical survey. Summary statistics of all well water and spring water variables are given in Tables 16 and 17, respectively. The skewness of the untransformed and logtransformed data of these two tables indicates that most of the variables tend toward lognormal distributions. It is also quite obvious that the spring waters are generally lower in element content but higher in dissolved oxygen. Before evaluating the regional distribution of the element concentrations, Figure 6, the reader may also inspect Tables 18 to 20 where the data is grouped according to the type of drawing system (Table 18), rock type (Table 19), and pressure system, type of tank, and type of pipe (Table 20). These groupings confirm certain trends, known from other ground water surveys, and suggest some new ones, but in general are not as effective in dividing the water as was hoped. The regional nature of the data and the strong effect that the evapotransport mechanism seems to have on the trace element distribution is probably responsible for the blurring of the grouped data. The very small number of samples of some groups also puts a large uncertainty on the significance of differences in concentrations. It should also be remembered that the element contents were determined on acidified and unfiltered samples. The geometric means will therefore reflect fairly closely the actual concentration of the average sample, but individual samples could be in error as a result of suspended matter from pipe scales entering the sample. This should be born in mind when studying the element maps, particularly single-point anomalies. The higher $O_2$ content of springs compared to that of wells, and the generally greater incidence of springs in hilly terraine compared to flats, can explain the observed $O_2$ distribution. The drop in the Rn content of waters from open wells or springs compared to waters from pressure systems is probably due to loss of Rn from the more open systems (Table 18). However, it was unexpected that He does not exhibit as pronounced a drop as Rn. In fact, the well water samples from hand pumped systems contain essentially as much He as the well water samples from pressure systems (systems with taps; Table 18). It is believed that a sampling problem is responsible for this apparent discrepency. It should be noted that the handpump well samples in Table 18 are also much higher in dissolved ionic species indicating that this particular set of samples came from wells that were tapping more mineralized aquifers. Such waters usually come from greater depths, or have spent more time underground. The correlation between He and depth is strong and positive ($r = 0.61$) and between Rn and depth nil ($r = 0.01$). Similarly the correlation between He and conductivity, and Rn and conductivity is 0.32 and 0.03, respectively. The results in Table 19 are an attempt to illustrate the effect of rock formation on trace element content of ground waters. Waters from the

Cypress Hills formation have the highest $O_2$ and Rn and the lowest He concentrations, indicating actively circulating, younger waters. In contrast, waters from the Bearpaw Formation, the oldest formation exposed in the area, have the lowest content of $O_2$ and the highest content of He and are characterized by generally higher concentrations of trace and major elements. The waters from the two formations of marine origin, namely the Bearpaw and Eastend, contain very high concentrations of Na and Cl and $SO_4$. Argon exhibits very little variation in concentration and is close to the atmospheric equilibrium concentration of 384 µL/L.

In Table 20 the results are grouped by type of pressure system, type of tank and type of pipe using only samples from the Bearpaw Formation. But factors other than rock type may have influenced these data. For example, the lower $O_2$, U, and Rn and higher He and Cond. are probably indicators of older deeper waters rather than a precharged pressure system. The same reason probably also explains the variations of these elements in the subsetting by tank type - except for Zn; the higher Zn values from waters from galvanized tanks may in fact be due to the Zn coating in these tanks. Similarly, systems with Fe pipes contain more Fe and systems with Cu pipes contain more Cu in solution but the increases are not so pronounced as to conclude that they are in fact due to the inferred causes. Other causes, such as changes in rock formation, rainfall, and regional drainage patterns appear to be the dominant causes of variations in the element patterns of the groundwaters in the area.

## REGIONAL DISTRIBUTION OF ELEMENTS

The regional distribution of the elements in well and spring waters are shown in Figure 6. These colour contour maps were produced by a computer mapping package (APPMAP) developed in the Resource Geochemistry Subdivision, Geological Survey of Canada. This package makes use of an Applicon colour plotter and Applicon library software residing on a CDC Cyber 730 computer at the Computer Science Centre of the Department of Energy, Mines and Resources. APPMAP interpolates from the irregularly spaced reconnaissance data grid to a regular 1,600 $m^2$ data grid. The interpolation is in the form of a moving average where weighting is by an inverse distance function ($1/d^3$) using the nearest five data points. The effect of this moving average is to filter out minor irregularities in the spatial data and emphasize the broader scale and regional features. For the element maps, the colour contours are erased in areas greater than 4 km from the nearest sample site. Thus, white areas within the map boundary represent areas with no data.

The most obvious regional feature of the element distribution maps is the rise in concentration in lower, dryer parts of the survey area. Geography and climate combine to effect an increase in concentration of the dissolved constituents in the ground waters. Evidently evapotransport plays a dominant role in the enrichment of dissolved solids in the well waters of the region. However, there are notable exceptions to this general trend. Rn, for example, is higher in the waters over the near the Cypress Hills. The fact that Rn is higher in the hills merely confirms the radioactive nature of the Cypress Hills Formation and the radioactive lignites of the Ravenscrag Formation, just below the Cypress Hills Formation. Because of its relatively short half life of 3.8 days, Rn cannot survive the journey into the lowlands. Ra, the immediate parent of Rn, with its 1,600 year half life would survive the passage into the lowlands, but is held bound in the soils near the source. U, on the other hand, is stable and soluble in surface and near surface, i.e., oxidizing, waters, and hence is found in greater concentration the further the water moves from the hills. The Rn and U highs in the central southern portion of the area suggest rocks with more radioactivity, possibly remnants of the Ravenscrag Formation. Perhaps, as weathering removed the radioactive formations, the U was remobilized and redeposited in the lower formations.

The dissolved oxygen and Eh patterns are similar to that of Rn, indicating that waters on and near the hills are richer in $O_2$ than the waters farther away from the hills. Younger, more actively circulating waters are responsible for this as well as for the generally lower pHs in this region. The He and $CH_4$ patterns are similar to each other but differ from the general distribution pattern of trace elements. These gases follow the depth pattern to some extent as well as frequency of oil and gas exploratory and production holes (Fig. 2). Whether the depth and borehole frequency can account completely for the observed He and $CH_4$ anomalies is open to debate. But is is not unreasonable to assume that nature has provided natural vents for these gases in the form of faults and fracture zones. The north-south and east-west trends in the anomaly patterns of these gases strongly suggest major regional structural features. In fact, the major north trending He anomaly runs strikingly parallel to the Eastend Syncline of the Late Mesozoic and the east-west arching He anomaly in the northern half of the area coincides with the Pontiex Syncline in the eastern border of the surveyed area (Kamen-Kaye, 1953). In any event, these gases leak to the surface from the oil and gas pools at depth in the area. Such anomalies in areas not yet fully explored, such as the one in the south western corner of the survey area, are therefore of considerable interest for gas and oil exploration. The wells in this corner also contain high Na and bicarbonate (see total alkalinity map) and unusual concentrations of As. Soft waters are usually encountered at greater depth, and there is a noticeable correlation between depth, Na, and bicarbonate over the whole region. Arsenic highs are associated with these deeper more carbonated wells in the western part of the survey area, but not in the eastern half suggesting a major change in the geochemistry. Similarly, the association of As with He and $CH_4$ in the western half is not evident in the eastern half. One is tempted to conclude the As anomalies are not associated with oil pools but rather with gas pools. Although there are no commercial gas pools in the survey area, the high As in the northwest corner of the area is close to the commercial gas pools just north of the town of Maple Creek. By analogy one could say that the high As and $Ch_4$ levels in the south-west corner similarly reflect gas pools. Subsurface oilfield brines may contain As, particularly if the surrounding rocks are primarily shales; shales, sandstones and carbonates contain 13, 1, and 1 ppm As respectively (Collins, 1975).

Apart from this interesting spatial distribution of As, its anomalous nature in many wells may also pose a health threat. At least eight sampled wells contained more than 50 ppb As, which is the maximum acceptable level in water used for domestic consumption, according to guide lines laid down by the Inland Waters Directorate of Environment Canada (Inland Waters Directorate, 1979). Selenium may be an even greater threat to health, for in more than 100 sampled wells the Se concentration exceeded the maximum acceptable level of 10 ppb, and about 60 wells contained over 50 ppb Se. Granted, many of these wells may be used only for watering livestock, but that is no guarantee that the Se will not reach humans if the dairy and meat products of these cattle are used for human consumption.

The trace elements Cu, Pb, Ni, Zn, Mn, and F, like U, As, and Se, show a weak positive correlation with the major elements, indicating that evapotransport has a marked influence on these elements. However, sporadic point anomalies of these trace elements suggest local contamination either as a result of unusual ground conditions or the nature of the plumbing systems. Ni, not a common metal in plumbing systems gives an unusually strong coherent northeast trending anomaly in the Gull Lake area and a smaller equally strong anomaly near the western border. The Gull Lake anomaly could have resulted from spills of Ni containing crudes or waters associated with high Ni crude. Hodgson (1954) reports higher than average Ni contents in some Canadian oils particularly those from shallower depth and with lower API gravity. The close correlation of Ni and low pH values also suggests man-made contamination.

Several of the anomalous F areas coincide with deep wells, others with Ni and/or Pb. Thse areas' positive correlation with He, $CH_4$, Na and Cl also suggest a deep origin for much of the F in the well waters. The Pb and Ni correspondence is not easily explained. Neither are a number of the point anomalies of Cu, Fe, Zn, and Mn. As noted earlier, some of these point anomalies may simply be contaminated samples as a result of dissolution of suspended pipe scale particles.

## CONCLUSIONS

The methodology and results of well water surveys, like the one described in this report, lend themselves to the study of the regional distribution of elements in groundwater, which may reveal hidden mineralization, health hazards, and regional hydrogeochemical processes such as evapotransport.

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## TABLES

**FIGURES**

**Table 1.** Observations recorded in the field

A. Water samples

Name of owner, address, township, range, section, quarter

UTM coordinates and zone

Type of sample: well-, stream-, lake-, spring-, etc. water

Type of water system - tap, hand pump, bucket, etc.

Type of pressure system - tank-, pipe

Water colour

Amount of suspended matter

Rock formation

B. Stream sediments

UTM coordinates and zones

Rock type and formation

Coarseness of sample material

**Table 2.** Names, units, abbreviations, and detection limits of variables determined on water samples.

| Variables and units | Abbr. | Detection limit | Value entered when undetectable |
|---|---|---|---|
| Argon, microlitres per litre | Ar | 2 | 1 |
| Arsenic, ppb | As | 0.5 | 0.2 |
| Bicarbonate, ppm | $HCO_3$ | 1.0 | 0.5 |
| Calcium, ppm | Ca | 0.5 | 0.2 |
| Carbon dioxide, calculated, ppm | $CO_2$ | 0.2 | 0.1 |
| Carbonate, ppm | $CO_3$ | 0.2 | 0.1 |
| Chloride, ppm | Cl | 0.2 | 0.1 |
| Conductivity, micromhos/$cm^2$ | Cond. | 5 | 2 |
| Copper, ppb | Cu | 1.0 | 0.5 |
| Depth of well, m | Depth | 1 | |
| Dissolved oxygen, ppm | $O_2$ | 0.2 | 0.1 |
| Eh, mv with respect to $H_2$ | Eh | 10 | 5 |
| Fluoride, ppm | F | 0.04 | 0.02 |
| Helium, nanolitres per litre | He | 10 | 5 |
| Hydrogen, mL/L | $H_2$ | 0.02 | 0.01 |
| Iron, ppb | Fe | 20.0 | 10.0 |
| Lead, ppb | Pb | 2.0 | 1.0 |
| Magnesium, ppm | Mg | 0.5 | 0.2 |
| Manganese, ppb | Mn | 10.0 | 5.0 |
| Methane, mL/L | $CH_4$ | 0.02 | 0.01 |
| Nickel, ppb | Ni | 2.0 | 1.0 |
| pH | pH | 2.0 | 1.0 |
| Potassium, ppm | K | 0.2 | 0.1 |
| Radon, pCi/L | Rn | 4 | 2 |
| Selenium, ppb | Se | 0.5 | 0.2 |
| Sodium, ppm | Na | 0.2 | 0.1 |
| Sulfate, ppm | $SO_4$ | 10 | 5 |
| Total alkalinity, ppm $CaCO_3$ | Alka | 1.0 | 0.5 |
| Uranium, ppb | U | 0.2 | 0.1 |
| Zinc, ppb | Zn | 3.0 | 1.0 |

**Table 3.** Names, units, abbreviations, and detection limits of variables determined on stream sediment samples.

| Variables and units | Abbr. | Detection limits* | Value entered when undetectable |
|---|---|---|---|
| Aluminum, % | Al | 0.5 | 0.2 |
| Arsenic, ppm | As | 0.2 | 0.1 |
| Barium, ppm | Ba | 50 | 25 |
| Berylium, ppm | Be | 1 | 0.5 |
| Calcium, % | Ca | 0.2 | 0.1 |
| Chromium, ppm | Cr | 7 | 3 |
| Cobalt, ppm | Co | 2 | 1 |
| Copper, ppm | Cu | 4 | 2 |
| Depth, dm | - | | |
| Flouride, ppm | F | 20 | 10 |
| Iron, % | Fe | 0.2 | 0.1 |
| K, % | K | 0.2 | 0.1 |
| Lanthanum, ppm | La | 12 | 5 |
| Lead, ppm | Pb | 3 | 1 |
| Magnesium, % | Mg | 0.2 | 0.1 |
| Manganese, ppm | Mn | 100 | 31 |
| Molybdenum, ppm | Mo | 2 | 1 |
| Nickel, ppm | Ni | 2 | 1 |
| Radium, pCi/g | Ra | 0.5 | 0.2 |
| Selenium, ppm | Se | 0.2 | 0.1 |
| Silver, ppm | Ag | 0.5 | 0.2 |
| Strontium, ppm | Sr | 30 | 15 |
| Titanium, ppm | Ti | 200 | 100 |
| Uranium, ppm | U | 0.2 | 0.1 |
| Vanadium, ppm | V | 10 | 5 |
| Width, m | - | | |
| Yttrium, ppm | Y | 10 | 5 |
| Zinc, ppm | Zn | 50 | 25 |

*Concentrations below which the relative standard deviation exceeds 50%

**Table 4.** Abbreviations used in tables

| Abbreviation | Meaning |
|---|---|
| $S_L$ | Standard deviation of log transformed data |
| Logtr. | Log transformed data |
| Max. | Maximum value |
| Min. | Minimum value |
| N | Number of samples |
| $S_A$ | Standard deviation of untransformed data |
| Untr. | Untransformed data |
| Var. | Variables |
| $\bar{X}_A$ | Arithmetic mean |
| $\bar{X}_G$ | Geometric mean |

**Table 5.** Comparison of distilled deionized water (blanks) and three reference solutions.

| | Blanks; N = 60 | | | Reference solution 1; N = 17 | | |
|---|---|---|---|---|---|---|
| Variables | Nominal conc.** | $\bar{X}_A$ | $S_A$ | Nominal conc.** | $\bar{X}_A$ | $S_A$ |
| Rn | 0 | 2* | 0.1 | 0 | 2** | 0 |
| Ar | 314 | 238 | 42 | 314 | 243 | 40 |
| He | 41 | 48 | 18 | 41 | 55 | 31 |
| $O_2$ | 8.0 | 7.6 | 1.0 | 8.0 | 7.9 | 0.9 |
| Eh | - | 408 | 100 | - | 702 | 40 |
| pH | 6 | 6.03 | 0.92 | - | 2.76 | 0.08 |
| Cond. | 0 | 19 | 55 | - | 799 | 63 |
| $SO_4$ | 0 | 5 | 1 | - | 26 | 10 |
| Cl | 0 | 0.3 | 0.8 | 4.9 | 4.0 | 0.8 |
| F | 0 | 0.03 | 0.01 | 0.06 | 0.08 | 0.02 |
| U | 0 | 0.1 | 0.05 | 0.4 | 0.5 | 0.2 |
| As | 0 | 0.3 | 0.3 | 0 | 0.3 | 0.2 |
| Se | 0 | 0.2 | 0.2 | 0 | 0.3 | 0.5 |
| Zn | 0 | 12 | 12 | 141 | 144 | 6 |
| Cu | 0 | 1.6 | 1.6 | 35 | 36 | 4 |
| Pb | 0 | 1.9 | 1.3 | 5 | 8 | 10 |
| Ni | 0 | 1.6 | 0.9 | 0 | 1.6 | 0.9 |
| Mn | 0 | 5 | 3 | 20 | 23 | 5 |
| Fe | 0 | 75 | 87 | 300 | 530 | 519 |
| Na | 0 | 1.2 | 0.9 | 1.0 | 2.1 | 0.5 |
| K | 0 | 0.5 | 0.2 | 1.0 | 1.1 | 0.3 |
| Ca | 0 | 0.8 | 0.5 | 14.0 | 14.8 | 0.8 |
| Mg | 0 | 0.2 | 0.0 | 0.6 | 0.8 | 0.3 |

**Table 5.** (Cont.)

| Variables | Reference solution 2; N = 22 | | | Reference solution 3; N = 18 | | |
|---|---|---|---|---|---|---|
| | Nominal conc.** | $\bar{X}_A$ | $S_A$ | Nominal conc.** | $\bar{X}_A$ | $S_A$ |
| Rn | 0 | 2** | 0.2 | 0 | 2** | 0 |
| Ar | 314 | 237 | 39 | 314 | 237 | 28 |
| He | 41 | 65 | 57 | 41 | 62 | 79 |
| $O_2$ | 8.0 | 7.4 | 0.8 | 8.0 | 8.1 | 1.2 |
| Eh | - | 736 | 19 | - | 754 | 30 |
| pH | - | 2.46 | 0.07 | - | 2.15 | 0.43 |
| Cond | - | 1577 | 95 | - | 2307 | 99 |
| $SO_4$ | - | 45 | 11 | - | 56 | 14 |
| Cl | 9.8 | 8.3 | 0.8 | 14.7 | 12.8 | 1.2 |
| F | 0.13 | 0.13 | 0.04 | 0.18 | 0.17 | .04 |
| U | 0.8 | 0.8 | 0.2 | 1.2 | 0.9 | 0.2 |
| As | 0 | 0.3 | 0.2 | 0 | 0.3 | 0.3 |
| Se | 0 | 0.2 | 0.1 | 0 | 0.2 | 0.1 |
| Zn | 282 | 287 | 17 | 423 | 418 | 12 |
| Cu | 70 | 75 | 7 | 105 | 109 | 6 |
| Pb | 10 | 11 | 3 | 15 | 15 | 2 |
| Ni | 0 | 2.0 | 1.1 | 0 | 1.4 | 0.7 |
| Mn | 40 | 41 | 4 | 60 | 62 | 5 |
| Fe | 600 | 658 | 89 | 900 | 1138 | 412 |
| Na | 2.0 | 3.5 | 1.6 | 3.0 | 4.0 | 1.2 |
| K | 2.0 | 1.9 | 0.2 | 3.0 | 2.9 | 0.3 |
| Ca | 28.0 | 29.1 | 0.8 | 42.0 | 42.7 | 1.2 |
| Mg | 1.2 | 1.3 | 0.2 | 1.8 | 1.9 | 0.1 |

* Value entered is half the detection limit of the analytical method.

** Nominal concentrations of dissolved gases were calculated assuming 20°C water in eqiulibrium with atmospheric air at an altitude of 900 m (average estimated temperature and altitude at Eastend, Saskatchewan where samples were prepared). For ionic species nominal concentrations were derived by dissolving weighed amounts of salts in acidic solutions.

**Table 6.** Results of paired t-tests of log transformed variables from 51 field duplicates.

| Variable | Duplicate | $\bar{X}_G$ | Max. | Min. | r | /t/ | p** |
|---|---|---|---|---|---|---|---|
| Depth | 1 | 17.1 | 108 | 1 | 1.00 | 1.00 | .32 |
| | 2 | 17.1 | 108 | 1 | | | |
| Rn | 1 | 338 | 2280 | 5 | .98 | 2.34 | .02 |
| | 2 | 315 | 1985 | 2* | | | |
| Ar | 1 | 441 | 787 | 258 | .57 | 1.09 | .28 |
| | 2 | 452 | 787 | 240 | | | |
| He | 1 | 187 | 15680 | 38 | .99 | 1.63 | .11 |
| | 2 | 179 | 13760 | 35 | | | |
| $H_2$ | 1 | 0.01* | 0.06 | 0.01* | .81 | 1.00 | .32 |
| | 2 | 0.01* | 0.06 | 0.01* | | | |
| $CH_4$ | 1 | 0.01* | 12.4 | 0.01* | .97 | .99 | .33 |
| | 2 | 0.01* | 12.1 | 0.01* | | | |
| $O_2$ | 1 | 3.3 | 11.4 | 1.0 | .93 | .63 | .53 |
| | 2 | 3.4 | 11.2 | 0.9 | | | |
| $CO_2$ | 1 | 15.4 | 253 | 3 | .90 | .92 | .36 |
| | 2 | 14.5 | 253 | 3 | | | |
| Eh | 1 | 374 | 560 | 77 | .81 | 1.23 | .23 |
| | 2 | 360 | 577 | 67 | | | |
| pH | 1 | 7.62 | 8.48 | 5.82 | .90 | .01 | .99 |
| | 2 | 7.62 | 8.58 | 5.52 | | | |
| Cond. | 1 | 1040 | 4500 | 230 | 1.00 | .01 | .99 |
| | 2 | 1040 | 4600 | 235 | | | |
| Alka | 1 | 320 | 1100 | 86 | .98 | .57 | .57 |
| | 2 | 317 | 1095 | 43 | | | |
| $HCO_3$ | 1 | 389 | 1343 | 105 | .98 | .60 | .55 |
| | 2 | 386 | 1336 | 52 | | | |
| $CO_3$ | 1 | 0.1* | 15 | 0.1* | 1.00 | .05 | .96 |
| | 2 | 0.1* | 14 | 0.1* | | | |
| $SO_4$ | 1 | 186 | 2900 | 5* | 1.00 | .11 | .91 |
| | 2 | 186 | 2300 | 5* | | | |
| Cl | 1 | 11.0 | 132 | 0.5 | .99 | .49 | .63 |
| | 2 | 10.9 | 132 | 0.6 | | | |
| F | 1 | 0.23 | .98 | 0.05 | .98 | .66 | .51 |
| | 2 | 0.23 | .99 | 0.05 | | | |
| U | 1 | 3.7 | 78 | 0.1* | .99 | .77 | .45 |
| | 2 | 3.6 | 78 | 0.1* | | | |
| As | 1 | 1.2 | 13.3 | 0.2* | .94 | 1.34 | .19 |
| | 2 | 1.3 | 13.3 | 0.2* | | | |
| Se | 1 | 1.3 | 104 | 0.2* | .98 | 2.25 | .03 |
| | 2 | 1.2 | 107 | 0.2* | | | |
| Zn | 1 | 271 | 19351 | 1.0* | .97 | .35 | .73 |
| | 2 | 265 | 19080 | 1.0* | | | |
| Cu | 1 | 10 | 219 | 0.5* | .97 | .17 | .87 |
| | 2 | 10 | 318 | 0.5* | | | |
| Pb | 1 | 3 | 61 | 0.5* | .81 | 1.86 | .07 |
| | 2 | 3 | 129 | 0.5* | | | |
| Ni | 1 | 2 | 36 | 1.0* | .84 | .65 | .52 |
| | 2 | 2 | 37 | 1.0* | | | |
| Mn | 1 | 55 | 2274 | 5* | .99 | .70 | .49 |
| | 2 | 57 | 2290 | 5* | | | |
| Fe | 1 | 506 | 14470 | 48 | .88 | .69 | .50 |
| | 2 | 471 | 15560 | 64 | | | |
| Na | 1 | 77.9 | 903 | 2.6 | 1.00 | 1.43 | .16 |
| | 2 | 77.0 | 845 | 3.1 | | | |
| K | 1 | 4.94 | 94.6 | 0.6 | 1.00 | .91 | .37 |
| | 2 | 4.92 | 95.4 | 0.6 | | | |
| Ca | 1 | 67.5 | 434 | 5.0 | .97 | .41 | .68 |
| | 2 | 66.5 | 430 | 5.6 | | | |
| Mg | 1 | 33.4 | 279 | 1.1 | 1.00 | .71 | .48 |
| | 2 | 33.2 | 281 | 1.0 | | | |

* Value entered is half the detection limit of the analytical method.

** p = probability that there is no significant difference between the pairs.

Table 7. Results of paired t-tests of log transformed variables from 41 anomalous Rn and/or U sites resampled at the end of the season.

| Variable | Duplicate | $\bar{X}_G$ | Max. | Min. | r | /t/ | p** |
|---|---|---|---|---|---|---|---|
| Depth | 1 | 16.6 | 182 | 5 | 1.00 | 1.33 | .19 |
| | 2 | 16.5 | 182 | 5 | | | |
| Rn | 1 | 559 | 4135 | 16 | .69 | 1.77 | .09 |
| | 2 | 397 | 2556 | 2* | | | |
| Ar | 1 | 419 | 596 | 191 | .63 | .58 | .57 |
| | 2 | 426 | 517 | 112 | | | |
| He | 1 | 116 | 11600 | 40 | .87 | .19 | .85 |
| | 2 | 114 | 14400 | 45 | | | |
| $H_2$ | 1 | 0.01* | 0.03 | 0.01* | -.04 | .56 | .58 |
| | 2 | 0.01* | 0.80 | 0.01* | | | |
| $CH_4$ | 1 | 0.01* | 132 | 0.01* | .96 | 1.04 | .30 |
| | 2 | 0.01* | 148 | 0.02* | | | |
| $O_2$ | 1 | 3.7 | 12.3 | 1.3 | .67 | 1.15 | .26 |
| | 2 | 3.4 | 9.5 | 0.7 | | | |
| $CO_2$ | 1 | 25 | 69 | 3 | .66 | 2.87 | .01 |
| | 2 | 19 | 69 | 2 | | | |
| Eh | 1 | 370 | 590 | 45 | .49 | 2.01 | .05 |
| | 2 | 417 | 607 | 160 | | | |
| pH | 1 | 7.56 | 8.11 | 7.16 | .64 | 3.31 | .00 |
| | 2 | 7.67 | 8.42 | 7.17 | | | |
| Cond. | 1 | 1517 | 7600 | 215 | .70 | 2.21 | .03 |
| | 2 | 1910 | 7700 | 292 | | | |
| Alka | 1 | 357 | 1100 | 128 | .99 | 2.93 | .01 |
| | 2 | 368 | 1125 | 128 | | | |
| $HCO_3$ | 1 | 436 | 1343 | 157 | .99 | 2.98 | .01 |
| | 2 | 449 | 1373 | 156 | | | |
| $CO_3$ | 1 | 0.1* | 0.1* | 0.1* | - | - | - |
| | 2 | 0.1* | 0.1* | 0.1* | | | |
| $SO_4$ | 1 | 339 | 4800 | 5* | .94 | .71 | .48 |
| | 2 | 367 | 5300 | 5* | | | |
| Cl | 1 | 14.8 | 413 | 0.1 | .91 | 2.59 | .01 |
| | 2 | 22.3 | 613 | 0.4 | | | |
| F | 1 | 0.31 | 0.94 | 0.12 | .80 | .79 | .44 |
| | 2 | 0.33 | 1.36 | 0.09 | | | |
| U | 1 | 23.4 | 220 | 0.5 | .97 | 1.48 | .15 |
| | 2 | 21.4 | 240 | 0.8 | | | |
| As | 1 | 1.4 | 9.3 | 0.2* | .56 | .79 | .43 |
| | 2 | 1.5 | 20.0 | 0.2* | | | |
| Se | 1 | 6.3 | 504 | 0.2* | .68 | .28 | .78 |
| | 2 | 6.8 | 366 | 0.2* | | | |
| Zn | 1 | 193 | 19350 | 6 | .76 | .45 | .66 |
| | 2 | 212 | 10440 | 6 | | | |
| Cu | 1 | 16 | 219 | 1.0 | .35 | 2.36 | .02 |
| | 2 | 9 | 323 | 0.5* | | | |
| Pb | 1 | 4 | 129 | 0.5* | .26 | 3.11 | .00 |
| | 2 | 2 | 26 | 0.5* | | | |
| Ni | 1 | 2 | 26 | 1.0* | .56 | 1.47 | .15 |
| | 2 | 2 | 20 | 1.0* | | | |
| Mn | 1 | 26 | 2274 | 5* | .79 | 1.91 | .06 |
| | 2 | 36 | 2060 | 5* | | | |
| Fe | 1 | 302 | 35830 | 10* | .49 | .35 | .73 |
| | 2 | 275 | 13350 | 22 | | | |
| Na | 1 | 102 | 1013 | 2.8 | .97 | 1.56 | .13 |
| | 2 | 113 | 1263 | 5.9 | | | |
| K | 1 | 5.9 | 19.4 | 0.9 | .98 | 2.02 | .05 |
| | 2 | 6.2 | 29.0 | 0.9 | | | |
| Ca | 1 | 129 | 669 | 5.8 | .92 | .47 | .64 |
| | 2 | 133 | 623 | 5.5 | | | |
| Mg | 1 | 78.0 | 704 | 0.7 | .95 | .18 | .86 |
| | 2 | 77.1 | 696 | 0.6 | | | |

* Value entered is half the detection limit of the analytical method.

** p = probability that there is no significant difference between the pairs.

**Table 8.** Means, standard deviations, and ranges of variables from two seasonal sites (19 samples each collected twice a week between June 1976 and August 1976).

| Variable | Frenchman R. water, town supply UTM EAST = 656100 UTM North = 5486600 | | | | Well water from a farm east of town UTM East = 658800 UTM North = 5486400 | | | |
|---|---|---|---|---|---|---|---|---|
| | $\bar{X}_A$ | $S_A$ | Max. | Min. | $\bar{X}_A$ | $S_A$ | Max. | Min. |
| Depth | 0.5 | 0 | 0.5 | 0.5 | 10 | 0 | 10 | 10 |
| Rn | 8 | 2 | 12 | 4 | 896 | 98 | 1075 | 738 |
| Ar | 308 | 19 | 340 | 281 | 462 | 50 | 518 | 340 |
| He | 44 | 3 | 48 | 40 | 54 | 7 | 60 | 32 |
| $H_2$ | 0.01* | 0 | 0.01* | 0.01* | 0.01* | 0 | 0.01* | 0.01* |
| $CH_4$ | 0.01* | 0 | 0.01* | 0.01* | 0.01* | 0 | 0.01* | 0.01* |
| $O_2$ | 8.2 | 1.0 | 10.5 | 6.3 | 2.5 | 0.5 | 3.7 | 1.7 |
| Eh | 518 | 165 | 818 | 321 | 418 | 65 | 567 | 328 |
| pH | 7.82 | 0.23 | 8.09 | 7.40 | 7.86 | 0.16 | 8.16 | 7.59 |
| Cond. | 209 | 23 | 580 | 430 | 1939 | 102 | 2100 | 1700 |
| Alka | 171 | 19 | 204 | 133 | 778 | 24 | 828 | 744 |
| $SO_4$ | 126 | 21 | 163 | 80 | 441 | 22 | 500 | 404 |
| Cl | 4.9 | 1.5 | 7.1 | 2.1 | 31.5 | 4.1 | 38.3 | 25.8 |
| F | 0.19 | 0.04 | 0.26 | 0.11 | 0.70 | 0.06 | 0.84 | 0.60 |
| U | 1.7 | 0.4 | 2.4 | 0.9 | 91.0 | 10.2 | 102 | 62 |
| As | 1.6 | 0.9 | 4.7 | 0.8 | 1.1 | 0.2 | 1.7 | 0.8 |
| Zn | 13 | 11 | 49 | 5 | 236 | 70 | 385 | 134 |
| Cu | 43 | 34 | 143 | 17 | 7 | 3 | 16 | 3 |
| Pb | 2 | 1 | 5 | 0.5* | 2 | 1 | 5 | 0.5* |
| Ni | 3 | 1 | 5 | 0.5* | 3 | 1 | 5 | 1.0* |
| Mn | 35 | 27 | 115 | 5* | 68 | 17 | 96 | 40 |
| Fe | 278 | 258 | 1227 | 10* | 238 | 151 | 560 | 58 |
| Na | 35.9 | 1.7 | 39.3 | 32.8 | 323 | 18 | 352 | 292 |
| K | 3.8 | 0.7 | 5.9 | 3.4 | 8.2 | 1.9 | 9.4 | 8.3 |
| Ca | 40.1 | 6.3 | 51.1 | 31.9 | 44.0 | 2.2 | 49.2 | 41.0 |
| Mg | 27.9 | 1.0 | 30.0 | 25.3 | 106 | 4.3 | 116 | 99 |

* Value entered is half the detection limit of the analytical method.

**Table 9.** Paired t-test results of log transformed values of variables from 62 well water samples before and after filtering and/or acidification.

| Variables | Treatment | $\overline{X}_G$ | $\overline{X}_A$ | $S_A$ | Max. | Min. | $p^2$ / $r^3$ n | fa | a |
|---|---|---|---|---|---|---|---|---|---|
| Zn | n | 17.2 | 42.5 | 59.3 | 234 | 1* | | .40 | .42 |
| | fa | 49.4 | 90.4 | 76.0 | 239 | 1* | .00 | .07 | .23 |
| | a | 76.5 | 308.2 | 1209.5 | 9528 | 1* | .00 | .07 | |
| Cu | n | 3.1 | 13.4 | 47.2 | 366 | 0.5* | | .79 | .80 |
| | fa | 5.6 | 17.3 | 44.0 | 315 | 0.5* | .00 | | .54 |
| | a | 8.1 | 24.0 | 52.3 | 368 | 0.5* | .00 | .04 | |
| Pb | n | 1.1 | 1.9 | 6.6 | 53 | 0.5* | | .06 | .25 |
| | fa | 1.8 | 2.2 | 1.4 | 8 | 0.5* | .00 | | .05 |
| | a | 2.4 | 4.1 | 4.9 | 22 | 0.5* | .00 | .07 | |
| Ni | n | 1.2 | 1.4 | 1.0 | 6 | 1.0* | | .37 | .48 |
| | fa | 1.7 | 2.4 | 2.8 | 17 | 1.0* | .00 | | .52 |
| | a | 2.4 | 4.0 | 6.4 | 45 | 1.0* | .00 | .00 | |
| Mn | n | 7.0 | 41.7 | 157.0 | 874 | 5* | | .35 | .37 |
| | fa | 39.3 | 270.0 | 542.3 | 2847 | 5* | .00 | | .84 |
| | a | 65.2 | 313.3 | 551.6 | 3044 | 5* | .00 | .00 | |
| Fe | n | 23.2 | 414 | 2111 | 16102 | 10* | | .49 | .60 |
| | fa | 62.2 | 391 | 1097 | 6054 | 10* | .00 | | .44 |
| | a | 726.1 | 2354 | 4505 | 26824 | 57 | .00 | .00 | |
| Na | n | 74.6 | 223 | 487 | 3764 | 1.2 | | .99 | .99 |
| | fa | 81.7 | 224 | 478 | 3686 | 2.5 | .00 | | .99 |
| | a | 79.4 | 222 | 448 | 3427 | 2.4 | .00 | .24 | |
| K | n | 4.7 | 8.2 | 14.2 | 91 | 0.4 | | .99 | .99 |
| | fa | 5.0 | 8.3 | 14.0 | 90 | 0.5 | .01 | | .99 |
| | a | 5.1 | 8.5 | 14.1 | 93 | 0.5 | .00 | .01 | |
| Ca | n | 29.9 | 54.3 | 72.1 | 375 | 1.7 | | .85 | .78 |
| | fa | 68.6 | 106.1 | 93.3 | 436 | 3.9 | .00 | | .87 |
| | a | 67.8 | 100.3 | 94.2 | 467 | 3.6 | .00 | .87 | |
| Mg | n | 30.2 | 60.5 | 97.1 | 701 | 0.2 | | .99 | .99 |
| | fa | 31.9 | 59.3 | 90.6 | 649 | 0.7 | .04 | | .99 |
| | a | 31.6 | 59.6 | 93.0 | 671 | 0.5 | .05 | .73 | |
| Cl | n | 8.5 | 30.8 | 56.1 | 264 | 0.3 | | .98 | .96 |
| | fa | 8.7 | 30.3 | 55.2 | 264 | 0.1* | .64 | | .94 |
| | a | 7.9 | 29.3 | 53.3 | 246 | 0.1* | .21 | .22 | |
| F[4] | n | 0.25 | 0.347 | 0.48 | 4.10 | 0.05 | | .96 | .96 |
| | fa | 0.21 | 0.297 | 0.45 | 4.00 | 0.04 | .00 | | .99 |
| | f | 0.22 | 0.317 | 0.46 | 4.10 | 0.04 | .00 | .00 | |
| U[4] | n | 4.6 | 16.4 | 27.2 | 140 | 0.1* | | .97 | .97 |
| | fa | 3.7 | 13.6 | 22.9 | 130 | 0.1* | .01 | | .99 |
| | f | 4.1 | 14.3 | 23.2 | 124 | 0.1* | .00 | .00 | |

1. n = no treatment; fa = filtered and acidified; a = acidified; f = filtered (0.45 microns).
2. p = probability that there is no significant difference between pairs.
3. r = correlation coefficient.
4. For F and U no analysis on acidified samples were made.

* value entered is half the detection limit of the analytical method.

**Table 10.** Paired t-test results of log transformed values of variables from 65 stream-, 6 man-made lake-, and 4 distilled water samples before and after filtering and/or acidification.

| Variable | Treatment | $\bar{X}_G$ | $\bar{X}_A$ | $S_A$ | Max. | Min. | p[2] r[3] a | fa | n | f |
|---|---|---|---|---|---|---|---|---|---|---|
| Zn | a | 1.6 | 2.4 | 2.3 | 12.2 | 1* | | .18 | -.08 | .06 |
| | fa | 1.2 | 2.0 | 3.4 | 22.7 | 1* | .02 | | .58 | .30 |
| | n | 1* | 1.0 | 1.6 | 10.7 | 1* | .00 | .00 | | .39 |
| | f | 1* | 1* | 1* | 2.3 | 1* | .00 | .00 | .00 | |
| Cu | a | 1.4 | 2.2 | 3.5 | 28.9 | 0.5 | | .69 | .69 | .53 |
| | fa | 2.0 | 2.5 | 2.5 | 19.2 | 0.5 | .00 | | .71 | .46 |
| | n | 1.4 | 2.2 | 4.2 | 34.4 | 0.5 | .76 | .00 | | .51 |
| | f | 0.5* | 0.9 | 1.7 | 12.5 | 0.5* | .00 | .00 | .00 | |
| Pb | a | 0.5* | 1.3 | 0.6 | 2.7 | 0.5* | | | | |
| | fa | 0.5* | 0.5* | - | 0.5* | 0.5* | | | | |
| | n | 0.5* | 0.5* | - | 0.5* | 0.5* | | | | |
| | f | 0.5* | 0.5* | - | 0.5* | 0.5 | | | | |
| Ni | a | 3.8 | 4.2 | 1.6 | 8.3 | 1.0* | | .62 | .42 | |
| | fa | 3.9 | 4.1 | 1.1 | 6.3 | 1.0* | .50 | | .22 | |
| | n | 1.0* | 1.2 | 1.0* | 3.6 | 1.0* | .00 | .00 | | |
| | f | 1.0* | 1.0* | 1.0* | 1.0* | 1.0* | | | | |
| Mn | a | 69 | 115 | 122 | 755 | 5* | | .42 | .28 | .29 |
| | fa | 15 | 34 | 57 | 276 | 5* | .00 | | -.10 | .61 |
| | n | 5* | 5 | 2 | 18 | 5* | .00 | .00 | | -.06 |
| | f | 5* | 7 | 6 | 47 | 5* | .00 | .00 | .05 | |
| Fe | a | 365 | 635 | 663 | 3337 | 10* | | .04 | .11 | .05 |
| | fa | 14 | 10* | 22 | 132 | 10* | .00 | | -.08 | .29 |
| | n | 10* | 10* | 10* | 31 | 10* | .00 | .00 | | .06 |
| | f | 10* | 10* | 10* | 32 | 10* | .00 | .00 | .07 | |
| Na | a | 44.1 | 80.0 | 66.9 | 255 | 0.2 | | .99 | .98 | 1.00 |
| | fa | 44.2 | 78.8 | 66.7 | 259 | 0.2 | .97 | | .98 | 1.00 |
| | n | 51.1 | 82.4 | 68.8 | 262 | 1.1 | .01 | .00 | | .98 |
| | f | 43.8 | 79.2 | 66.3 | 245 | 0.2 | .51 | .59 | .00 | |
| K | a | 4.4 | 5.9 | 3.1 | 14.6 | 0.1* | | 1.00 | 1.00 | 1.00 |
| | fa | 4.1 | 5.5 | 2.9 | 13.6 | 0.1* | .00 | | 1.00 | 1.00 |
| | n | 4.4 | 5.9 | 3.2 | 15.9 | 0.1* | .25 | .00 | | 1.00 |
| | f | 4.3 | 5.8 | 3.0 | 14.1 | 0.1* | .00 | .00 | .00 | |
| Ca | a | 38.0 | 51.4 | 23.3 | 113 | 0.2* | | 1.00 | .99 | 1.00 |
| | fa | 36.1 | 48.7 | 22.3 | 107 | 0.2* | .00 | | .99 | 1.00 |
| | n | 32.9 | 45.7 | 20.2 | 102 | 0.2* | .00 | .00 | | 1.00 |
| | f | 34.5 | 46.2 | 20.5 | 104 | 0.2* | .00 | .00 | .03 | |
| Mg | a | 26.0 | 37.9 | 22.7 | 110 | 0.2* | | 1.00 | 1.00 | 1.00 |
| | fa | 25.6 | 37.5 | 22.6 | 109 | 0.2* | .00 | | 1.00 | 1.00 |
| | n | 26.5 | 38.6 | 22.4 | 107 | 0.2* | .00 | .00 | | 1.00 |
| | f | 26.7 | 38.5 | 23.2 | 112 | 0.2* | .07 | .01 | .72 | |
| Cl | a | 2.8 | 4.1 | 2.9 | 10.9 | 0.1* | | .99 | .98 | .98 |
| | fa | 3.0 | 4.3 | 2.9 | 10.9 | 0.1* | .00 | | .98 | .98 |
| | n | 3.3 | 4.4 | 2.8 | 10.9 | 0.1* | .00 | .01 | | .97 |
| | f | 3.1 | 4.5 | 2.9 | 11.1 | 0.1* | .00 | .38 | .13 | |
| F[4] | n | 0.18 | 0.20 | 0.07 | 0.37 | 0.02* | | | | .99 |
| | f | 0.18 | 0.20 | 0.06 | 0.39 | 0.02* | | | .47 | |
| U[4] | n | 2.8 | 3.8 | 2.7 | 11.6 | 0.1* | | | | .98 |
| | f | 2.8 | 3.8 | 2.7 | 11.8 | 0.1* | | | .28 | |

1. n = no treatment; fa = filtered and acidified; a = acidified; f = filtered (0.45 microns).
2. p = probability that there is no significant difference between pairs.
3. r = correlation coefficient.
4. F and U analyses were carried out in the field laboratory on freshly collected samples only.

* Value entered is half the detection limit of the analytical method.

**Table 11.** Summary statistics of lake water variables from the regional survey.

| Variables | Man-made lakes; N = 6 $\bar{X}_G$ | $S_L$ | Max. | Min. | Natural lakes; N = 14 $\bar{X}_G$ | $S_L$ | Max. | Min. |
|---|---|---|---|---|---|---|---|---|
| Area | 6.2 | 0.937 | 500 | 2 | 1.8 | 0.634 | 9 | 0.2 |
| Depth** | 3.4 | 0.139 | 5 | 2 | 2.2 | 0.286 | 10 | 1 |
| Temp. | 19 | 0.040 | 23 | 18 | 18 | 0.070 | 22 | 11 |
| Eh | 372 | 0.079 | 430 | 267 | 277 | 0.343 | 452 | 28 |
| pH | 8.59 | 0.015 | 9.14 | 8.30 | 8.87 | 0.035 | 10.30 | 7.64 |
| Cond. | 453 | 0.108 | 570 | 280 | 1556 | 0.677 | >10000 | 269 |
| $SO_4$ | 118 | 0.141 | 152 | 63 | | | | |
| Alka | 166 | 0.073 | 208 | 126 | 433 | 0.400 | 3010 | 151 |
| $HCO_3$ | 180 | 0.082 | 232 | 140 | 360 | 0.502 | 2490 | 37 |
| $CO_3$ | 4.3 | 0.893 | 28.0 | 0.1* | 14.4 | 1.284 | 580 | 0.1* |
| $CO_2$ | 0.8 | 0.449 | 2.0 | 0.1* | 0.5 | 1.004 | 43 | 0.1* |
| $O_2$ | 8.6 | 0.030 | 9.5 | 7.8 | 4.6 | 0.477 | 13.0 | 0.4 |
| Rn | 2* | 0.123 | 4 | 2* | 2* | 0.515 | 123 | 2* |
| U | 2.6 | 0.209 | 4.6 | 1.1 | 4.6 | 0.532 | 19.0 | 0.2 |
| F | 0.17 | 0.146 | 0.24 | 0.12 | 0.20 | 0.353 | 0.54 | 0.02 |
| Cl | 2.6 | 0.100 | 3.2 | 1.7 | | | | |
| Zn | 1.4 | 0.277 | 3.4 | 1* | | | | |
| Cu | 1.3 | 0.223 | 2.2 | 0.5* | | | | |
| Pb | 0.5* | 0.176 | 2.7 | 0.5* | | | | |
| Ni | 3.4 | 0.130 | 5.2 | 2.2 | | | | |
| Mn | 45 | 0.217 | 84 | 21 | | | | |
| Fe | 282 | 0.313 | 718 | 121 | | | | |
| Na | 34.0 | 0.218 | 46.2 | 12.4 | | | | |
| K | 5.7 | 0.275 | 8.9 | 1.6 | | | | |
| Ca | 40.7 | 0.085 | 47.7 | 28.5 | | | | |
| Mg | 23.5 | 0.134 | 32.8 | 13.7 | | | | |

* Value entered is half the detection limit of the analytical method.
** Sample site depth.

**Table 12.** Summary statistics of stream water variables from the regional survey of 3 streams - Frenchman R., Swiftcurrent Creek, and Battle Creek (N = 65).

| Variables | $\overline{X}_G$ | $\overline{X}_A$ | $S_A$ | Max. | Min. | Skewness Logtr. | Skewness Untr. |
|---|---|---|---|---|---|---|---|
| Width | 8.2 | 9.1 | 3.8 | 20 | 2 | -1.001 | .185 |
| Depth | 3.8 | 4.5 | 2.6 | 14 | 1 | -.346 | 1.206 |
| Temp. | 19 | 19 | 1 | 23 | 15 | -.489 | -.156 |
| Eh | 361 | 364 | 49 | 479 | 279 | .207 | .453 |
| pH | 8.38 | 8.37 | 0.23 | 8.85 | 7.88 | -.238 | -.176 |
| Cond. | 685 | 773 | 395 | 1710 | 300 | .179 | .952 |
| $SO_4$ | 175 | 294 | 254 | 930 | 5 | -.914 | .920 |
| Alka | 222 | 230 | 61.5 | 404 | 141 | .459 | .851 |
| $HCO_3$ | 261 | 271 | 77.4 | 493 | 152 | .396 | .873 |
| $CO_3$ | 1.5 | 4.8 | 4.4 | 17 | 0.1* | -.513 | .461 |
| $CO_2$ | 1.6 | 2.3 | 1.9 | 10 | 0.1* | -1.208 | |
| $O_2$ | 7.8 | 8.0 | 1.8 | 12.6 | 3.9 | -.385 | .458 |
| Rn | 3.7 | 4.6 | 3.4 | 14 | 2* | .478 | 1.203 |
| U | 3.4 | 4.2 | 2.6 | 11.6 | 0.1* | -.244 | .901 |
| F | 0.21 | 0.21 | 0.05 | 0.40 | 0.12 | .091 | 1.040 |
| Cl | 3.5 | 4.5 | 2.8 | 10.9 | 0.4 | -.805 | .472 |
| Zn | 1.7 | 2.6 | 2.5 | 12.2 | 1* | .038 | 2.101 |
| Cu | 1.5 | 2.3 | 3.7 | 28.9 | 0.5* | .503 | 6.004 |
| Pb | 0.5* | 0.5* | 0.5* | 2.7 | 0.5* | 1.474 | 1.538 |
| Ni | 4.1 | 4.4 | 1.0* | 8.3 | 2.2 | -.154 | .481 |
| Mn | 84 | 127 | 126 | 755 | 10 | -.016 | 2.461 |
| Fe | 467 | 700 | 684 | 3337 | 81 | .274 | 1.803 |
| Na | 63.0 | 88.9 | 67.2 | 255 | 4.7 | -.642 | .855 |
| K | 5.5 | 6.2 | 2.9 | 14.6 | 1.6 | -.535 | .341 |
| Ca | 52.2 | 55.5 | 20.8 | 113 | 21.4 | .281 | 1.123 |
| Mg | 36.9 | 41.5 | 21.8 | 110 | 13.5 | .387 | 1.301 |

* Value entered is half the detection limit of the analytical method.

**Table 13.** Comparison of arithmetic means of water variables from three streams.

| Variable | Frenchman River $\bar{X}_A$ | Frenchman River $S_A$ | Battle Creek $\bar{X}_A$ | Battle Creek $S_A$ | Swiftcurrent Creek $\bar{X}_A$ | Swiftcurrent Creek $S_A$ |
|---|---|---|---|---|---|---|
| N | 28 | | 14 | | 23 | |
| Width | 9.8 | 3.3 | 8.0 | 3.7 | 9.0 | 4.5 |
| Depth | 3.5 | 2.2 | 5.8 | 3.6 | 4.9 | 1.8 |
| Temp. | 19 | 1 | 20 | 1 | 19 | 1 |
| Eh | 383 | 47 | 326 | 33 | 365 | 47 |
| pH | 8.34 | 0.24 | 8.43 | 0.24 | 8.37 | 0.22 |
| Cond. | 898 | 513 | 617 | 311 | 716 | 185 |
| $SO_4$ | 371 | 326 | 181 | 198 | 268 | 133 |
| Alka | 234 | 65 | 202 | 22 | 242 | 70 |
| $O_2$ | 7.4 | 1.2 | 9.8 | 1.7 | 7.8 | 1.8 |
| Rn | 6 | 4 | 4 | 3 | 4 | 3 |
| U | 5.6 | 3.2 | 3.4 | 2.1 | 3.0 | 0.9 |
| F | 0.24 | 0.05 | 0.17 | 0.03 | 0.20 | 0.04 |
| Cl | 4.6 | 2.8 | 4.2 | 4.3 | 4.6 | 1.6 |
| Zn | 3.4 | 2.6 | 2.2 | 3.0 | 1.9 | 1.6 |
| Cu | 3.7 | 5.4 | 0.9 | 0.7 | 1.5 | 0.7 |
| Pb | 1.3 | 0.6 | 1.1 | 0.5 | 1.5 | 1.7 |
| Ni | 4.9 | 1.9 | 3.4 | 1.0 | 4.3 | 0.9 |
| Mn | 185 | 162 | 42 | 17 | 108 | 68 |
| Fe | 1056 | 857 | 354 | 227 | 478 | 375 |
| Na | 103 | 80 | 60 | 55 | 89 | 51 |
| K | 7.0 | 3.5 | 4.4 | 2.6 | 6.4 | 1.7 |
| Ca | 62 | 29 | 47 | 7 | 52 | 9 |
| Mg | 49 | 28 | 31 | 14 | 3.9 | 12 |

**Table 14.** Comparison of arithmetic means of water variables from 3 sample suites from the Frenchman River sampled at different times.

| Sample suite | 1 | | 2 | | 3 | |
|---|---|---|---|---|---|---|
| Sample time | July 13-23/76 | | Aug. 6/76 | | Aug. 19/76 | |
| No. of samples | 22 | | 22 | | 22 | |
| Parameter | $\overline{X}_A$ | $S_A$ | $\overline{X}_A$ | $S_A$ | $\overline{X}_A$ | $S_A$ |
| Width | 9.3 | 3.3 | 10.3 | 1.7 | 8.1 | 3.0 |
| Depth | 3.8 | 1.5 | 3.8 | 1.8 | 6.2 | 2.1 |
| Temp. | 20 | 1 | 21 | 2 | 17 | 1 |
| Eh | 362 | 54 | 396 | 108 | 424 | 33 |
| pH | 8.26 | 0.11 | 8.02 | 0.11 | 8.16 | 0.10 |
| Cond. | 835 | 282 | 853 | 221 | 864 | 383 |
| Alka | 223 | 41 | 248 | 31 | 267 | 57 |
| $O_2$ | 6.4 | 1.7 | 7.4 | 0.6 | 6.9 | 0.6 |
| Rn | 11 | 4 | 16 | 11 | 12 | 7 |
| U | 4.4 | 1.8 | 4.6 | 1.1 | 5.4 | 2.7 |
| F | 0.27 | 0.05 | 0.28 | 0.02 | 0.27 | 0.06 |

**Table 15.** Summary statistics of stream sediment variables, Frenchman River, semi-detailed survey (N = 22).

| Variable | $\bar{X}_A$ | $S_A$ | Max. | Min. |
|---|---|---|---|---|
| Width | 8.1 | 3.1 | 16 | 4 |
| Depth | 6.2 | 2.1 | 10 | 3 |
| As | 8.9 | 3.7 | 20 | 4.4 |
| Se | 0.3 | 0.2 | 1.1 | 0.1 |
| F | 437 | 86 | 600 | 305 |
| U | 2.8 | 0.5 | 4.4 | 2.3 |
| Ra | 1.1 | 0.6 | 2.9 | 0.3 |
| Al | 6.1 | 0.8 | 7.8 | 4.5 |
| Ca | 3.7 | 0.6 | 5.0 | 1.9 |
| Mg | 1.2 | 0.3 | 1.9 | 0.9 |
| Fe | 3.5 | 0.8 | 4.9 | 2.4 |
| K | 1.4 | 0.3 | 2.0 | 1.0 |
| Be | 2.7 | 0.2 | 3.0 | 2.2 |
| La | 36 | 11 | 58 | 19 |
| Y | 17 | 4 | 25 | 9 |
| Ag | 0.2 | 0 | 0.2 | 0.2 |
| Pb | 20 | 8 | 50 | 12 |
| Zn | 161 | 30 | 229 | 106 |
| V | 72 | 17 | 98 | 39 |
| Mo | 3 | 0.5 | 4 | 2 |
| Cr | 55 | 13 | 79 | 29 |
| Cu | 15 | 4 | 23 | 8 |
| Co | 8 | 3 | 12 | 4 |
| Ni | 16 | 4 | 25 | 9 |
| Sr | 180 | 22 | 234 | 144 |
| Ba | 732 | 97 | 997 | 571 |
| Mn | 555 | 205 | 1012 | 151 |
| Ti | 4011 | 721 | 5760 | 2807 |

**Table 16.** Summary statistics of variables from all wells.

| Variable | $N_1$** | $N_2$** | $\bar{X}_G$ | $\bar{X}_A$ | $S_A$ | Max. | Min. | Skewness Untr. | Skewness Logtr. |
|---|---|---|---|---|---|---|---|---|---|
| Depth | 739 | 0 | 18.6 | 30.6 | 38.0 | 500 | 1 | 5.38 | .07 |
| Rn | 863 | 30 | 214 | 360 | 337 | 4135 | 2 | 3.53 | -1.85 |
| $O_2$ | 863 | 0 | 3.0 | 3.7 | 2.6 | 14.0 | 0.4 | 1.26 | .14 |
| Eh | 865 | 0 | 363 | 387 | 104 | 906 | 7 | -.59 | -4.09 |
| Cond. | 865 | 0 | 1202 | 1519 | 1204 | 15000 | 110 | 3.33 | -.03 |
| pH | 864 | 0 | 7.59 | 7.63 | 0.38 | 9.00 | 4.86 | -.48 | -1.28 |
| $CO_3$ | 865 | 812 | 0.1* | 0.9 | 6.0 | 156 | 0.1 | 20.74 | 4.28 |
| Alka | 865 | 0 | 347 | 384 | 165 | 1811 | 8 | 1.80 | -1.27 |
| $HCO_3$ | 865 | 0 | 427 | 466 | 198 | 1891 | 10 | 1.54 | -1.27 |
| $CO_2$ | 865 | 1 | 16 | 23 | 24 | 339 | 0.1* | 5.24 | -.38 |
| U | 865 | 60 | 3.5 | 12.2 | 21.1 | 220 | 0.1* | 4.18 | -.32 |
| F | 864 | 0 | 0.23 | 0.29 | 0.29 | 4.10 | 0.04 | 7.16 | .45 |
| $SO_4$ | 865 | 52 | 224 | 588 | 862 | 10700 | 5 | 3.91 | -.57 |
| He | 861 | 0 | 224 | 1101 | 3338 | 34000 | 37 | 6.51 | 1.00 |
| Ar | 865 | 0 | 437 | 439 | 86 | 1035 | 81 | -.52 | -1.98 |
| $H_2$ | 864 | 830 | 0.01 | 0.03 | 0.29 | 6.8 | 0.01* | 20.72 | 7.27 |
| $CH_4$ | 864 | 752 | 0.02 | 0.88 | 7.30 | 132 | 0.01* | 12.60 | 3.86 |
| As | 830 | 143 | 1.1 | 2.9 | 7.4 | 94.9 | 0.2* | 6.75 | .91 |
| Se | 865 | 360 | 1.3 | 16.0 | 66.1 | 1241 | 0.2* | 10.27 | .88 |
| Zn | 865 | 22 | 240 | 1032 | 3381 | 75721 | 1* | 14.16 | .11 |
| Cu | 865 | 40 | 8.9 | 26.0 | 78.2 | 1649 | 0.5* | 13.55 | .27 |
| Pb | 865 | 330 | 2.6 | 5.0 | 11.9 | 175 | 0.5* | 8.13 | .97 |
| Ni | 865 | 360 | 2.2 | 5.2 | 24.9 | 497 | 1* | 14.67 | 1.50 |
| Cl | 865 | 12 | 12.6 | 44.5 | 96.8 | 1500 | 0.1* | 7.05 | -.10 |
| Mn | 865 | 170 | 69.2 | 348 | 812 | 9638 | 5* | 5.93 | .16 |
| Fe | 865 | 20 | 501 | 2429 | 11648 | 243815 | 10* | 15.45 | .31 |
| Na | 864 | 0 | 91.2 | 202.9 | 259.3 | 3427 | 2.0 | 4.32 | -.44 |
| K | 864 | 0 | 5.5 | 7.4 | 7.6 | 94 | 0.1 | 5.73 | -.29 |
| Ca | 865 | 0 | 75.9 | 118.5 | 113.2 | 687 | 1.5 | 1.94 | -.77 |
| Mg | 864 | 0 | 37.2 | 69.6 | 82.6 | 704 | 0.2* | 3.18 | -.96 |

* Value entered is half the detection limit of the analytical method.

** $N_1$ = no. of sites sampled and analysed; $N_2$ = no. of samples below the detection limit of the analytical method.

**Table 17.** Summary statistics of variables from all springs.

| Variable | $N_1$** | $N_2$** | $\bar{X}_G$ | $\bar{X}_A$ | $S_A$ | Max. | Min. | Skewness Untr. | Skewness Logtr. |
|---|---|---|---|---|---|---|---|---|---|
| Depth | 20 | 0 | 2.5 | 2.9 | 1.4 | 5.0 | 1.0 | -.06 | -.66 |
| Rn | 75 | 2 | 170 | 399 | 361 | 1686 | 2* | 1.25 | -1.26 |
| $O_2$ | 75 | 0 | 5.0 | 6.1 | 3.1 | 10.6 | 1.1 | -.26 | -.86 |
| Eh | 75 | 0 | 380 | 399 | 103 | 806 | 97 | .03 | -2.11 |
| Cond. | 75 | 0 | 501 | 674 | 723 | 5308 | 140 | 4.15 | .90 |
| pH | 75 | 0 | 7.59 | 7.65 | 0.35 | 8.66 | 6.74 | .05 | -.15 |
| $CO_3$ | 75 | 74 | 0.1 | 0.4 | 1.8 | 14 | 0.1* | 6.65 | 6.03 |
| Alka | 75 | 0 | 224 | 246 | 112 | 577 | 67 | 1.00 | -.05 |
| $HCO_3$ | 75 | 0 | 269 | 300 | 137 | 704 | 81 | 1.01 | -.05 |
| $CO_2$ | 75 | 0 | 10 | 14 | 14 | 83 | 0.1* | 2.63 | -.14 |
| U | 75 | 7 | 1.7 | 3.8 | 5.4 | 32 | 0.1* | 3.22 | -.45 |
| F | 75 | 0 | 0.18 | 0.22 | 0.15 | 0.71 | 0.05 | 1.88 | .49 |
| $SO_4$ | 75 | 17 | 40 | 122 | 209 | 1400 | 5* | 3.72 | .14 |
| He | 75 | 0 | 72 | 158 | 545 | 4600 | 38 | 7.63 | 3.12 |
| Ar | 75 | 0 | 398 | 400 | 66 | 531 | 222 | -.57 | -1.08 |
| $H_2$ | 75 | 75 | 0.01 | 0.01* | 0 | 0.03 | 0.01* | 8.66 | 8.66 |
| $CH_4$ | 75 | 71 | 0.01 | 0.07 | 0.3 | 2.64 | 0.01* | 7.21 | 3.51 |
| As | 72 | 11 | 1.8 | 4.2 | 8.6 | 61.1 | 0.2* | 4.85 | .47 |
| Se | 75 | 43 | 0.7 | 5.7 | 25.8 | 215 | 0.2* | 7.57 | 1.40 |
| Zn | 75 | 18 | 19 | 176 | 560 | 4251 | 1.0* | 5.87 | .49 |
| Cu | 75 | 12 | 5.0 | 34.7 | 129 | 1029 | 0.5* | 6.72 | .77 |
| Pb | 75 | 33 | 2.2 | 3.5 | 6 | 49.4 | 0.5* | 6.38 | .86 |
| Ni | 75 | 32 | 2.2 | 3.0 | 3.3 | 21.4 | 1.0* | 3.73 | .76 |
| Cl | 75 | 8 | 1.8 | 9.2 | 30.3 | 183.7 | 0.1* | 5.27 | .45 |
| Mn | 75 | 41 | 23 | 176 | 452 | 2695 | 5* | 3.98 | .84 |
| Fe | 75 | 2 | 302 | 1184 | 2918 | 18477 | 10* | 4.20 | .65 |
| Na | 75 | 0 | 18.2 | 54.7 | 96.4 | 468.7 | 2.2 | 2.89 | .61 |
| K | 75 | 0 | 2.6 | 4.4 | 4.4 | 25.3 | 0.5 | 2.55 | .24 |
| Ca | 75 | 0 | 55.0 | 63.4 | 42.7 | 321.8 | 14.2 | 3.47 | .42 |
| Mg | 75 | 0 | 21.9 | 27.8 | 23.9 | 169.7 | 5.1 | 3.37 | .29 |

* Value entered is half the detection limit of the analytical method.

** $N_1$ = no. of sites sampled and analysed; $N_2$ = no. of samples below the detection limit of the analytical method.

**Table 18.** Comparison of geometric means of water variables grouped by type of water and drawing system.

| | Wells | | | Springs | |
|---|---|---|---|---|---|
| Variables | Tap | Hand pump | Bucket | Tap | Bucket |
| N | 728 | 74 | 62 | 45 | 30 |
| Depth | 19.5 | 14.5 | 14.8 | 2.6 | 2.4 |
| Rn | 257 | 81 | 79 | 214 | 123 |
| Ar | 437 | 427 | 407 | 407 | 372 |
| He | 234 | 224 | 117 | 66 | 79 |
| $H_2$ | 0.01* | 0.01* | 0.01* | 0.01* | 0.01* |
| $CH_4$ | 0.01* | 0.03 | 0.02 | 0.01* | 0.02 |
| $O_2$ | 3.0 | 2.6 | 3.0 | 4.9 | 5.2 |
| $CO_2$ | 16 | 15 | 13 | 9 | 10 |
| Eh | 372 | 347 | 302 | 389 | 372 |
| pH | 7.59 | 7.76 | 7.59 | 7.59 | 7.59 |
| Cond. | 1202 | 1479 | 977 | 525 | 479 |
| Alka | 355 | 372 | 302 | 214 | 234 |
| $HCO_3$ | 427 | 447 | 372 | 263 | 288 |
| $CO_3$ | 0.1* | 0.1* | 0.1* | 0.1* | 0.1* |
| $SO_4$ | 224 | 339 | 138 | 44 | 34 |
| Cl | 12.0 | 25.7 | 10.5 | 2.5 | 1.0 |
| F | 0.24 | 0.24 | 0.20 | 0.17 | 0.20 |
| U | 3.5 | 3.8 | 3.8 | 2.1 | 1.3 |
| As | 1.1 | 1.5 | 1.6 | 1.7 | 2.1 |
| Se | 1.3 | 1.5 | 1.5 | 1.0 | 0.4 |
| Zn | 209 | 646 | 355 | 35 | 7 |
| Cu | 9.1 | 6.5 | 7.4 | 10.5 | 1.7 |
| Pb | 2.4 | 4.6 | 3.4 | 2.5 | 1.9 |
| Ni | 2.2 | 3.0 | 3.2 | 2.0 | 2.3 |
| Mn | 65 | 141 | 78 | 19 | 32 |
| Fe | 417 | 2239 | 741 | 257 | 389 |
| Na | 93.3 | 126 | 45.7 | 18.6 | 17.4 |
| K | 5.2 | 7.1 | 6.6 | 2.8 | 2.2 |
| Ca | 72.4 | 93.3 | 87.1 | 56.2 | 52.5 |
| Mg | 35.5 | 53.7 | 45.7 | 22.4 | 20.9 |

* Value entered is half the detection limit of the analytical method.

**Table 19.** Comparison of geometric means of variables in well waters from different rock formations.

| Variable | Cypress Hills $\bar{X}_G$ | Cypress Hills $S_L$ | Ravenscrag $\bar{X}_G$ | Ravenscrag $S_L$ | Eastend $\bar{X}_G$ | Eastend $S_L$ | Bearpaw $\bar{X}_G$ | Bearpaw $S_L$ |
|---|---|---|---|---|---|---|---|---|
| N | 88 | | 50 | | 148 | | 579 | |
| Depth | 24.4 | .296 | 23.4 | .343 | 25.3 | .404 | 16.3 | .457 |
| Rn | 375 | .412 | 239 | .459 | 220 | .468 | 196 | .629 |
| Ar | 433 | .069 | 431 | .062 | 445 | .098 | 433 | .094 |
| He | 98 | .437 | 194 | .582 | 324 | .640 | 233 | .715 |
| $H_2$ | 0.01* | .051 | 0.01* | .280 | 0.01* | .279 | 0.01 | .239 |
| $CH_4$ | 0.01 | .118 | 0.01* | .108 | 0.01* | .461 | 0.02 | .745 |
| $O_2$ | 5.0 | .322 | 3.9 | .290 | 3.0 | .266 | 2.6 | .277 |
| $CO_2$ | 9.7 | .384 | 17.6 | .453 | 15.4 | .456 | 16.9 | .346 |
| Eh | 408 | .071 | 385 | .103 | 372 | .129 | 353 | .218 |
| pH | 7.65 | .019 | 7.53 | .027 | 7.65 | .025 | 7.62 | .021 |
| Cond. | 618 | .307 | 905 | .274 | 1166 | .251 | 1360 | .288 |
| Alka | 229 | .146 | 328 | .205 | 362 | .183 | 373 | .191 |
| $HCO_3$ | 280 | .145 | 399 | .204 | 439 | .182 | 454 | .190 |
| $CO_3$ | 0.1* | .238 | 0.1* | .438 | 0.2 | .646 | 0.1* | .408 |
| $SO_4$ | 66 | .733 | 141 | .675 | 242 | .608 | 272 | .696 |
| Cl | 17.2 | 2.414 | 9.3 | 1.396 | 9.5 | 1.193 | 20.2 | .744 |
| F | 0.20 | .223 | 0.20 | .266 | 0.20 | .264 | 0.26 | .272 |
| U | 2.9 | .740 | 1.5 | .842 | 1.4 | .883 | 4.9 | .723 |
| As | 1.5 | .408 | 0.8 | .391 | 0.7 | .414 | 1.3 | .516 |
| Se | 2.3 | .948 | 1.4 | .938 | 0.9 | .942 | 1.3 | .853 |
| Zn | 169 | .524 | 241 | .735 | 173 | .725 | 274 | .770 |
| Cu | 8.8 | .472 | 9.2 | .557 | 6.2 | .662 | 9.7 | .604 |
| Pb | 2.0 | .423 | 2.1 | .427 | 2.3 | .445 | 2.8 | .406 |
| Ni | 1.9 | .293 | 2.0 | .342 | 2.2 | .443 | 2.5 | .392 |
| Mn | 18 | .728 | 41 | .684 | 67 | .739 | 91 | .835 |
| Fe | 334 | .605 | 546 | .650 | 646 | .642 | 503 | .744 |
| Na | 21.4 | .579 | 54.8 | .731 | 106.2 | .611 | 114.0 | .576 |
| K | 3.2 | .402 | 5.7 | .399 | 6.7 | .786 | 5.9 | .306 |
| Ca | 63.5 | .316 | 53.6 | .448 | 52.9 | .569 | 87.1 | .439 |
| Mg | 29.5 | .339 | 28.0 | .540 | 25.4 | .662 | 44.1 | .546 |

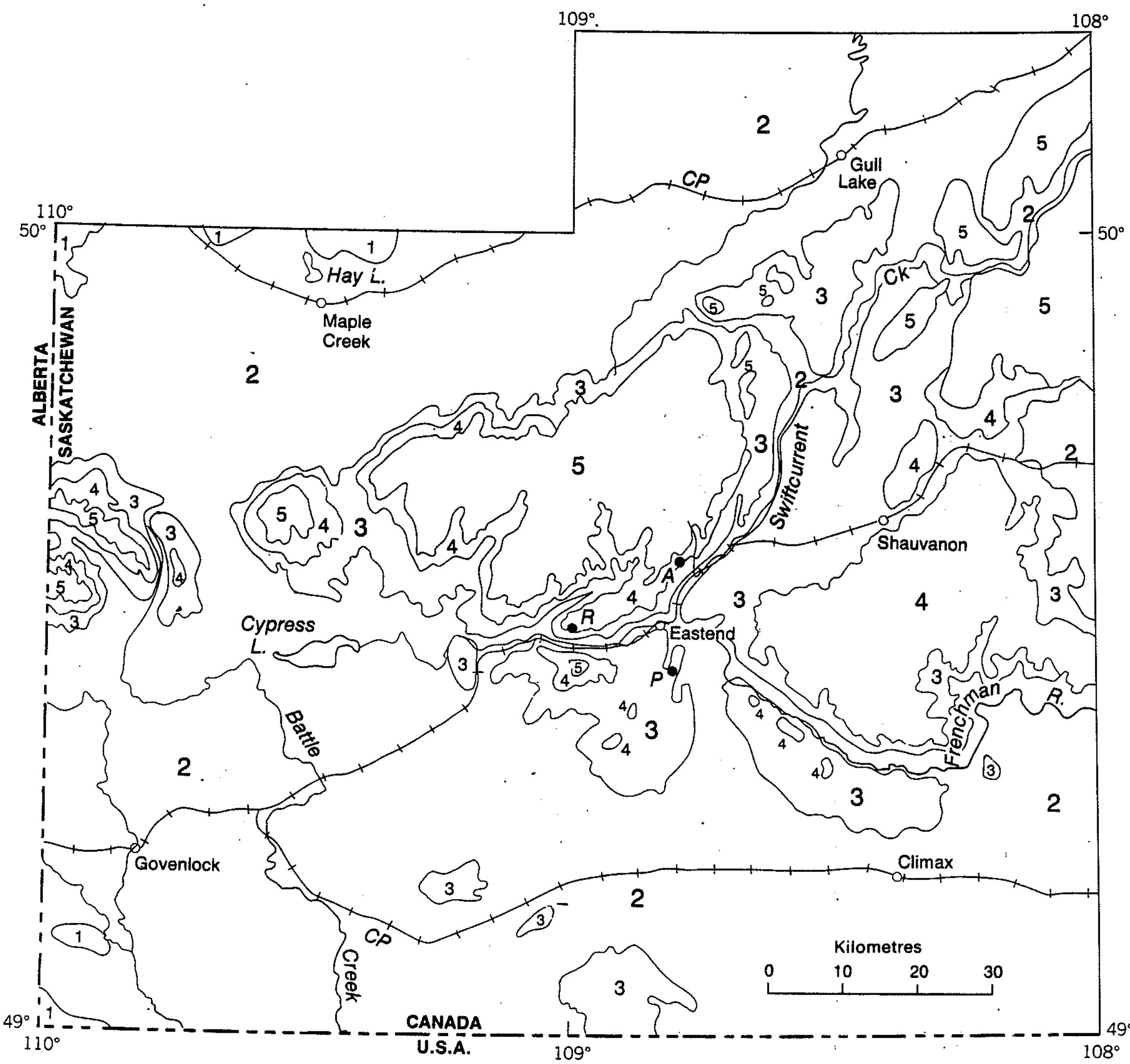
* Value entered is half the detection limit of the analytical method.

**Table 20.** Effect of pressure system, type of tank, and type of pipe on the concentration of well water variables from the Bearpaw Formation.

| Variable | | N | Rn | Ar | He | $O_2$ | $CO_2$ | Eh | pH | Cond. |
|---|---|---|---|---|---|---|---|---|---|---|
| Type of pressure system (galvanized tanks and Cu pipes only) | | | | | | | | | | |
| - autoair* | $\bar{X}_G$ | 168 | 246 | 435 | 211 | 2.9 | 15.3 | 350 | 7.66 | 1234 |
| | $S_L$ | | .564 | .086 | .696 | .281 | .358 | .204 | .018 | .274 |
| - precharged | $\bar{X}_G$ | 7 | 213 | 442 | 405 | 2.0 | 17.7 | 380 | 7.74 | 1418 |
| | $S_L$ | | .226 | .113 | 1.021 | .219 | .575 | .070 | .027 | .320 |
| Type of tank (autoair pressure system and Cu pipes only) | | | | | | | | | | |
| - galvanized | $\bar{X}_G$ | 168 | 246 | 435 | 211 | 2.9 | 15.3 | 350 | 7.66 | 1234 |
| | $S_L$ | | .564 | .086 | .696 | .261 | .358 | .204 | .018 | .274 |
| - glass lined | $\bar{X}_G$ | 9 | 262 | 457 | 299 | 2.2 | 30.3 | 370 | 7.45 | 2441 |
| | $S_L$ | | .826 | .080 | .909 | .259 | .376 | .147 | .017 | .290 |
| Type of pipe (autoair pressure system and galvanized tanks only) | | | | | | | | | | |
| - Cu | $\bar{X}_G$ | 168 | 246 | 435 | 211 | 2.9 | 15.3 | 350 | 7.66 | 1234 |
| | $S_L$ | | .493 | .086 | .696 | .281 | .358 | .204 | .018 | .274 |
| - Fe | $\bar{X}_G$ | 45 | 250 | 441 | 536 | 2.3 | 15.3 | 346 | 7.68 | 1421 |
| | $S_L$ | | .386 | .069 | .877 | .236 | .493 | .182 | .036 | .221 |
| - plastic | $\bar{X}_G$ | 150 | 280 | 437 | 220 | 2.7 | 17.8 | 373 | 7.61 | 1355 |
| | $S_L$ | | .190 | .066 | .676 | .260 | .294 | .165 | .016 | .256 |

| Variable | | U | As | Se | Zn | Cu | Pb | Ni | Mn | Fe |
|---|---|---|---|---|---|---|---|---|---|---|
| Type of pressure system (galvanized tank and Cu pipes only) | | | | | | | | | | |
| - autoair* | $\bar{X}_G$ | 4.8 | 1.2 | 1.2 | 252 | 14.1 | 2.7 | 2.2 | 68 | 407 |
| | $S_L$ | .706 | .516 | .778 | .700 | .632 | .362 | .329 | .846 | .649 |
| - precharged | $\bar{X}_G$ | 2.0 | 1.0 | 0.5 | 241 | 6.1 | 3.3 | 2.6 | 106 | 406 |
| | $S_L$ | 1.002 | .839 | .606 | .952 | .734 | .602 | .487 | .724 | .533 |
| Type of tank (autoair pressure system and Cu pipes only) | | | | | | | | | | |
| - galvanized | $\bar{X}_G$ | 4.8 | 1.2 | 1.2 | 252 | 14.1 | 2.7 | 2.2 | 68 | 407 |
| | $S_L$ | .706 | .516 | .778 | .700 | .632 | .362 | .329 | .846 | .649 |
| - glass lined | $\bar{X}_G$ | 7.8 | 0.7 | 0.5 | 97 | 8.0 | 1.9 | 4.7 | 461 | 835 |
| | $S_L$ | .424 | .117 | .400 | .786 | .798 | .370 | .633 | 1.014 | .650 |
| Type of pipe (autoair pressure system and galvanized tanks only) | | | | | | | | | | |
| - Cu | $\bar{X}_G$ | 4.8 | 1.2 | 1.2 | 252 | 14.1 | 2.7 | 2.2 | 68 | 407 |
| | $S_L$ | .706 | .516 | .778 | .700 | .632 | .362 | .329 | .846 | .649 |
| - Fe | $\bar{X}_G$ | 2.3 | 1.1 | 0.7 | 260 | 6.9 | 3.0 | 2.2 | 65 | 502 |
| | $S_L$ | .732 | .545 | .704 | .761 | .641 | .417 | .438 | .769 | .593 |
| - plastic | $\bar{X}_G$ | 5.9 | 1.3 | 2.0 | 299 | 10.0 | 2.4 | 2.2 | 90 | 348 |
| | $S_L$ | .714 | .508 | .973 | .672 | .581 | .395 | .280 | .826 | .771 |

*autoair = automatic air volume control





Lake and stream survey

Well water survey

LEGEND

CENOZOIC

TERTIARY

OLIGOCENE-EOCENE

| 5 | *CYPRESS HILLS FORMATION: quartzite and chert gravel, interbedded with sand, silt, and clay; locally a conglomerate with carbonate cement* |
|---|---|

PALEOCENE

| 4 | *RAVENSCRAG FORMATION: interbedded sand, silt, clay, and lignite; local carbonaceous zones, kaolinitic zones, concretionary zones, and calcareous zones* |
|---|---|

MESOZOIC

CRETACEOUS

| 3 | *FRENCHMAN FORMATION: interbedded sand, silt, and clay; local bentonitic zones, carbonaceous zones, and calcareous zones*<br>*WHITEMUD FORMATION: upper portion-plastic kaolinitic clay and sand, includes Battle Clay; middle portion-carbonaceous, silty clay; lower portion-partially kaolinized sand and silt*<br>*EASTEND FORMATION: fine-grained sand and silt; locally carbonaceous in upper portion; sand commonly calcareous* |
|---|---|
| 2 | *BEARPAW FORMATION: noncalcareous, silty clay-shale, locally bentonitic and concretionary; includes several sand members* |
| 1 | *JUDITH RIVER FORMATION: interbedded sand, silt, and clay-shale; commonly carbonaceous and noncalcareous; local bentonitic zones and thin coal beds* |

*Anxiety Butte* ............ *A*    *Ravensrag* ............ *R*    *Whitemud Pit* ............ *P*

FIG. 1.

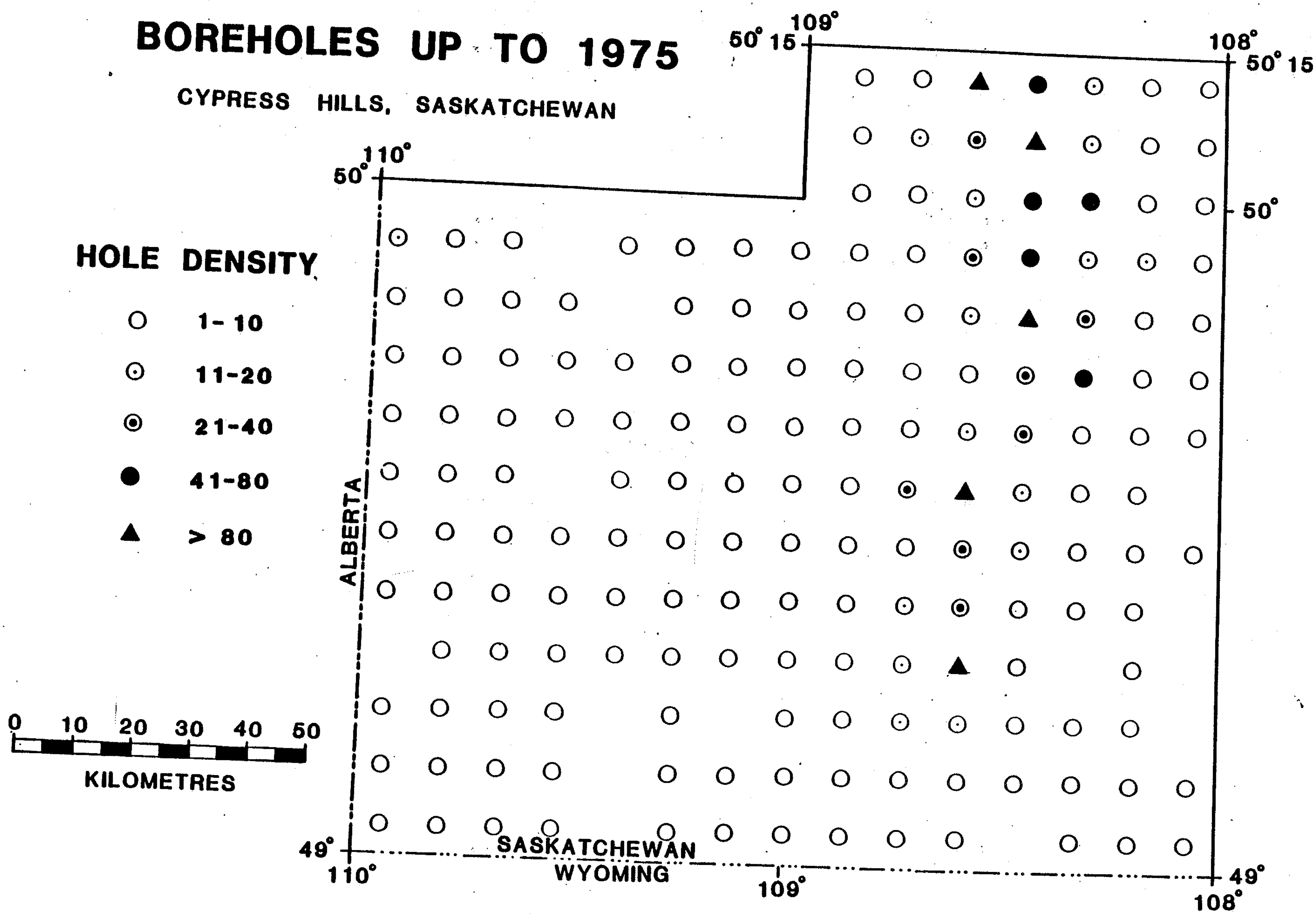

BOREHOLES UP TO 1975
CYPRESS HILLS, SASKATCHEWAN
HOLE DENSITY
1- 10
11-20
21-40
41-80
> 80
0 10 20 30 40 50
KILOMETRES
110°
50°
109°
50° 15
108°
50° 15
50°
ALBERTA
SASKATCHEWAN
WYOMING
49°
110°
109°
49°
108°

FIG. 2.

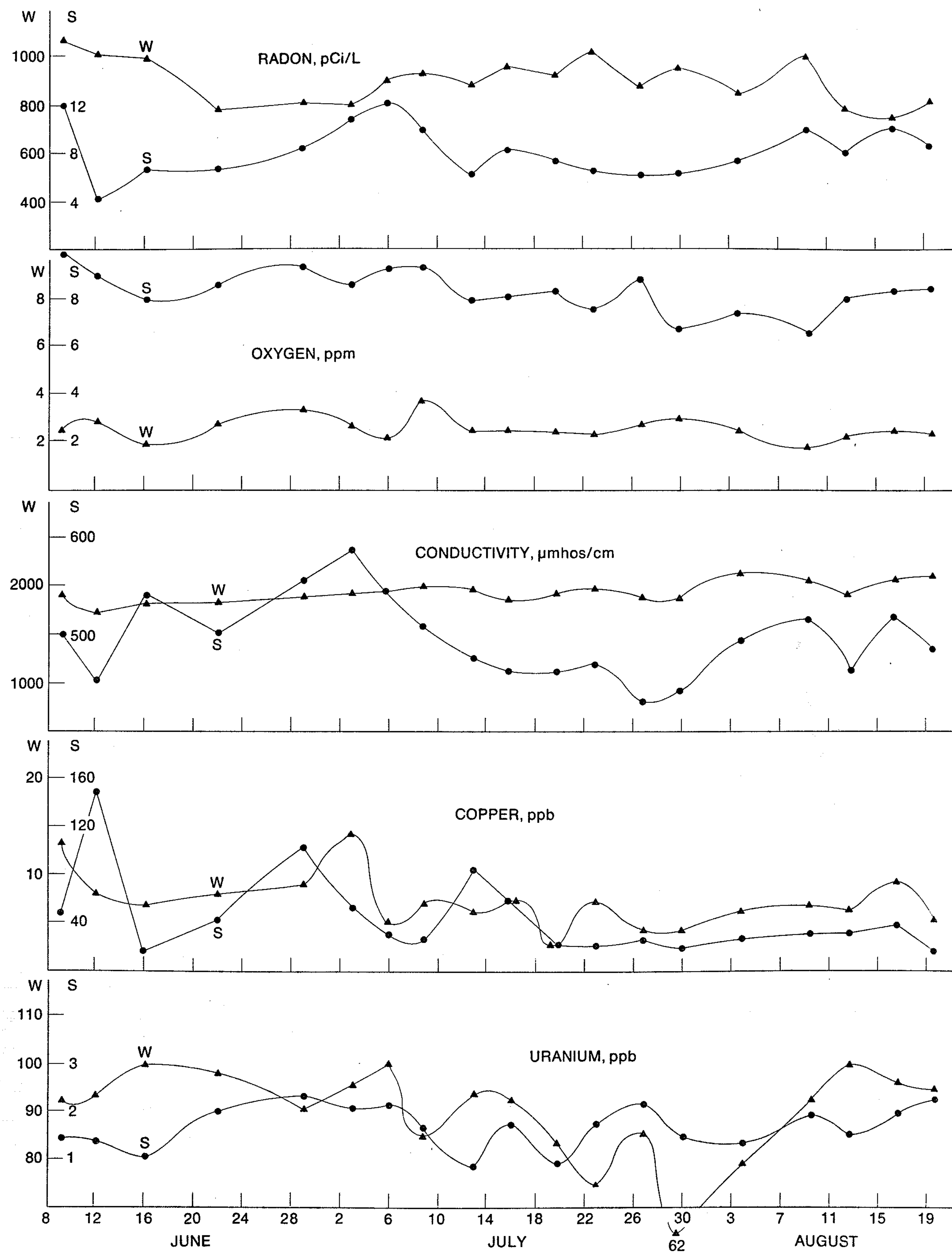
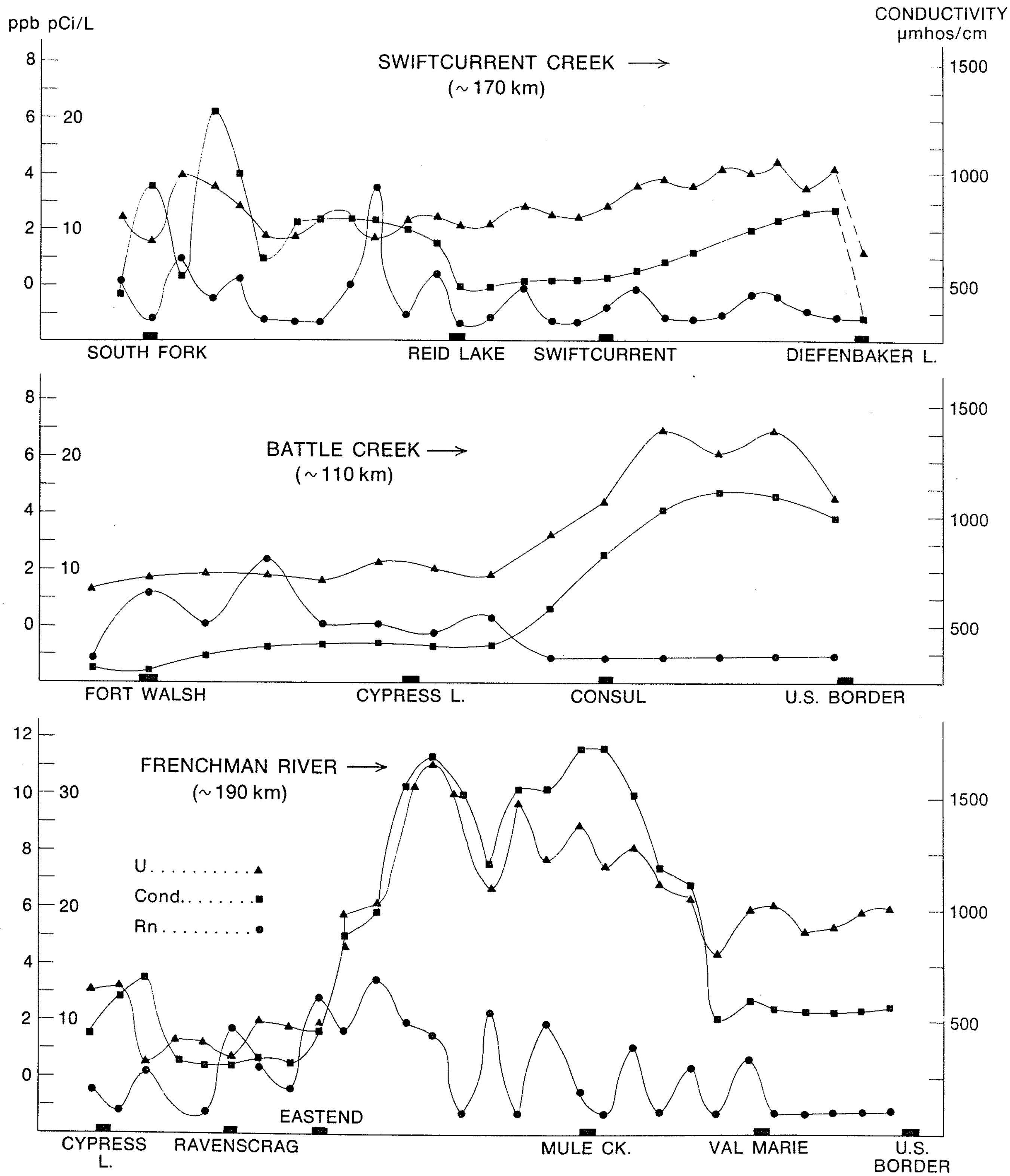

RADON, pCi/L
OXYGEN, ppm
CONDUCTIVITY, µmhos/cm
COPPER, ppb
URANIUM, ppb
W
S
JUNE
JULY
AUGUST
62

FIG. 3



ppb pCi/L
CONDUCTIVITY µmhos/cm
SWIFTCURRENT CREEK →
(~170 km)
SOUTH FORK
REID LAKE
SWIFTCURRENT
DIEFENBAKER L.
BATTLE CREEK →
(~110 km)
FORT WALSH
CYPRESS L.
CONSUL
U.S. BORDER
FRENCHMAN RIVER →
(~190 km)
U. . . . . . . . . . . ▲
Cond. . . . . . . . ■
Rn. . . . . . . . . . ●
CYPRESS L.
RAVENSCRAG
EASTEND
MULE CK.
VAL MARIE
U.S. BORDER


FIG. 4.

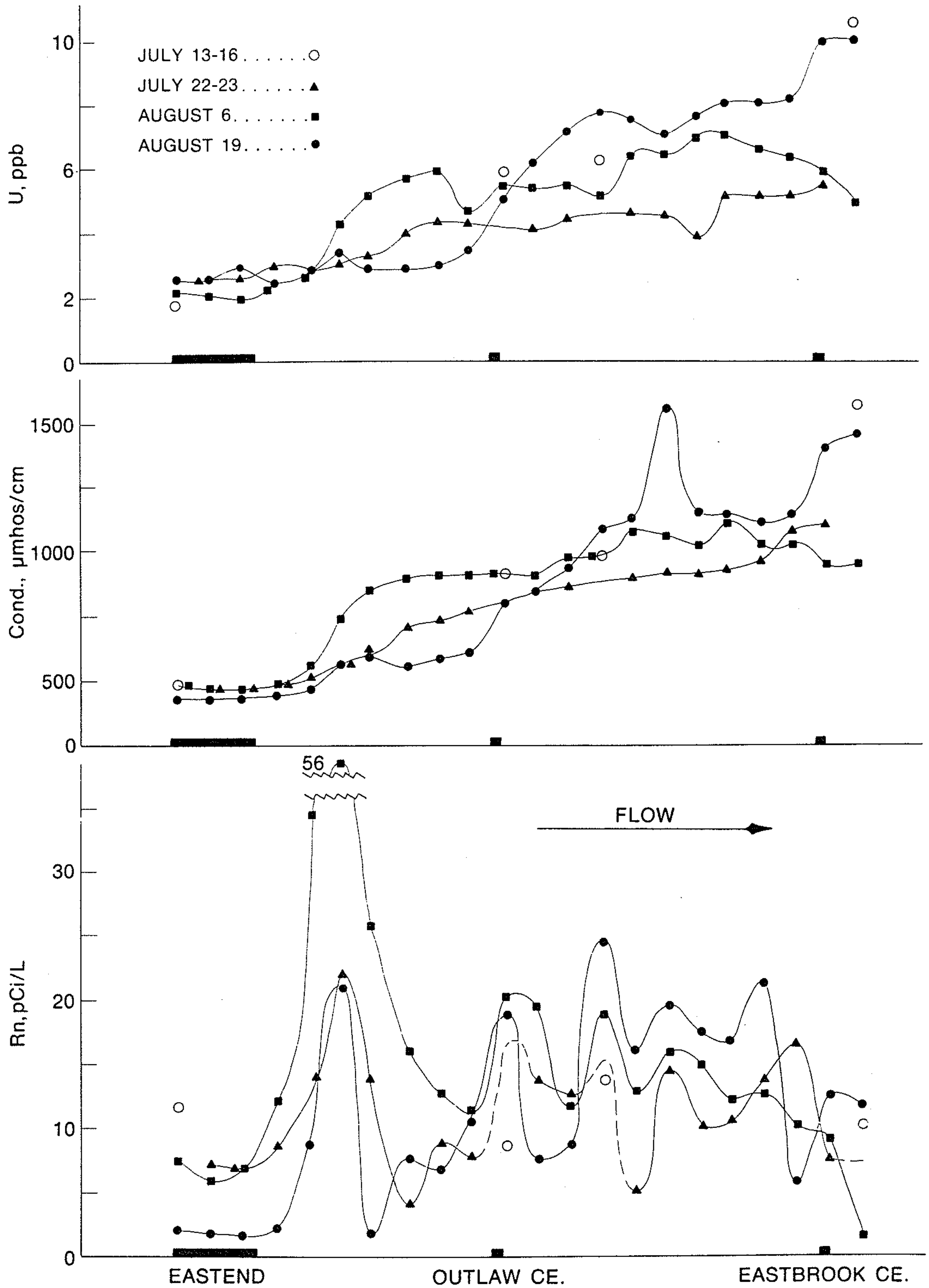

10
6
2
0
U, ppb
JULY 13-16
JULY 22-23
AUGUST 6
AUGUST 19
1500
1000
500
0
Cond., µmhos/cm
56
FLOW
30
20
10
0
Rn, pCi/L
EASTEND
OUTLAW CE.
EASTBROOK CE.

FIG. 5.

# SITES

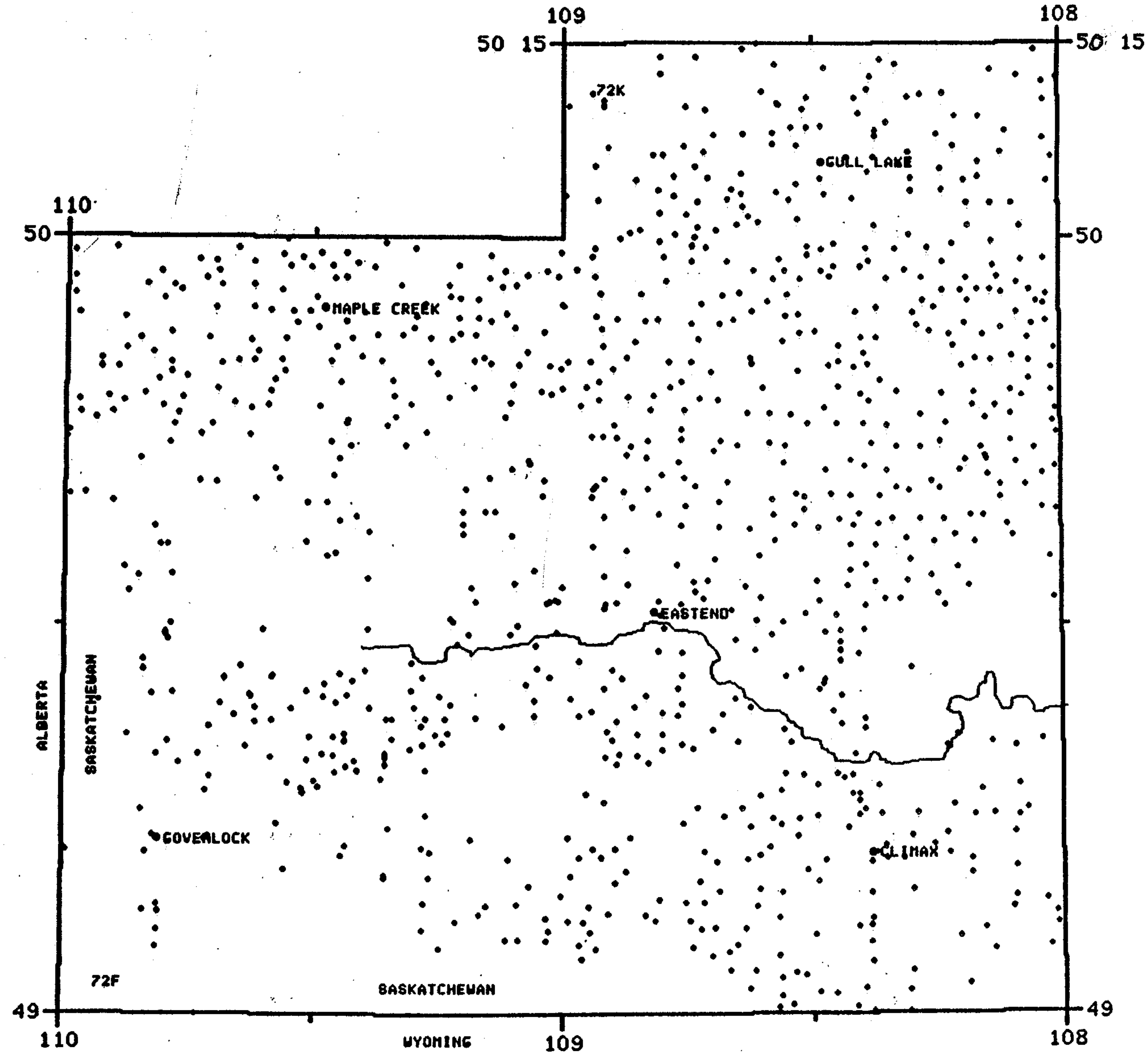
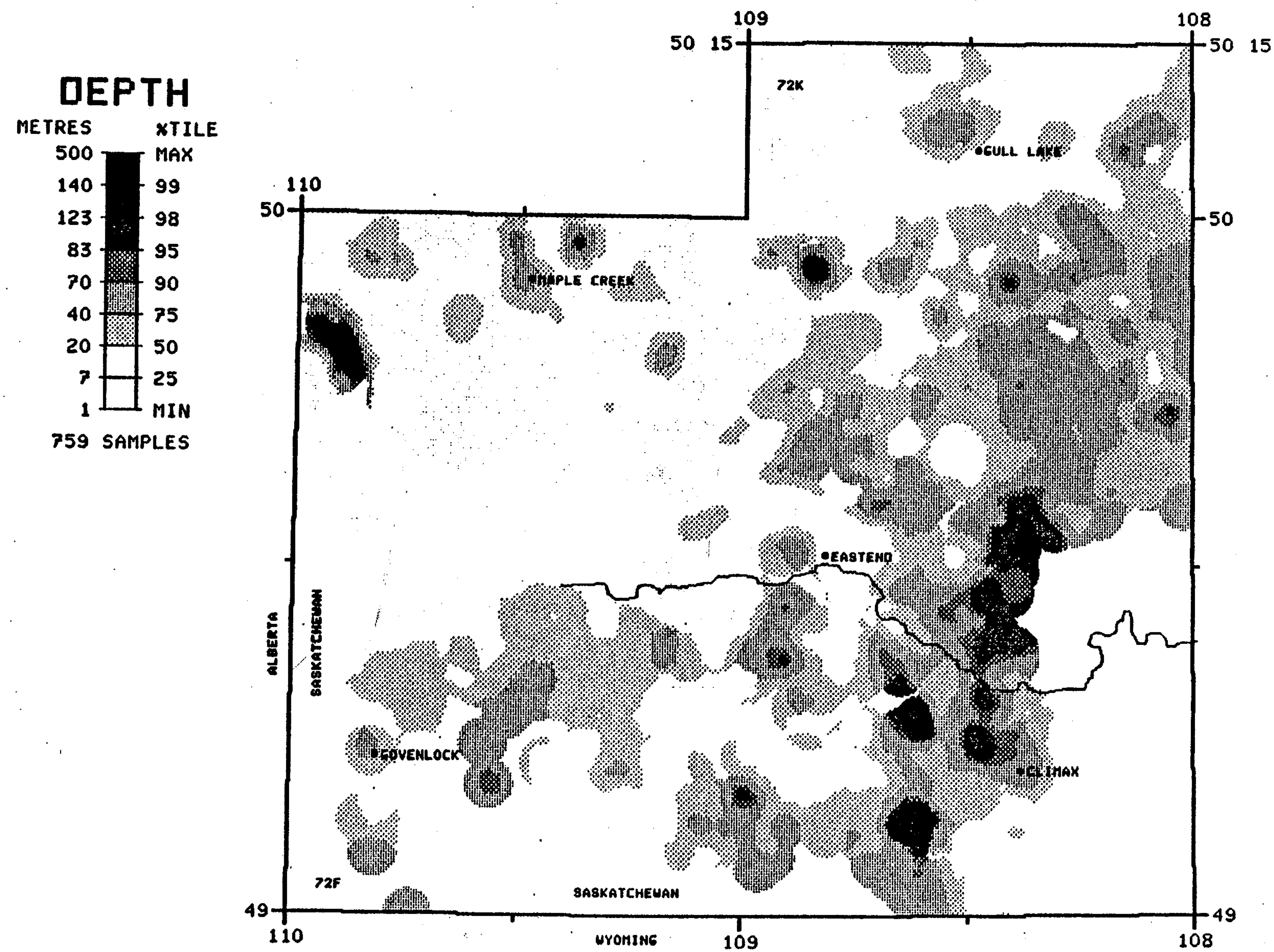

109
108
50 15
50 15
110
50
50
72K
GULL LAKE
MAPLE CREEK
EASTEND
ALBERTA
SASKATCHEWAN
GOVENLOCK
CLIMAX
72F
SASKATCHEWAN
49
49
110
WYOMING
109
108

FIG 6-1



DEPTH
METRES
%TILE
500
MAX
140
99
123
98
83
95
70
90
40
75
20
50
7
25
1
MIN
759 SAMPLES
110
109
108
50 15
50
49
72K
72F
GULL LAKE
MAPLE CREEK
EASTEND
GOVENLOCK
CLIMAX
ALBERTA
SASKATCHEWAN
WYOMING


FIG 6-2

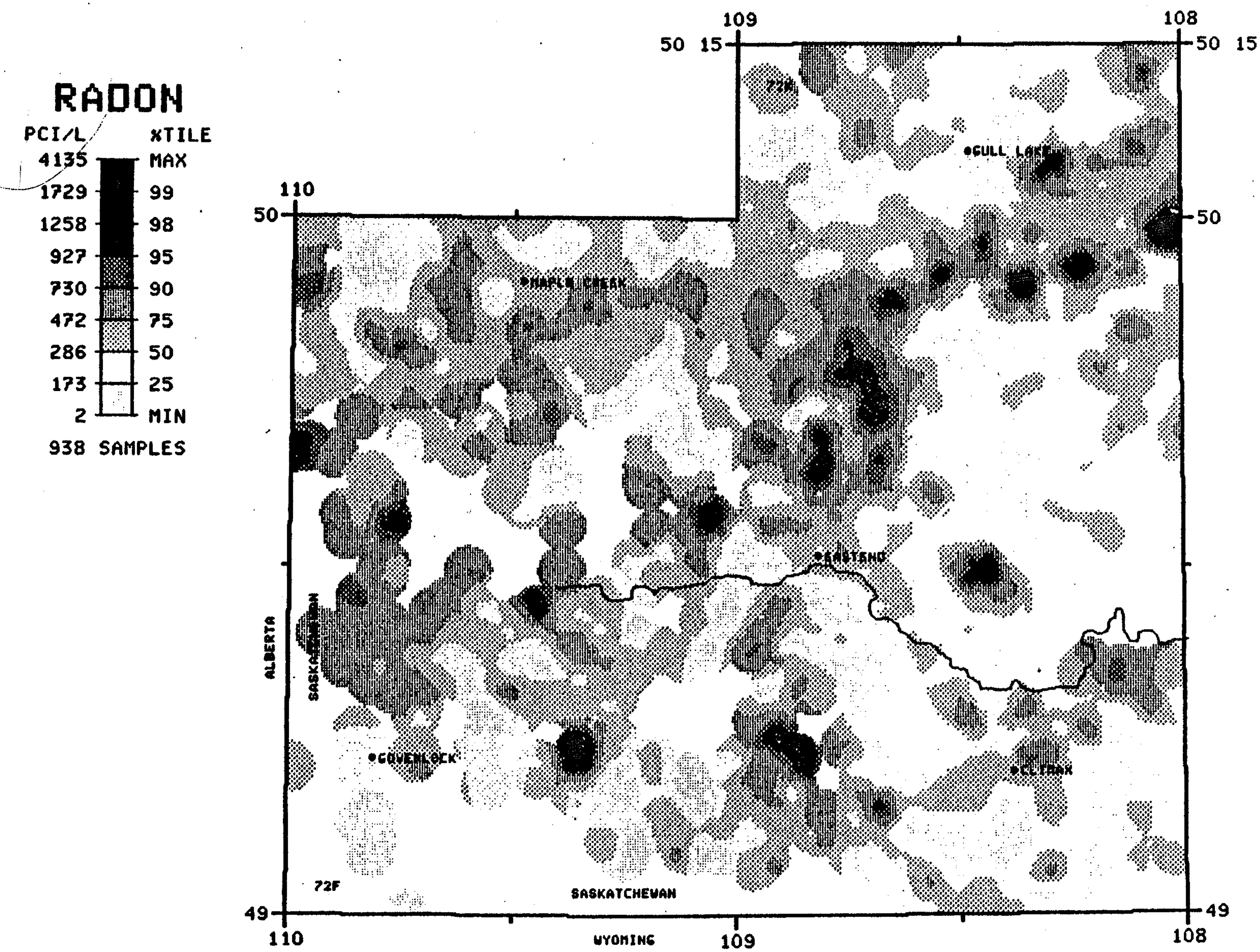

RADON
PCI/L
XTILE
4135 MAX
1729 99
1258 98
927 95
730 90
472 75
286 50
173 25
2 MIN
938 SAMPLES
110
109
108
50 15
50
49
MAPLE CREEK
GULL LAKE
EASTEND
GOVENLOCK
CLIMAX
72K
72F
ALBERTA
SASKATCHEWAN
WYOMING

FIG 6-3

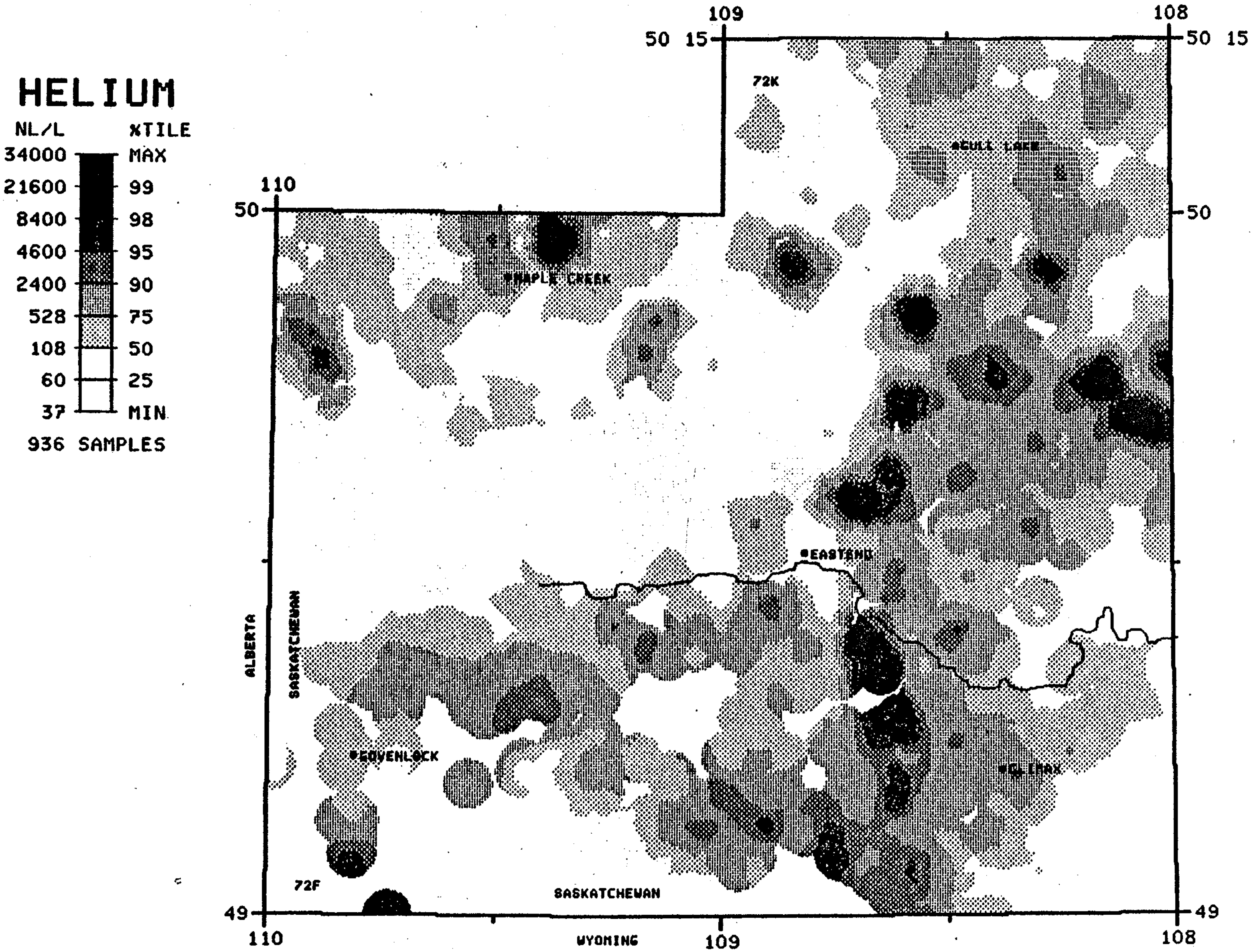

HELIUM
NL/L XTILE
34000 MAX
21600 99
8400 98
4600 95
2400 90
528 75
108 50
60 25
37 MIN
936 SAMPLES
109
108
50 15
50 15
110
50
50
72K
GULL LAKE
MAPLE CREEK
EASTEND
ALBERTA
SASKATCHEWAN
GOVENLOCK
CLIMAX
72F
SASKATCHEWAN
49
49
110
WYOMING
109
108

FIG 6-4

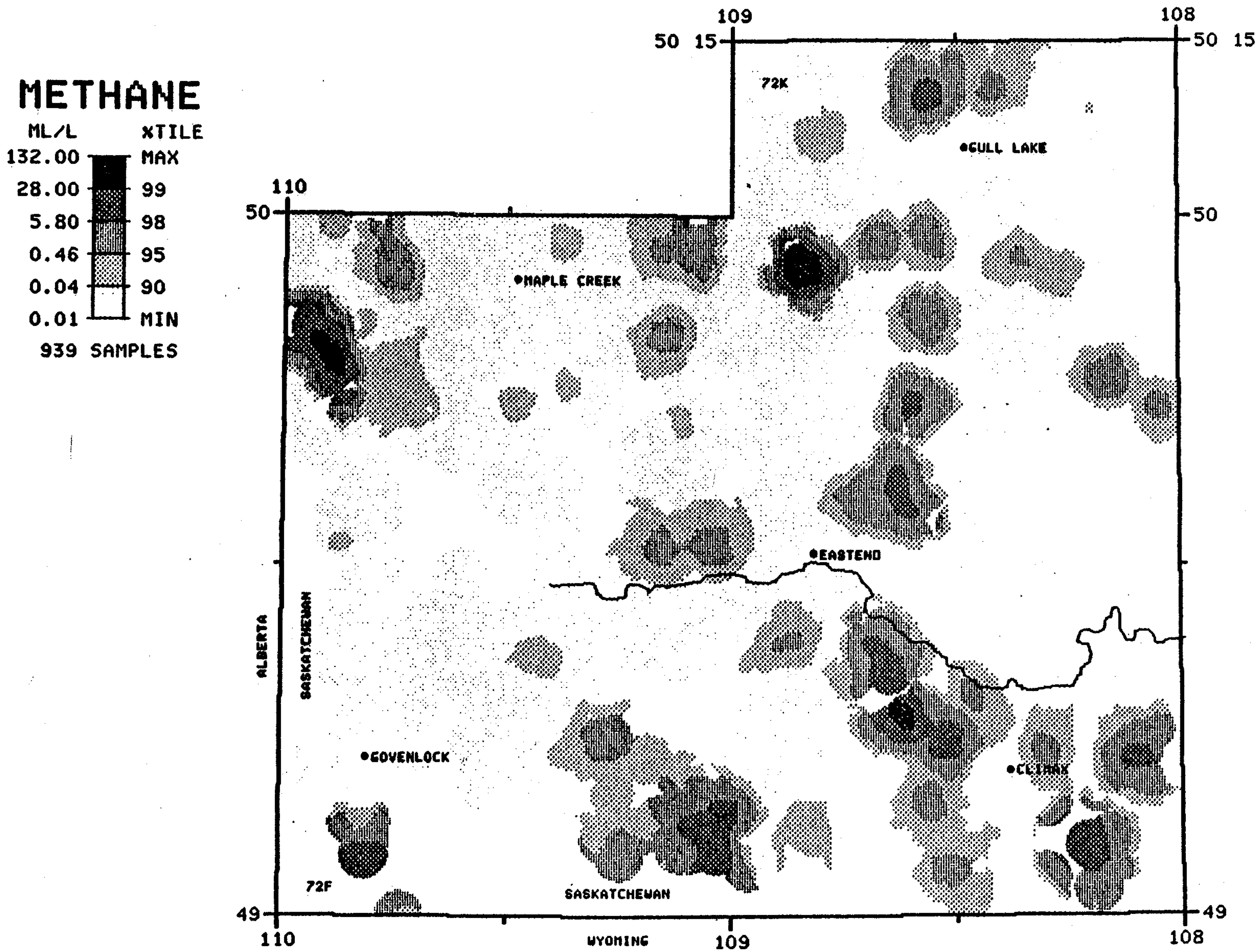

METHANE
ML/L XTILE
132.00 MAX
28.00 99
5.80 98
0.46 95
0.04 90
0.01 MIN
939 SAMPLES
110
109
108
50 15
50
49
72K
GULL LAKE
MAPLE CREEK
EASTEND
ALBERTA
SASKATCHEWAN
GOVENLOCK
CLIMAX
72F
SASKATCHEWAN
WYOMING

FIG 6-5

# DISSOLVED O2

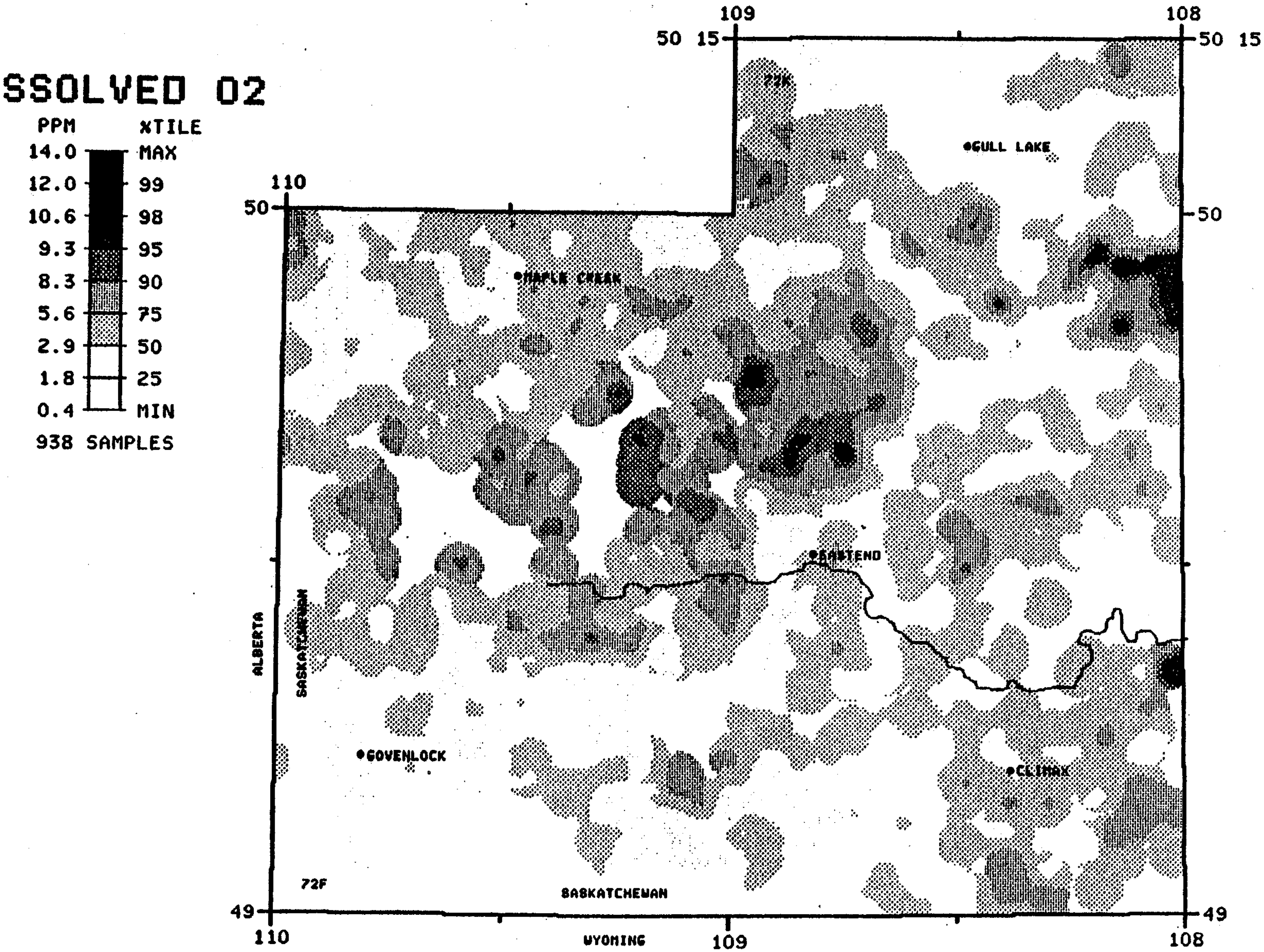



FIG 6-6

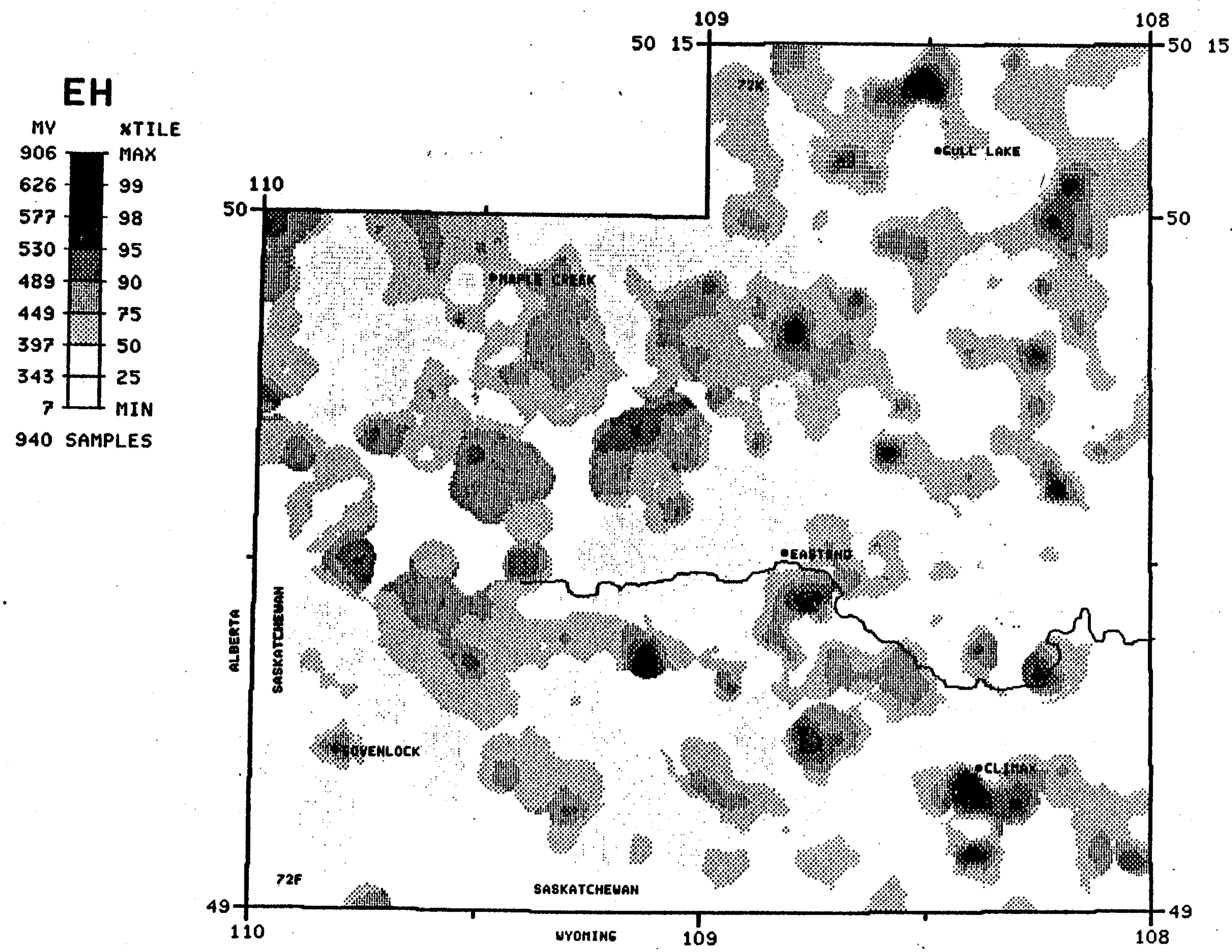

EH
MV XTILE
906 MAX
626 99
577 98
530 95
489 90
449 75
397 50
343 25
7 MIN
940 SAMPLES
109
108
50 15
50 15
110
50
50
GULL LAKE
MAPLE CREEK
72K
EASTEND
ALBERTA
SASKATCHEWAN
GOVENLOCK
CLIMAX
72F
SASKATCHEWAN
49
49
110
WYOMING
109
108

FIG 6-7

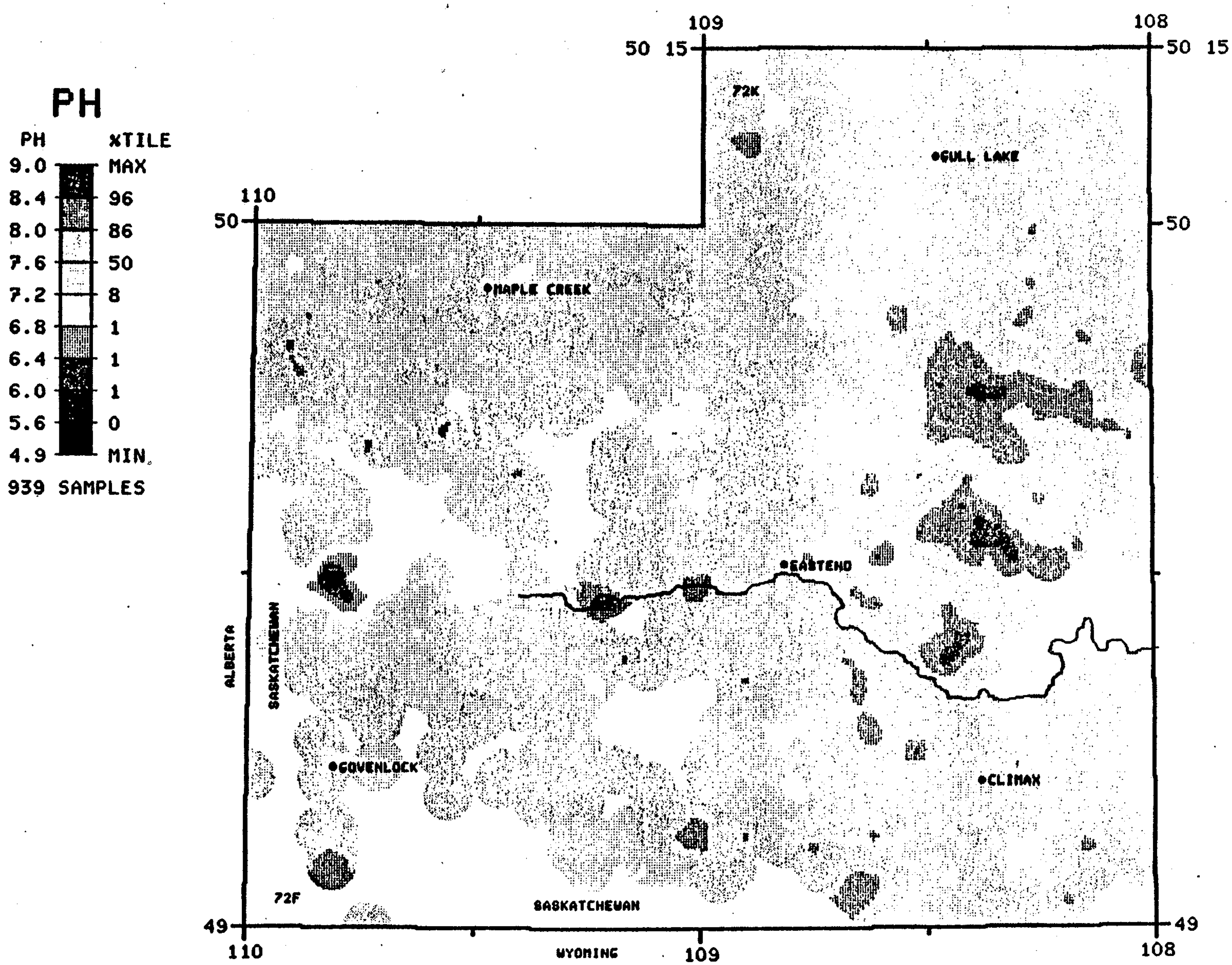

PH
PH
XTILE
9.0 MAX
8.4 96
8.0 86
7.6 50
7.2 8
6.8 1
6.4 1
6.0 1
5.6 0
4.9 MIN
939 SAMPLES
109
108
50 15
50 15
110
50
50
72K
GULL LAKE
MAPLE CREEK
EASTEND
ALBERTA
SASKATCHEWAN
GOVENLOCK
CLIMAX
72F
SASKATCHEWAN
49
49
110
WYOMING
109
108

FIG 6-8

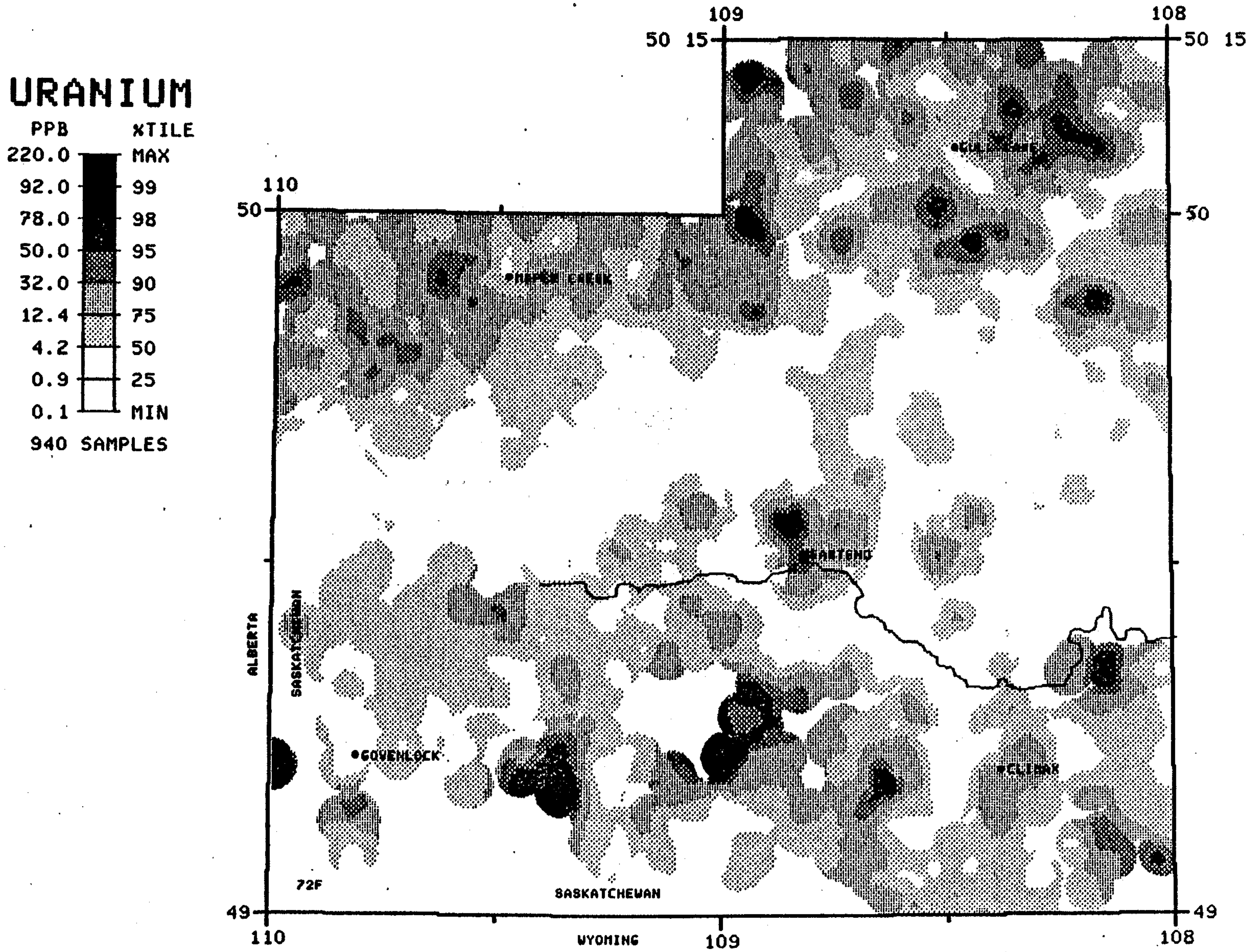

URANIUM
PPB
%TILE
220.0 MAX
92.0 99
78.0 98
50.0 95
32.0 90
12.4 75
4.2 50
0.9 25
0.1 MIN
940 SAMPLES
109
108
50 15
50 15
110
50
50
GOVENLOCK
ALBERTA
SASKATCHEWAN
72F
SASKATCHEWAN
49
49
110
WYOMING
109
108

FIG 6-9

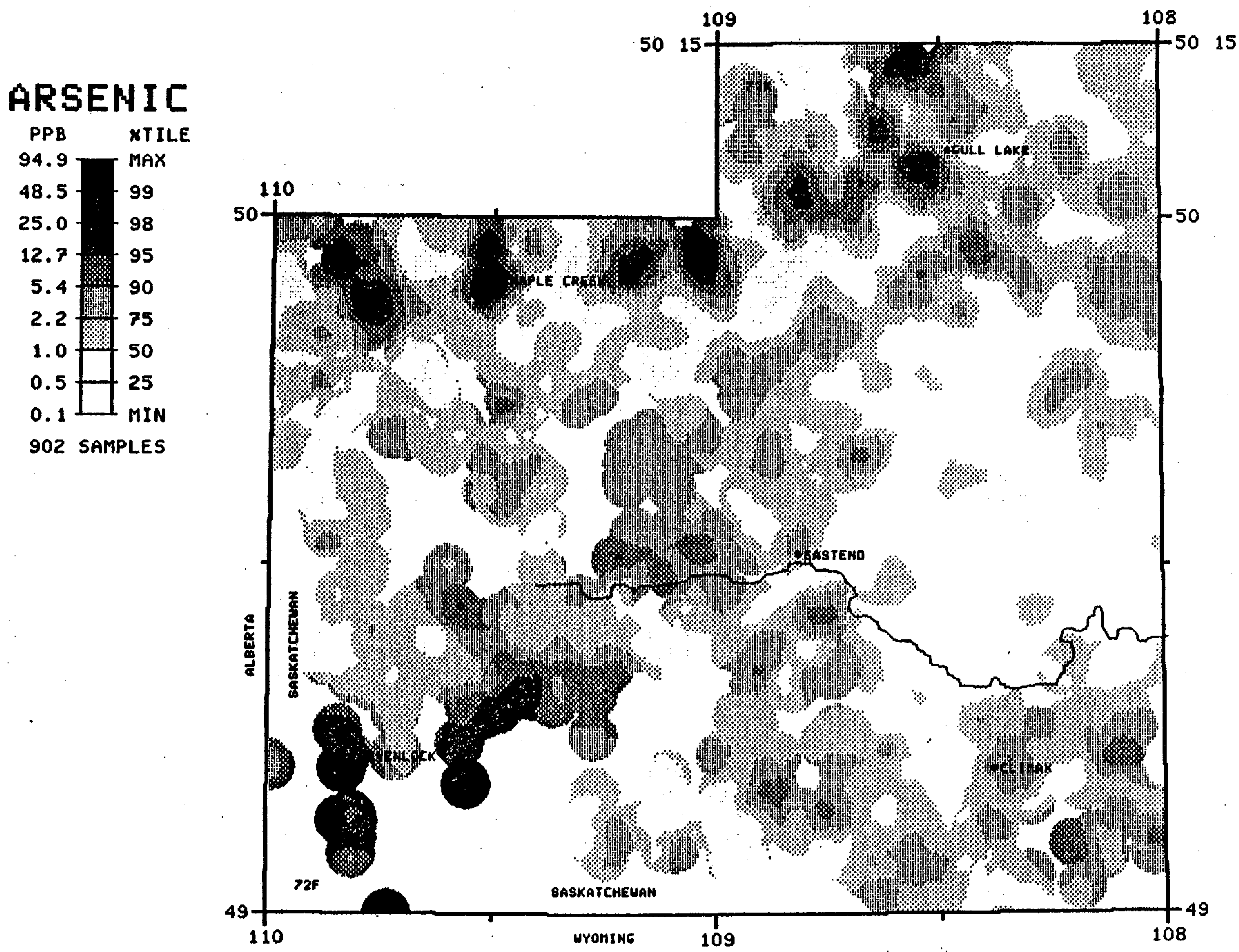

ARSENIC
PPB XTILE
94.9 MAX
48.5 99
25.0 98
12.7 95
5.4 90
2.2 75
1.0 50
0.5 25
0.1 MIN
902 SAMPLES
110
109
108
50 15
50
49
GULL LAKE
EASTEND
CLIMAX
SASKATCHEWAN
ALBERTA
WYOMING
72F

FIG 6-10

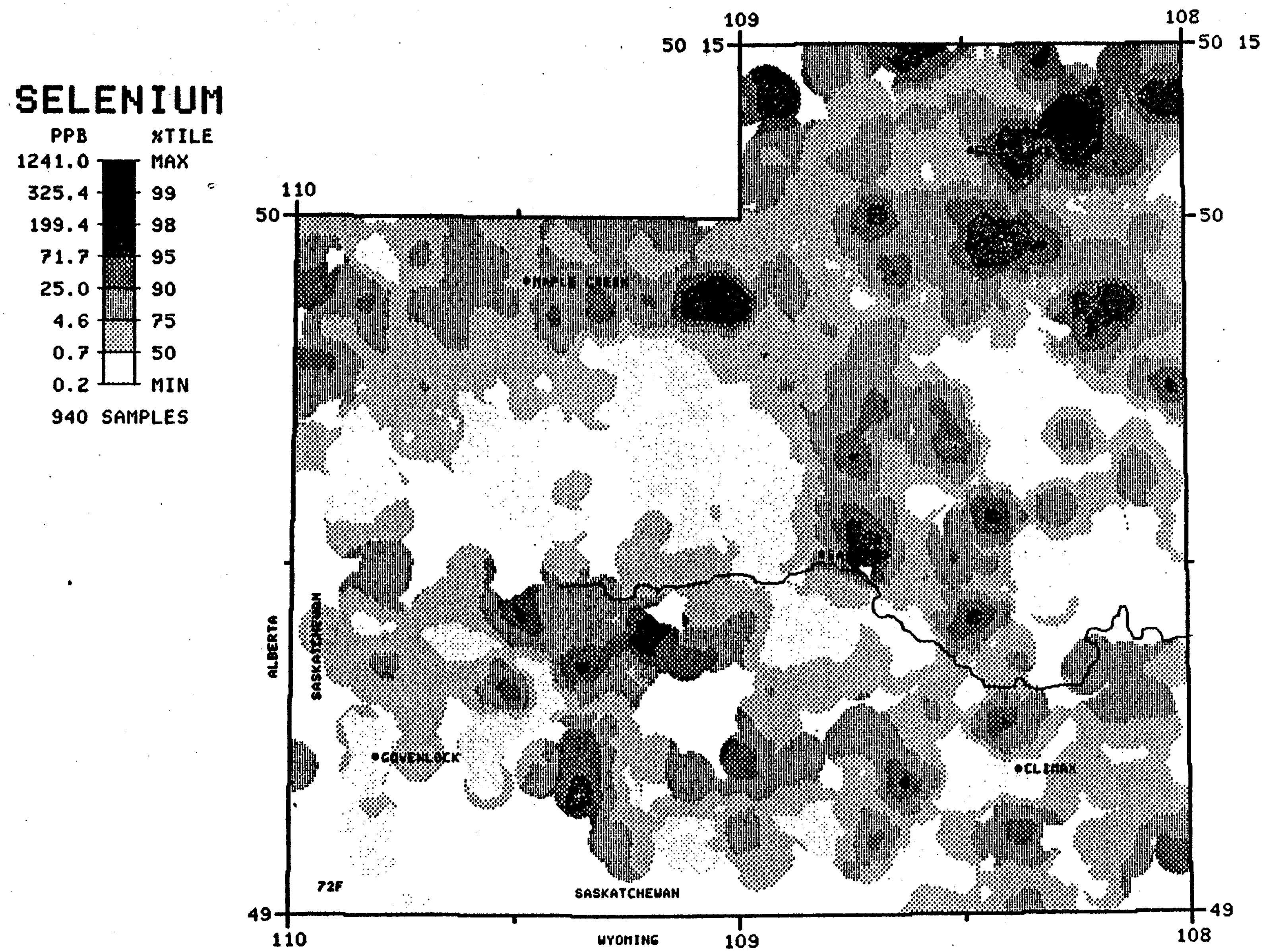
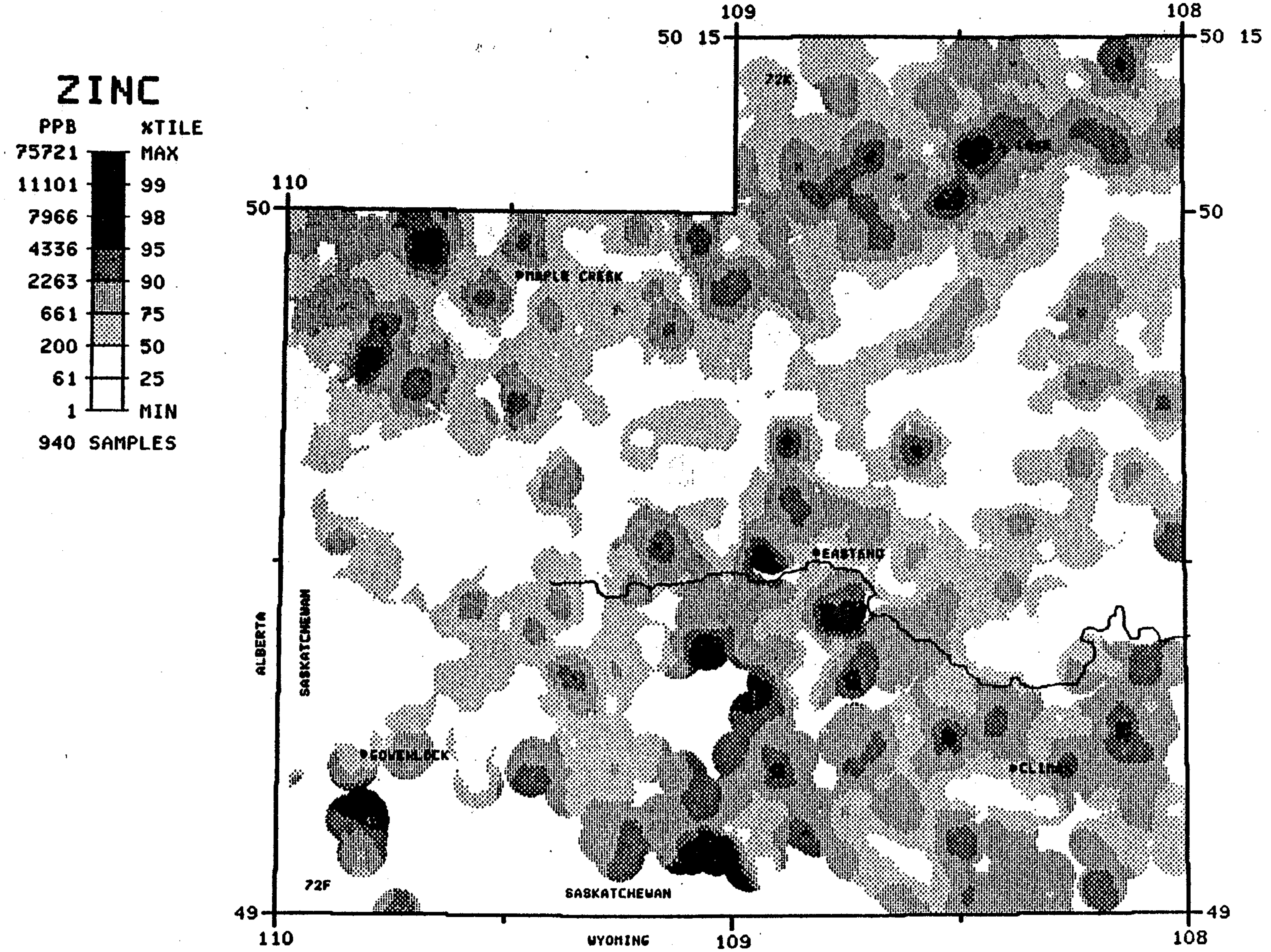

SELENIUM
PPB
%TILE
1241.0
MAX
325.4
99
199.4
98
71.7
95
25.0
90
4.6
75
0.7
50
0.2
MIN
940 SAMPLES
110
50
109
50 15
108
50 15
50
MAPLE CREEK
ALBERTA
SASKATCHEWAN
GOVENLOCK
CLIMAX
72F
SASKATCHEWAN
WYOMING
49
110
109
108
49

FIG 6-11



ZINC
PPB
XTILE
75721
MAX
11101
99
7966
98
4336
95
2263
90
661
75
200
50
61
25
1
MIN
940 SAMPLES
109
108
50 15
50 15
110
50
50
72K
MAPLE CREEK
EASTEND
ALBERTA
SASKATCHEWAN
GOVENLOCK
CLIMAX
72F
SASKATCHEWAN
49
49
110
WYOMING
109
108


FIG 6-12

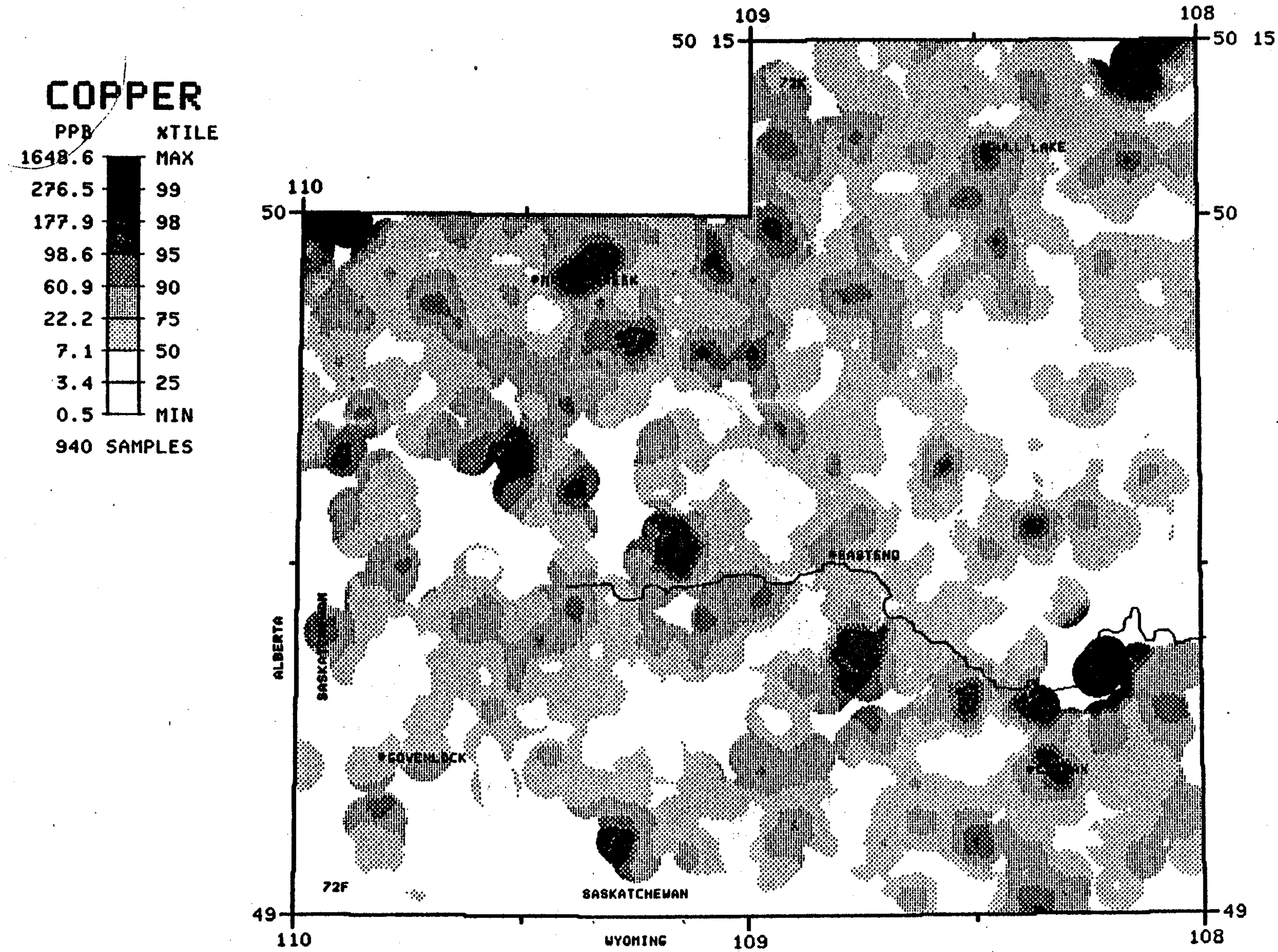

COPPER
PPB
XTILE
1648.6 MAX
276.5 99
177.9 98
98.6 95
60.9 90
22.2 75
7.1 50
3.4 25
0.5 MIN
940 SAMPLES
110
109
108
50 15
50
49
72K
72F
EASTEND
GOVENLOCK
SASKATCHEWAN
ALBERTA
WYOMING

FIG 6-13

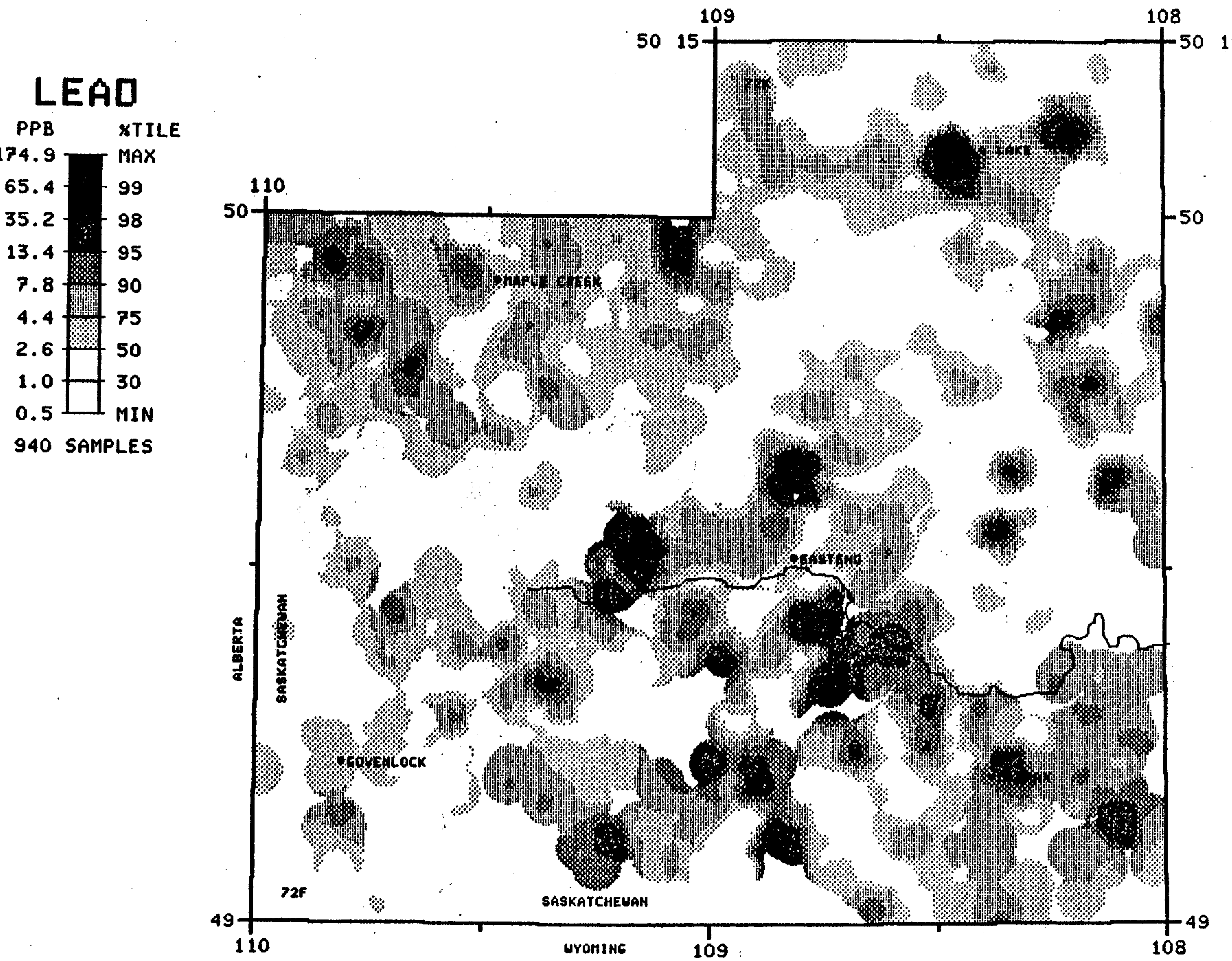

LEAD
PPB
XTILE
174.9 MAX
65.4 99
35.2 98
13.4 95
7.8 90
4.4 75
2.6 50
1.0 30
0.5 MIN
940 SAMPLES
110
109
108
50 15
50
49
MAPLE CREEK
EASTEND
GOVENLOCK
ALBERTA
SASKATCHEWAN
WYOMING
72F

FIG 6-14

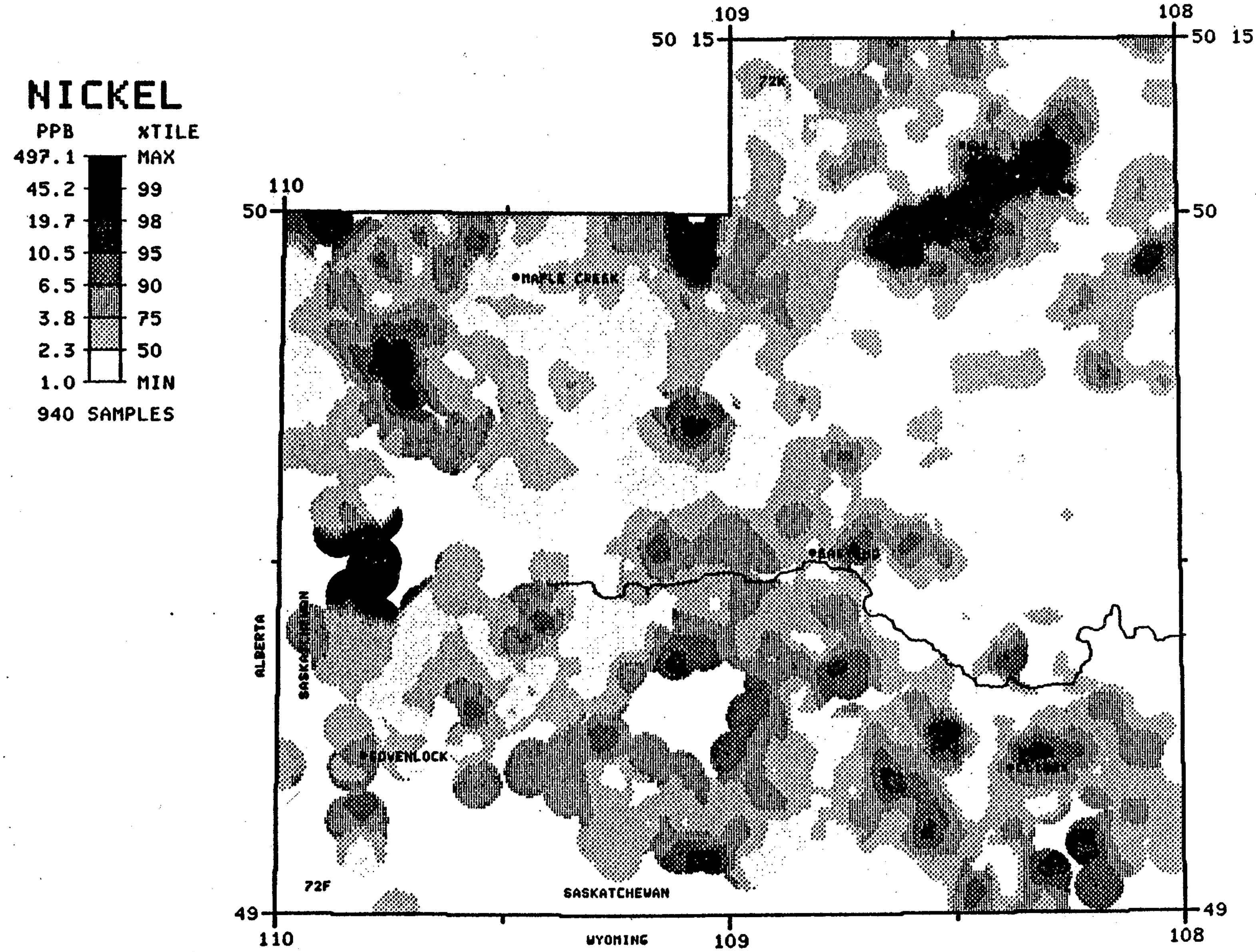

NICKEL
PPB
XTILE
497.1 MAX
45.2 99
19.7 98
10.5 95
6.5 90
3.8 75
2.3 50
1.0 MIN
940 SAMPLES
110
50
109
50 15
108
50 15
50
72K
MAPLE CREEK
ALBERTA
SASKATCHEWAN
ROVENLOCK
72F
SASKATCHEWAN
49
110
WYOMING
109
108
49

FIG 6-15

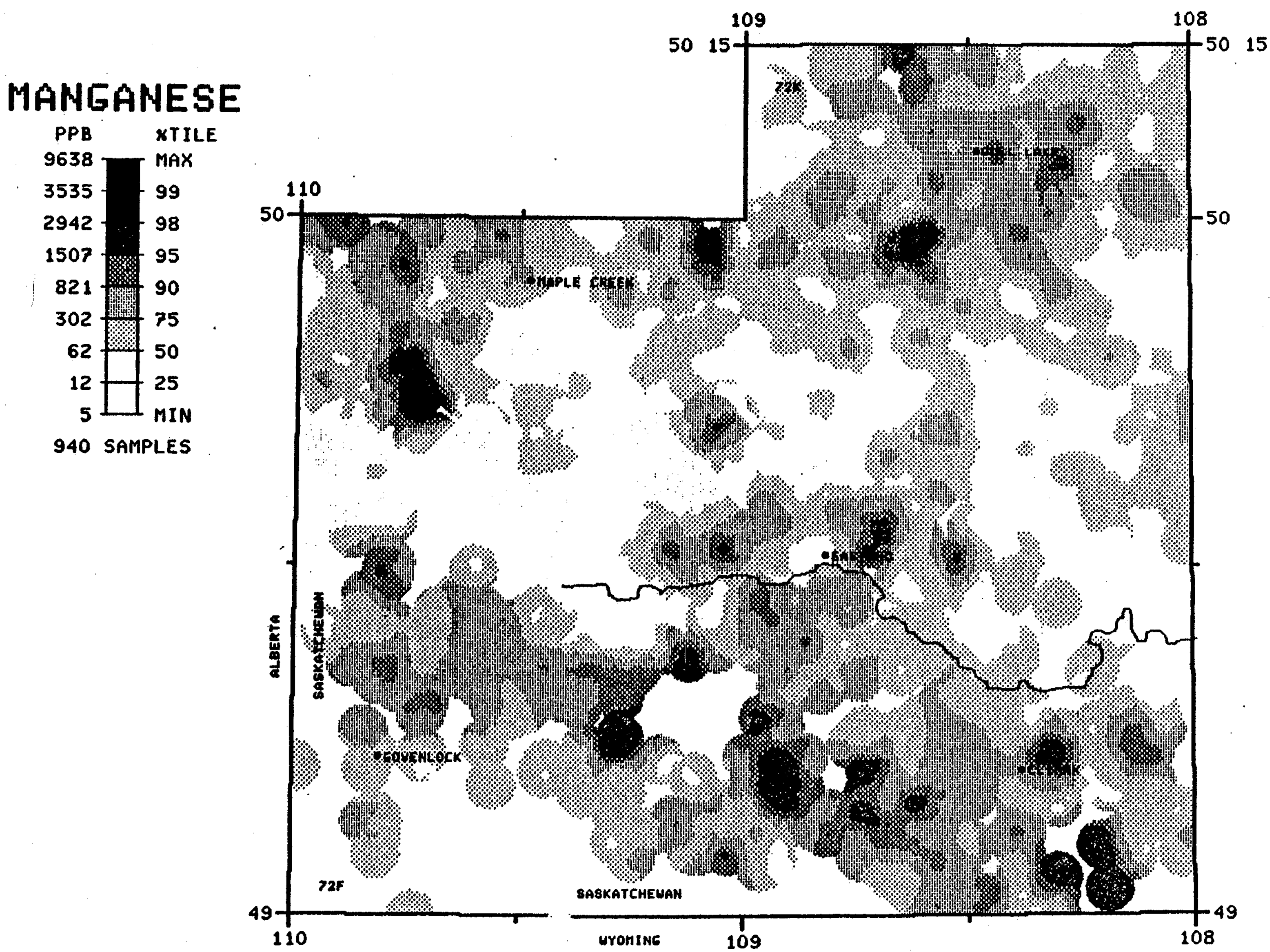
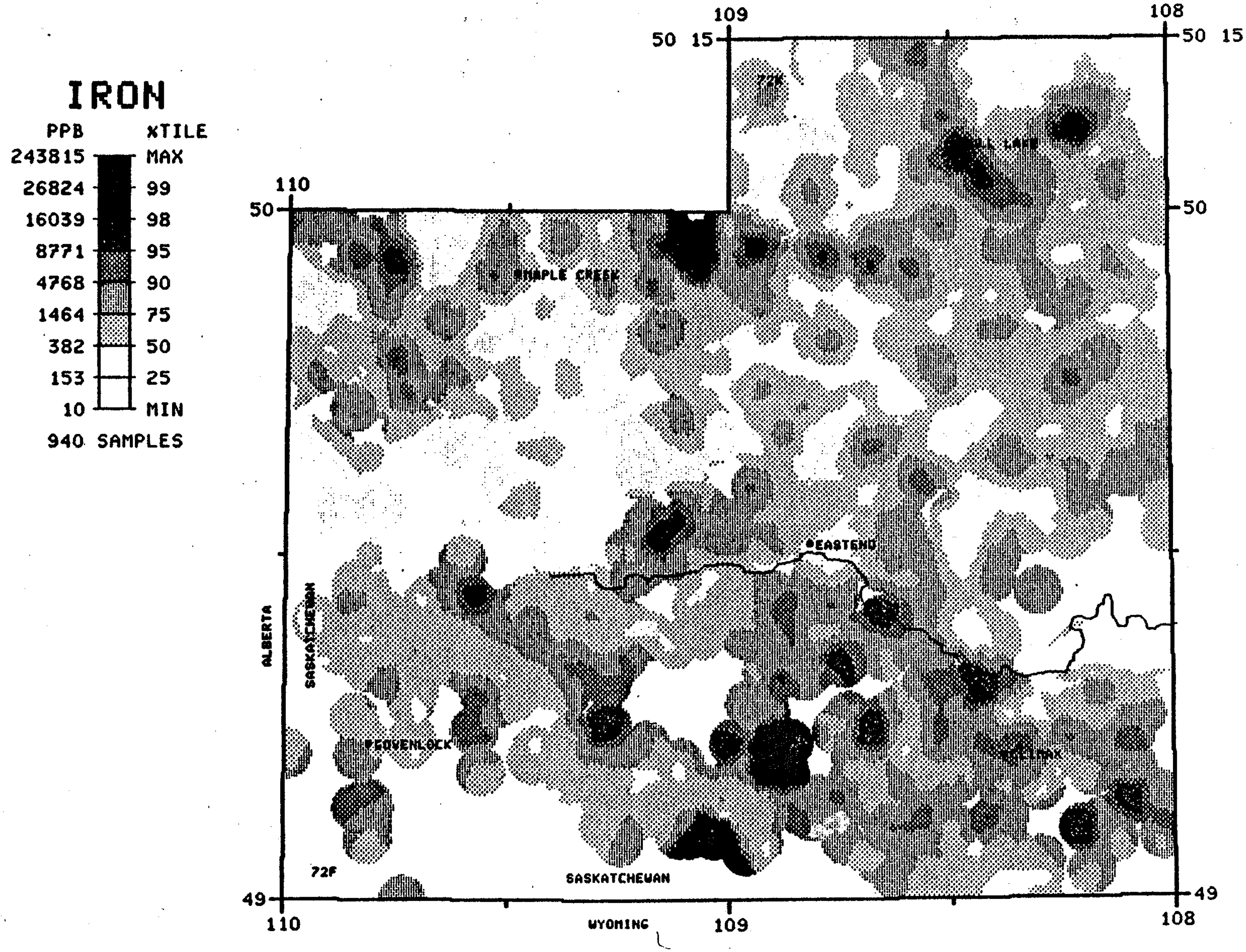

MANGANESE
PPB
XTILE
9638 MAX
3535 99
2942 98
1507 95
821 90
302 75
62 50
12 25
5 MIN
940 SAMPLES
110
109
108
50 15
50
49
72K
MAPLE CREEK
72F
SASKATCHEWAN
WYOMING
ALBERTA
GOVENLOCK

FIG. 6-16



IRON
PPB
XTILE
243815
MAX
26824
99
16039
98
8771
95
4768
90
1464
75
382
50
153
25
10
MIN
940 SAMPLES
110
50
109
50 15
108
50 15
50
49
110
109
108
49
72K
MAPLE CREEK
EASTEND
CLIMAX
GOVENLOCK
ALBERTA
SASKATCHEWAN
72F
SASKATCHEWAN
WYOMING

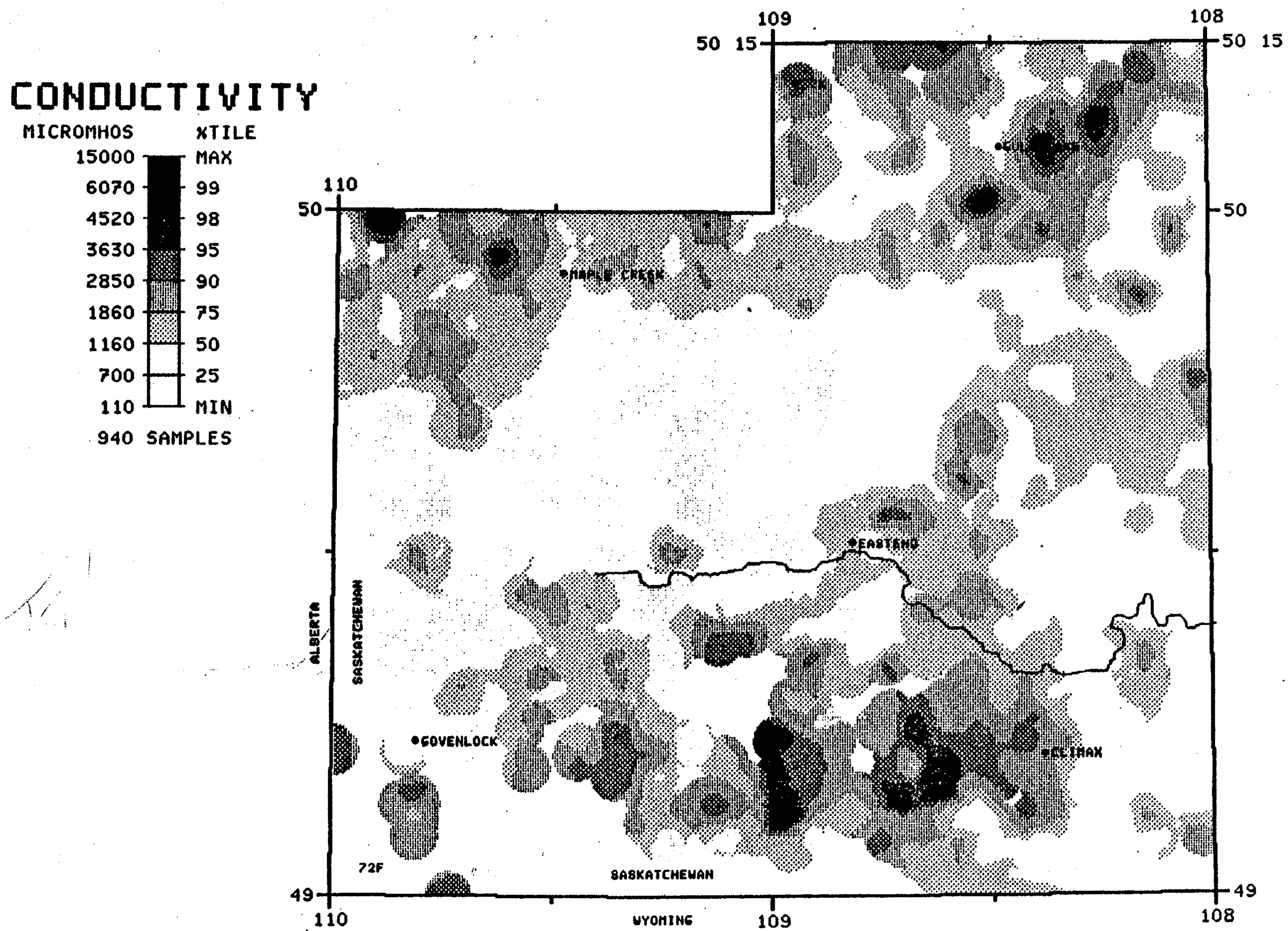

CONDUCTIVITY
MICROMHOS
XTILE
15000 MAX
6070 99
4520 98
3630 95
2850 90
1860 75
1160 50
700 25
110 MIN
940 SAMPLES
110
109
108
50 15
50 15
50
50
49
49
110
109
108
MAPLE CREEK
EASTEND
CLIMAX
GOVENLOCK
ALBERTA
SASKATCHEWAN
SASKATCHEWAN
WYOMING
72F

FIG 6-18

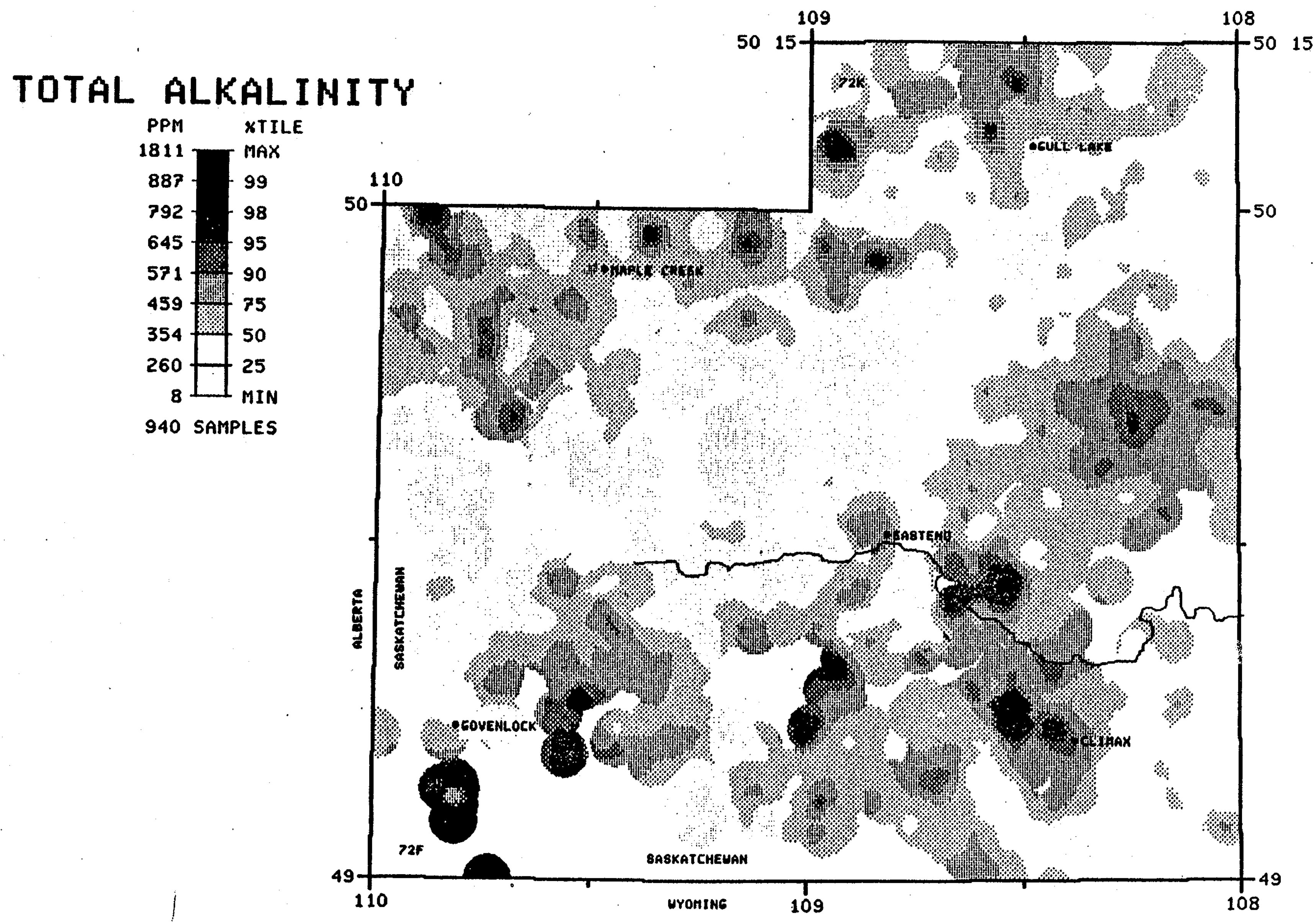

TOTAL ALKALINITY
PPM
XTILE
1811
MAX
887
99
792
98
645
95
571
90
459
75
354
50
260
25
8
MIN
940 SAMPLES
110
109
108
50 15
50
49
72K
GULL LAKE
MAPLE CREEK
EASTEND
GOVENLOCK
CLIMAX
72F
ALBERTA
SASKATCHEWAN
SASKATCHEWAN
WYOMING

FIG. 6-10

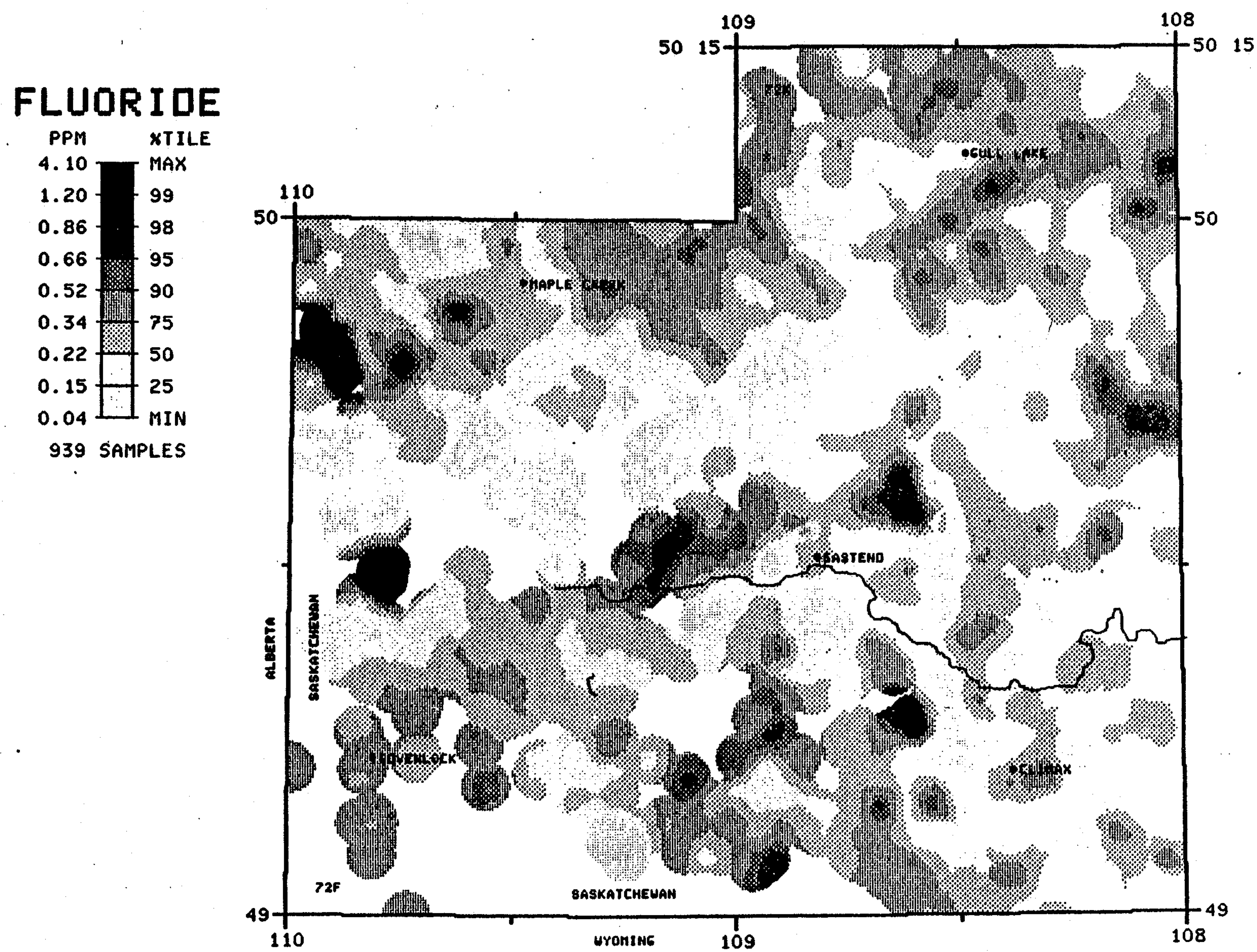
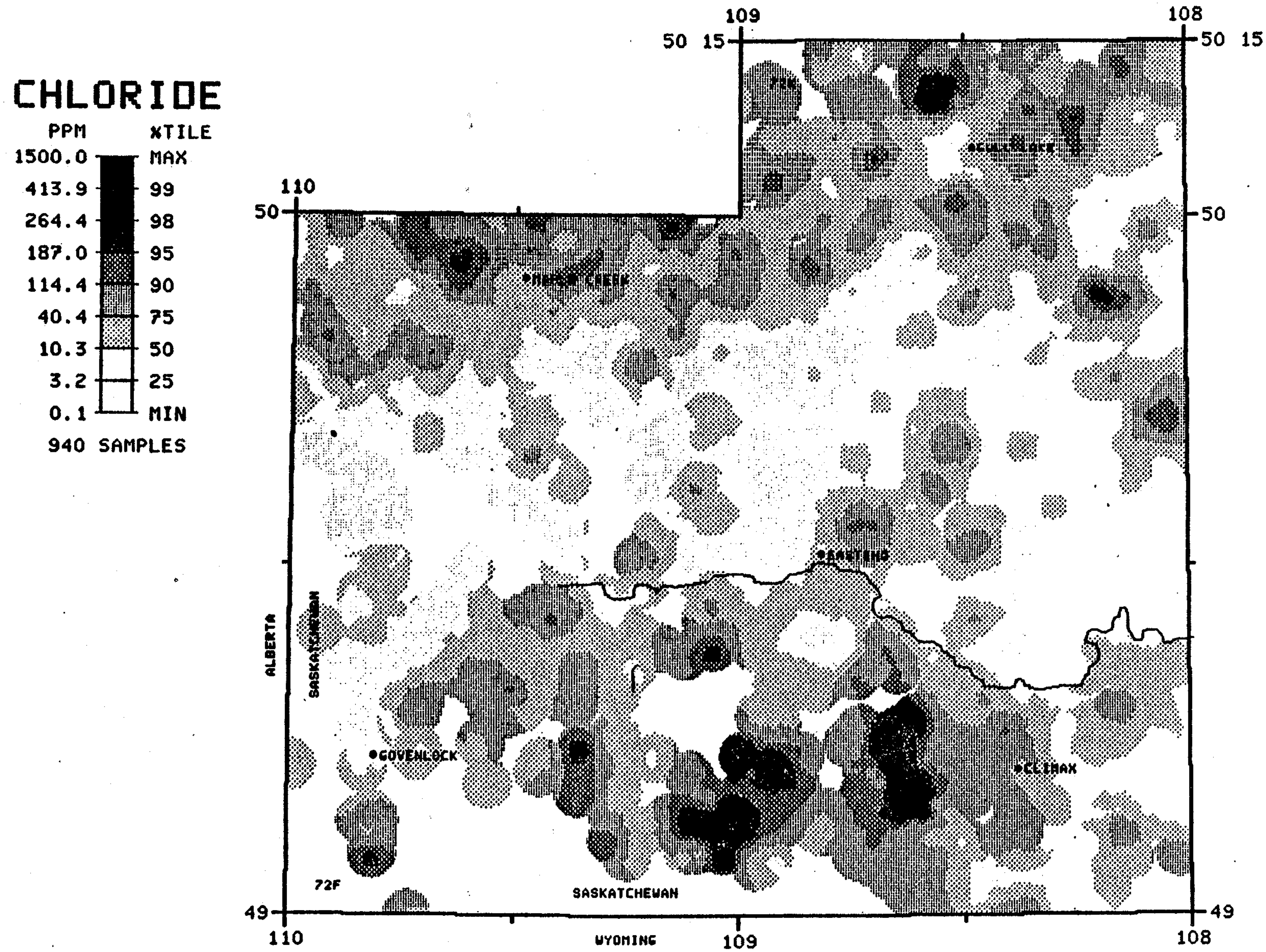
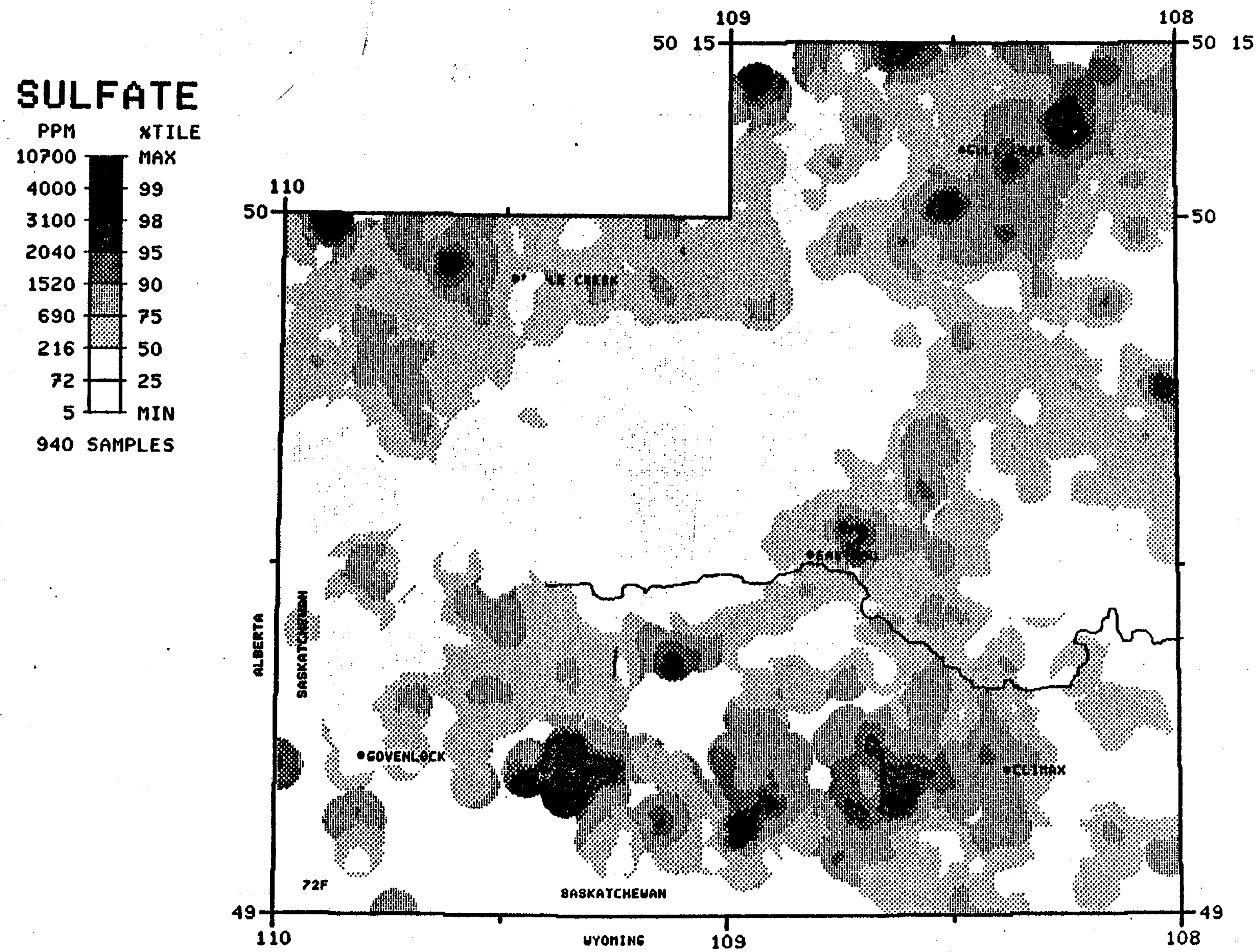

FLUORIDE
PPM
%TILE
4.10
MAX
1.20
99
0.86
98
0.66
95
0.52
90
0.34
75
0.22
50
0.15
25
0.04
MIN
939 SAMPLES
110
109
108
50 15
50
49
MAPLE CREEK
GULL LAKE
EASTEND
CLIMAX
72K
72F
ALBERTA
SASKATCHEWAN
WYOMING

FIG 6-20


CHLORIDE
PPM
%TILE
1500.0 MAX
413.9 99
264.4 98
187.0 95
114.4 90
40.4 75
10.3 50
3.2 25
0.1 MIN
940 SAMPLES
110
109
108
50 15
50
49
ALBERTA
SASKATCHEWAN
WYOMING
72F
GOVENLOCK
CLIMAX



SULFATE
PPM
XTILE
10700
MAX
4000
99
3100
98
2040
95
1520
90
690
75
216
50
72
25
5
MIN
940 SAMPLES
110
109
108
50 15
50
49
ALBERTA
SASKATCHEWAN
WYOMING
GOVENLOCK
CLIMAX
72F


FIG 6-22

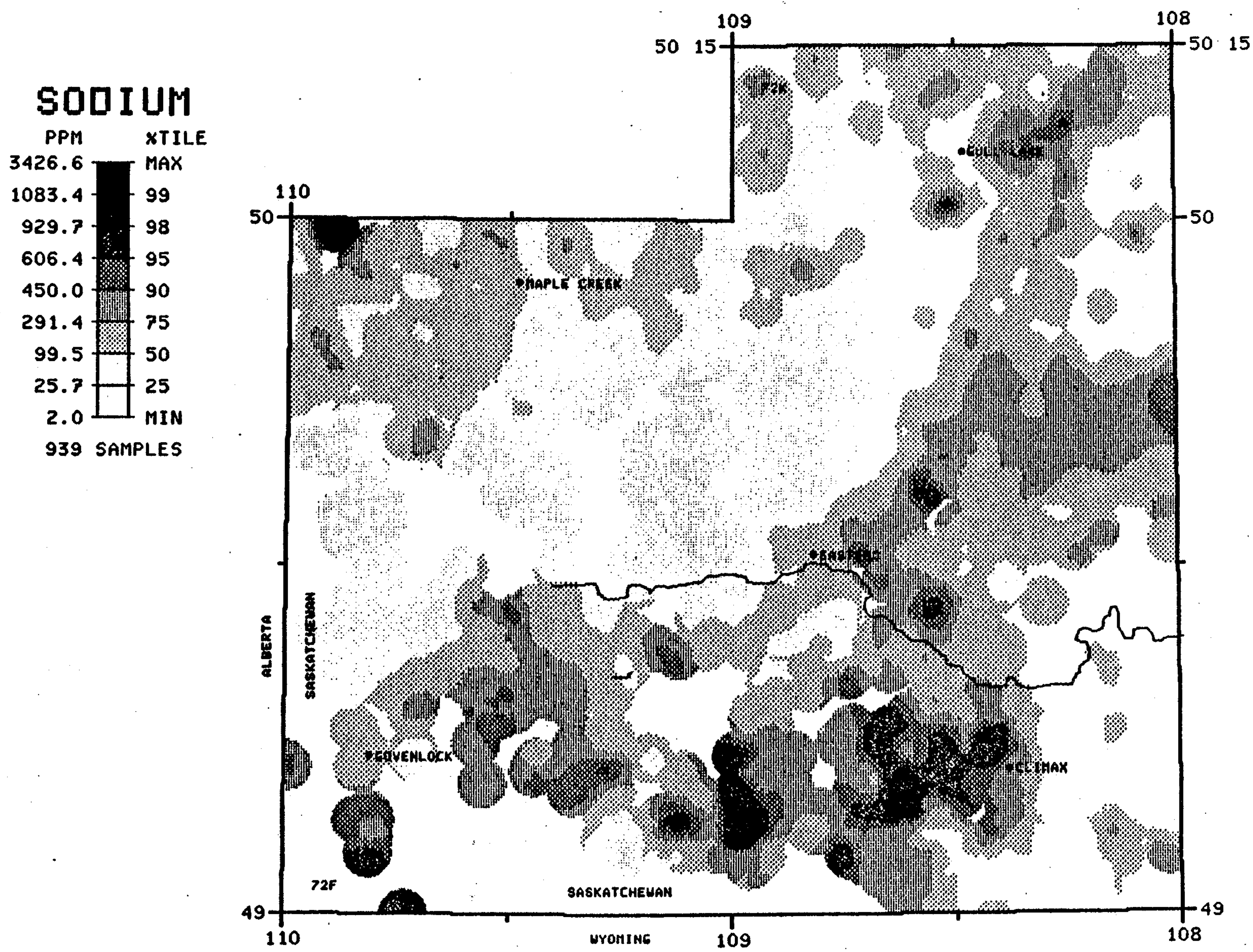
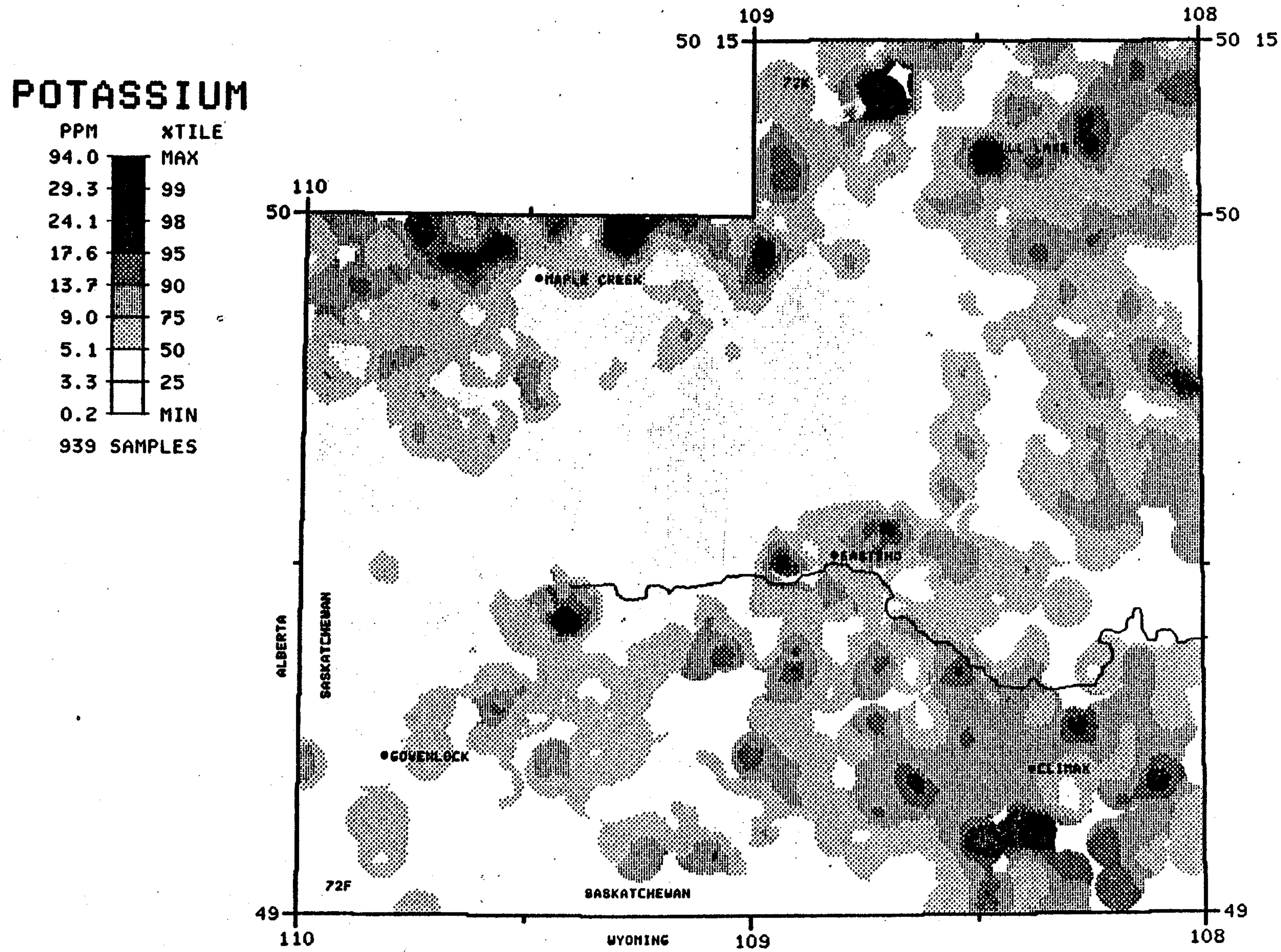

SODIUM
PPM XTILE
3426.6 MAX
1083.4 99
929.7 98
606.4 95
450.0 90
291.4 75
99.5 50
25.7 25
2.0 MIN
939 SAMPLES
109
108
50 15
50 15
110
50
50
MAPLE CREEK
GULL LAKE
72K
ALBERTA
SASKATCHEWAN
GOVENLOCK
CLIMAX
72F
SASKATCHEWAN
WYOMING
49
49
110
109
108

FIG 6-23



POTASSIUM
PPM XTILE
94.0 MAX
29.3 99
24.1 98
17.6 95
13.7 90
9.0 75
5.1 50
3.3 25
0.2 MIN
939 SAMPLES
109
108
50 15
50 15
110
50
50
MAPLE CREEK
72K
ALBERTA
SASKATCHEWAN
GOVENLOCK
CLIMAX
72F
SASKATCHEWAN
WYOMING
49
49
110
109
108


FIG 6-24

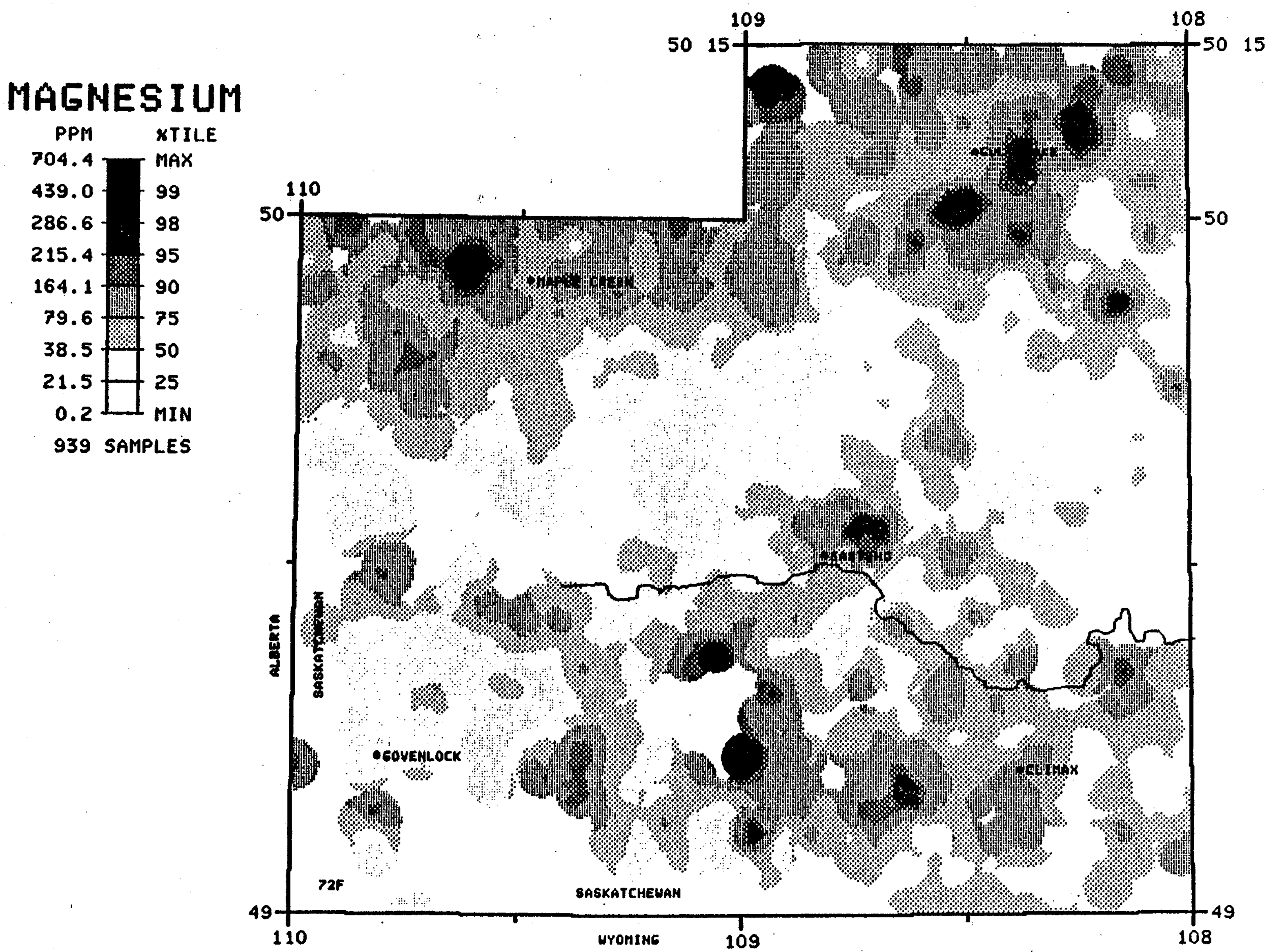

MAGNESIUM
PPM XTILE
704.4 MAX
439.0 99
286.6 98
215.4 95
164.1 90
79.6 75
38.5 50
21.5 25
0.2 MIN
939 SAMPLES
109
108
50 15
50 15
110
50
50
MAPLE CREEK
GOVENLOCK
CLIMAX
ALBERTA
SASKATCHEWAN
SASKATCHEWAN
WYOMING
72F
49
49
110
109
108

FIG. 6.25

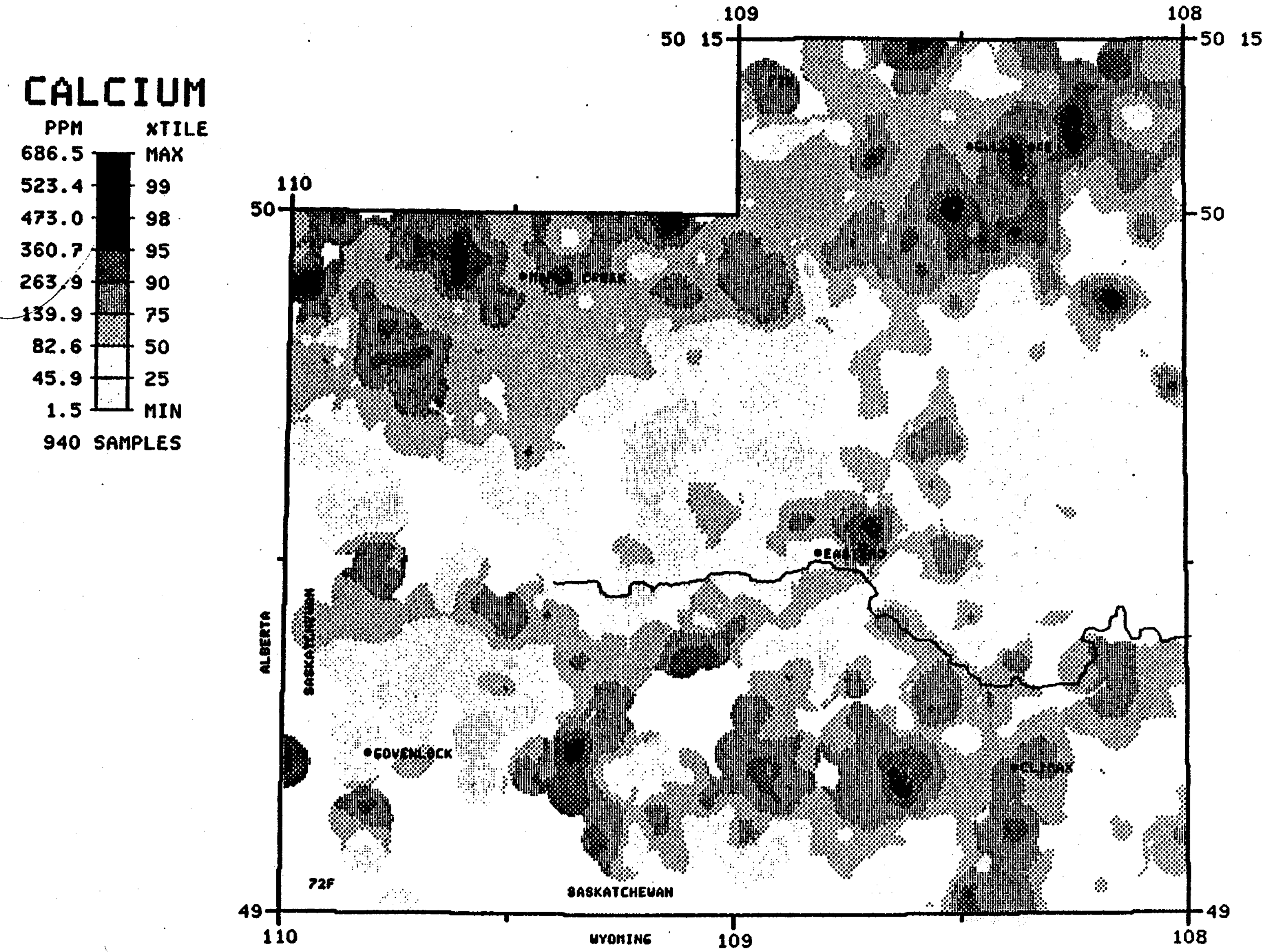

CALCIUM
PPM
XTILE
686.5
MAX
523.4
99
473.0
98
360.7
95
263.9
90
139.9
75
82.6
50
45.9
25
1.5
MIN
940 SAMPLES
110
109
108
50
50 15
49
ALBERTA
SASKATCHEWAN
WYOMING
GOVENLOCK
72F

FIG 6-26