UNDERSTANDING GROUNDWATER SYSTEMS OF THE SOUTHERN LARAMIE BASIN, ALBANY COUNTY, WYOMING THROUGH APPLIED CHEMICAL AND PHYSICAL DATA

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Abstract

Jim B. Finley

Two distinct groundwater systems in the southern Laramie Basin, Wyoming, are inferred from water composition diagrams developed using physico-chemical data collected at springs and wells. The two groundwater systems are: (1) the Casper comprised of, in ascending order, Precambrian igneous and metamorphic rocks, Pennsylvanian Fountain Fm. (arkosic sandstone), and Permo-Pennsylvanian Casper Fm. (interbedded sandstone, limestone, dolomite(?)), and (2) Permian age Satanka shale and Forelle limestone followed by the Triassic age Chugwater shale and mudstone, collectively named the Redbed groundwater system. Sub-aquifers are existent in both groundwater systems as a result of interbedded impermeable material. A series of faults deform the Casper system where it outcrops along the western flank of the Laramie Range. The Redbed system confines the Casper system from just east of the city of Laramie continuing west into the basin. Casper wells west of the confining contact are free-flowing. Both aquifers receive recharge through local precipitation, and ground-water flow direction is generally east to west.

Water in the Casper system has a uniform chemical composition over most of the study area, dominated by Ca (13 - 85 mg/L) and HCO_3 (129 - 251 mg/L). Chemical speciation calculations conducted using WATEQ2 (Ball et al., 1980) demonstrate that equilibrium with respect to calcite (limestone) is attained almost immediately upon infiltration and recharge. Low concentrations of Na, K, and Cl reflect precipitation input modified by a slight evapotranspiration signature, and no effect of equilibration with shales, K-feldspar, or halite.

Higher solute concentrations are observed in the Redbed system with the following ranges: Ca 37 - 480 mg/L; Mg 20 - 126 mg/L; HCO_3 181 - 392 mg/L; and SO_4 12 - 1580 mg/L. The large range in concentrations for the major elements are the result of wells sampling from sub-aquifers within the Redbed system. Concentrations of Na, K, and Cl are also low, reflecting the effect of evapotranspiration enhancement.

Mixing between the two groundwater systems is inferred from water composition diagrams in a small cluster of Casper wells (C15, C16, C22, C41, C48, C49, C65, C93) located in the middle of the basin. Two competing hypotheses exist for the mixing mechanism: (1) instantaneous mixing within the well during extraction, caused by either well failure or a screened interval spanning the contact between the Casper and Redbed groundwater systems, or (2) mixing of waters at the contact between the two groundwater systems. In the Redbed system, mixing occurs via two mechanisms, (1) along faults, and (2) in wells completed over more than one sub-aquifer.

Major element chemistry obtained for this study indicate no evidence of anthropogenic contamination in either aquifer. However, no chemical data currently exist for either pesticides or human waste by-products. Local sources of contamination from industry (petroleum, railroad ties) are known to exist, but specific analyses are required for detection.

CHAPTER 1

INTRODUCTION

by Breton W. Bruce

This paper describes a conceptional model developed for the main groundwater bearing rock units in the southern Laramie Basin located in the southeast corner of the state of Wyoming. The defined study area lies on the eastern flank of the basin, completely within Albany County, and includes the areas of Township 14-17N and Range 72 and 73 West (see Figure 1.1). The model identifies distinct aquifers based on unique water chemistries and relates these different waters to rock/water interactions and flow characteristics. Other questions addressed are the source, evolution, and discharge of water for each aquifer, the possibility of aquifer interconnection and water "mixing" (either natural or due to well penetration), and the level of groundwater contamination from anthropogenic sources.

PREVIOUS STUDIES

Previous work in this study area has focused on the physical controls of groundwater circulation; Lundy (1977), Lundy and Huntoon (1978), Huntoon and Lundy (1979), Huntoon (1985), Davis (1976), the local geology and petrology; Benniran (1973), Howe (1970), Kirn (1972), and the hydrologic parameters of local aquifers; Evers (1973), Goodrich (1942), Nelson (1976), Webster (1976).

INVESTIGATIVE APPROACH

The strategy for this investigation is a reevaluation of existing groundwater chemical data to determine water groups, and hence geochemical groups, and a search for the "geo-meaning" for these groups in the physical parameters known to exist. Data on which this model are based were generated previously (Lundy and Huntoon, 1978) by the sampling and analysis of 77 wells and springs existing in the Precambrian granitic rocks of the Laramie Range of the Medicine Bow Mountains, the Pennsylvanian/Permian Casper Formation, and the Permo/Triassic "redbeds" of the area (Satanka and Chugwater Formations) These data are supplemented with a small amount of data acquired from the archives of the Wyoming State Engineers Office and the U.S. Geological Survey. The available data consist of concentrations of the major ions in solution (Ca,Mg,Na,K,Cl,SO4,HCO3,NO3,and SiO2), total dissolved solids (TDS), water temperature, specific conductance, pH, well depth, and water level data. These data are depicted graphically in several ways to enhance chemical

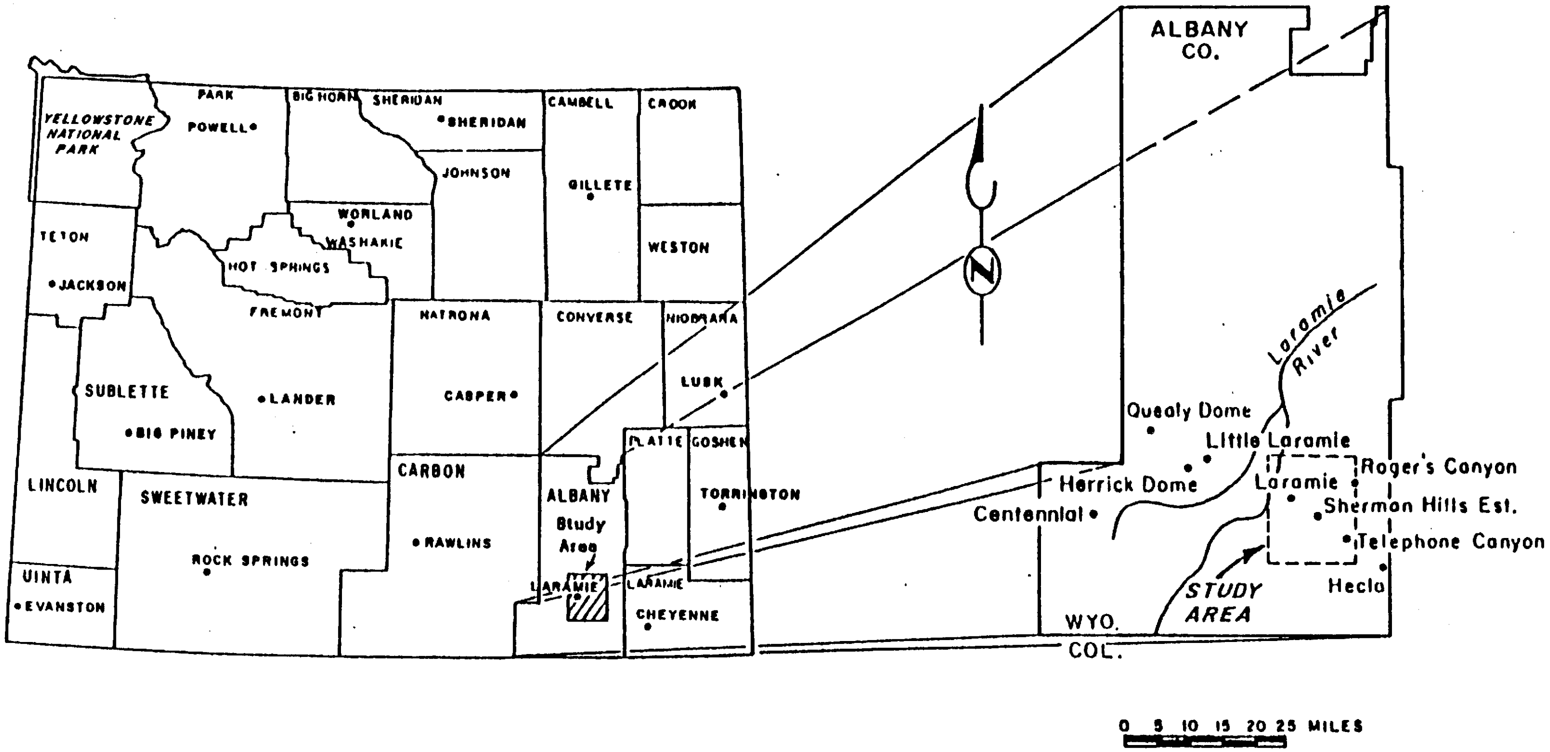


Figure 1.1 Location of the study area in Albany County, Wyoming, including localities referred to in text.

From Lundy and Huntoon (1978)

groups and to show spacial trends and patterns. From interpretations of these graphs the "geo-meaning" is sought.

GEOLOGY

The aquifers of interest for this investigation are the most widely exploited aquifers of the area and include the Precambrian granitic rocks which form the mountain range on the eastern edge of the study area, the Casper Fm. of Penn.-Perm. age (which, for the confines of this paper, also includes the Fountain Fm.), and the Permo-Triassic redbeds of the Satanka and Chugwater Fm. A generalized stratigraphic column is shown in Figure 1.2.

The Casper Fm. is a series of sandstone and limestone interlayers with a relatively constant thickness of 750 feet. The sandstones are well sorted subarkoses which are cemented in decreasing abundance with calcite, clay, silica, and hematite (Kirn, 1972). The limestones are microcrystalline and the lower limestones have been identified as dolomite (Brenniran, 1970). The Fountain Fm. is a poorly sorted arkose (Kirn, 1972).

Underlying the Casper aquifer are Precambrian granites and gniesses. All of the rocks of this age are considered one unit in this study.

Overlying the Casper exists approximately 1000 feet of the Permo-Triassic redbeds composed of shales, siltstones, and mudstones with thin layers of limestone, dolomite, and gypsum (Pearson, 1972 and Howe, 1970).

A geological map showing the surface orientation of the important rock units is shown in Figure 1.3.

STRUCTURAL GEOLOGY

The study area is located on the eastern flank of a Laramide foreland basin where rock units crop out on the uplifted Precambrian rocks to the east. The units generally strike north-south and dip approximately 2 - 8 degrees toward the west with decreasing dips towards the basin center (Lundy and Huntoon, 1978). Figure 1.4 is a generalized cross-section (Lundy and Huntoon, 1978). Superimposed on this trend are a number of folds and faults likely associated with the Laramide compression that formed the basin and local mountain ranges. There exist two sets of faults, one trending east-west and the other north-south. Lundy and Huntoon (1978), Huntoon and Lundy (1979), and Huntoon (1985) expound on the significance of the features to groundwater circulation.

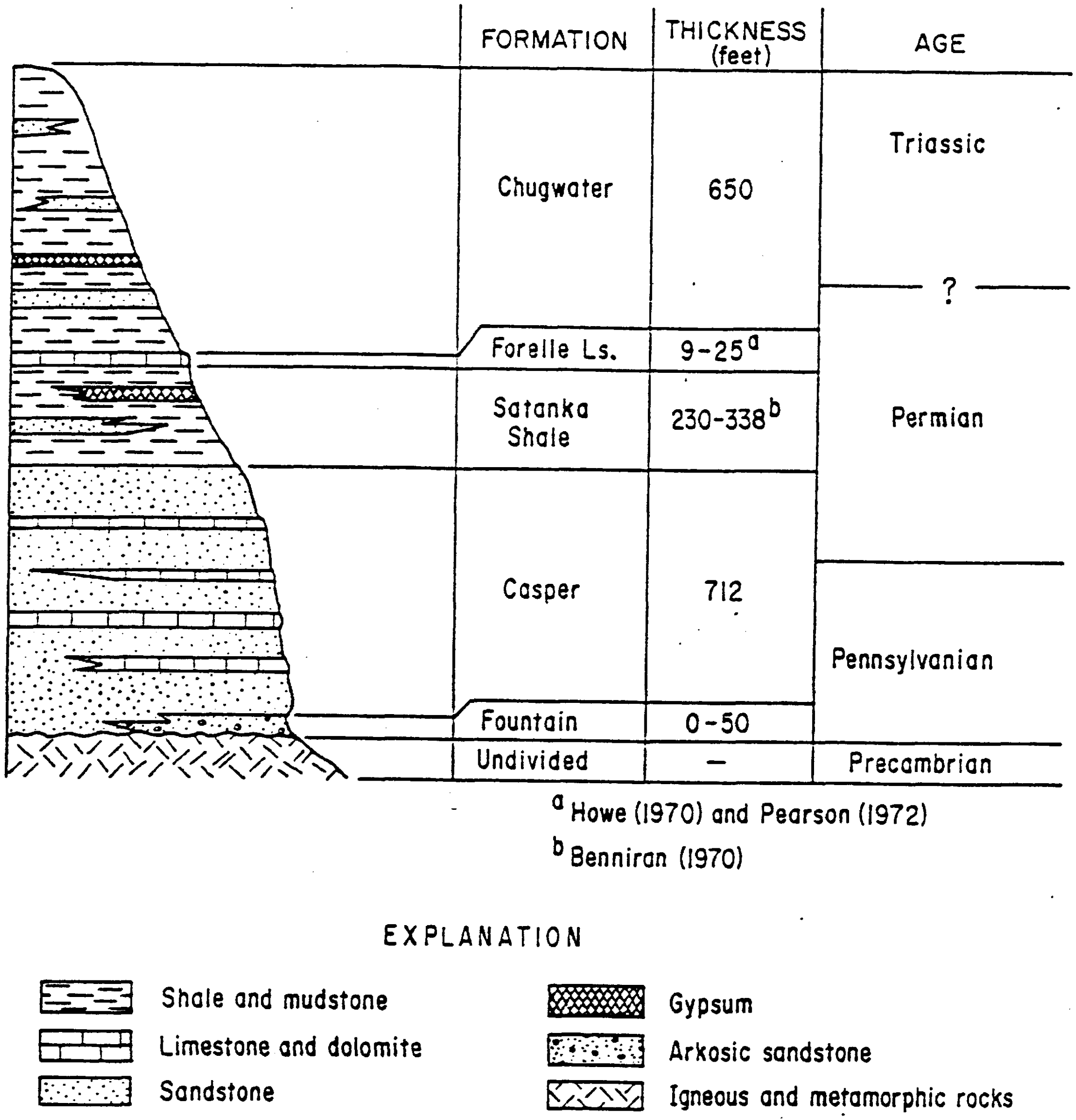


Figure 1.2 Generalized lithology, thickness and age of the Precambrian through Triassic rocks in the vicinity of Laramie, Wyoming.

From Lundy and Huntoon (1978)

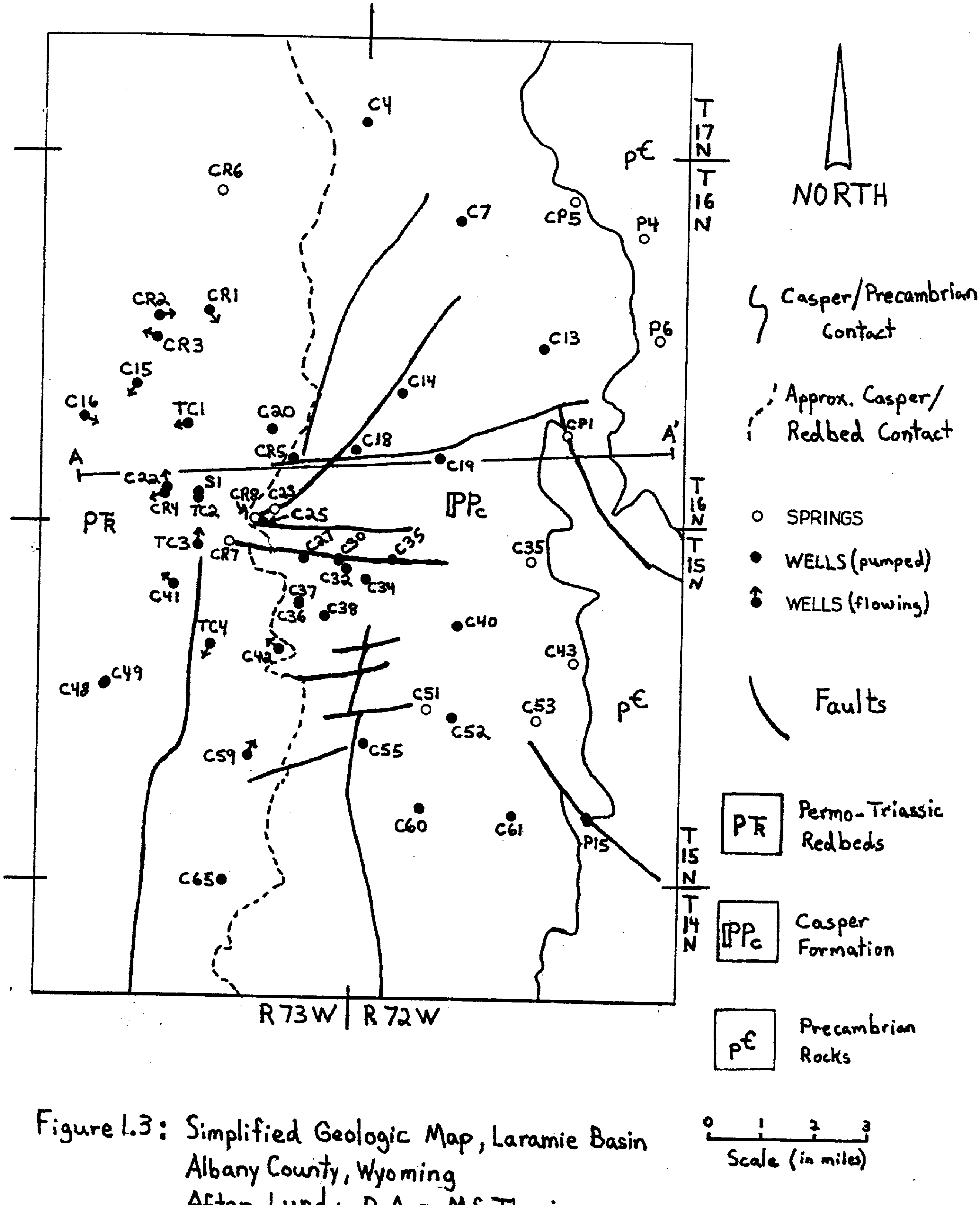
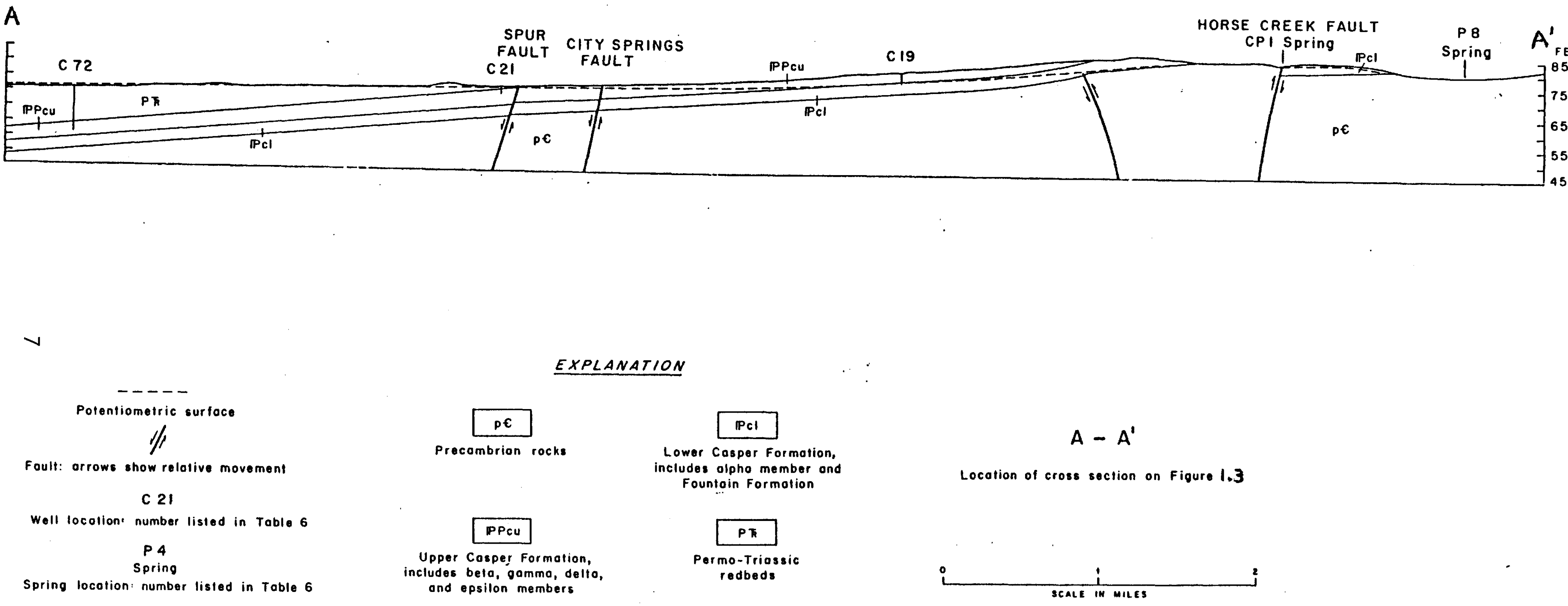


Figure 1.3: Simplified Geologic Map, Laramie Basin
Albany County, Wyoming
After Lundy, D.A. – M.S. Thesis
Univ. of Wyoming (1978)



Don A. Lundy
Univ. Wyo. M.S. Thesis
1978

Figure 1.4: East-West cross section shown on Figure 1.3
From Lundy and Huntoon (1978)

WATER INVENTORY

Water sources in the Laramie area are similar.to.other semi-arid, high-plains provinces (see Figure 1.5). There is only one major surface stream, the Laramie River, which is the surface drain for the entire Laramie basin. There are numerous small creeks and ephemeral streams that flow towards the Laramie River, many of which are sourced from spring discharge.(four of the larger creeks are shown in figure 1.5). There are few natural bodies of surface water, however, approximately 10-15 artificial water impoundments, including a large sewage disposal facility, exist in the area.

The major demands for water in the study area are the city of Laramie (approx. population 30,000), and rural domestic and livestock needs. The greatest portion of current water use is sourced from groundwater wells completed in the local.aquifers. There is also some use of spring discharge and waters form the Laramie River.

FOCUS OF THIS INVESTIGATION

The questions on which this study will focus are:

1. How many geochemical "water groups" are there in the study area?
2. Do these geochemical groups define separate aquifers?
3. Is there aquifer interconnection and water "mixing"?
4. What is the level of groundwater contamination in the area?

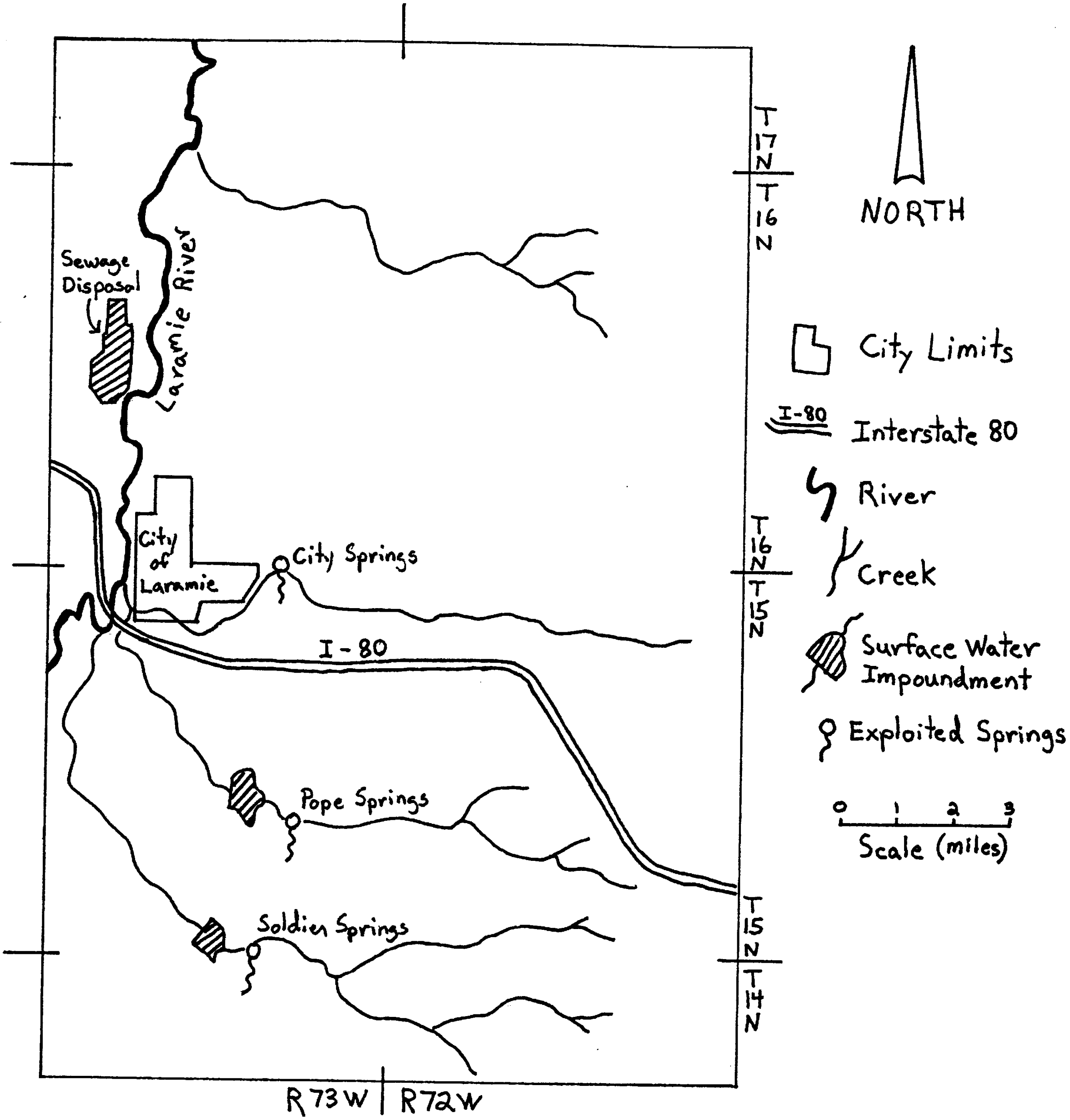


Figure 1.5: Water inventory map of the Southern Laramie Basin

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CHAPTER 2. GEOCHEMICAL GROUPS

Rolfe Spiegel

Groundwater samples from the southern Laramie Basin yield chemical data that fall into three general groups (see Figs 2.1, 2.2 and 2.3). Criterea for distinguishing unique geochemical groups are: clusters of points on composition diagrams (Figs 2.1, 2.3 and 2.4); distinct patterns on fingerprint diagrams (Fig. 2.2); occurrences of chemically similar waters within the same stratigraphic units/intervals. Groundwaters belonging to the three geochemical groups are as follows; (a) group are from the Casper formation, (b) from the Redbeds, and (c) mixtures of the first and second groups. Samples from Precambrian rocks are similar to the Casper group but may define a geochemical subgroup within the Casper group (Fig. 2.4). Casper waters can be further subdivided based on geographical location (chapter 4).

Sulfate shows the highest absolute concentration of all of the major ions. Likely sources for sulfate ion are dissolution of evaporite minerals such as gypsum and anhydrite. Sulfate ion concentrations range from .1 meq/l in sample C14 of the Casper aquifer to 32.9 meq/l in sample TC3 of the Chugwater Formation. Composition plots of SO4 vs TDS show the three primary geochemical groups (Figs 2.1 and 2.3).

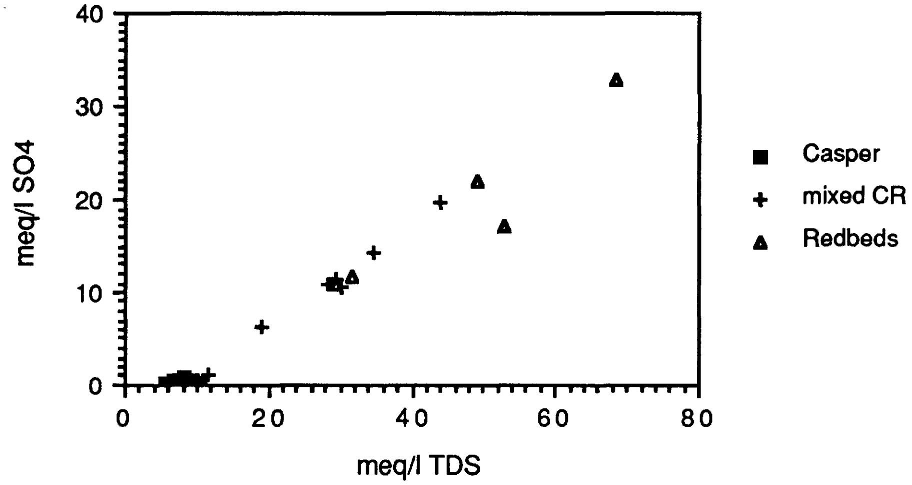

Fig. 2.1. Composition plot of all sampled groundwaters. Casper waters have lowest concentration SO4, Redbeds waters are highest, and mixed CR waters are intermediate.

Chloride shows the greatest variation in concentration for all measured samples (Figs 2.2 and 2.3). Concentrations range from .03 meq/l (lower limits of detection) in several samples from the Casper aquifer, to 1.2 meq/l in sample TC2. Because sodium and chloride concentrations are uniformly low, (Fig 2.3) and well below saturation with respect to NaCl, NaCl is not present in the rock

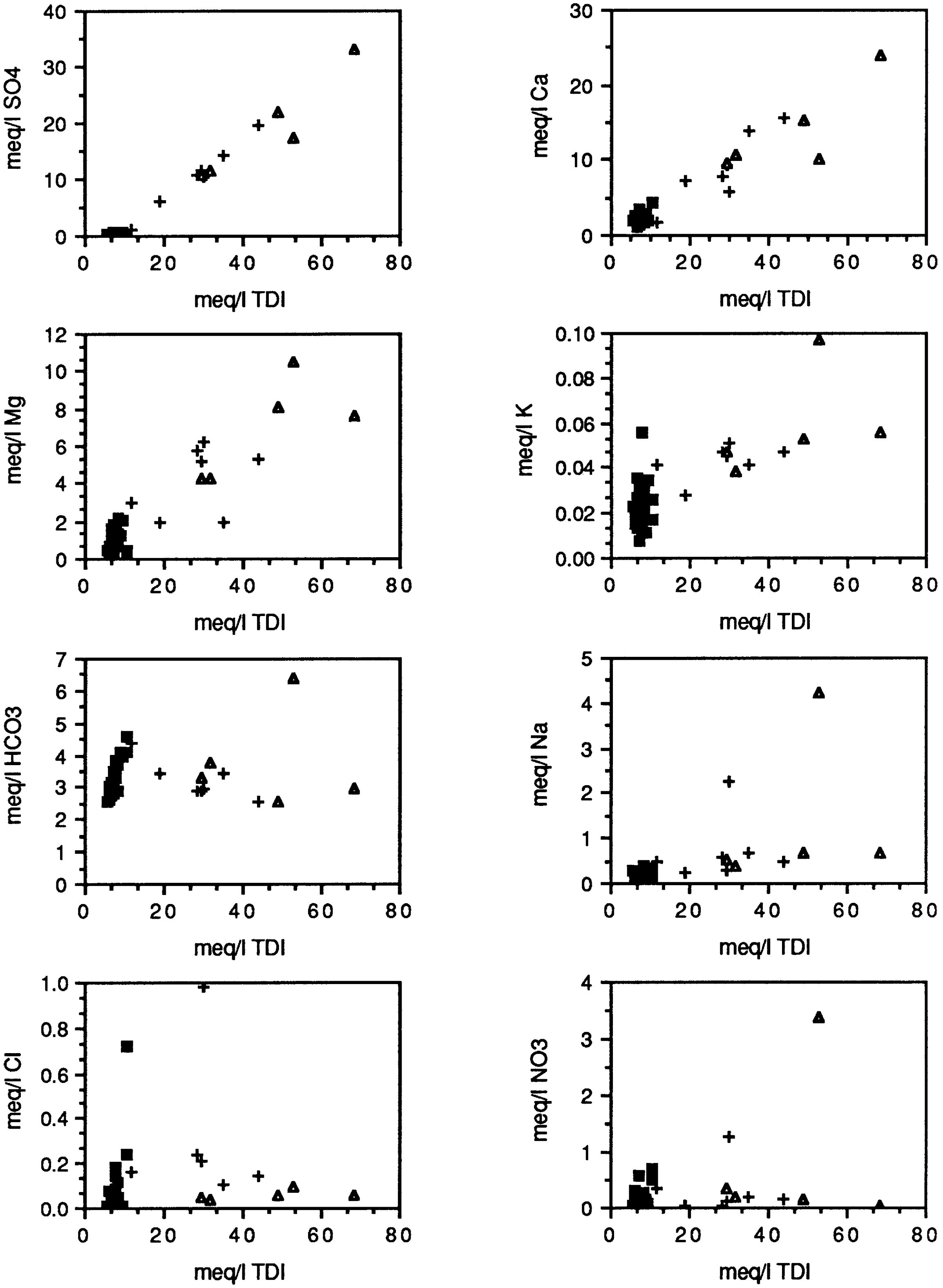

Fig 2.3. Composition diagrams for all measured ions plotted against TDI. Casper waters are solid squares, mixed CR waters are plusses, Redbed waters are open triangles. Concentrations of K, Na, and Cl are low in all samples. Concentrations of Ca, Mg, and SO4 increase with increasing TDI.

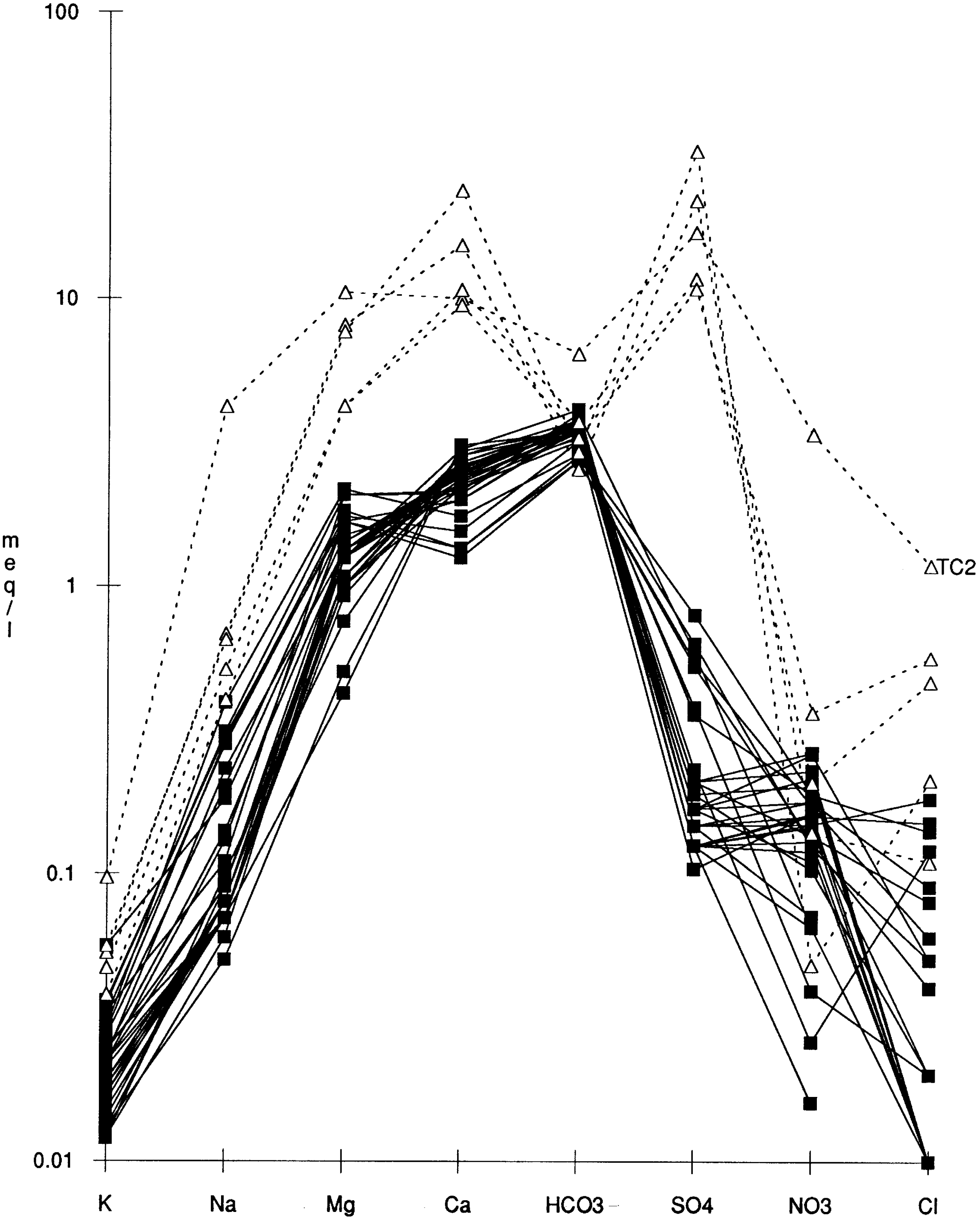

Fig. 2.2. Fingerprint diagram of all sampled Casper (solid squares) and Redbed (open triangles) waters. Capser waters show less variation in concentration for any given ion than do Redbed waters. Note that sample TC2 does not follow pattern of rest of Redbed waters.

matrix; Na and Cl are probably marine in origin and enter the groundwater system with infiltrating rainwater.

Casper Formation waters have lower K, Na, Mg, Ca and SO4 concentrations than Redbed waters, and equal or lesser concentrations of HCO3, NO3, and Cl (Figs 2.2 and 2.3). The high bicarbonate concentration indicates dissolution of limestone and to a lesser degree, dolomite, within the aquifer. Concentrations of calcium higher than magnesium reflect the predominance of calcite over dolomite. Low sulfate concentration reflects the absence or only minor occurrence of gypsum or anhydrite. Locally high concentrations of nitrate could reflect anthropogenic additions to natural levels in some locations.

Precambrian waters resemble Casper waters, except for slightly higher SiO2 (Fig 2.4). Little data are available on the Precambrian rocks within the study area, and so due to the similar chemical signature of the Precambrian groundwaters, they are grouped with the Casper groundwaters. However, since the Precambrian rocks are lithologically different and since the samples from these rocks show similar (but small) differences from the Casper groundwaters, they are defined as a subgroup of the Casper. It should be noted though, that they do not constitute a very significant proportion of the total groundwater discharge within the study area.

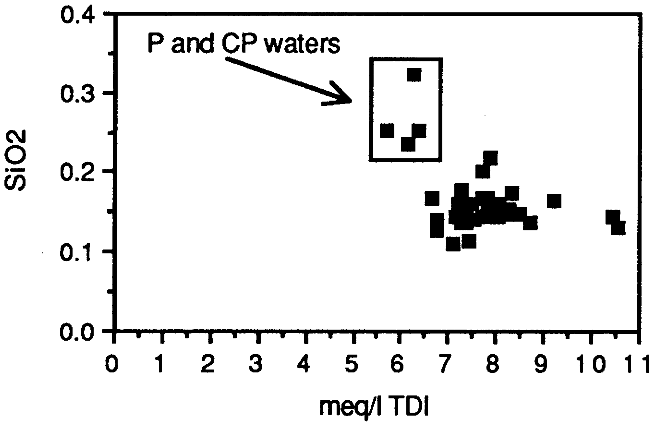

Fig. 2.4. Composition plot of Casper, Precambrian (P), and mixtures of Casper/Precambrian (CP) waters. Precambrian subgroup in boxed section.

Redbed groundwaters include groundwaters from both the Chugwater Formation and the Satanka Formation. The only sample from the Satanka Formation (S1) is here grouped with the Chugwater Formation groundwaters, based 1) on lithologic similarities of the Satanka and Chugwater Formations, and 2) chemical similarities of the water samples from those formations. Redbed groundwaters are characterized by high sulfate concentrations, up to 100 times the sulfate concentrations in Casper Formation groundwaters. Redbed groundwaters have similar concentrations of bicarbonate and nitrate to Casper Formation groundwaters. Sodium, magnesium, and calcium show similar concentrations relative to each other but higher than Casper Formation groundwaters (Fig. 2.2). Higher dissolved silica in the Chugwater aquifer is probably reflective of the high shale content relative to the Casper aquifer; water in equilibrium with quartz and certain types of shale (in the pH range of these waters) will have a higher concentration of dissolved silica than water in equilibrium with only quartz. Sample TC2 shows notable digressions from the pattern of the other Redbed samples (Fig. 2.2). Possible causes could be; 1) the higher temperature, indicating that the water was produced from significantly deeper within the aquifer than the other three samples or, 2) that TC2 is the only non artesian water of the four Chugwater waters, indicating differences in permeability and/or lithology in the producing zone.

Several water samples were obtained from combinations of the Redbed and Casper aquifers. These waters are mixed before they reach the surface either by wells which are completed in both the Redbeds and Casper Formation, or in the case of springs, by circulation within fault zones which cut both the Redbeds and Casper Formation. These waters are characterized by concentrations of major ions intermediate between Casper and Redbed groundwaters (Figs 2.1 and 2.3). The variable concentrations of ions in different samples reflect different proportions of Redbed and Casper aquifer waters that make up the sample.

Wells completed at several depths within the Casper aquifer show little variation about an average value for concentrations of major ions, indicating homogeneity and/or good circulation within the Casper aquifer (see chapters 3 and 4 for discrepancies). In addition to being produced from a "homogeneous" lithologic unit, Casper waters form good clusters on composition diagrams and similar patterns on fingerprint diagrams. In contrast, Redbed waters show large variations in concentrations and so do not make as consistent or tightly clustered patterns as Casper waters. This large variation in concentrations could be due to several factors; 1) variable lithological properties, 2) hydrologically isolated subunits within the aquifer, or 3) a combination of both. The third possibility is the most likely; thin carbonate layers within the Redbeds aquifers could serve as confining layers that prevent circulation within the aquifer.

3. FLOW DIRECTIONS AND DEPTH OF CIRCULATION

Xunhong Chen

CASPER AQUIFER

Casper aquifer consists of permeable sandstones and thinner, less permeable, limestones. It is confined by the underlying precambrian granite and overlying Satanka shales and mudstones. By comparison of two pairs of wells completed respectively above and below specific limestone beds (Table 1), Lundy (1978) concluded that limestones in Casper aquifer are regional confining beds and all intervening sandstones are subaquifers. He suggests five subaquifers in Casper Formation exist in the vicinity of Laramie area(Fig. 3.1).

Table 3.1 Comparison of wells completed in different subaquifers and their water heads. Deeper wells show higher water levels because of the higher pressure in lower subaquifer. See Fig. 3.1 for the names of subaquifers.

Well # **Water level data**	**Pair 1**		**Pair 2**	
	C36	**C37**	**C9**	**C10**
Well elevation (ft)	**7346**	**7346**	**7325**	**7325**
Well depth (ft)	**100**	**135**	**220**	**385**
Water head in the summer (ft)	**7303**	**7328**	**7226**	**7251**
Well completed in subaquifer	**epsilon**	**delta**	**epsilon**	**delta**
Distance between wells of each pair (ft)	**150**		**150**	

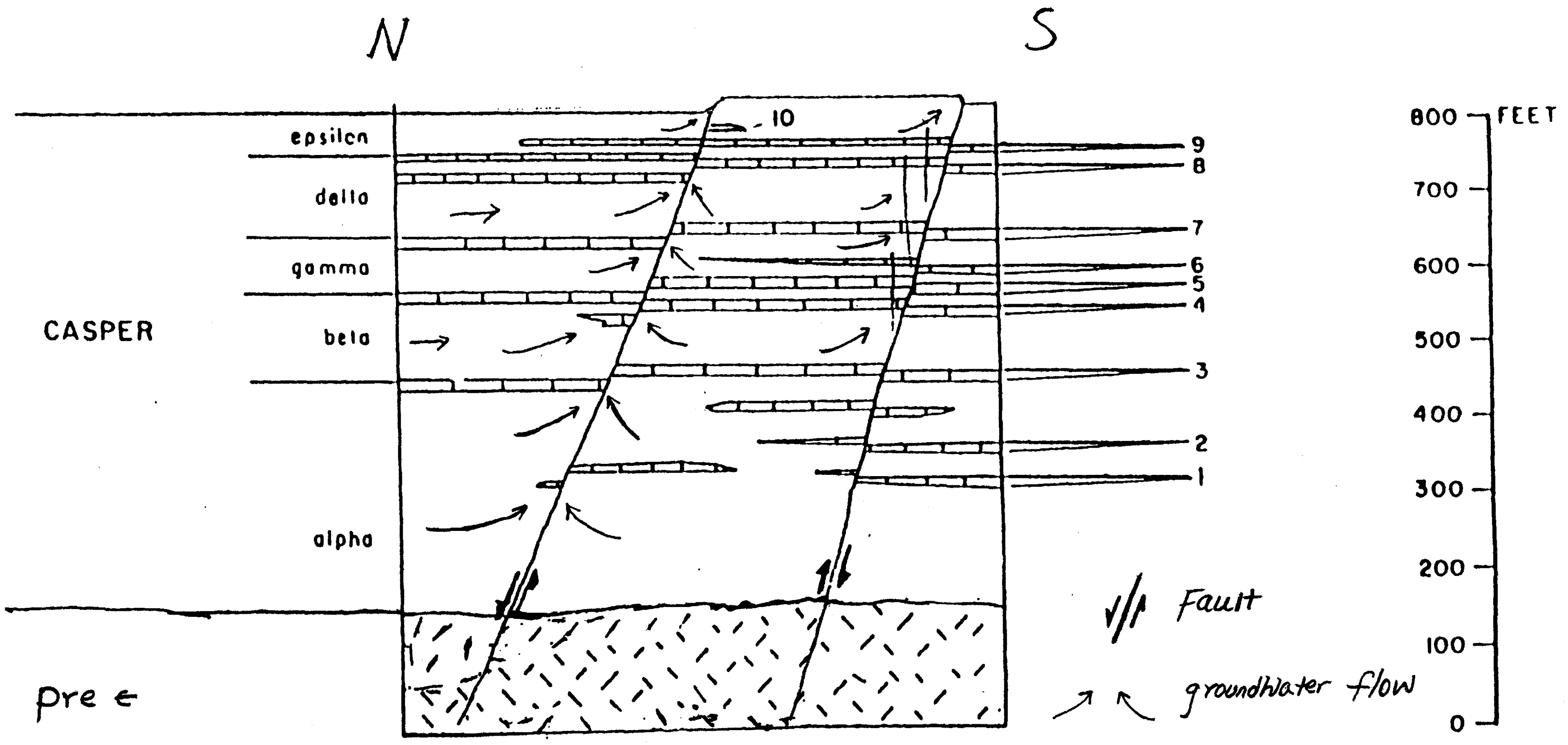

Figure 3.1, Sandstone subaquifers in the Casper Formation. Displacement by normal and reverse faults is likely to make hydraulic connection between subaquifers. Groundwater flows to fault zones because of intensified fracturing (Modified from Lundy, 1978)

The Casper aquifer dips westward and is severed by several faults (fig. 3.2). The significance of the faults and associated fractures lies in their permeability to groundwater. For example, the conductivity of well C25 in the fractured zone is 17 feet/day, while the conductivity of well C50 in unfractured area is only 0.22 feet/day (Lundy, 1978). The faults make the connection of groundwater between subaquifers (Fig. 3.1).

RECHARGE INTO THE CASPER SYSTEM

Recharge into the Casper system takes place on the Casper outcrops by infiltration on the west flank of the Laramie Range and through Quaternary permeable deposits that overlie the Casper Formation in east Laramie. The recharged water is mainly from the melting snow in the spring and rain in the summer. Water infiltrates into separated subaquifers. The interbedded sandstones in unfractured areas account for most of the water storage in the Casper aquifer (Huntoon, and Lundy, 1979).

Fig. 3.3 shows that most wells have higher water level in the summer than in the winter. This is attributed to higher recharge rate in the summer, and frozen ground conditions that inhibit infiltration in the winter (Lundy, 1978).

GROUNDWATER FLOW IN THE CASPER SYSTEM

Groundwater flow in the Casper Formation is controlled by the topography, dip of the rock strata, and fractures. Figure 3.4 shows that water level is very close to topography in the NW side of the transect due to saturation of the Casper aquifer and below the topograpgy in the middle and SE parts of the transect because of high discharge rate in fractured zone and unsaturation of the Casper aquifer (see Fig. 3.2 for the location of Transect AA').

The general direction of groundwater flow in the unfractured parts of the Casper aquifer is westward. The direction of groundwater flow close to the fractured zones is

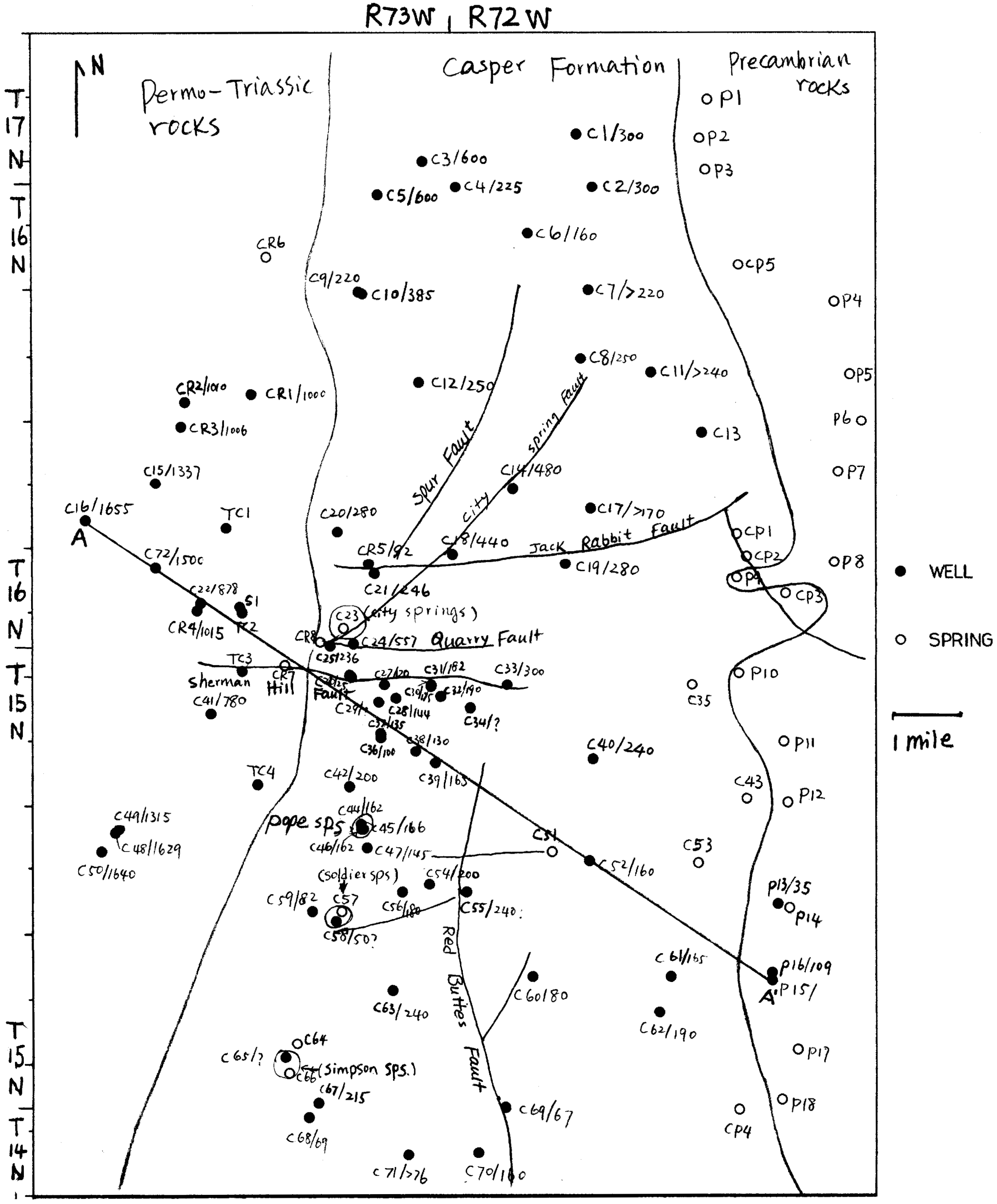

Figure 3.2, Geology, locations of wells and springs, faults, and Transect AA', depths of wells, and Formations (P-Precambrian rocks, C-Casper and Fountain Formations, CR-Casper Formation and Permo-Triassic redbeds, and TC-Triassic Chugwater Formation); C19/280, 19-well number, 280-depth of well in feet (data from Lundy 1978)

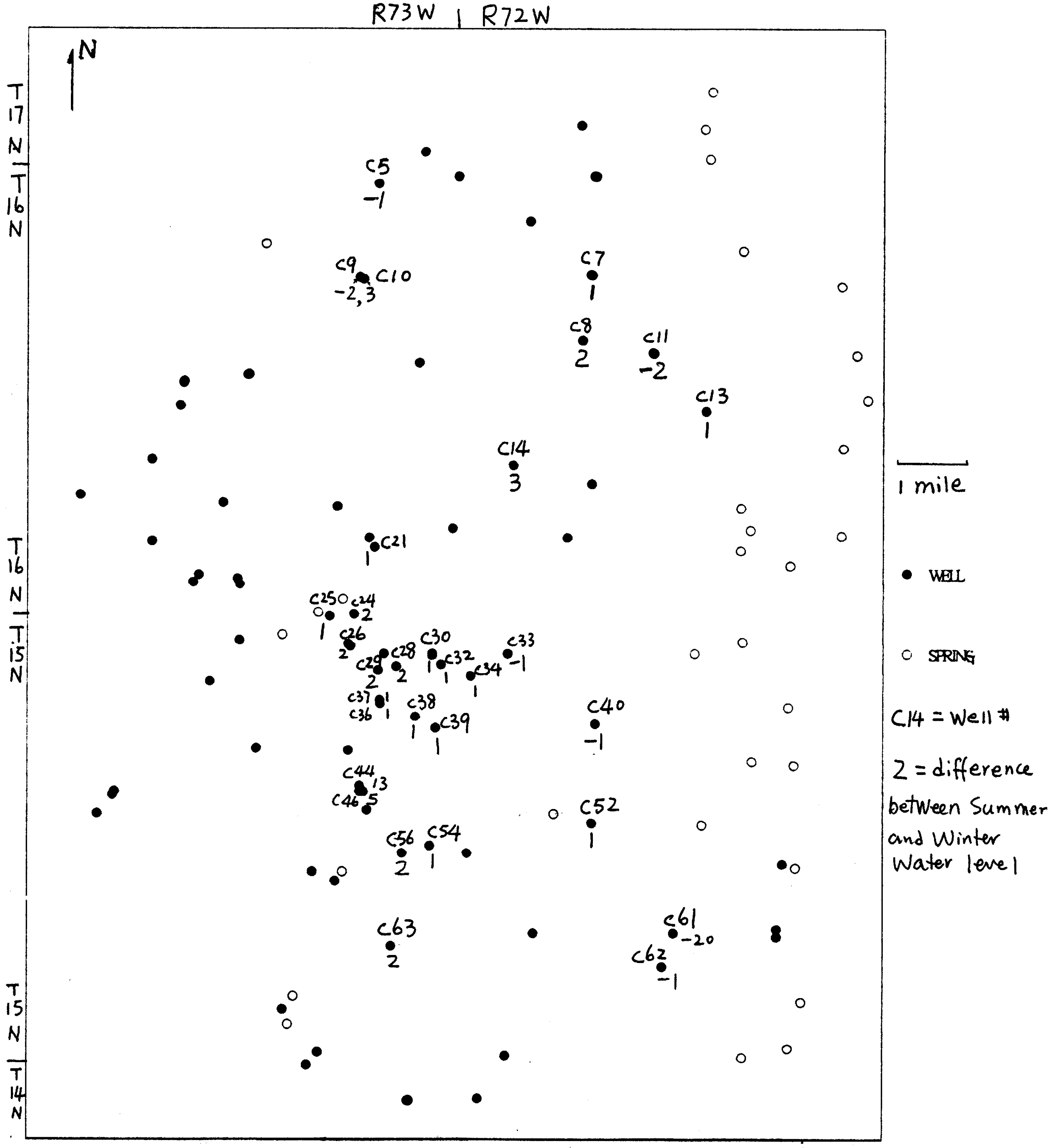

Figure 3.3, Water level in the summer minus water level in the winter. Most wells show higher water levels in the summer (data from Lundy, 1978).

significantly influenced by the large transmissivities of fractures. For example, the direction of water flow on both sides of the Quarry-Sherman fractured zone converts to fault planes (Fig. 3. 5)

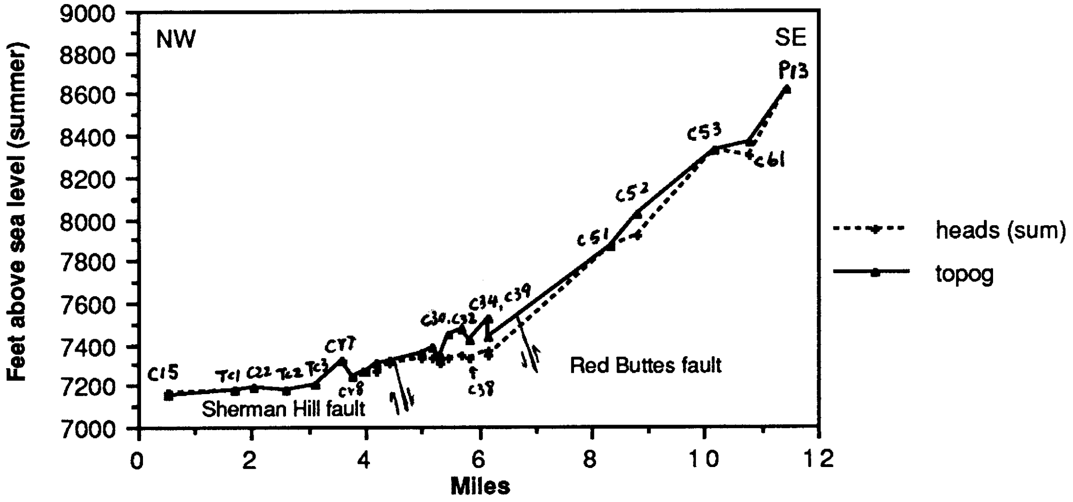

Figure 3. 4, Topography and water heads in the summer along Transect AA'.

The gradient of potentiometric surface changes from about 500 feet/mile in the east to 50 feet/mile in the west. The gradient near the fractured areas is lower than in unfractured areas. For example, the gradients around the City Spring fault and Sherman Hill fault are lower than the neighboring areas (Fig. 3.5). The contour of potentiometric surface around the east end of the Sherman Hill fault is convex to east and the contour around the west end is convex to west (see figure 3.5). Huntoon and Lundy (1979) state the reasons for the change in gradient (1) loss of water from the aquifer through springs and wells, and (2) an increase in the saturated thickness of the aquifer toward the west.

The fractured zones have the largest transmissivities which result in local lowering

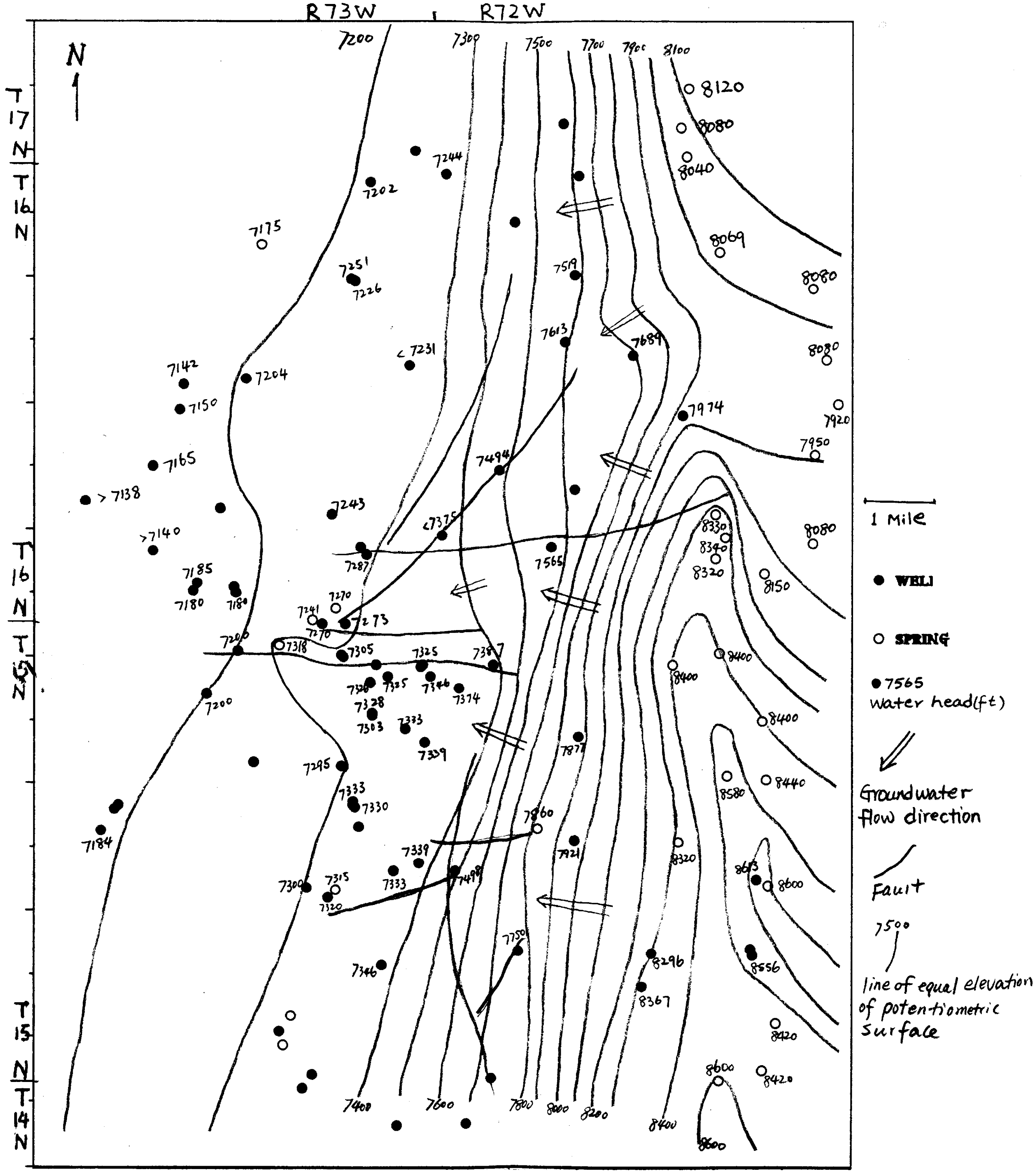

Figure 3.5, Water heads in feet above sea level, iso-potential contours, flow direction and faults in the southern Laramie Basin. Faults have locally affected the gradient of water head and the flow direction of groundwater in fractured zones. (See Fig. 3.2 for the names of faults, data from Table 6 and faults adopted from Figure 8 of Lundy, 1978)

of the water heads. Therefore groundwater in the sandstone subaquifers flows to the fault zones and moves upward through fault planes as springs.

Displacement by faults, such as City Spring fault, Sherman Hill fault, and Quarry fault, resulted in fractures in the overlying Satanka Formation. The example is that Sherman Hill fault offsets the Triassic Chugwater Formation (Huntoon and Lundy, 1979). Groundwater in the Casper aquifer could move upward through those fractures into Satanka Formation and mixes with water of the Satanka Formation.

CIRCULATION PATTERNS DEDUCED FROM TEMPERATURE/DEPTH RATIO

Groundwater temperatures increase with well depths. Figure 3.6 shows a positive correlation between water temperatures and well depths. However, the ratio of groundwater temperature to well depth varies since water temperatures are affected by the deeper water circulation in fractured areas.

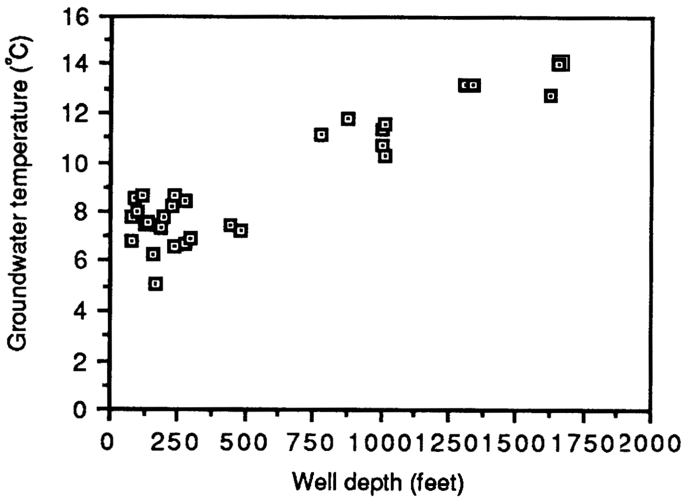

Figure 3.6 Correlation between groundwater temperatures and well depths. Data from Lundy (1978).

Figure 3.7 shows that the temperature/depth ratios in unfractured area are lower than in fractured parts along transect AA'. The higher temperature/depth ratio in fractured zone suggests that some waters in the wells are from subaquifers which are deeper than the well depth. This information implies the hydraulic connection between subaquifers in fractured area.

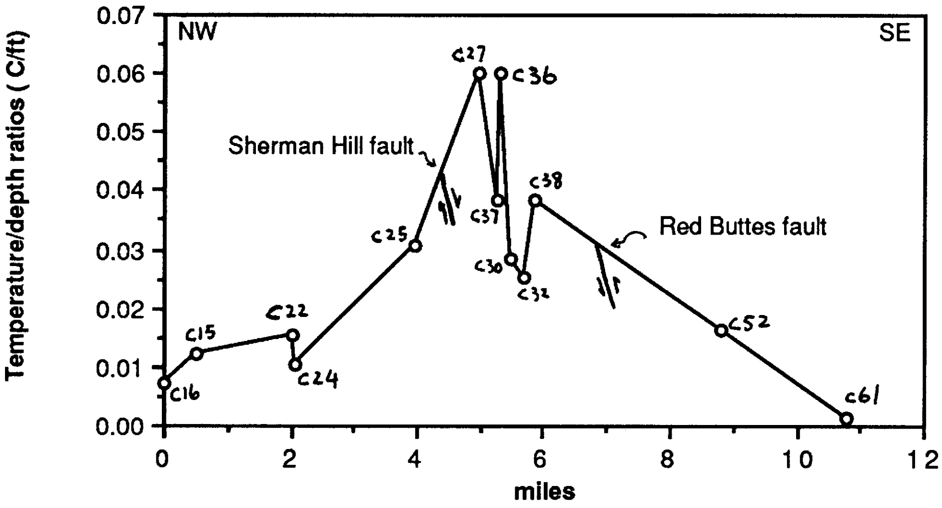

Figure 3.7, Temperature/depth ratios along transect AA'. The temperature/depth ratios is calculated by the folowing formula:

ΔT= ((T(measured)-T(average ambient))/(0.5 well depth)

since the well mixes waters from different depths. The average ambient temperature in this area is 5.0°C.

VARIATION OF WATER CHEMICALS WITH LITHOLOGY

Groundwater chemicals are apparently influenced by lithology in the study area. The composition of SO_4, Ca, and Mg in wells of CR- and TC- is significantly higher than in other wells. Gypsum and dolomite in the Satanka Formation and Chugwater Formation attribute to the higher values of Mg and SO_4 in groundwater of those wells. Figure 3.8 shows the the variation of SO_4, Mg, Ca, and HCO_3 along the transect AA'. For example, The values of SO_4 in wells TC1, CR4, S1, TC2, TC3, AND CR7 are 10 to

20 times as high as the values in all C- wells along the transect. However, the composition profile of HCO_3 does not show a significant change in TC- and CR- wells (Figure 3.8d).

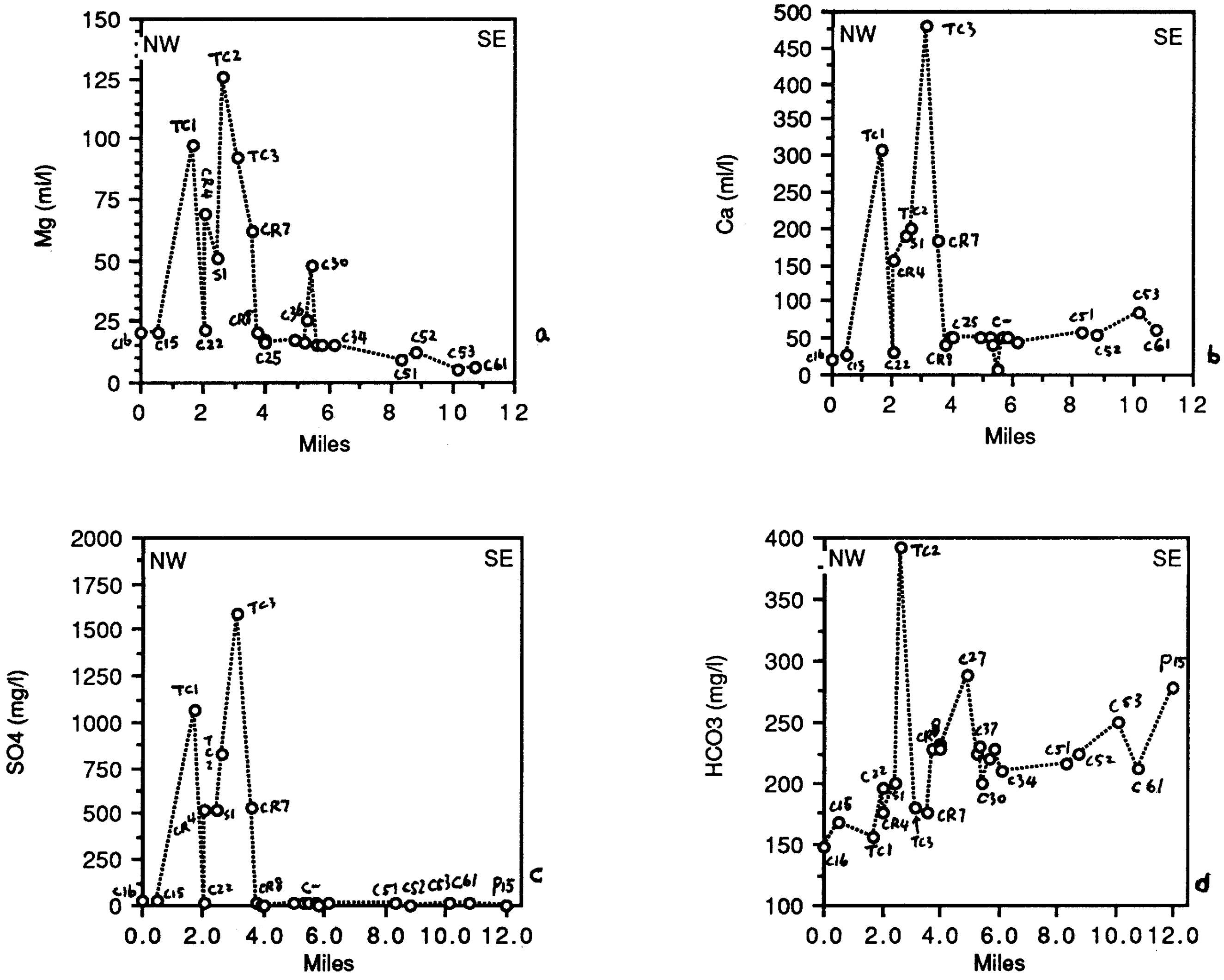

Figure 3.8, Composition profiles of SO_4, Mg, Ca, and HCO_3 along transect AA'. Data from Lundy (1978).

DISCHARGE

Discharge from the Casper aquifer occurs through springs and seeps. Springs of high discharge rate, such as City Springs, Pope Springs, Soldier Springs, and

Simpson Springs, occur in a zone of N-S trend in east of Laramie. This zone represents the intersection of landsurface and potentiometric surface. Ground-water of Casper aquifer seeps upward through faults to the surfaces. Creeks carry water westward to the Laramie River.

CONCLUSIONS

1) The direction of ground-water flow in unfractured parts of the Casper aquifer is controlled by the westward dip of the Casper Formation and topography.

2) The fractured zones account for the largest transmissivities in the Casper aquifer and affect the direction of groundwater flow.

3) The fractured zones provide the hydraulic link between sandstone subaquifers of the Casper aquifer. Groundwater in unfractured areas flows to the fractured zone and then moves upward through fault planes and finally seeps in ground. Springs of high discharge are associated with fractures.

4) The ratio of groundwater temperature to well depth in fractured zone is higher than the ratio in unfractured area.

5) Higher values of SO_4 and Mg in groundwater are attributed to the Permo-Triassic redbeds.

REFERENCES

Huntoon, P.W. and Lundy, D.A., 1979, Fractured-controlled ground-water circulation and well siting in the vicinity of Laramie, Wyoming: Ground water, vol.17, no.5, p.463-469.

Lundy, D.A., 1978, Hydrology and geochemistry in the vicinity of Laramie, Albany County, Wyoming, Water Resource Series No. 75, Wyoming Water Resources Research institute, University of Wyoming.

4. CHEMISTRY OF THE CASPER WATER

MARK R. BLANCHARD

INTRODUCTION

The Casper aquifer system is composed of the Casper Limestone and the underlying Fountain Formation. It is confined above by the Satanka Shale and below by Precambrian crystalline rocks. Flow in the aquifer occurs in sandstone layers, which are hydraulically separated by limestone layers (Huntoon and Lundy, 1979). The Casper outcrops on the eastern side of the study area and dips westward into the basin (Geology, Chapter 1).

The locations of wells and springs for which chemical data are available are shown in Figure 4.1. Data used in this analysis are reported in Table 4.1 (Lundy and Huntoon, 1978, WATSTORE, 1990). Sodium, potassium, chloride, and nitrate concentrations are generally less than 10 ppm. Calcium, magnesium, sulfate, and bicarbonate concentrations are one to two orders of magnitude greater.

COMPOSITION DIAGRAMS

Figures 4.2 and 4.3 are composition diagrams for all the Casper data. Notice in figure 4.2 that there is one cluster of points having sulfate concentrations less than or equal to 11 ppm, while another, less well constrained, cluster occurs in which sulfate concentrations are greater than or equal to 17 ppm. To make this clear on the graphs different symbols have been assigned to the two groups. All the sites which fall into the higher sulfate group occur

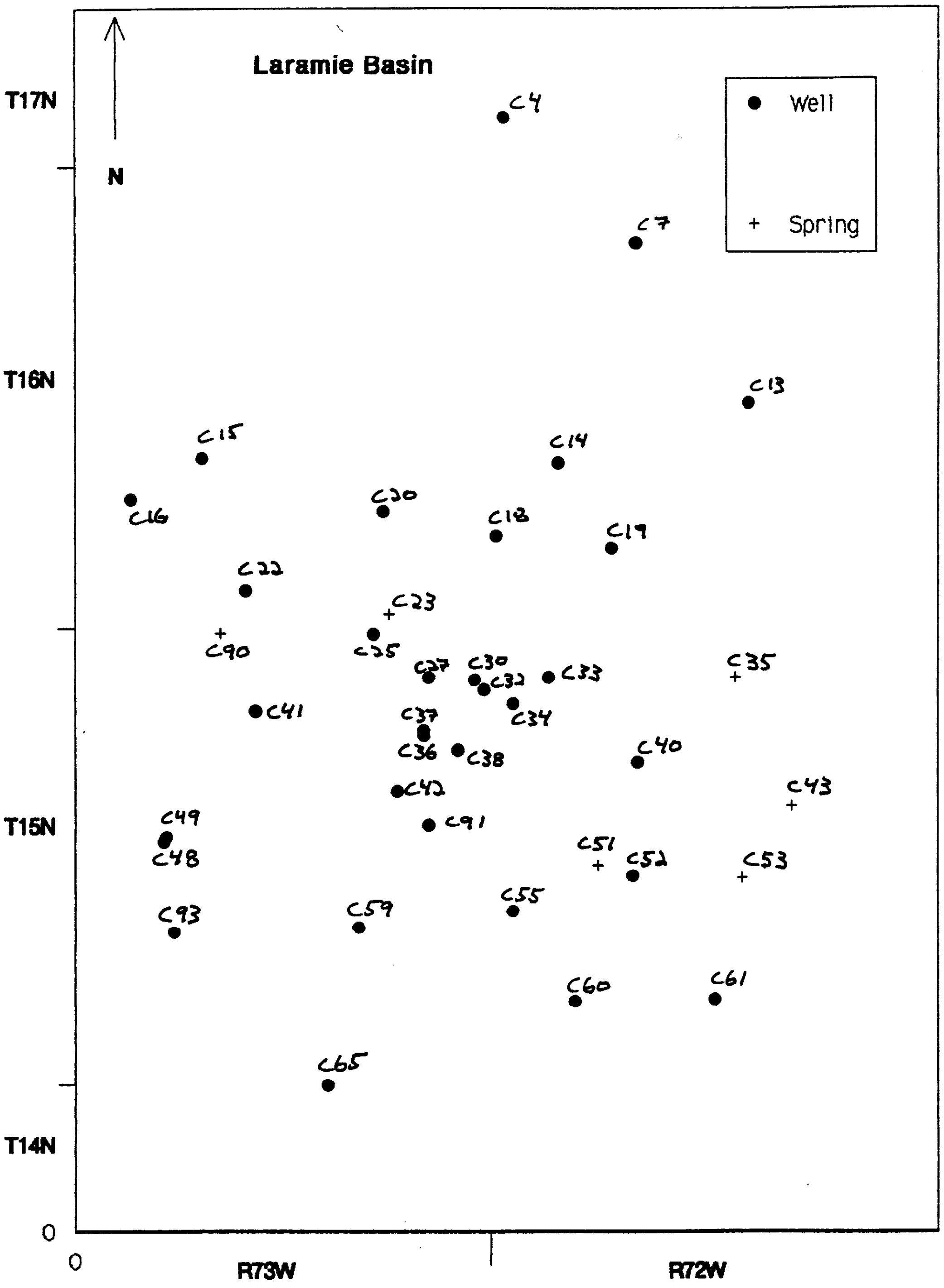

Figure 4.1. Study area map showing locations of all Casper aquifer wells and springs for which water chemistry data are available.

Table 4.1. Data for the Casper wells and springs used in this report. See Figure 4.1 for locations.

Site	Date	Depth (ft)	Elevation (ft)	Water Level (ft)	Temperature (C	Field pH	Ca (ppm)	Mg (ppm)	Na (ppm)	K (ppm)	Cl (ppm)	SO4 (ppm)	HCO3 (ppm)	NO3 (ppm)	SiO2 (ppm)	TDS (ppm)	SIcal	SIdol	SIgyp	SIanhy	Pco2	Ca/Mg
C4	7/15/76		7244	7244	8.2	7.7	40	18	4.1	2.2	3.04	8	215	5.5	12	203	-0.066	-1.02	-2.82	-3.08	3.24E-03	1.35
C7	7/27/76	220	7693	7519	7	7.7	40	17	3.3	0.88	1.76	7	190	18	8.9	196	-0.135	-1.21	-2.87	-3.12	2.83E-03	1.43
C13	7/19/76	200	8043	7974	6.3	7.7	54	15	2	0.46	0.59	9	226	3.2	9.8	211	0.048	-1.04	-2.65	-2.90	3.33E-03	2.18
C14	7/23/76	480	7494	7494	7.2	7.6	44	12	1.9	0.52	0.11	5	195	5	8.4	178	-0.178	-1.48	-2.96	-3.22	3.63E-03	2.22
C15	7/15/76	1337	7157	7165	13.2	7.6	27	20	4.6	1.05	1.38	25	167	4	10.1	180	-0.367	-1.29	-2.49	-2.75	3.34E-03	0.82
C16	8/5/76	1655	7138	7138	8.3	8.6	13	20	5.8	1.22	1.68	25	129	0.8	2.9	139	0.148	-0.05	-2.77	-3.03	2.55E-04	0.39
C16	6/24/76	1655	7138	7138	9.7	8.3	18	20	7	1.08	1.99	27	146	1	5.5	159	0.063	-0.33	-2.61	-2.87	5.85E-04	0.55
C16	8/5/76	1655	7138	7138	14.5	8	25	20	7	1.39	1.98	26	167	5.3	7.6	181	0.030	-0.43	-2.52	-2.77	1.40E-03	0.76
C18	6/30/76	275	7620	245	7.5	7.8	46	15	1.9	0.61	0.1	6	213	0.5	8.2	188	0.085	-0.87	-2.88	-3.14	2.56E-03	1.86
C19	7/26/76	300	7840	7565	6.7	7.6	53	11	1.6	0.65	0.01	8	209	3.4	8.3	193	-0.084	-1.43	-2.69	-2.95	3.85E-03	2.92
C20	7/16/76	280	7331	7243	8.4	7.7	40	20	3	0.85	0.64	6	219	4.5	10	198	-0.056	-0.94	-2.95	-3.21	3.31E-03	1.21
C22	7/13/76	878	7185	7185	11.8	8	31	21	6.5	1.25	0.77	18	195	1.2	10.6	192	0.145	-0.33	-2.59	-2.84	1.57E-03	0.90
C23	8/4/76	0	7270	7270	8.2	7.3	52	16	1.9	0.71	0.33	6	227	4	8.7	207	-0.362	-1.77	-2.85	-3.10	7.97E-03	1.97
C25	7/26/76	236	7270	7270	8.6	7.4	49	17	2	0.85	0.11	6	233	2	8.6	205	-0.260	-1.51	-2.87	-3.12	6.69E-03	1.75
C27	7/21/76	120	7366		8.6	7.4	50	17	2.1	0.85	1.71	8	228	8	9.2	214	-0.262	-1.52	-2.74	-2.99	6.55E-03	1.78
C30	7/20/76	175	7441	7325	7.5	7.2	48	12	1.9	0.68	0.37	9	200	6.2	9.7	192	-0.568	-2.29	-2.68	-2.93	8.53E-03	2.43
C32	7/20/76	190	7470	7346	7.4	7.1	50	15	1.6	0.72	0.01	7	220	5.5	10	203	-0.632	-2.34	-2.78	-3.04	1.13E-02	2.02
C33	7/20/76	300	7615	7387	6.9	7.5	57	13	2	0.93	0.05	10	231	8.1	10.5	220	-0.122	-1.45	-2.58	-2.84	5.27E-03	2.66
C34	7/20/76		7527	7374	7.1	7.5	44	15	1.5	0.83	0.48	8	210	6.6	9.3	194	-0.262	-1.55	-2.77	-3.03	4.82E-03	1.78
C35	7/22/76	0	8400	8400	6	7.1	62	5	1.6	0.83	0.05	7	212	2.2	9	197	-0.575	-2.84	-2.67	-2.93	1.07E-02	7.52
C36	8/3/76	100	7346	7303	8	7.4	42	25	2.5	1.28	4.25	11	230	0.8	8.9	214	-0.349	-1.47	-2.68	-2.94	6.54E-03	1.02
C37	7/23/76	135	7346	7328	7.6	7.3	49	16	1.9	0.76	5.4	7	223	4.9	8.7	208	-0.405	-1.85	-2.79	-3.05	7.77E-03	1.86
C38	7/21/76	130	7415	7333	7.5	7.3	51	15	1.6	0.74	0.37	6	229	5	9.1	208	-0.377	-1.84	-2.84	-3.10	7.97E-03	2.06
C40	7/22/76	177	7960	7877	6.4	7.4	60	15	1.3	0.47	0.03	7	251	4.9	8.2	225	-0.184	-1.55	-2.72	-2.98	7.00E-03	2.43
C41	7/21/76	780	7200	7200	11.1	7.5	43	25	7.1	1.37	0.43	28	244	2	9.9	242	-0.167	-1.04	-2.29	-2.55	5.83E-03	1.04
C42	6/30/76	200	7295	7295	7.8	7.9	48	17	1.7	0.86	0.5	6	221	4.6	9.7	202	0.222	-0.55	-2.87	-3.13	2.13E-03	1.71
C43	7/22/76	0	8580	8580	6.3	7.3	67	0	0.9	0.32	0.04	6	208	5	6.7	194	-0.312		-2.70	-2.96	7.17E-03	0.00
C48	7/23/76	1629	7182		12.8	7.5	27	22	6.7	1.1	1.7	30	174	3.8	8.7	191	-0.468	-1.46	-2.42	-2.68	4.29E-03	0.74
C49	7/23/76	1315	7180		13.2	7.6	35	26	9	1.13	0.01	38	176	5.8	8.9	215	-0.252	-1.06	-2.24	-2.49	3.49E-03	0.82
C51	7/2/76	0	7860	7860	6.3	7.5	59	9	2.2	0.47	6.41	7	215	4.6	9.6	210	-0.142	-1.68	-2.71	-2.96	4.88E-03	3.98
C52	7/27/76		8014	7921	6.3	7.5	54	12	1.6	0.96	0.37	6	223	3.7	8.6	208	-0.164	-1.57	-2.81	-3.07	5.06E-03	2.73
C53	7/22/76	0	7339	8320	6.3	7	85	5	8.2	0.67	25.6	8	250	16	7.8	285	-0.506	-2.83	-2.53	-2.79	1.51E-02	10.30
C55	8/3/76	240	7542	7498	6.6	7.3	52	13	1.5	0.58	0.16	6	213	4.9	8.4	197	-0.412	-2.00	-2.82	-3.08	7.34E-03	2.43
C59	7/2/76	200	7300	7300	7.8	7.4	47	16	3.2	0.95	2.98	10	215	4.2	9.6	206	-0.325	-1.66	-2.66	-2.91	6.12E-03	1.78
C60	7/2/76	80	7782	7750	6.8	7.6	57	12	1.9	0.54	0.44	10	214	7	13.2	213	-0.047	-1.34	-2.58	-2.83	3.94E-03	2.88
C61	8/3/76	165	8362	8296	5.1	7.2	62	6	1.2	0.5	0.01	7	212	4.6	6.9	197	-0.477	-2.58	-2.67	-2.93	8.74E-03	6.27
C65	7/7/76	0	7340	7340	8.1	6.7	45	16	5.3	0.91	4.86	17	203	5.8	10.1	210	-1.203	-3.39	-2.44	-2.69	2.08E-02	1.71
C90	4/22/43				0		53	18	0	0	1.2	5.9	240	5.9	9.8	215	-0.648	-2.26	-2.85	-3.11	1.54E-02	1.79
C90	9/28/44				0		53	17	0	0	1.8	3.4	240	6.8	3.9	207	-0.645	-2.28	-3.09	-3.34	1.54E-02	1.89
C90	5/6/47				0		43	17	0	0	6	5.8	210	0	12	202	-0.785	-2.47	-2.92	-3.18	1.35E-02	1.53
C90	10/22/51				8		53	16	1.3	1	3	3	230	5.6	8.8	201	-0.698	-2.46	-3.13	-3.39	1.43E-02	2.01
C91	5/26/41				0		47	18	0	0	3.2	1.4	240	3.1	8	208	-0.694	-2.30	-3.51	-3.77	1.54E-02	1.58
C91	4/22/43				0		48	20	0	0	1	4	240	4.9	0	195	-0.688	-2.25	-3.06	-3.13	1.54E-02	1.46
C93	1/10/69				13		31	24	8.3	1.3	2.4	37	180	0	8.8	202	-0.958	-2.46	-2.29	-2.54	1.21E-02	0.78

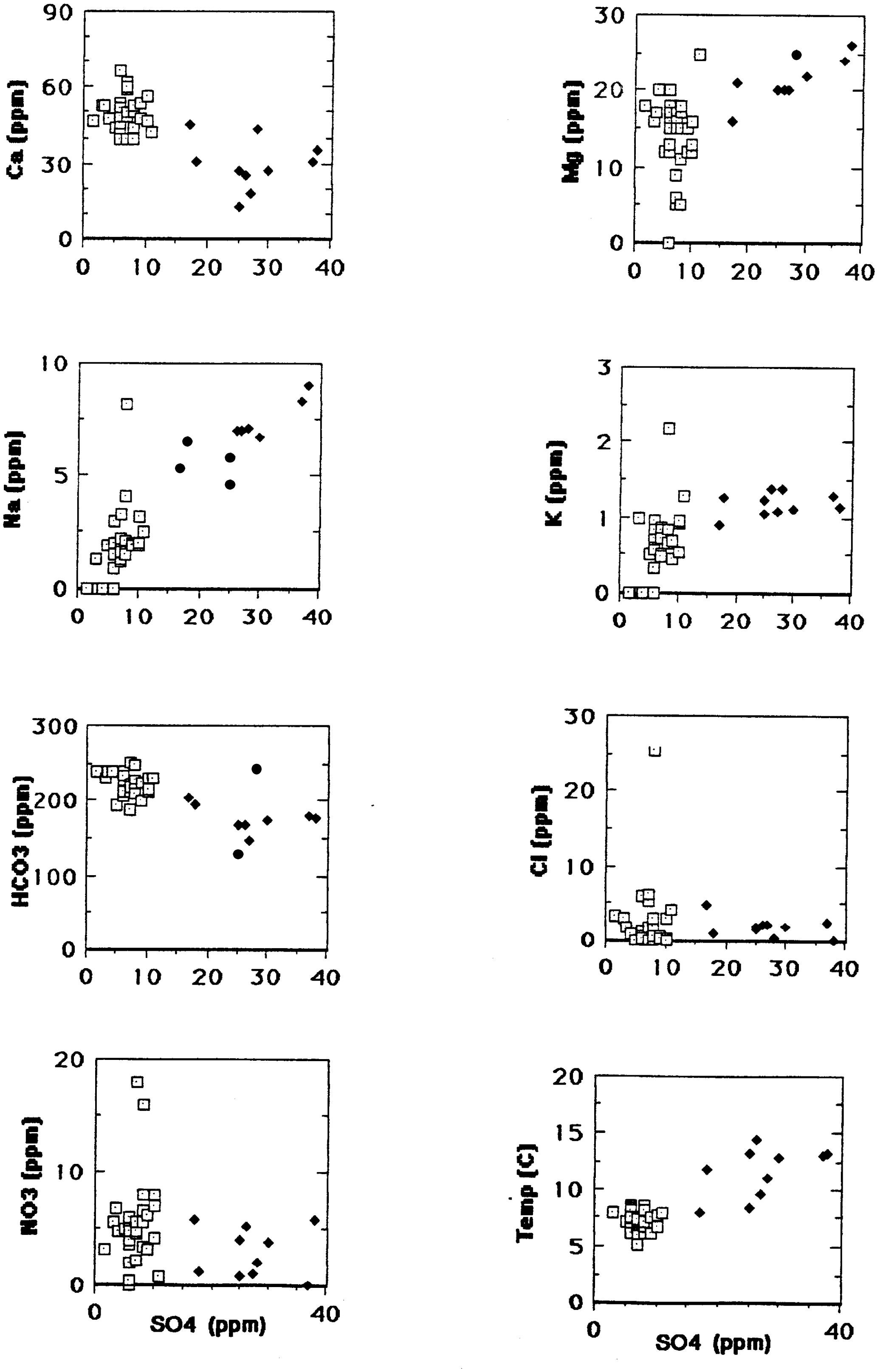

Figure 4.2. Composition diagrams showing various parameters plotted against sulfate. The sites in the western portion of the study area have sulfate concentrations greater than or equal to 17ppm and are given a different symbol(◆). The trends of calcium, magnesium, and bicarbonate are especially important.

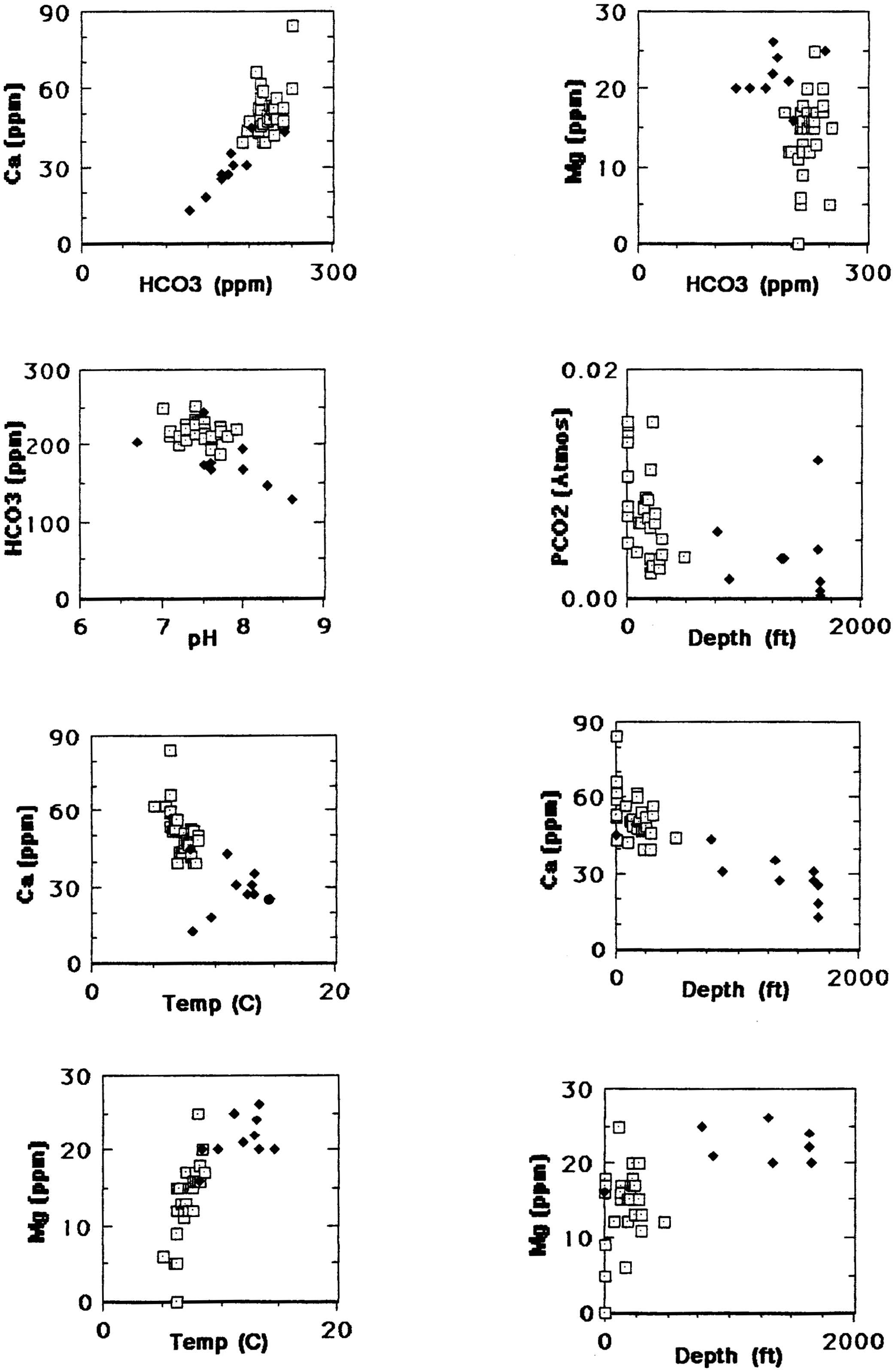

Figure 4.3. Composition diagrams which reflect the influence of the carbonate system. The positive correlation of calcium with bicarbonate reflects dissolution of calcite. PCO2 decreases with depth, indicating a closed system.

on the western side of the study area whereas those of the lower sulfate group occur in the central and eastern areas, indicating a difference in the western waters from the rest of the Casper.

PATTERNS REVEALED IN TRANSECTS

Figure 4.4 shows the locations of three transects that were chosen to lie roughly parallel (X & Y) and perpendicular (Z) to flow (Chapter 3). Data from springs and wells lying within a mile on either side of these transects were plotted in figures 4.5 through 4.7.

Plots along transects X and Y are shown in figures 4.5 and 4.7. The basinward increase in well-depth is reflected by the temperature increase (Figures 4.5 & 4.6). Total Dissolved Solids are generally constant across the basin, with a slight increase in site C41 shown in transect X. Magnesium, sodium, and potassium increase slightly basinward with the obvious increases appearing in the western sites C41, C48, and C49.

Nitrate, chloride, and silica concentrations are constant with a few local variations. Calcium decreases slightly. Sulfate is generally constant across the transects, with the exception of the sites farthest west. In these the concentration of sulfate increases two to three times. Bicarbonate is similar in that it is generally constant with slight variation in the western sites.

Transect Z is oriented north to south, which is roughly perpendicular to flow. Notice that the difference in hydraulic head across transect Z is only 100 feet, whereas it is 800 - 1400 feet across transects X and Y (Figure 4.7), reflecting the dominance of

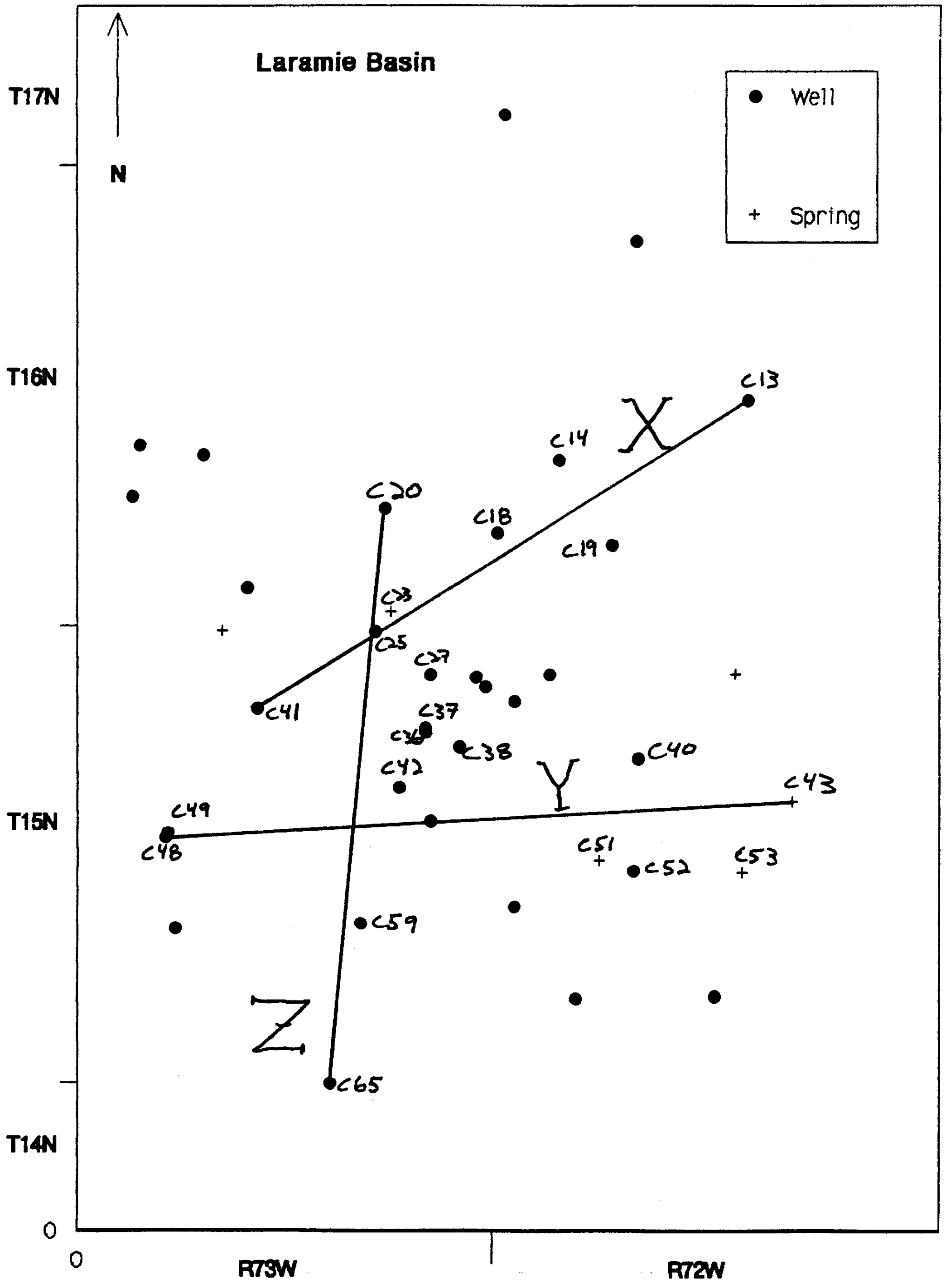

Figure 4.4. Study area map showing locations of transects X, Y, and Z.

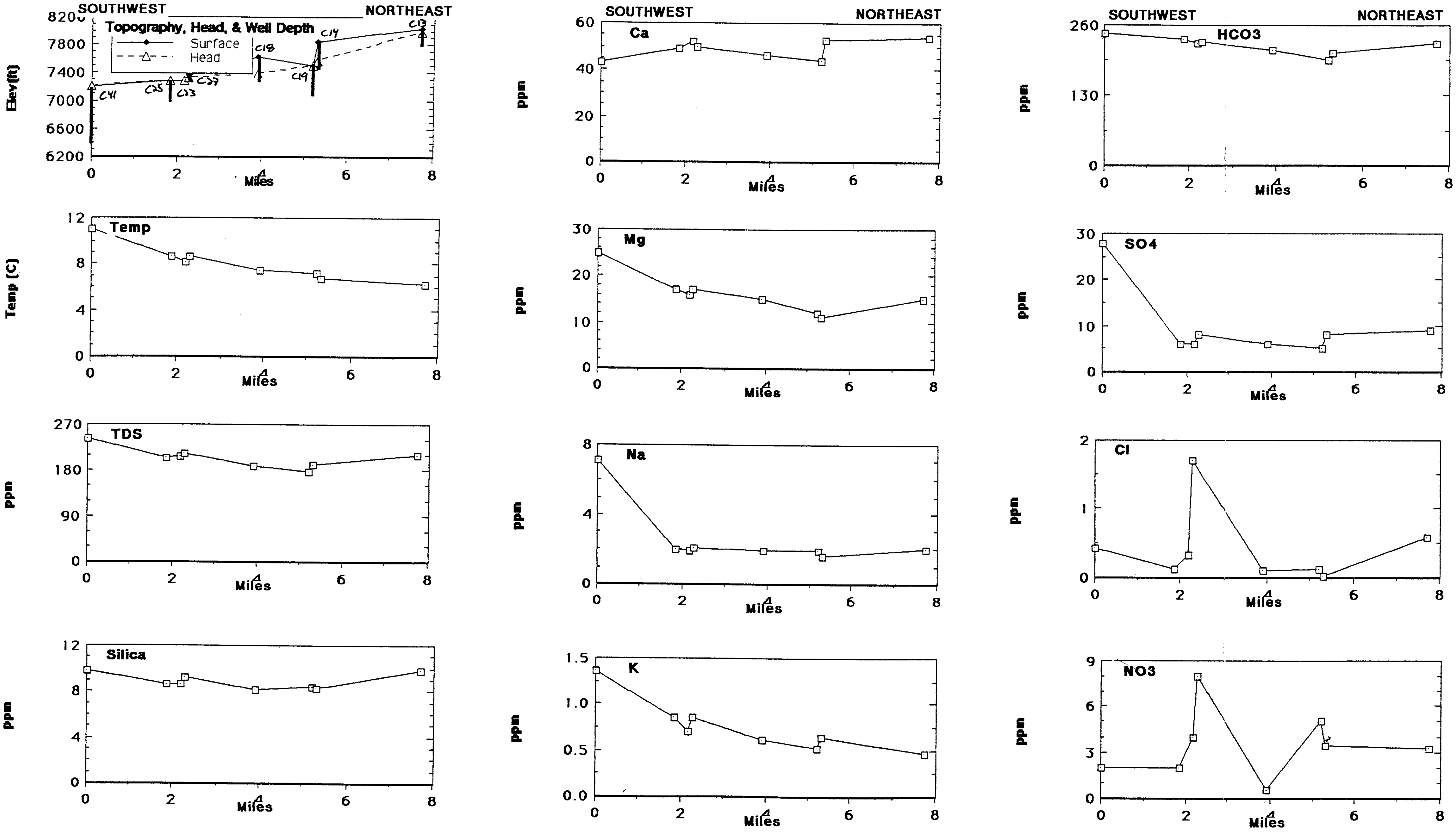

Figure 4.5. Transect X plots. Parameters shown plotted from site C13 in the northeast of the study area to site C41 in the southwest.

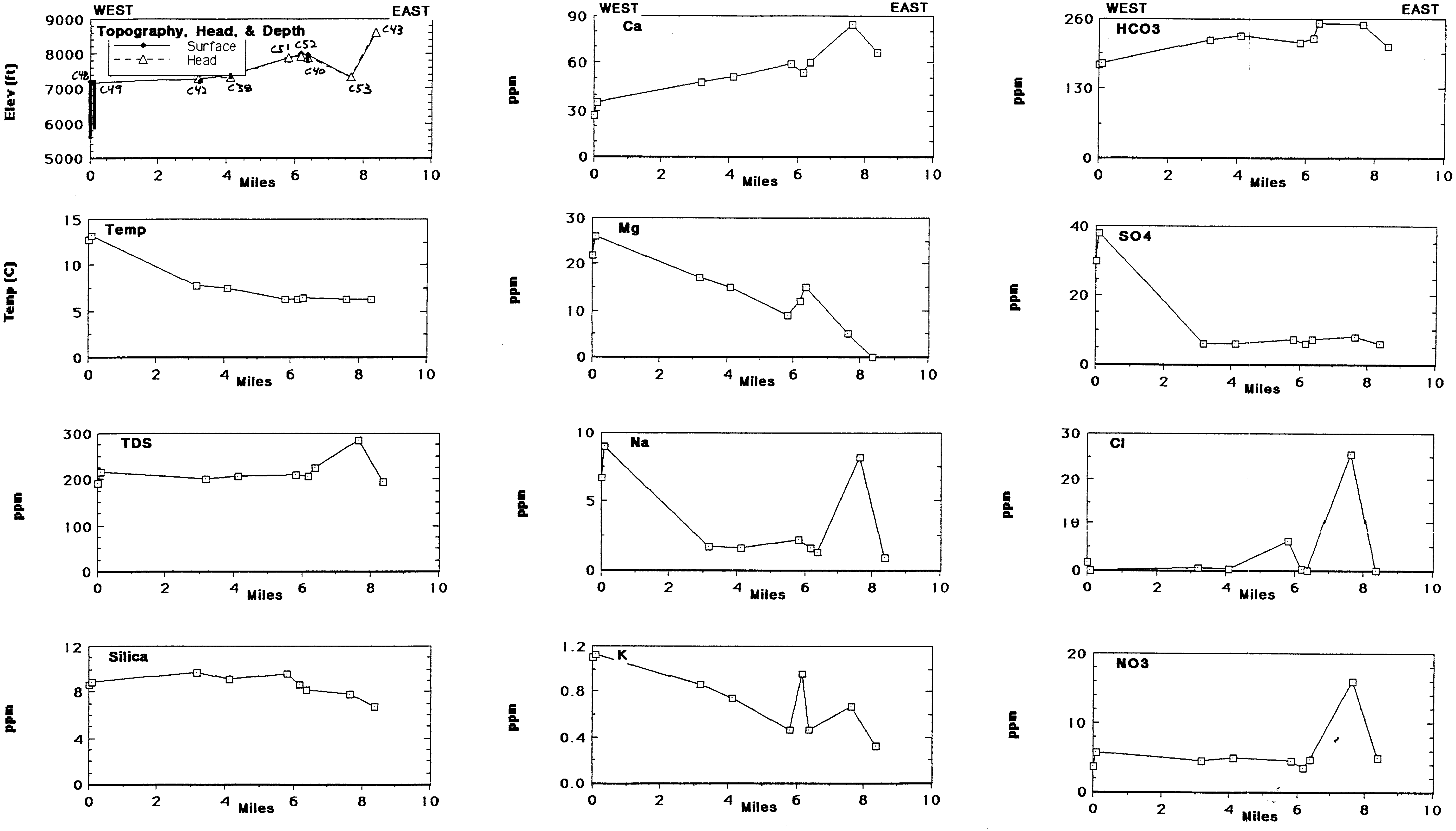

Figure 4.6. Transect Y plots. Parameters shown plotted from site C43 in the east of the study area to site C48 in the west.

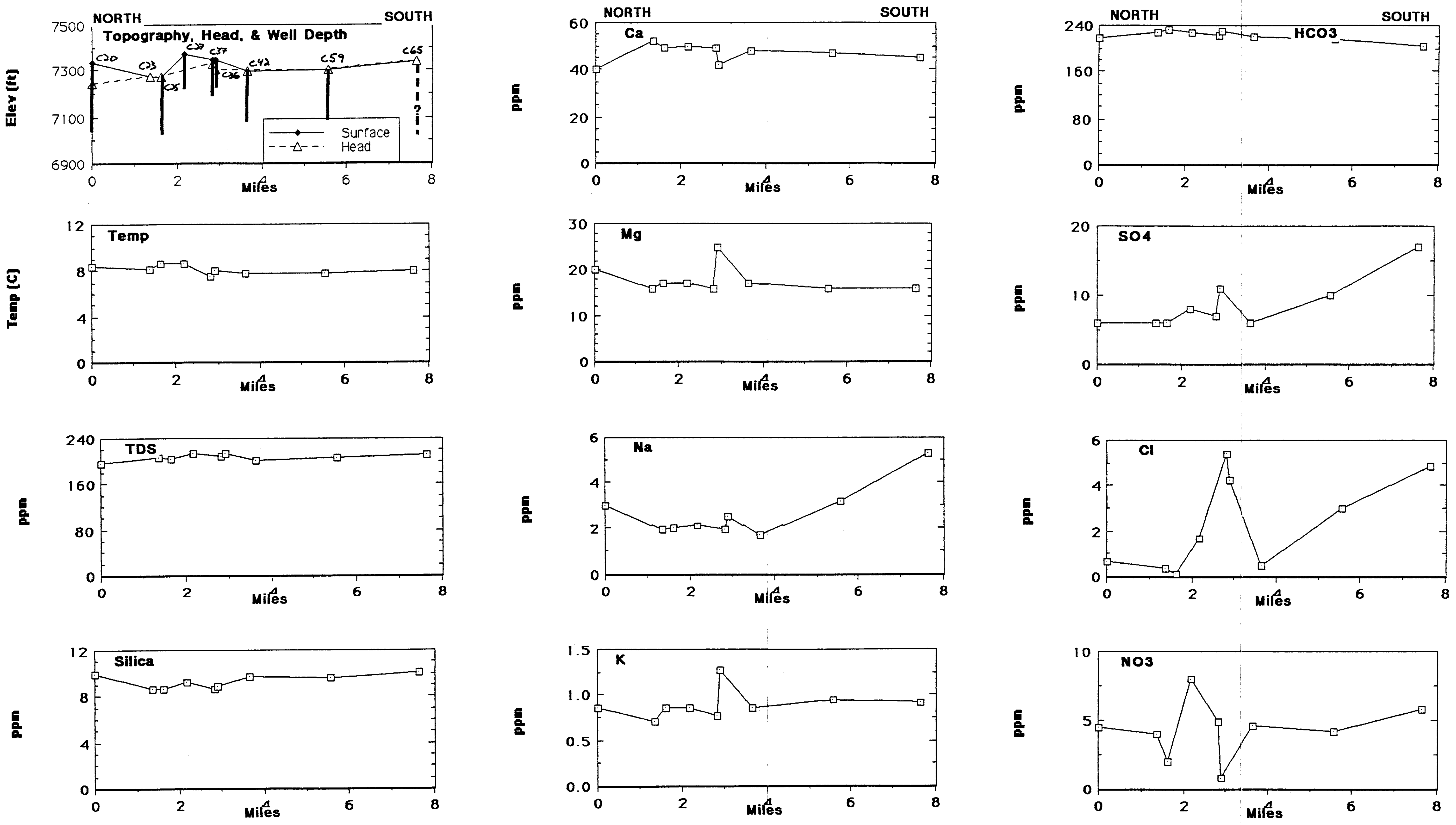

Figure 4.7. Transect Z plots. Parameters shown plotted from site C20 in the north of the study area to site C65 in the south.

east to west flow. Other than the higher levels of sulfate in well C65, all parameters remain constant across Transect Z.

Parameters Calculated by WATEQ4F

Figure 4.8 shows the saturation indices of calcite, dolomite, gypsum, and anhydrite, calculated by WATEQ4F (Plummer et al., 1976), across transects X and Y. These represent common phases that might interact with a water to produce calcium, magnesium, bicarbonate, and sulfate as dominant ions. The Casper water is effectively saturated with respect to calcite across the transects. It is undersaturated with respect to the other phases considered.

The molar ratio of calcium to magnesium is also shown in figure 4.8. This ratio is equal to or greater than unity in all cases, indicating water more likely equilibrating with calcite than dolomite. This ratio actually decreases basinward. Considering that the water is saturated with respect to calcite, the probable explanation for this is the precipitation of calcite.

Several immediate observations can be made from the data. Sodium, potassium, and chloride concentrations are low, indicating that the water has not contacted salt phases. The low sodium and potassium concentrations also indicate that cation exchange has been negligible. The low silica and potassium concentrations indicate that little weathering of feldspars or shales has occurred. Precipitation of dolomite, gypsum, or anhydrite does not occur as the water is undersaturated with respect to these minerals. Furthermore, the saturation indices of the four phases considered are relatively constant across the study area. This means that

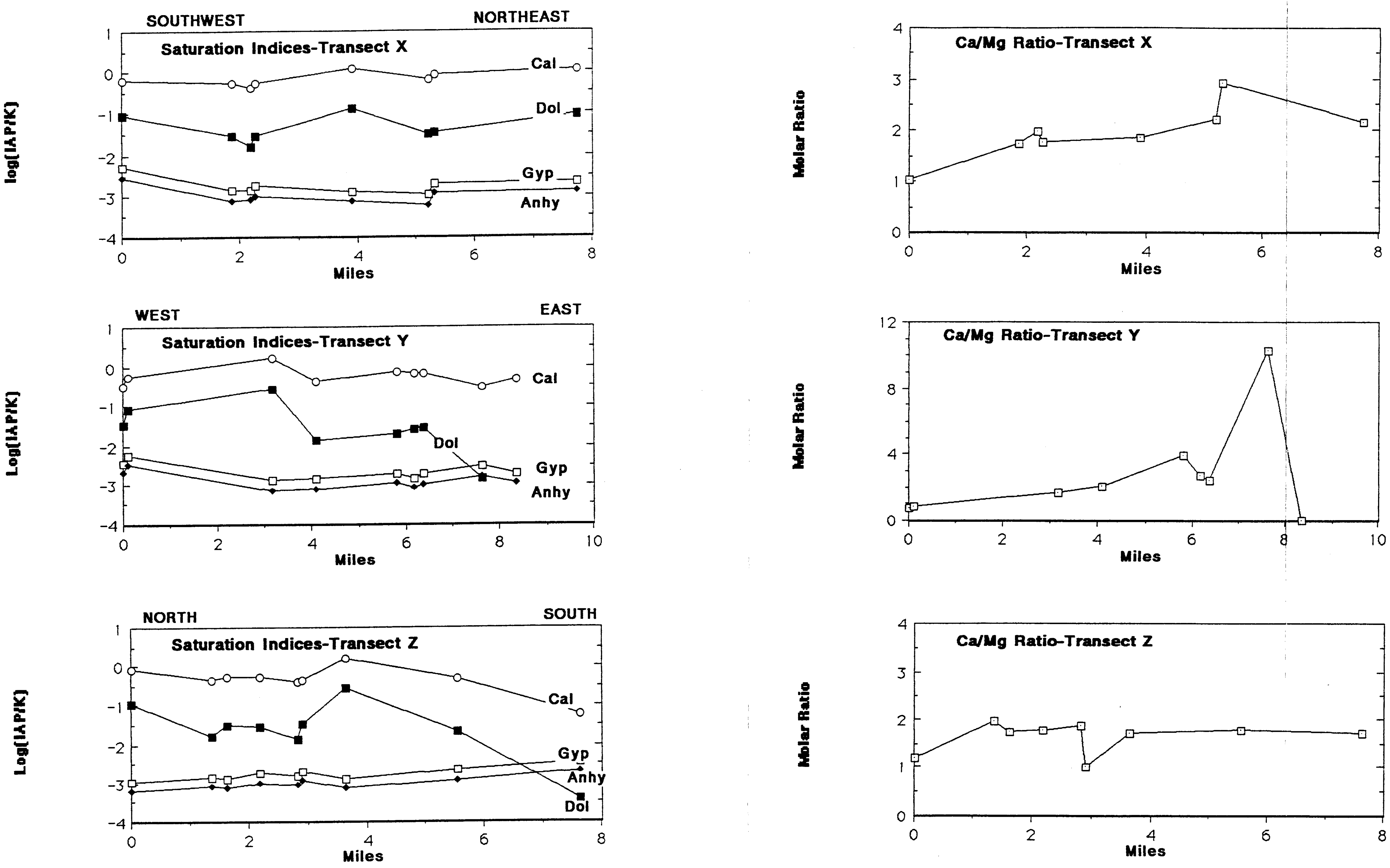

Figure 4.8. Transect X, Y, and Z plots of data calculated by WATEQ4F. Notice that the water is essentially saturated with respect to calcite and that the calcium/magnesium ratio decreases from east to west.

recharge water rapidly reaches the saturation states characterizing Casper water.

In addition to the above observations, several questions arise from inspection of the transects.

1. Why does the Ca/Mg ratio decrease across the basin? If the decrease in calcium concentration is caused by precipitation of calcite, why is this precipitation occurring?
2. Why does sulfate concentration increase across the basin?
3. Is the different water chemistry of the western sites caused by mixing of two waters or by the evolution of one water?

CHARACTERIZATION OF CASPER WATER WITH FINGERPRINT DIAGRAMS

Figure 4.9 shows fingerprint diagrams along the transects X, Y, and Z. Only four sites along each transect were chosen to provide clarity in the diagrams. Along transect X, the westernmost well, C41, shows significant variation from the other sites. Along transect Y the middle sites show the same relative abundances, but site C53 in the east and C48 in the west of the study area both show a distinct fingerprints. Other than these exceptions, the patterns of the sites along transects X and Y are congruent, indicating one water type. Finally, the sites along transect Z show one water type.

In order to better characterize the water across the study area, fingerprint diagrams were plotted in which the data were arranged according to location in the east, central, or southwestern portion of the area (Figure 4.10). The water of the wells of the southwestern area are clearly the same. The same can be said of the water of the central area wells. The difference of C53 from the other eastern

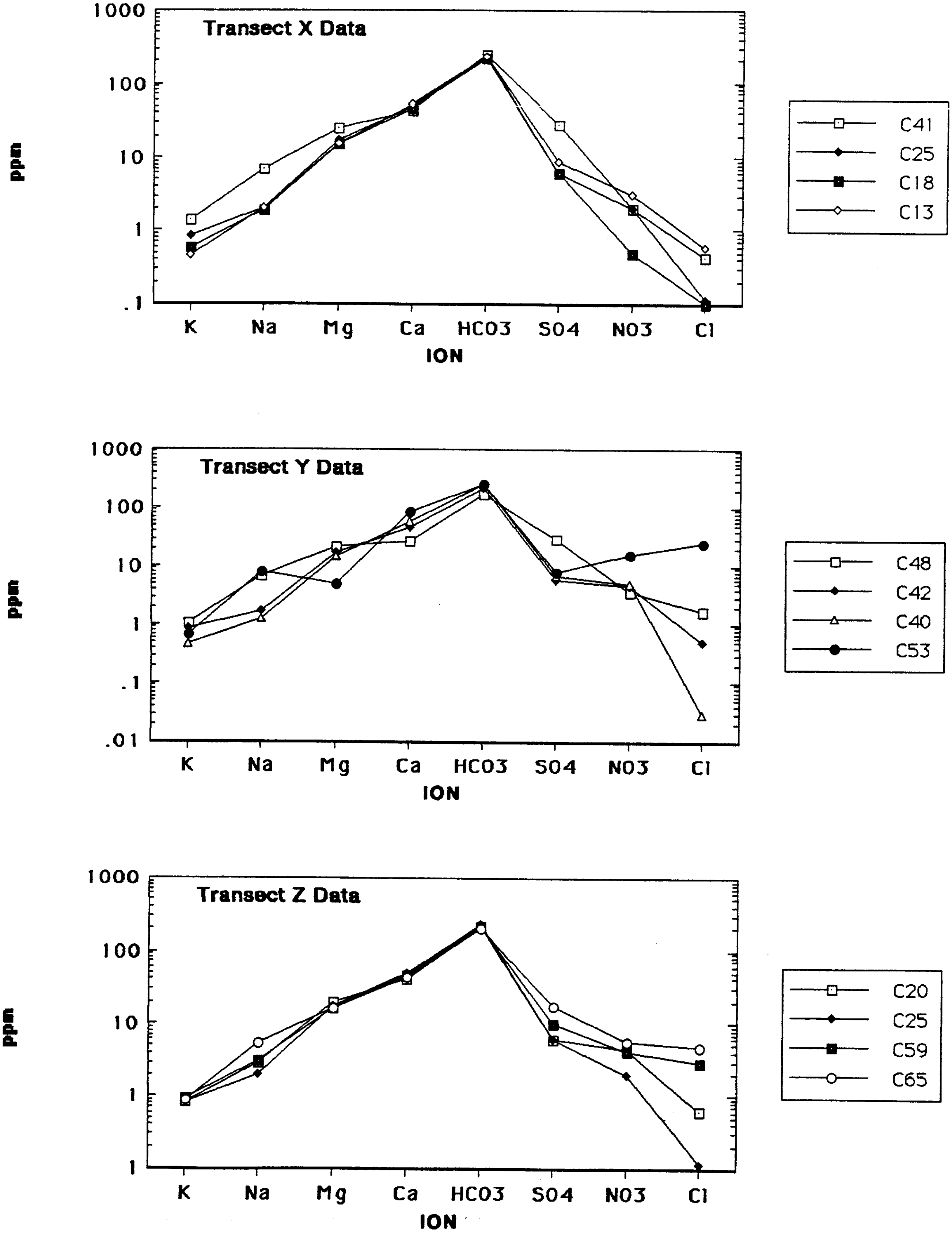

Figure 4.9. Fingerprint diagrams of data from transects X, Y, and Z. Sites in the west of the study area exhibit a slightly different pattern, indicating mixing or evolution of the water.

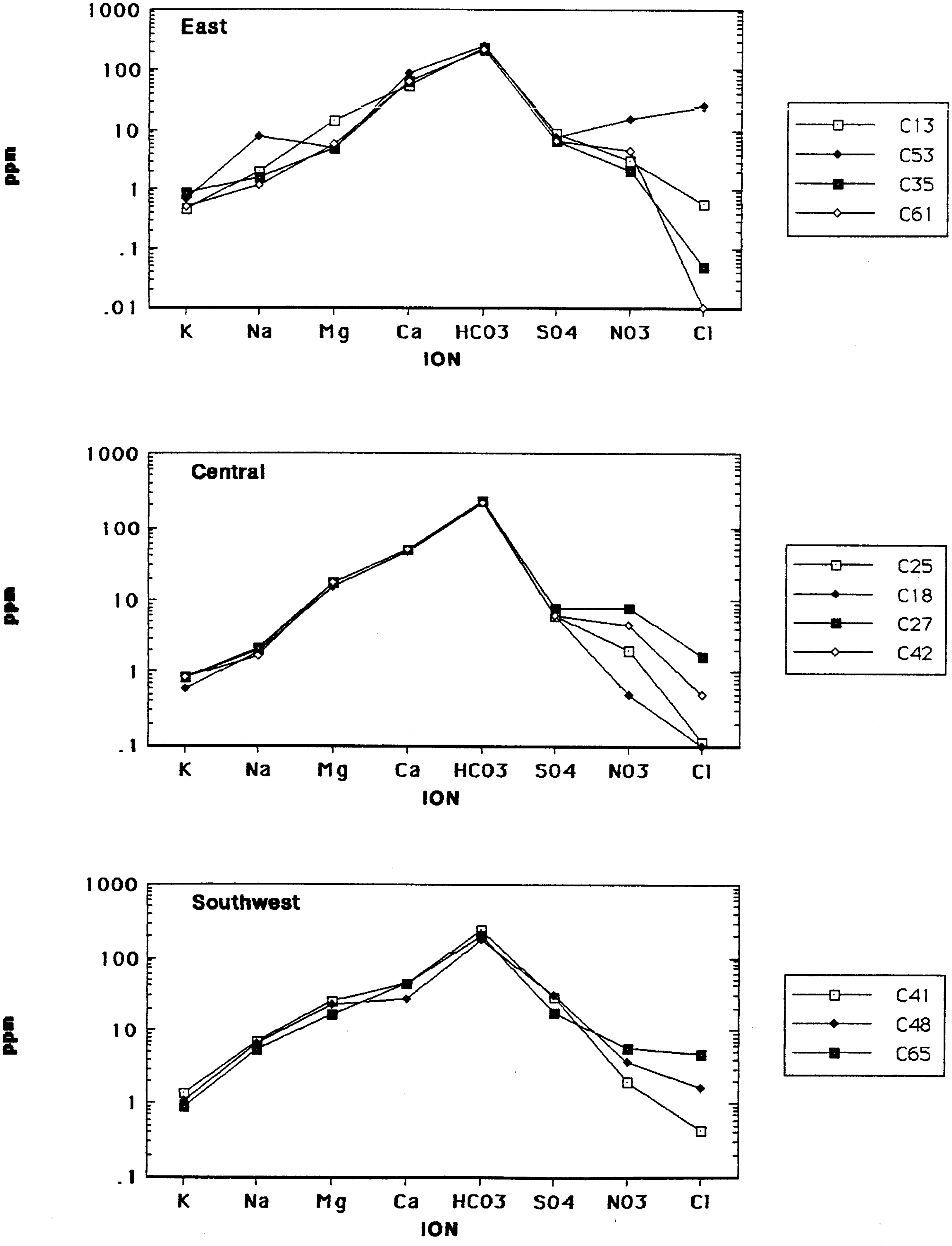

Figure 4.10. Fingerprint diagrams of data from the east, central, and southwest portions of the study area. Two main patterns are shown - one for most of the aquifer and another for the southwest area.

sites can be attributed to two factors. First, this spring is located on the edge of the recharge area. Therefore, water discharging from C53 has had less time for reaction with the aquifer material. Second, this spring is seasonal. C13 has a fingerprint nearly the same as C35 and C61, with the exception of a higher magnesium concentration than would be expected by the pattern shown.

The fingerprint diagrams show then, that one water type occurs in the Casper across most of the study area, and that the waters of the southwest wells are consistently different from this water.

MIXING WITH REDBED WATER

The most probable source of sulfate is the dissolution of gypsum or anhydrite. However, Casper water is highly undersaturated with respect to these minerals, indicating that they do not occur in significant quantities in the Casper aquifer. Therefore the elevated sulfate levels in the western sites indicate that a higher concentration sulfate water is mixing with Casper water. The only source for this second water is the overlying redbeds because the Casper is confined below by Precambrian crystalline rocks. Redbed waters have sulfate concentrations ranging from 200 to 1500 ppm.

Any hypothesis about mixing of waters in the western sites must account for several trends shown in the composition diagrams. First, calcium and bicarbonate are negatively correlated with sulfate while magnesium is positively correlated with sulfate (Figure 4.2). Second, calcium is positively correlated with bicarbonate and bicarbonate is positively correlated with pH (Figure 4.3). Third, while magnesium is not clearly negatively correlated with bicarbonate it is certainly not positively correlated (Figure 4.3).

The main control on the water chemistry of the Casper is dissolution of, and equilibration with calcite. The positive correlation between calcium and bicarbonate, the negative correlation between bicarbonate and pH, and the fact that the water is saturated with respect to calcite, demonstrate this control (Drever, 1988). The Casper aquifer must be a closed system because PCO2 decreases with depth (Figure 4.3). Casper water either contacts very little dolomite as it flows through the aquifer or there is no dolomite in the Casper with which it may react because the the water is consistently undersaturated with respect to dolomite across the study area.

The basic premise then, is that in the western portion of the study area redbed water somehow mixes with Casper water, which previously equilibrated with calcite as it flowed from east to west. Starting with this premise there are two hypotheses that will account for the trends noted above.

Hypothesis A - In Situ Mixing

Hypothesis A is that at the top of the Casper aquifer a small amount of mixing occurs with the calcium and sulfate rich waters of the overlying redbeds. The input of additional calcium will cause precipitation of calcite, with a corresponding decrease in bicarbonate ion concentration. This accounts for the increase in sulfate concentration and the decrease in bicarbonate ion concentration. However, calcium concentration should either remain constant or increase, when in fact it decreases. Furthermore, the difference between the low and high concentrations of bicarbonate is greater than can be accounted for by the increase in sulfate concentration, and the increase in magnesium is still a problem.

The only way to explain the decrease of calcium and bicarbonate is to invoke additional precipitation of calcite. The cause for this is the process of dedolomitization. The decreases in calcium and the carbonate destabilize dolomite. Dolomite dissolves and calcite is reprecipitated. This explains the decreasing calcium concentration and the increasing magnesium concentration.

In order for Hypothesis A to work, there must be hydraulic interaction between the upper Casper and the lower Satanka. There are two explanations for this. First, it is unreasonable to assume that the Satanka is a perfect confining boundary. Aquifer boundaries do not necessarily coincide with formation boundaries. The lower section of the Satanka is more than likely incorporated into the Casper aquifer in numerous areas. Second, the drilling of wells more than likely has enhanced the hydraulic connection between the Casper and the overlying redbeds.

Hypothesis B - Mixing Within Wells

Hypothesis B differs from A in time scale. According to this hypothesis water in the redbeds reacts readily with gypsum or anhydrite. This is followed by dedolomitization of dolomite lenses in the redbeds. Note that at this point the redbed water and the Casper water are still separate. Mixing occurs within a well. The bulk of the water moving up the well is Casper water, but a small volume of redbed water also moves into the well, increasing the magnesium and sulfate concentrations in the water. Because of the differences between the two waters, the mixed water is suddenly oversaturated with respect to calcite. Thus calcite precipitates as the water is moving up the well.

In order for Hypothesis B to work, redbed water must be able to flow into the well. This is quite reasonable because the screened intervals of wells often overlap the Casper/Satanka boundary (Figure 4.11).

Comparison and Contrast of the Two Hypotheses

Both hypotheses explain the changes in calcium, magnesium, sulfate, and bicarbonate ions. The significant differences between the two are where reaction with dolomite occurs and what the timescale of calcite precipitation is. In the first case, the reactions occur in an integrated section of upper Casper and lower Satanka over an extended period of time. In the second case dedolomitization occurs completely within the redbeds while the final calcite precipitation occurs within the wells.

A distinction as to the better hypothesis cannot be made from the saturation indices of dolomite in the two units. Neither the Casper nor the redbeds are saturated. The only plausible sources for magnesium in the Casper are dolomite or magnesium bearing limestone because the low sodium and potassium concentrations indicate little cation exchange. The Casper carbonates are mostly limestone, but some dolomite and dolomitic limestones have been identified (Benniran, 1970). A correlation between the saturation index of calcite and magnesium would support the existence of magnesium bearing calcite, but this correlation does not exist (Figure 4.12). However, this does not disprove the possibility of

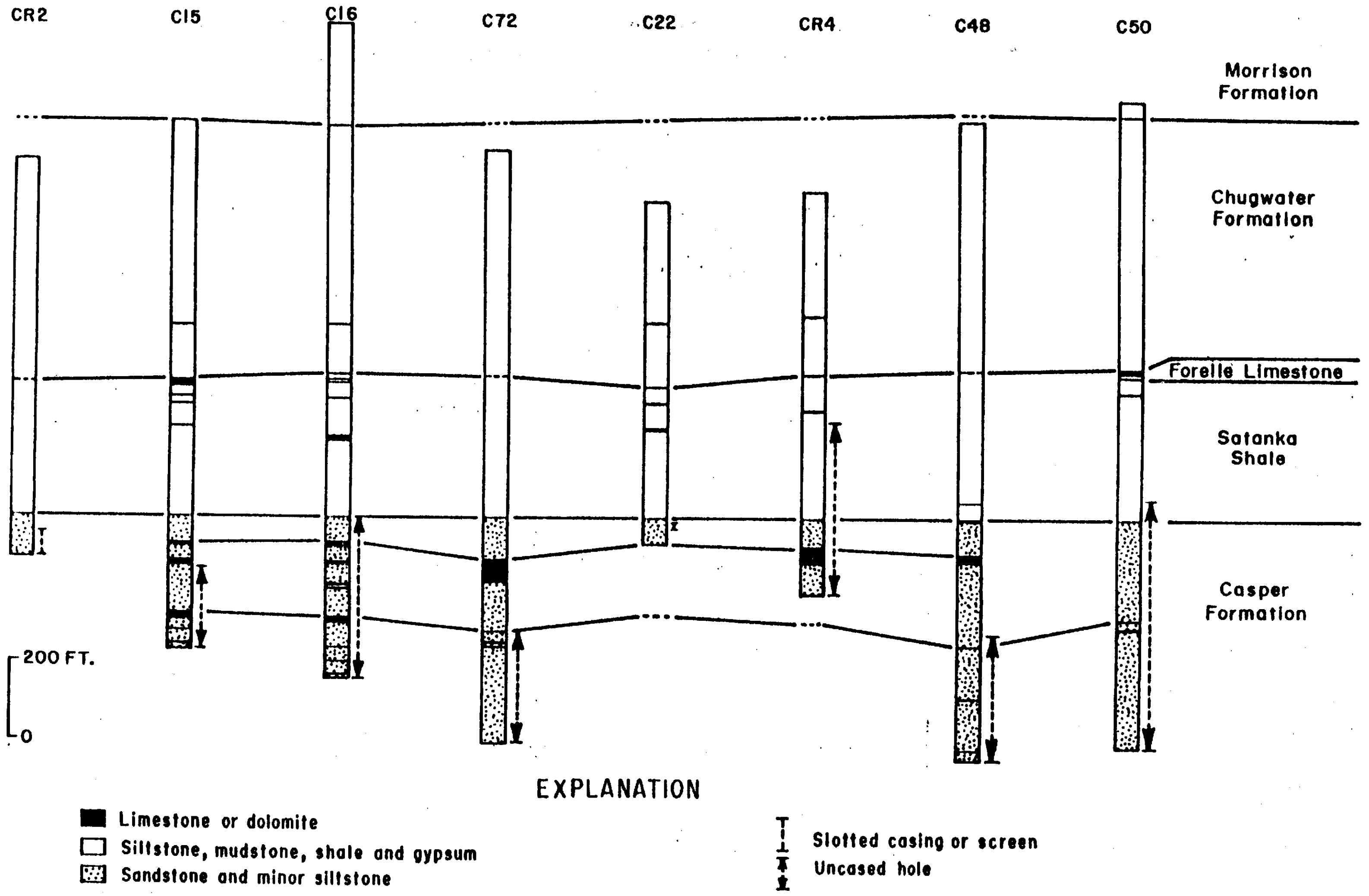

Figure 4.11. Lithologic correlation of columnar sections from wells in the vicinity of Laramie, Wyoming. Note that many wells are open both to the Casper and the Satanka formations. See Figure 4.1 for locations. (Figure from Lundy and Huntoon, 1978)

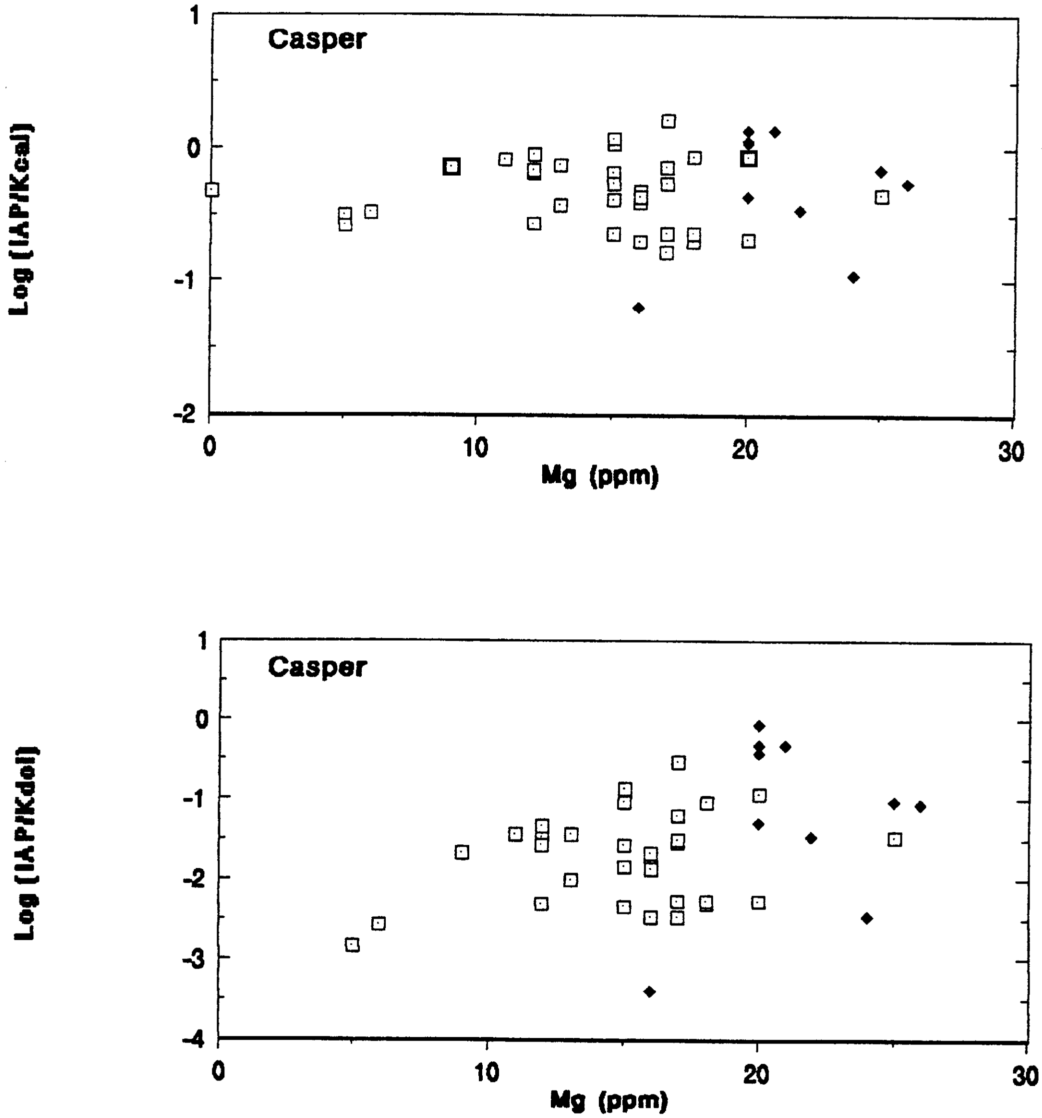

Figure 4.12. Saturation indices of calcite and dolomite plotted against magnesium concentration.

magnesium rich calcite. The saturation index of dolomite within the Casper is somewhat positively correlated with magnesium, indicating reaction with dolomite, but this trend is not particularly convincing (Figure 4.12).

A decision cannot be made based on the saturation indices of gypsum either. The mixed waters are undersaturated with gypsum (Figure 4.8). This is obviously not a problem in Hypothesis B because the gypsum saturated water of the redbeds is only contributing a small volume. If one speculated within the context of Hypothesis A that the water ought to be saturated with gypsum this actual undersaturation would be contradictory. However, the volume of water from the upper Casper/lower Satanka should be low compared to the overall volume of water flowing in the Casper. Thus either hypothesis can explain the gypsum saturation state of the mixed waters.

Hypothesis A and Hypothesis B are both plausible. The data available do not allow a definite decision between them. An age dating parameter might allow distinction because the higher transmissivity of the Casper would likely cause Casper water to be younger than redbed water. Mixing calculations using oxygen-18 and deuterium data might also allow distinction if the values in the Casper and redbeds differ enough. In the end, however, it should be noted that they are not mutually exclusive. That is, chemical reactions may be occurring in the Casper/Redbed contact zone and within wells.

CONCLUSIONS

1. The main control on the water chemistry of the Casper aquifer is the dissolution of, and equilibration with calcite.
2. Recharge water reacts quite rapidly with the aquifer material, reaching saturation states characteristic of the Casper water in the upgradient portion of the aquifer.
3. There are no significant salt deposits within the Casper aquifer.
4. Weathering reactions of feldspars or shales are not important in determining water chemistry. Neither is cation exchange important.
5. Redbed water mixes with Casper water in the western side of the study area. Mixing may occur naturally along the Casper/Satanka contact, as a result of well construction within the wells themselves, or as a combination of both.

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5. CHEMISTRY OF THE REDBED WATER

by Karen McCormack

INTRODUCTION

The redbed units conformably overlie the Casper Formation in the Laramie Basin and act as confining layers. The chemical character of water contained within the redbeds gives valuable insight to the processes affecting the groundwater system in the study area. These redbeds consist of the Satanka Shale, the Forelle Limestone, and the Chugwater Formation (Figure 1.2). The lithology of the redbeds is, in descending order of abundance, shale, sandstone, limestone and dolomite. All of the units have lenses or thin beds of gypsum (Thomas, 1934). Although there are three distinct mappable units within the redbeds, they are herein combined because of the lack of information to determine from which units the wells draw water. Wells that tap the redbeds are typically completed down the the Casper, so that the whole stratigraphic section is represented in the water rather than a particular interval within the redbeds.

The studied wells and springs of the redbeds lie in the west portion of the study area, west of the Casper-Satanka surface contact, with the exceptions of CR 5 and CR 8, which lie approximately on the contact (Fig. 5.1). Five of the samples are from wells drilled solely into the redbeds (TC and S wells). Eight of the samples are from wells and springs that tap the Casper aquifer and the redbeds. Chemical data for the sampling sites are shown in Table 5.1.

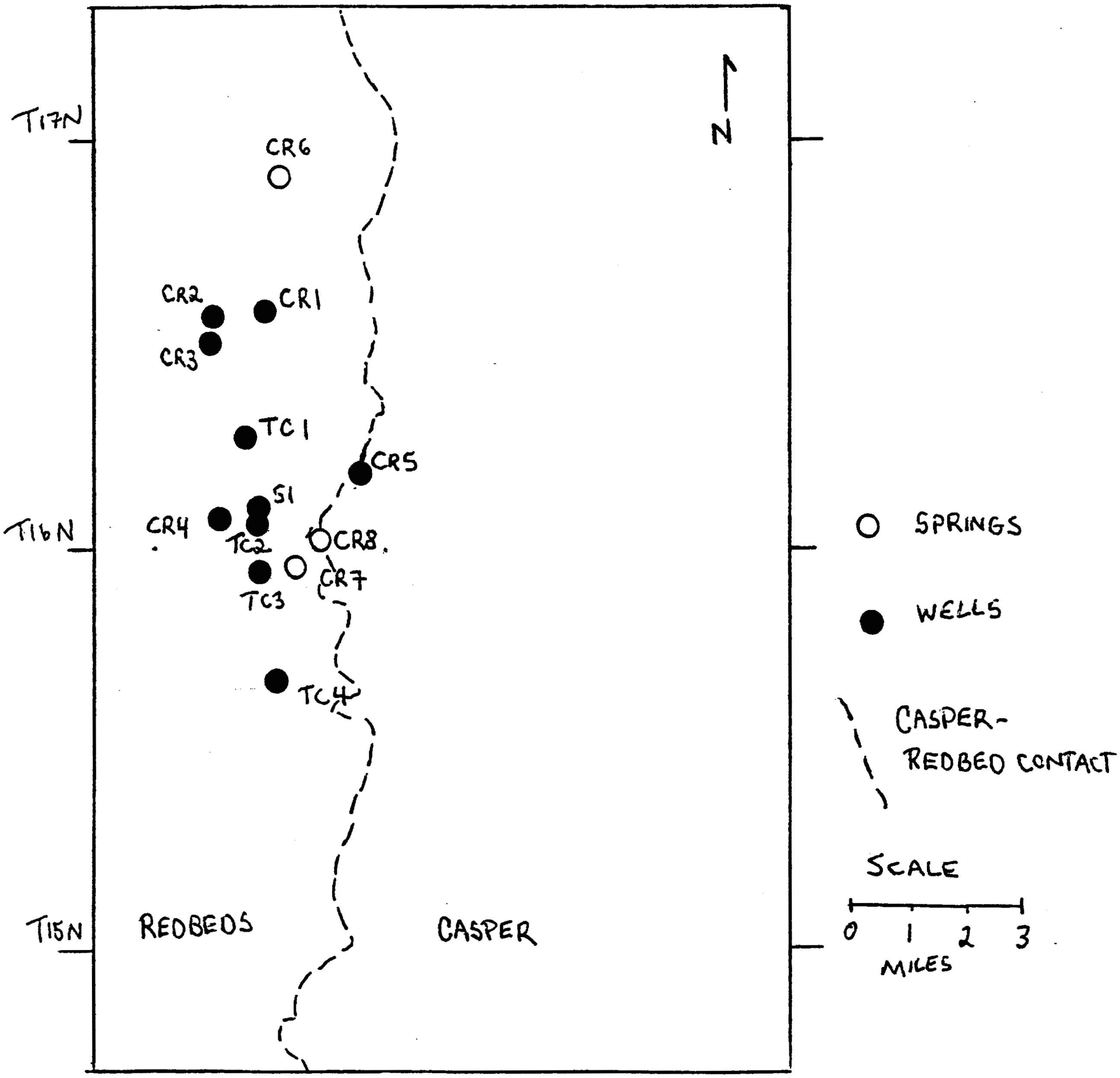


Figure 5.1. Locations of wells and springs that yield water from the redbed units. TC and S wells and springs tap solely the redbeds. CR wells and springs tap the Casper Formation in addition to the redbeds (modified after Huntoon and Lundy, 1978).

Table 5-1. Water chemistry for wells and springs yielding water from the redbeds in the southern Laramie Basin, Wyoming.

	WELL NO.	T (C)	pH	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Cl (mg/l)	SO4 (mg/l)	HCO3 (mg/l)	NO3 (mg/l)	SiO2 (mg/l)	TDS (mg/l)
1	CR1	10.800	7.700	142.000	23.000	6.000	1.110	0.160	304.000	209.000	1.500	11.000	596.000
2	CR2	12.600	7.400	278.000	24.000	15.500	1.580	3.960	691.000	210.000	5.500	11.200	1138.000
3	CR3	11.500	7.300	118.000	75.000	52.000	2.000	34.800	506.000	181.000	39.000	13.400	934.000
4	CR4	10.700	7.700	155.000	69.000	12.800	1.830	8.560	521.000	176.000	1.000	22.400	882.000
5	CR5	8.700	7.500	37.000	36.000	11.300	1.580	5.520	57.000	265.000	10.500	10.400	306.000
6	CR6	7.900	6.900	310.000	63.000	11.200	1.820	4.810	950.000	155.000	4.500	23.400	1449.000
7	CR7	7.200	7.000	184.000	62.000	7.000	1.740	7.460	553.000	176.000	3.600	23.700	933.000
8	CR8	7.700	7.200	40.000	20.000	3.100	1.130	2.100	12.000	228.000	3.100	10.800	209.000
9	S1	9.300	7.300	190.000	51.000	11.800	1.840	19.780	519.000	201.000	11.200	17.400	926.000
10	TC1	13.500	7.200	308.000	97.000	15.600	2.080	3.850	1060.000	156.000	4.300	34.400	1596.000
11	TC2	9.000	7.400	200.000	126.000	97.000	3.800	41.800	822.000	392.000	105.000	30.100	1619.000
12	TC3	8.300	7.200	480.000	92.000	15.000	2.200	7.350	1580.000	179.000	1.500	18.200	2300.000
13	TC4	8.200	6.300	214.000	51.000	9.300	1.480	16.300	562.000	228.000	6.400	15.000	996.000

CHEMICAL CHARACTERISTICS OF THE REDBED WATER

Water from the redbeds has a chemical signature distinctly different from the Casper water. This signature is effectively shown by fingerprint diagrams (Figure 5.2). Samples of redbed water can be divided into three categories based on varying ion abundances. These categories reflect the varying influence of mixing with Casper water within the well, and natural mixing with Casper and recharge water. Evidence of this mixing will be further demonstrated later. Notice that the most saline waters are plotted on the top diagram, intermediate waters are plotted on the middle diagram and the most dilute waters are plotted on the lower diagram.

The most saline water samples are those from wells completed solely in the redbeds. This water is consistently rich in Ca ++, SO4 =, and HCO3-., ranging from 190-480 mg/l, 562-1580 mg/l, and 156-392 mg/l, respectively. Mg+ and SiO2 are intermediate in abundance, ranging from 51-126 mg/l and 15-34 mg/l. Ions with minor abundances are Cl-, NO3-, K+, and Na+. There is variation in the concentration of minor ions as well as the major ions. K ranges from 1 to 4 mg/l. Na ranges an order of magnitude, from 9 to 97 mg/l. Cl ranges an order of magnitude, from 4 to 41. NO3 ranges two orders of magnitude, from 1 to 105. Thus, although the redbed water can be recognized as distinct from the Casper water, it is not uniform throughout the study area.

CHEMICAL EQUILIBRIA

The dominant chemical processes operating within the redbeds can be defined by the degree of equilibrium that the waters have reached with respect to particular minerals. The water data were processed with WATEQ (Truesdell

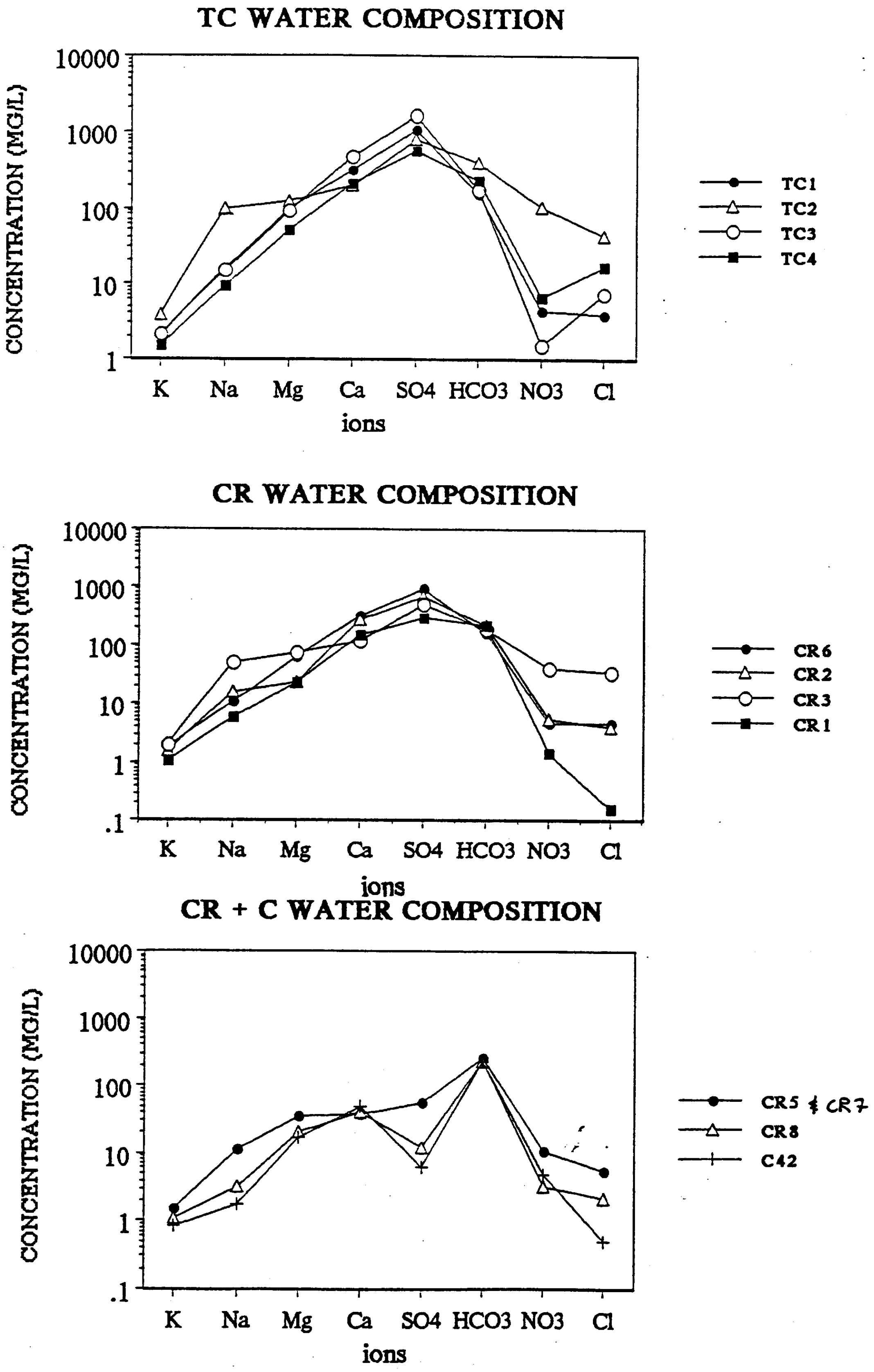


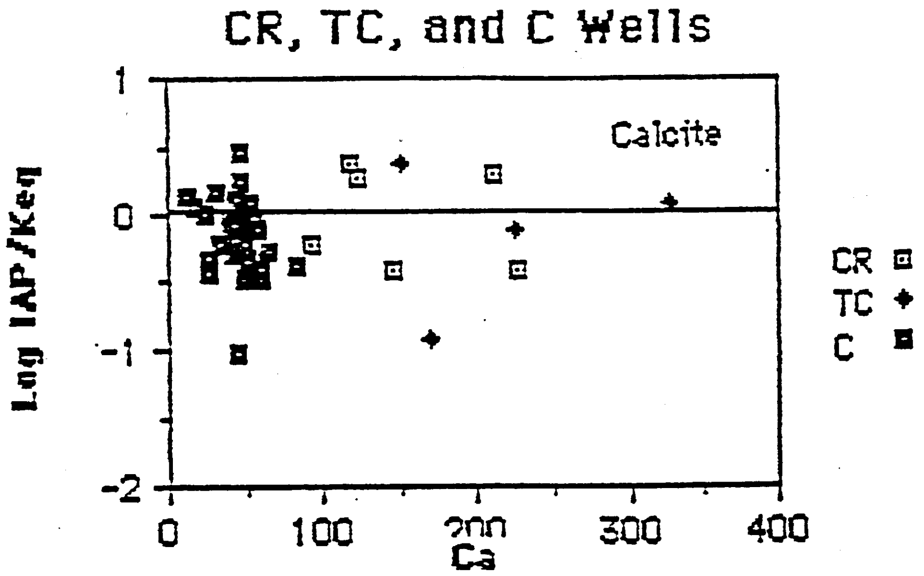
Figure 5.2. Fingerprint diagrams of water samples from the redbed units. The upper diagram shows the most saline water samples of the redbeds. The middle diagram shows water samples diluted from interaction with Casper water. The lower diagram shows the most dilute water samples.

and Jones, 1984). Gypsum equilibrium is the major control on the redbed water chemistry. Figure 5.3 shows that the redbed water ranges from saturated to slightly undersaturated. Mixed Casper-redbed waters are more undersaturated, reflecting the influence of the more dilute Casper water. Notice that wells number TC-3 lies closest to saturation on the mixing line. This sample was also the most saline sample shown on the fingerprint diagrams (see Figure 5.2). TC-3 must be the saline endmember of the redbeds because it contains the maximum allowable amount of Ca++ and SO4=.

Redbed waters are predominantly saturated with respect to calcite, with equal numbers of samples lying slightly above and below the saturation line (Figure 5.4). Thus calcite has been dissolved from limestones or authigenic cements in the redbeds. Redbed water is predominantly undersaturated with respect to dolomite (Figure 5.4). This undersaturation can be explained by two hypotheses

1. Lack of dolomite in the rocks.
2. Lack of time necessary for water to equilibrate with dolomite.

Notice the three deviant samples in Figure 5.4 that are saturated with respect to dolomite. Notice also that there is no discernable mixing demonstrated on the calcite and dolomite equilibria plots. This indicates that there is an apparently random distribution of the degree of saturation of these minerals, which may be caused by either: heterogeneity of the rocks, or variations in residence time of the water in the rocks. If the rocks are heterogeneous the water may be exposed to only small volumes of a particular mineral. If the residence times are variable, the water in some areas will not have enough time to equilibrate with the rocks. Whichever is the case, both these hypotheses lead to the conclusion that water movement is slow or



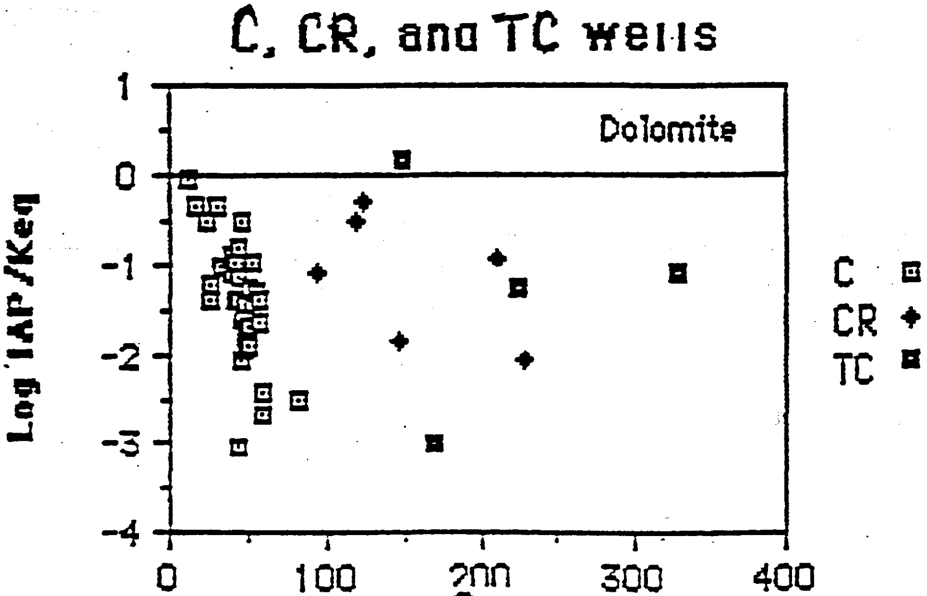


Figure 5.4. Calcite and dolomite saturation indices plotted against concentrations of Ca++.

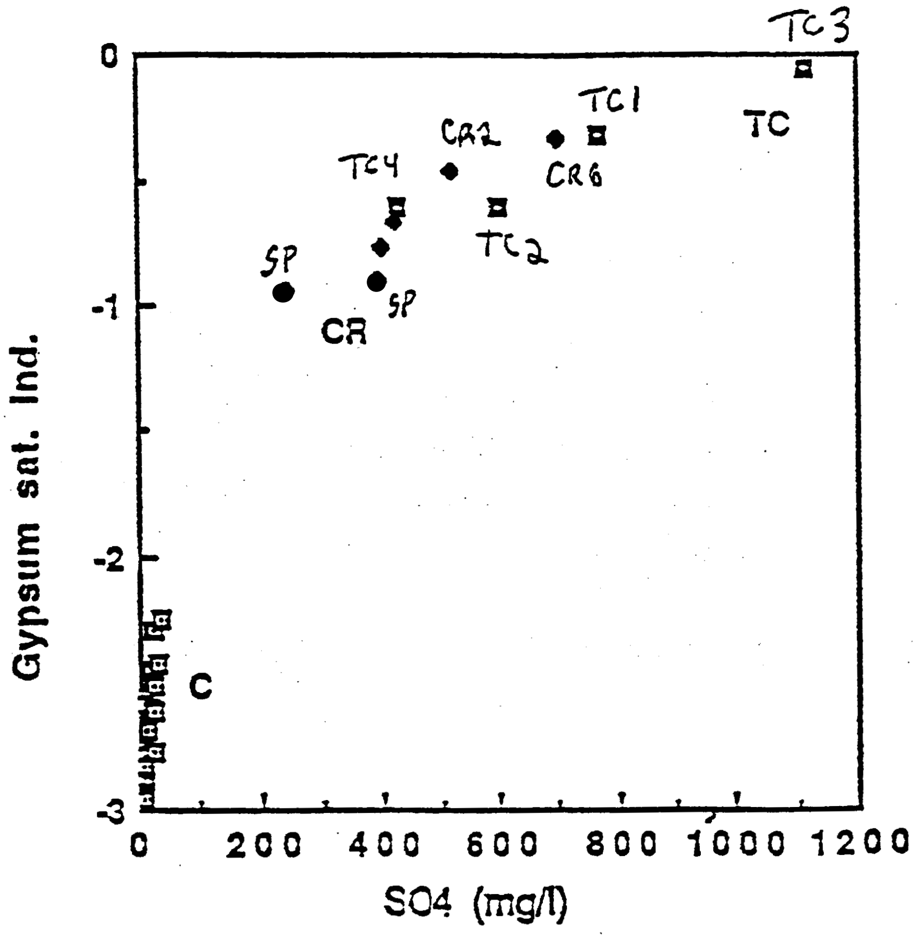


Figure 5.3. Gypsum saturation plotted against concentrations of SO4=, showing degrees of saturation with respect to gypsum. A zero value means that water is saturated. Calculated using WATEQ (Truesdell and Jones, 1974).

restricted within the redbeds, and has not had an opportunity to become homogeneous.

MIXING OF WATERS

Mixing of different waters has caused some of the redbed water samples to be diluted. The question remains, however, as to the degree of natural mixing that occurs versus that caused by open or improper well completion. Any natural mixing should be represented by the four TC wells, while the well-induced mixing should be represented by the CR wells. Composition plots of some individual ions against SO4= show this mixing trend. A plot of Ca++ against SO4= clearly shows the end member water- represented by TC3- undergoing dilution (Figure 5.5). The concentration of these two ions in the redbed water indicates presence of gypsum in the rocks. SiO2 plotted against SO4= also shows the mixing of waters that results in a decrease in SiO2. The high concentration of SiO2 in the redbed water is attributed to interaction with clays in the redbeds. Finally, a plot of Mg++ versus SO4= shows a rough trend of decreasing Mg++ with dilution.

DILUTE END MEMBER OF MIXING

Possible water inputs to the redbed units include both the Casper water and water directly from precipitation. Because these two types of water are both fresh, it is difficult to tell them apart. The concentrations Na+, Cl-, K+ and NO3=, are relatively low, but higher than in precipitation. They are also lower than one would expect from interaction with halite or potassium feldspar within the redbeds. This indicates that halite is not present in the rocks. Potassium feldspar is present but is probably protected by preferential dissolution of calcite.

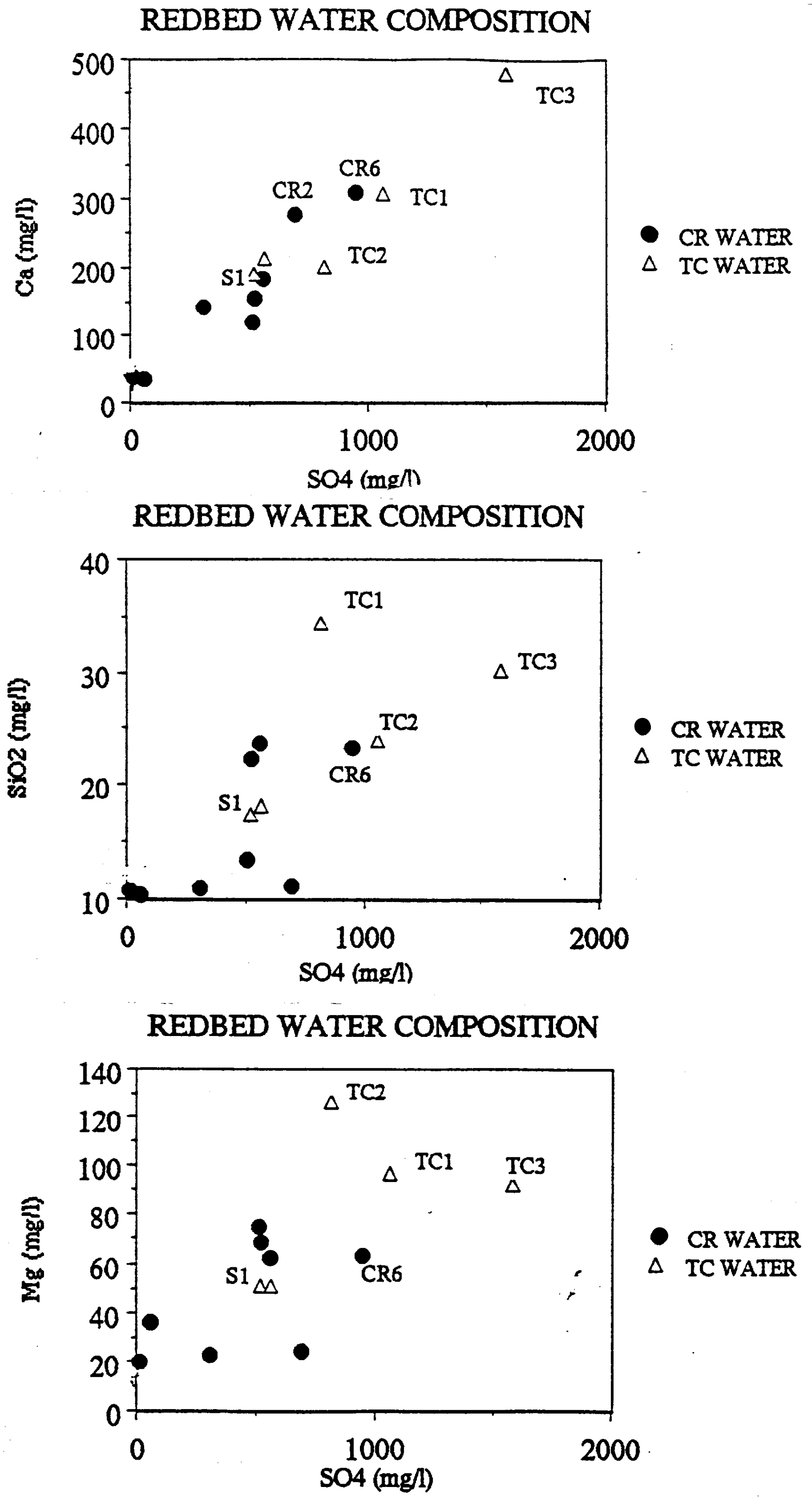


Figure 5-5. Composition diagrams of the data of Table 5-1. A mixing line emerges, most clearly delineated on the Ca-SO4 diagram.

It is likely that recharge water was concentrated by evaporation on the surface before entering the ground. This slight elevation is apparent also in the Casper water, however it is more pronounced in the redbed water, perhaps reflecting the slower infiltration rate of the redbeds.

CONCLUSIONS

Several conclusions about the groundwater system in the Laramie Basin are made from studying the water chemistry of the redbeds.

1. Redbed waters have a chemical signature distinctly different than Casper waters. Specifically, redbed waters are enrichedin Ca^{++} and $SO_4^{=}$.
2. Redbed water chemistry reflects reactions with gypsum, anhydrite, shales, calcite, and to a lesser extent, dolomite.
3. Hydraulic connection within the redbeds is poor. Water moves slowly or is isolated by individual confining layers. This process can be expected in a confining unit.
4. Mixing and dilution of redbed water occur from interaction with Casper water and recharge from precipitation.
5. Mixing predominates where it is well-induced. It is less predominant where natural. In the natural case Casper water may leak upward slowly due to the hydraulic gradient and equilibrate with the redbeds.
6. The concentrations of Na^{+} and Cl^{-} in the redbeds indicates that halite is not present in the rocks. The minor ions are explained by evaporative concentration of recharge water.
7. SiO_2 concentrations indicate interaction with shales.

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6 . CONCLUSIONS - THE CONCEPTUAL MODEL

Younus,Mohammad

GENERAL MODEL

1- The study area is a segment of a well defined catchment area which has its input recharge mainly by local precipetation.

2- The direction of groundwater flow in the Casper aquifer is generally east to west, with a gradient of 120 feet / mile.

3- On the basis of geochemical studies, the project area is defined into two distinct groundwater aquifers as given below:

a) Casper+ pre- Cambrian Aquifer

b) Red beds Aquifer

Pre- Cambrian waters in the east may be interconnected locally with Casper waters.

SOLUTE INPUT BY PRECIPITATION

1- Cl, K, Na are low in the local groundwaters and seem to originate from precipitation alone, with some concentration caused by evapotranspiration prior to infiltration.

2- Evapotranspiration is very minor in the casper intake area(Cl from 0.01 to 25.60 mg / l) and slightly higher in the red beds intake area(Cl from 0.16 to 41.88 mg / l).

CASPER WATERS

1- The Casper waters have the following composition:

Ca : 13.00 to 85.00 mg / l HCO3 : 129.00 to 251.00 mg / l

Mg : 5.00 to 26.00 mg / l SO4 : 5.00 to 38.00 mg / l

Na : 0.90 to 9.00 mg / l Cl : 0.01 to 25.60 mg / l

K : 0.32 to 2.20 mg / l

2- The compsition of groundwater in the Casper Formation indicates the dominency of sand stone/ lime stone and absence of gypsum, dolomite and halite.

RED BEDS WATERS

1- Red beds waters have the following composition(distinct from the Casper water) :

Ca : 37.00 to 480.00 mg / l HCO3 : 181.00 to 392.00 mg / l

Mg : 20.00 to 126.00 mg / l SO4 : 12.00 to 1580.00 mg / l

Na : 3.10 to 97.00 mg / l Cl : 0.16 to 41.88 mg / l

K : 1.11 to 3.80 mg / l

2- Red bed waters vary in composition indicating storage in distinct sub-aquifers.

3- Water composition indicates the red beds include shale(high SiO2), dolomite(high Mg) and gypsum(SO4, Mg).

MIXING IN RED BEDS :

Mixing of Casper and red beds waters occours,

a) Naturally, e.g. along faults.

b) Caused by well construction.

CONTAMINATION

The groundwater in the study area is generally not contaminated in terms of major ions, but no data is available for pectisides and specific waste products.

RECOMMENDATIONS

1- It is recommended to get data of age indicators(tritium, C-14 and Cl-36) and stable isotopes(D and O-18) in order to determine the time scales of the chemical interactions, and to further check the observed mixing trends.

2- Analyses of parameters related to potential groundwater contamination, e.g. pesticides and specific waste products.

3- Laramie people live on their own recharge area, so they should be carefull to avoid contamination by their own activities.