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Geochemical Interpretations of Groundwater Flow Systems in the Central Columbia Plateau

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STUDY AREA

The Pasco Basin is a structural and topographic basin of approximately 2000 square miles located within the Yakima Fold Belt Subprovince of the Columbia Plateau, and is structurally the lowest point in the Plateau. The basin consists of an undetermined thickness of lower Miocene and younger flood basalts with interbedded and overlying sedimentary units. This sequence rests upon an Eocene or older folded sedimentary sequence.

The basin is bounded on the north, south and west by east-west trending Yakima folds which, along with related folds within the basin, plunge to the east. Subsurface structures may be related to the intersection of both east-west trending and north-west trending structural features. Faults have been proposed to explain structural relationships at Wallula Gap and along the northeastern flank of Rattlesnake Hills. Two faults are present at Gable Mountain (Guzowski, 1982).

A large amount of data is available on the hydrology of the unconfined alluvial system, but deeper systems remain poorly understood. The location of regional recharge and discharge areas as well as groundwater flowpaths remain uncertain. In an attempt to define the system, geochemical data was analyzed in order to determine patterns which may indicate areas of discharge. The analysis selected for use was a factor analysis.

The study area comprised a large portion of the Columbia Plateau, but due to sparseness of data points, the area centering on the Pasco Basin is emphasized. All data over the entire region was used in the analysis but plots are shown only for the smaller region.

Factor Analysis

A form of numerical analysis, factor analysis was applied to the Columbia Plateau water chemistry data in order to determine intermediate and regional groundwater flow patterns. Water chemistry data from 85 wells within 8 counties in the Columbia Plateau were used as the basis of this analysis (Figure 1). Water chemistry data was acquired from Battelle PNL, U.S.G.S. Watstore Water Quality File and Rockwell Hanford Operations and is listed in Appendix A.

When raw chemical data is plotted, it produces a pattern with noise superimposed on it due to variations in local conditions, sampling and analytical errors. The noise must be filtered in order to form an accurate conceptual model. Factor analysis provides such a filter while relating covarient variables. The factor analysis (Davis, 1973) Routine Factor of the Statistical Package for the Social Sciences (Nie, et. al., 1975) was chosen to reduce the raw chemical data. The final method used was the PA1 or principal factoring with no iterations and the final factor solution was the orthogonal, Varimax rotated factor solution with Kaiser normalization.

WELL NUMBERS AND LOCATIONS

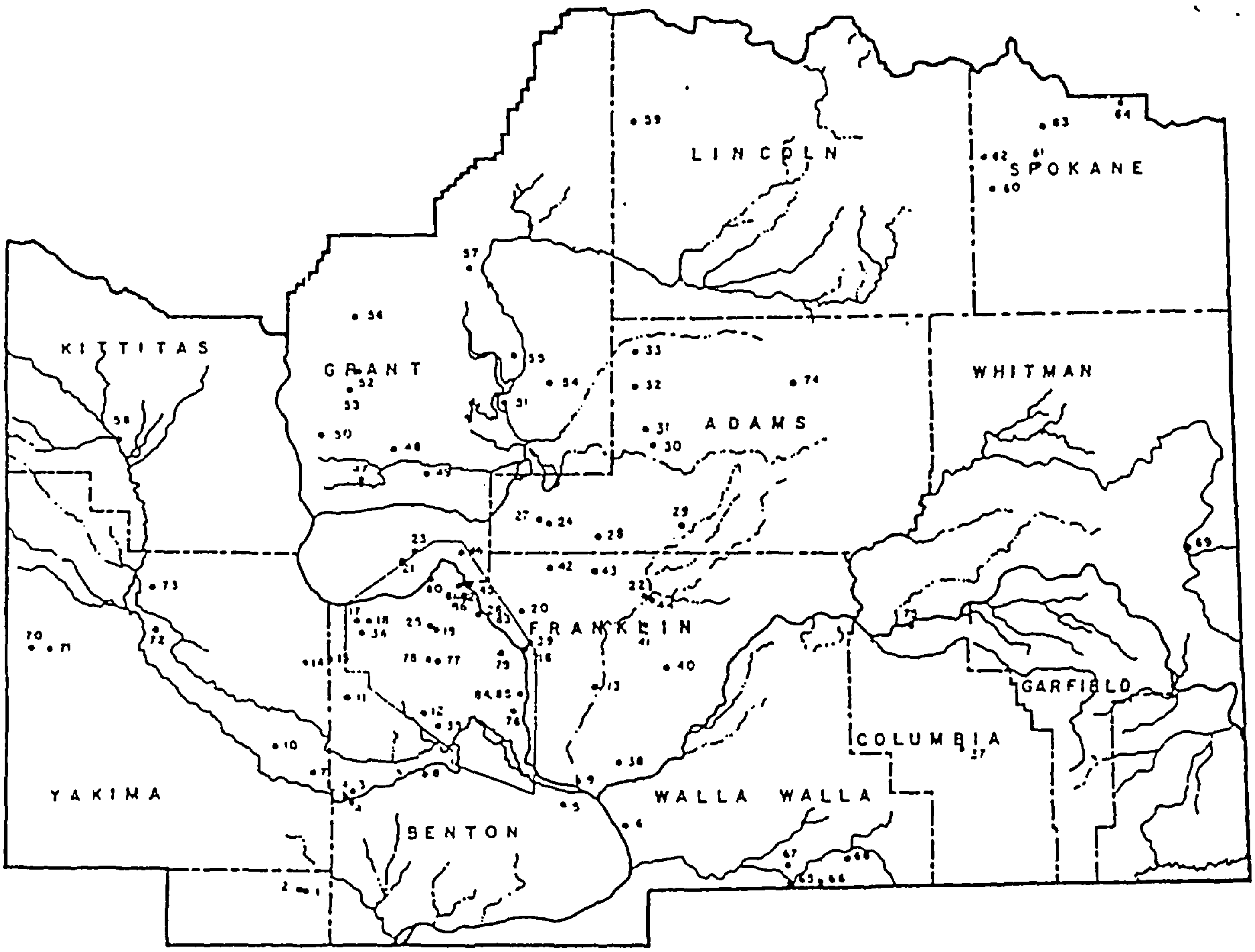


Figure 1

Sixteen variables were used in the analysis. They were: HCO_3 (ppm) silica (ppm), iron (ppm), magnesium (ppm), sodium (ppm), potassium (ppm), carbonate (ppm), sulfate (ppm), chloride (ppm), fluoride (ppm), nitrate (ppm), calcium (ppm), specific conductivity (u/mohs), pH, temperature (^{o}F) and depth (ft).

Factor analysis separates variables on the basis of communality. Communality is a measure of the ability of the analysis to account for the variability of the variables. Communalities near one account for a high percentage of variability, while low, near zero communalities show inability to recognize linear relationships with other variables, either because of a lack of variability or due to randomness of variability. On the basis of low communality, HCO_3 was eliminated from the analysis. This variable contributes little or no hydrogeologic information in this factor analysis program since the distribution pattern in the study area either varies randomly or is uniform.

The program was then run again in its final form eliminating the bicarbonate data. This analysis produced the following eigenvalues and percent of variance using fifteen variables.

Table 1: Eigen values and percent of variance accounted for by 15 factors with the PA1 analysis.

TABLE 1

FACTOR	EIGENVALUE	PCT OF VAR	CUM PCT
1	6.02063	40.1	40.1
2	3.11764	20.8	60.9
3	2.09770	14.0	74.9
4	1.22480	8.2	83.1
5	.88189	5.9	89.0
6	.74999	5.0	94.0
7	.47258	3.2	97.1
8	.28861	1.9	99.0
9	.17214	1.1	100.2
10	.12562	.8	101.0
11	.07978	.5	101.5
12	.03136	.2	101.8
13	.02619	.2	101.9
14	.00229	.0	101.9
15	-.29123	-1.9	100.0

The eigenvalue cutoff for factor extraction was 1.5, so the 15 variables were reduced to three factors, accounting for 74.9% of the total variability of the data. Table 2 shows the final communalities of the PA1 analysis.

Table 2. Final communalities of variables in PA1 analysis.

TABLE 2

VARIABLE	COMMUNALITY
SIO	.49803
FE	.84436
MG	1.01895
NA	.93163
K	.63716
CO3	.73749
SO4	.70716
CL	.89275
F	.86296
NO3	.84102
CA	.85661
SPEC	.96011
PH	.83177
TEMP	.54544
DEPTH	.07052

Table 3 shows the final factor loading matrix obtained from the PA1 analysis. Factor loadings show the relationships of variables to principal factors. This table shows that the variables sodium, carbonate, chloride, fluoride, specific conductivity and pH cluster about Factor 1. Silica, iron, magnesium, potassium and temperature tend to group around Factor 2 and sulfate, calcium, nitrate, specific conductivity and magnesium group about Factor 3. A negative sign before a variable in a factor grouping indicates that it is inversely proportional to the other variables in the cluster.

Table 3. Varimax-rotated factor loading matrix. Underlined loadings are considered significant (greater than .5).

TABLE 3

	FACTOR 1	FACTOR 2	FACTOR 3
SIO	.19974	.64232	-.21345
FE	.11681	.89787	.15668
MG	.07353	.85733	.52776
NA	.93169	.24901	-.03968
K	.19721	.77254	-.03818
CO3	.77738	.28934	-.22237
BO4	.37939	-.04522	.74912
CL	.87863	.10229	.33211
F	.86248	.34317	.03640
NO3	-.07990	.05521	.91191
CA	-.21220	-.22198	.87310
SPEC	.78335	.09233	.58134
PH	.79517	.39305	-21212
TEMP	.24179	.66109	-.22347
DEPTH	.19693	-.08084	-.15877

The three factors represent the filtered combination of the 15 variables used in the analysis. Each factor represents a chemically distinct water type. Figures 2 through 10 are based on solution of the linear factor equation with coefficients from the factor score coefficient matrix. From these coefficients, the value of each factor at each well location can be plotted (Klovan, 1975). The resulting factor scores are in standard from, i.e., a mean of 0.0 and a standard deviation of 1.0. Factor scores can be used as any other variable and are plotted and manipulated in the same way. These scores are shown in Appendix B. These values should be thought of as a normal distribution and represent a gradient of the water type. For a more exact interpretation, the variables have been plotted by arbitrarily dividing deep, intermediate, and shallow wells. The 600 ft depth was chosen as the boundary between shallow and intermediate and the 1000 ft depth was chosen as the boundary between intermediate and deep wells.

Factor 1 contains the variables sodium, CO_3, chloride, fluoride, pH and specific conductivity (Table 3). The chemical constituents are atypical of water in equilibrium with basalt (Atlantic Richfield, 1976) and are thought to originate either from a sedimentary sequence which is thought to underlie the basalts or possibly from an acidic lava which predates the more mafic flood basalts. ARCO found this sodium chloride type of water in deep well DC-1. Newcomb (1972), recognized a water type similar to this and attributed it to a sedimentary origin. The distribution of Factor 1 (Figures 2 to 4) indicates the greatest concentration at wells DC-6 and DC-14, located near the horn of the Columbia River. These two wells are flowing, from depths greater than 1700 ft below the surface (Fenix & Scisson, 1970.) The Factor 1 scores in the deep wells drop off markedly to negative values on the east side of the river indicating a different water type. While there is a fairly large difference in well depth, in the deep wells, from one side of the river to the other, (1400 ft, on the east as opposed to 3100 ft on the west), the general trend is still quite strong in the intermediate depth wells (Figure 3). Factor 1 scores of 1.75 still appear in this depth range (600-1000 ft below the

FACTOR I

SHALLOW WELLS (< 600 ft.)

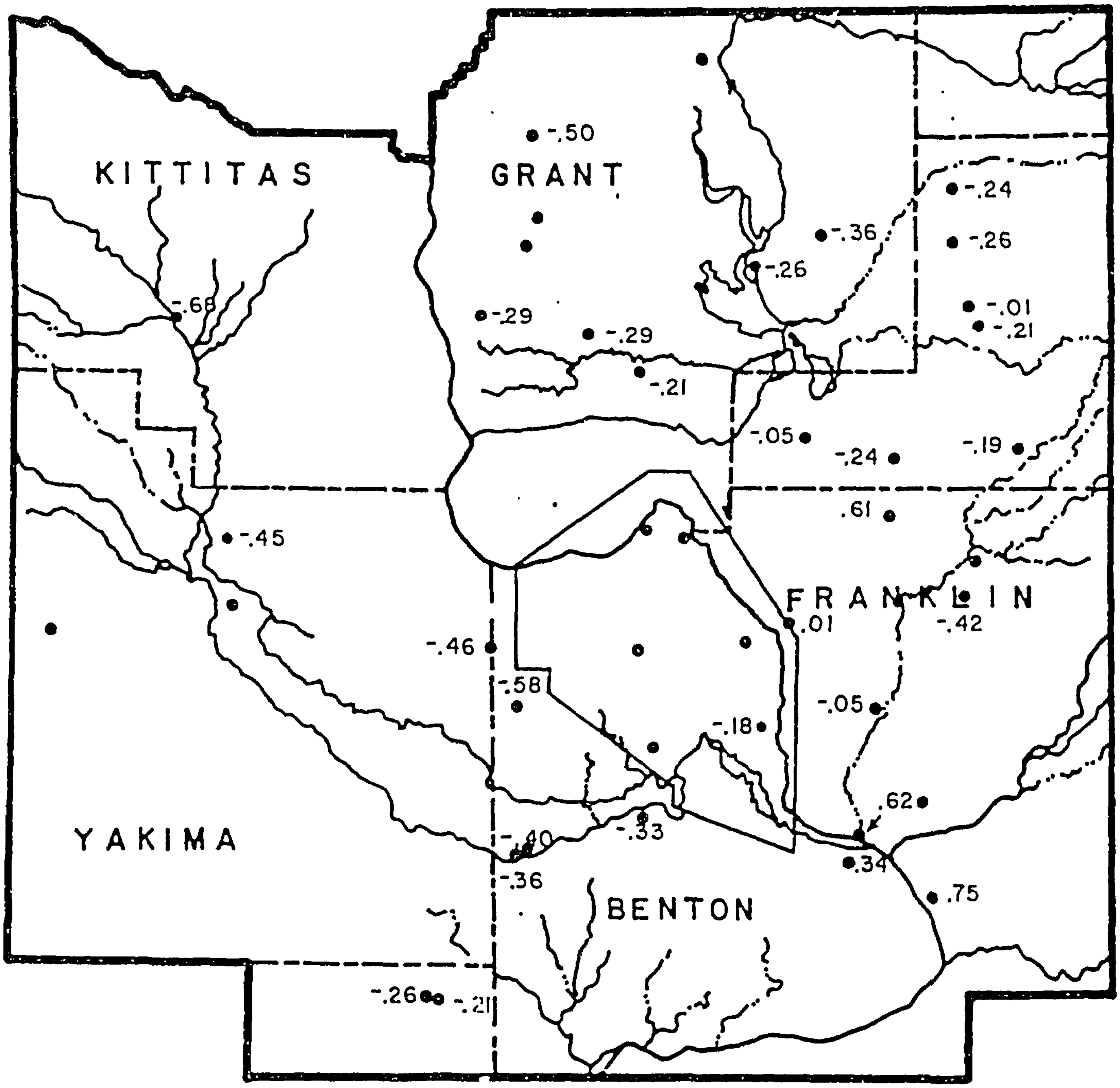


Figure 2

FACTOR I

INTERMEDIATE WELLS (600-1000 ft.)

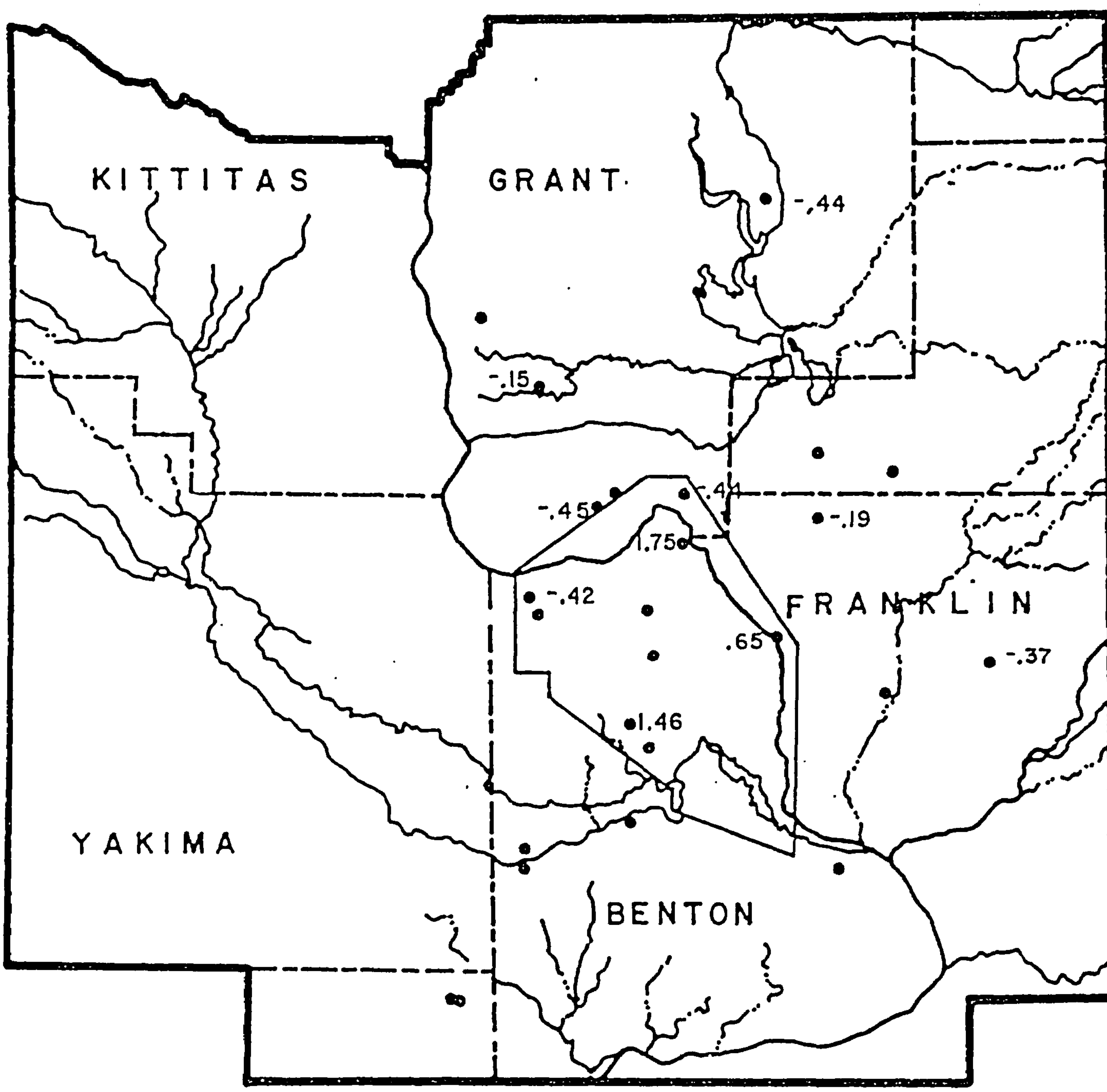


Figure 3

FACTOR I - DEEP WELLS (>1000.ft.)

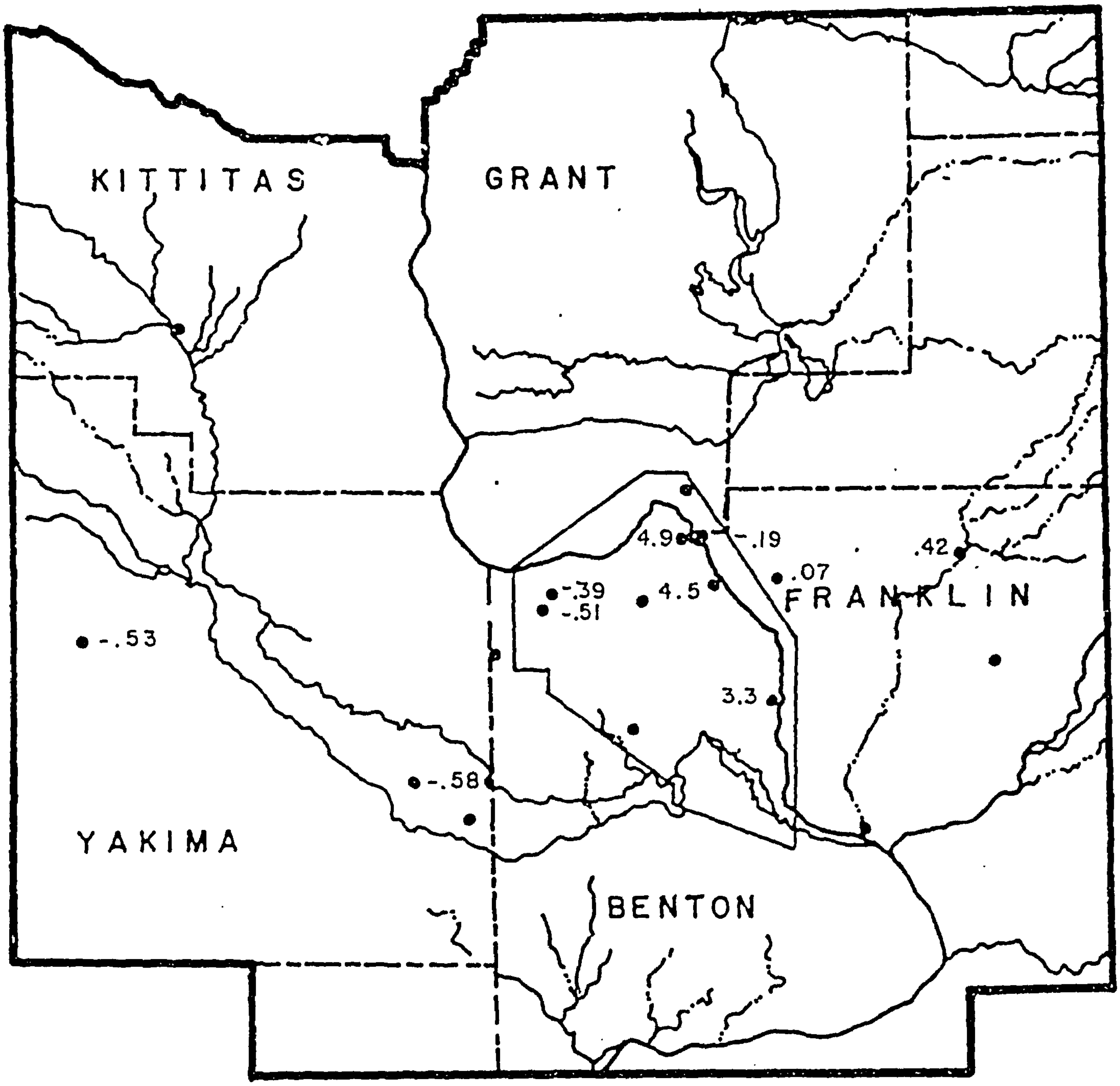


Figure 4

surface). One could infer a mixing of water types as the water migrates from depth towards the surface.

Factor 2 contains the variables silica, iron, magnesium, potassium and temperature. This factor is indicative of water which has been in equilibrium with basalt. It is high in mafic minerals and silica which comprise the mineralogy of basalt. The potassium may be related to clays present in weathered basalts or sedimentary interbeds (Deutsch et al, 1982). Factor 2 is distributed fairly evenly across the study area (Figures 5 through 7), which would be expected from a basalt system, except for deep wells near the Columbia and near the horn. In this area, negative values arise to the west of the river indicating an inverse relationship or a sharp weakening of Factor 2. This would support mixing with Factor 1. Note on Figure 7 that the highest factor scores occur immediately adjacent to the river on the east side, while the lowest scores occur immediately adjacent to the river on the west side, indicating a type boundary at the river.

Factor 3 contains the variables sulfate, calcium, nitrate, specific conductivity and magnesium. This water is indicative of artificial recharge of irrigation water due to concentration of minerals. High sulfate, calcium, and nitrate are typical, while magnesium indicates its strong correspondence to Factor 2 water. Factor scores are highest in areas where irrigation is most extensive (Figures 8 through 10). Extensive irrigation is practiced in the area through center pivot systems and the Columbia Irrigation Project. Table 3 also indicates small negative or inverse relationships of temperature and depth.

FACTOR 2

SHALLOW WELLS (< 600 ft.)

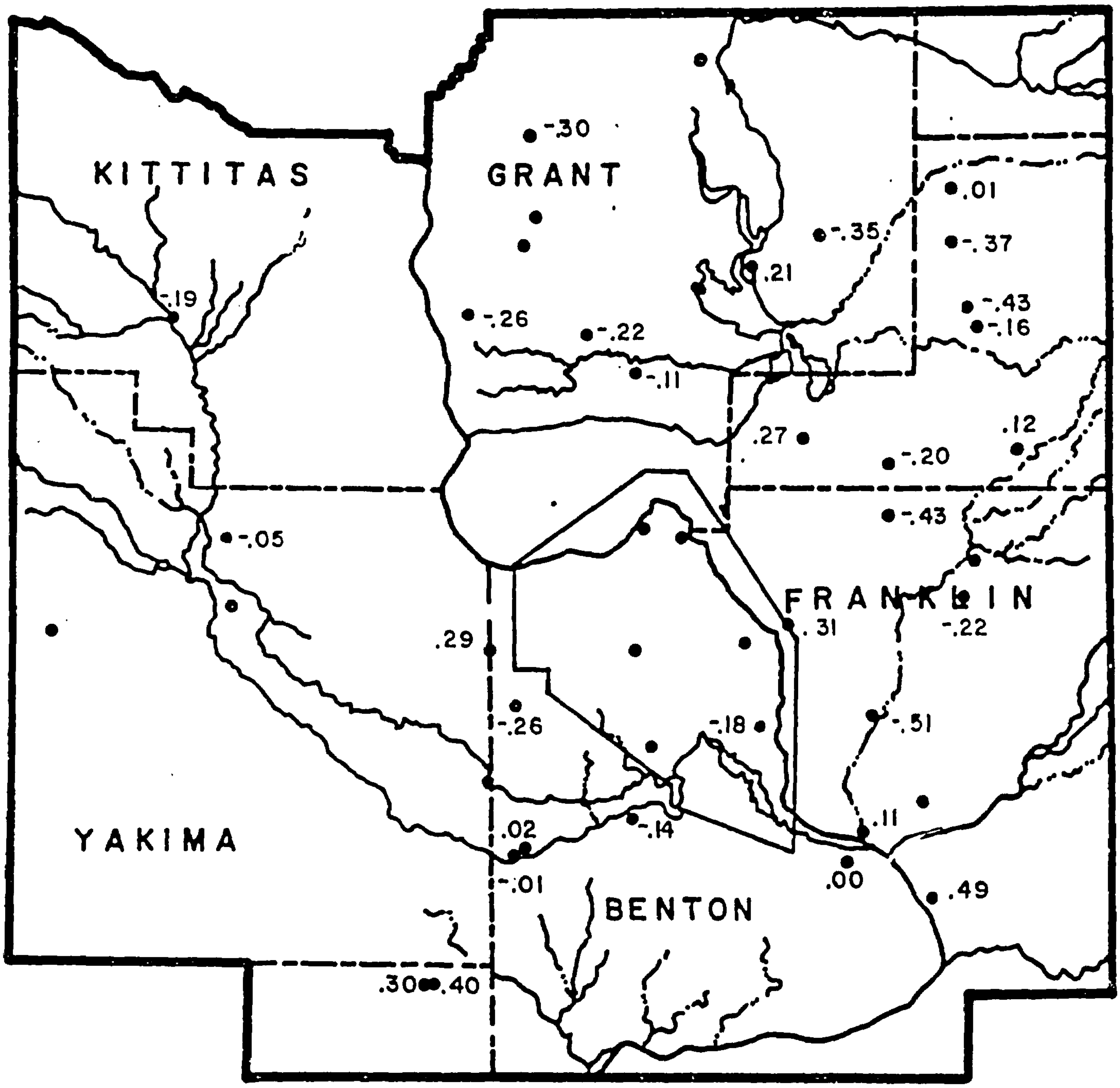


Figure 5

FACTOR 2

INTERMEDIATE WELLS (600-1000 ft.)

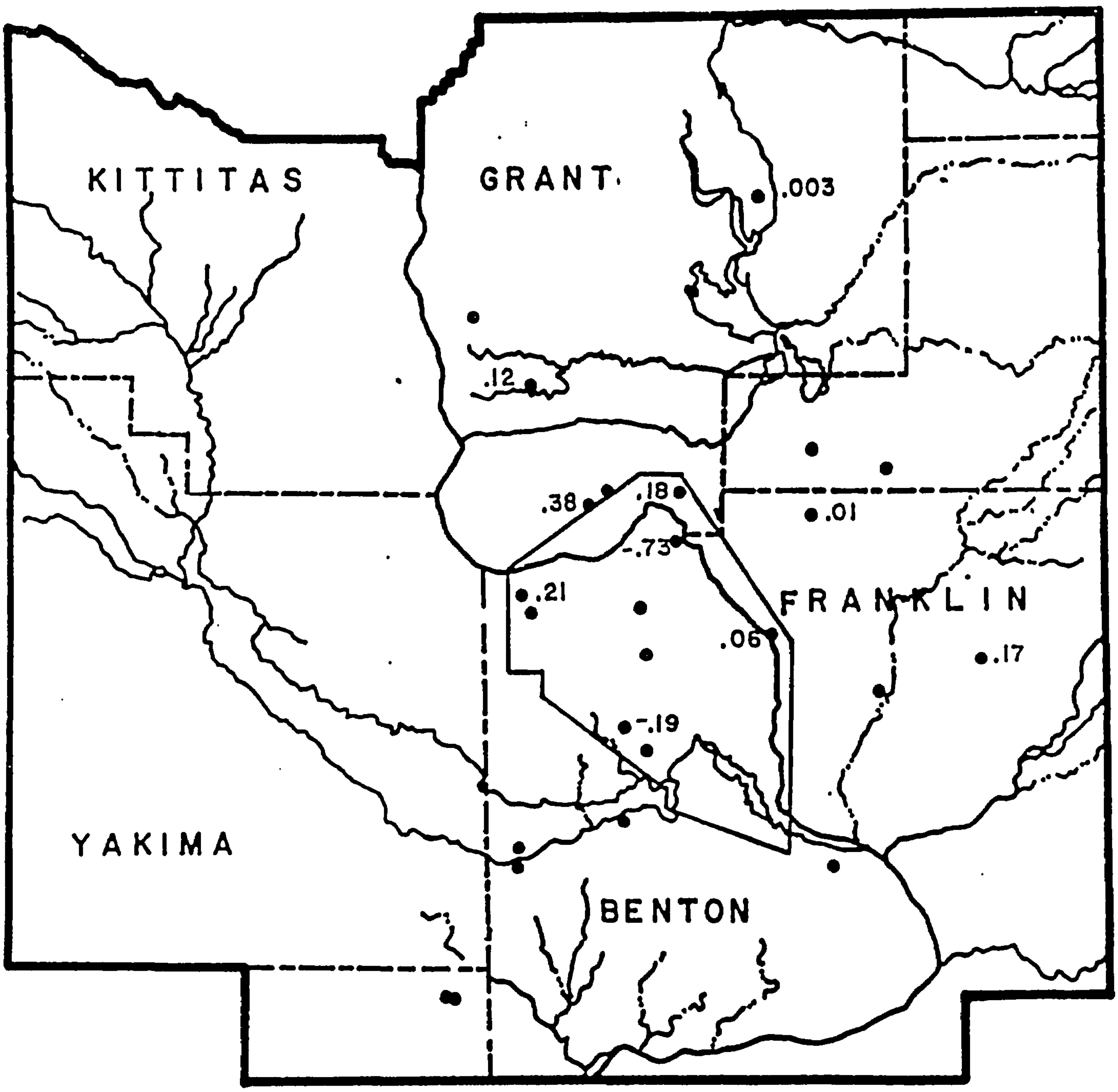


Figure 6

FACTOR 2 - DEEP WELLS (>1000 ft.)

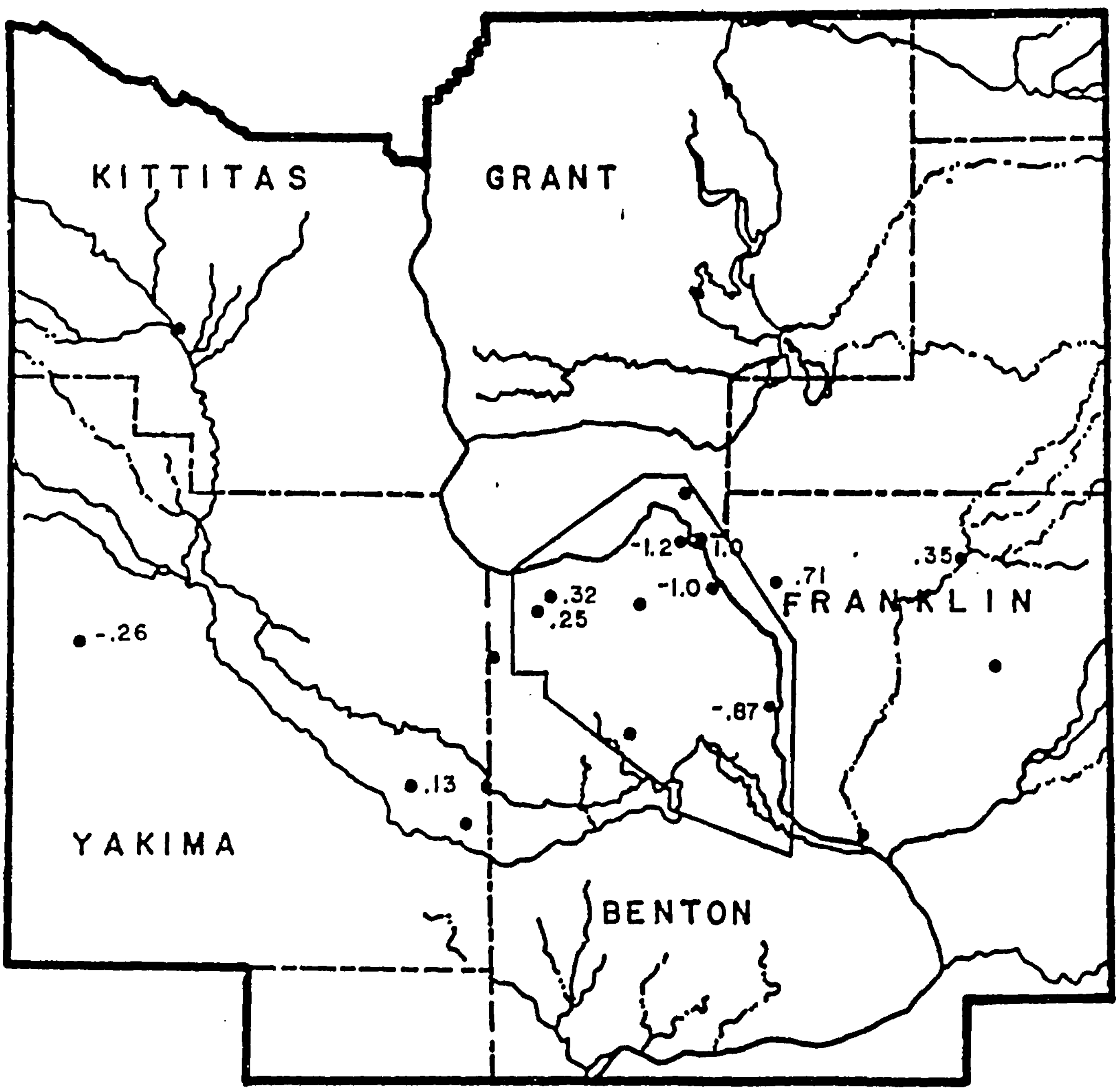


Figure 7

FACTOR 3

SHALLOW WELLS (<600 ft.)

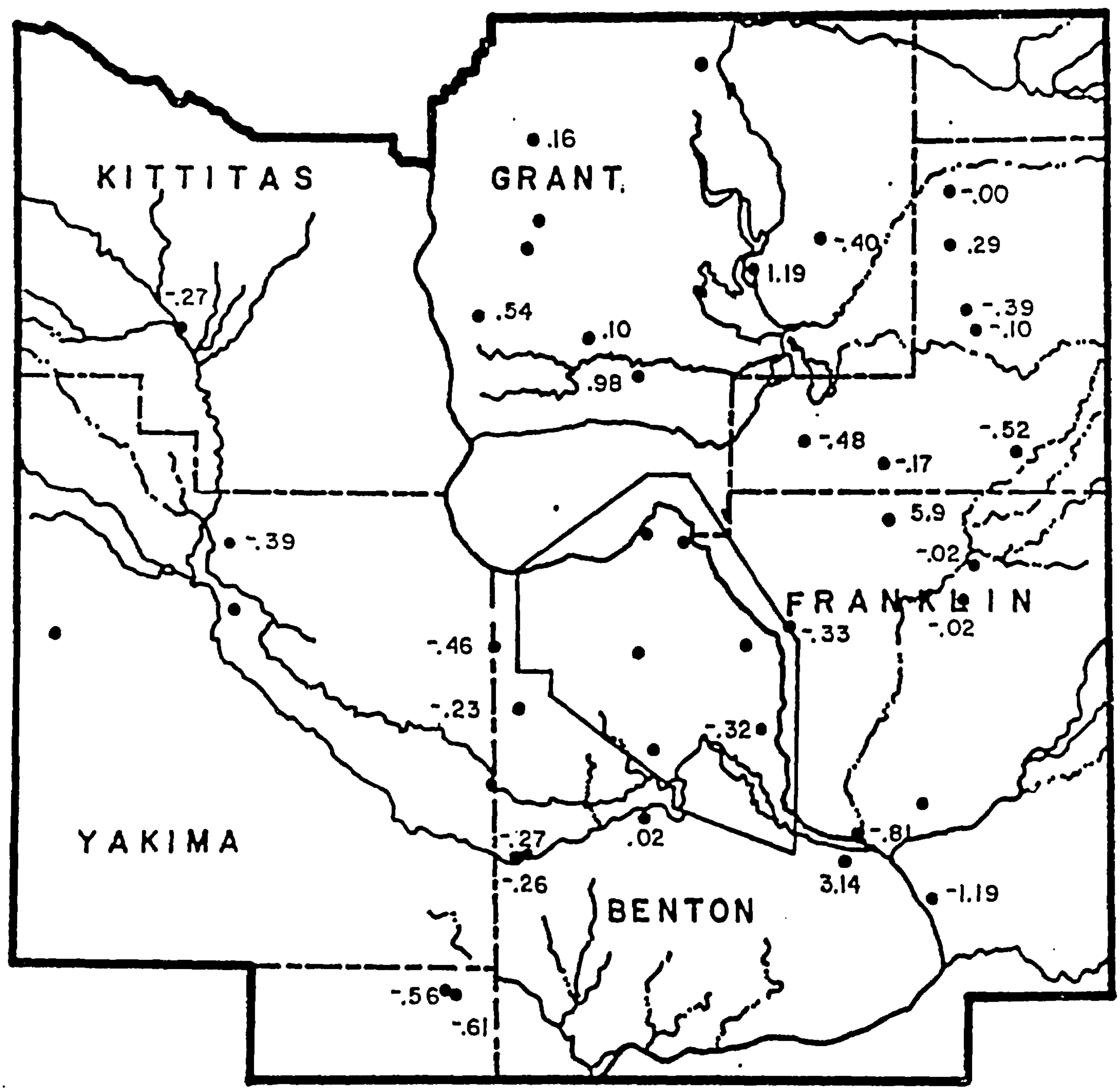


Figure 8

FACTOR 3

INTERMEDIATE WELLS (600- 1000 ft.)

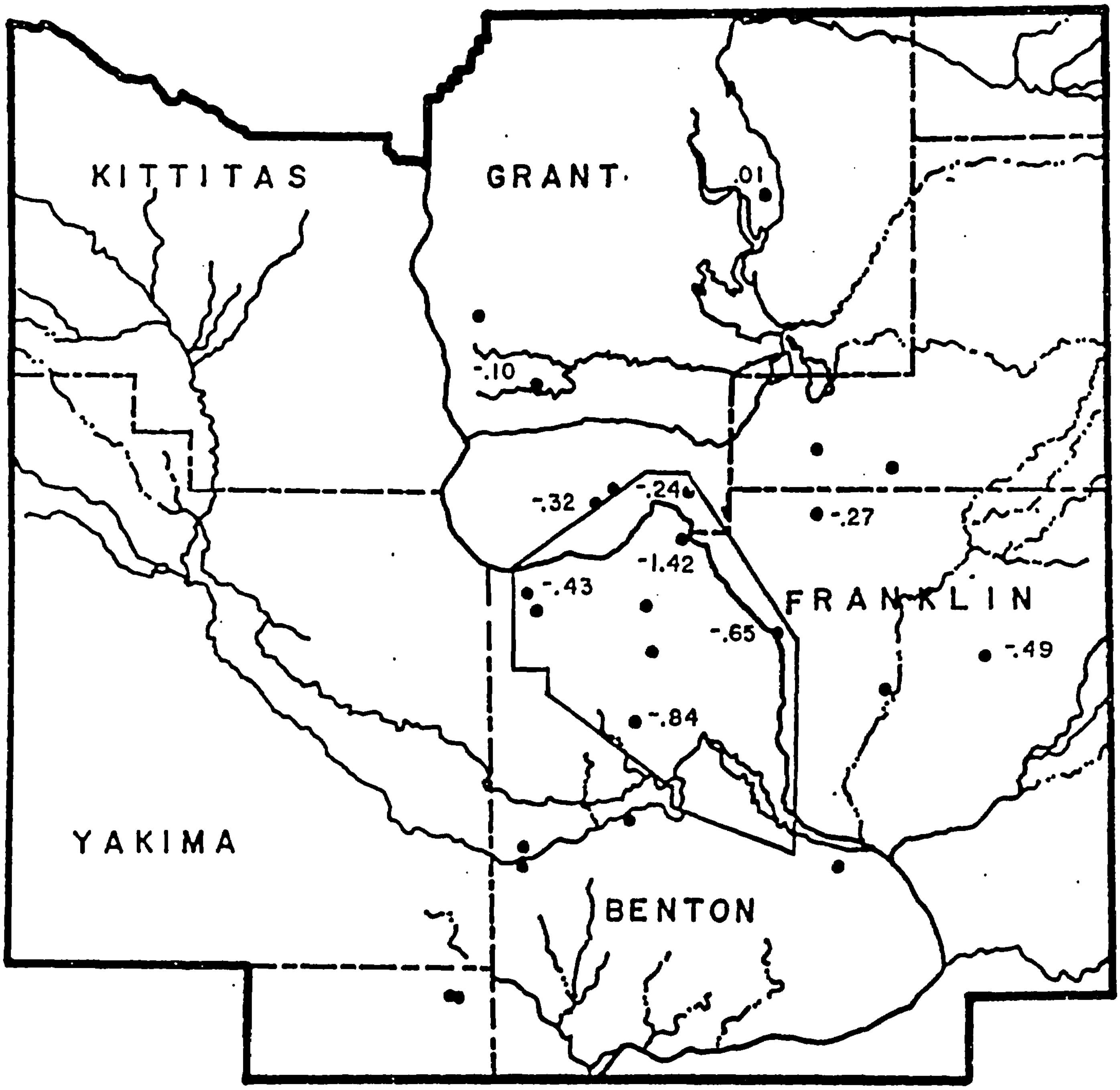


Figure 9

FACTOR 3 - DEEP WELLS (>1000 ft.)

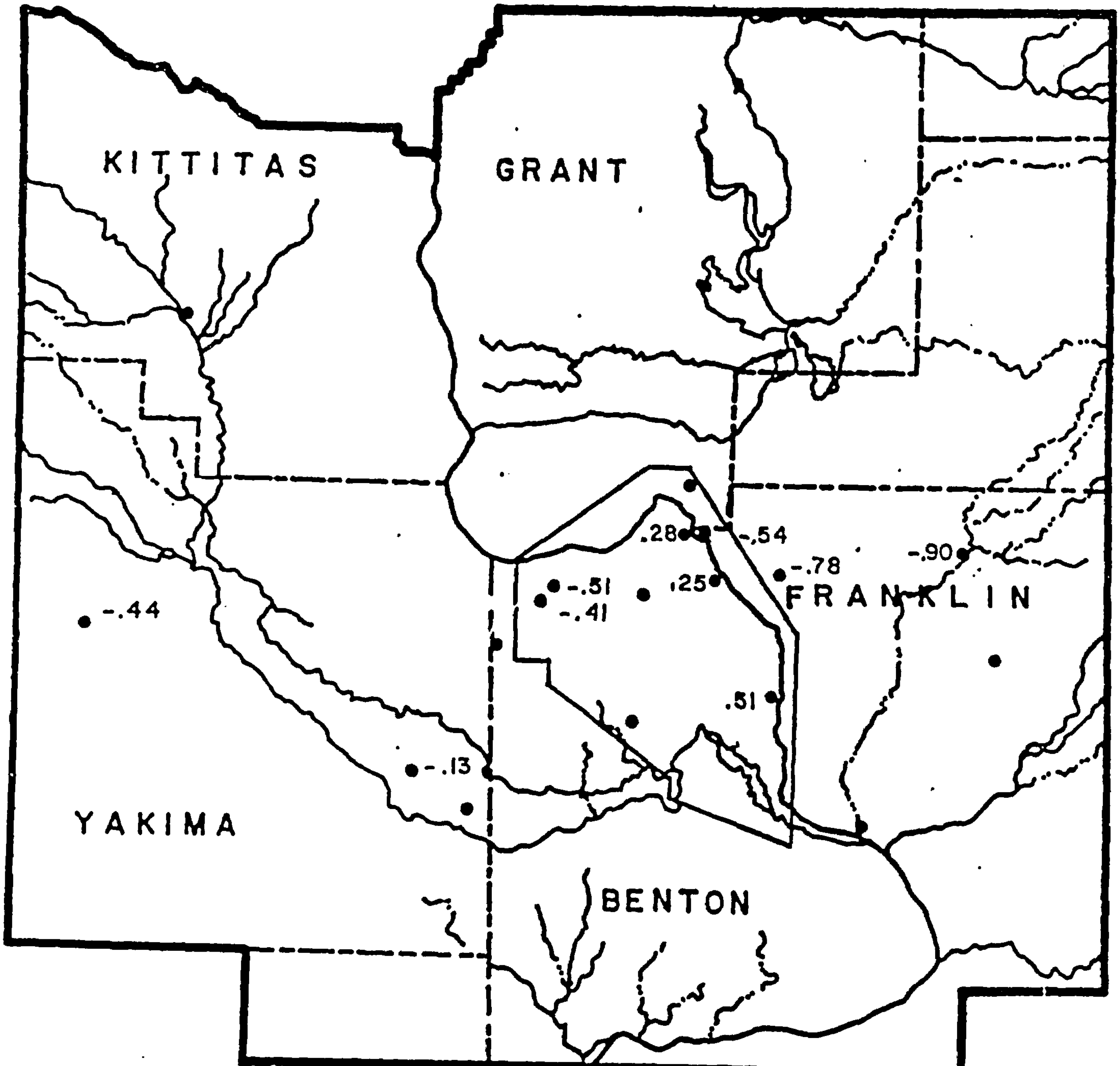


Figure 10

Certain factor scores and geochemical plots of chloride and fluoride (Figures 11 through 14) also drop off sharply to the east of the river indicating that discharge is fairly localized within the basin, and especially along the river. The previously suspected discharge area for the basalts has been the Wallula Gap area, a deeper system has not previously been identified. The apparent discharge area for parts of the deeper system and probably some of the basalt system is the Columbia River based on geochemistry.

Evidence of Structural Control on Streams in the Columbia Plateau and Effect on the Groundwater Flow Systems.

Previous groundwater studies of the central Columbia Plateau region do not consider the effects of structural features on the discharge patterns of flow systems. One potential mechanism for the observed chemical patterns could be discharge of the systems due to the presence of a controlling structure at depth.

Evidence for structural control of the surfacc hydrology can be seen in the nearby Lewiston Basin. Fault patterns in the basalt have been studied in this basin, which is located in the easternmost part of the Columbia Plateau. These patterns are thought to reflect the older structural grain of the underlying rock (Hooper and Camp 1981). Planes of weakness in the basement could accomodate the stresses recieved during the Miocene. The coincidence of faults in the basalt with older structures in the basement can be seen in the Limekiln fault, the Lewiston structure and in Hell's Canyon (Hooper and Camp,1981). Hooper and Camp (1981) also note that in all NW-SE trending faults plotted in their Lewiston Basin study, some vertical displacement is apparent.

CHLORIDE - INTERMEDIATE WELLS

CONCENTRATION IN PPM

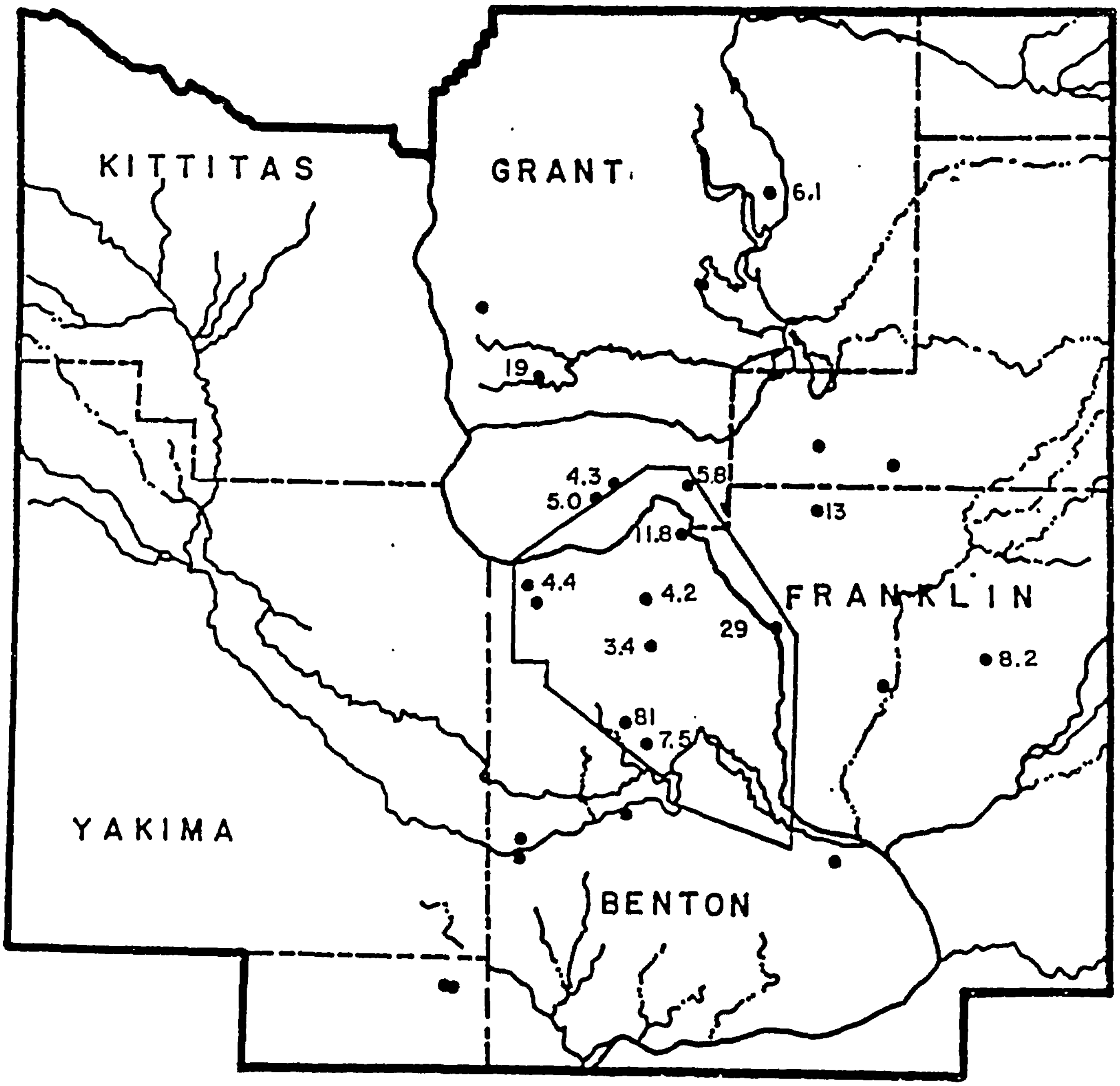


Figure 11

CHLORIDE DEEP WELLS

CONCENTRATION IN PPM

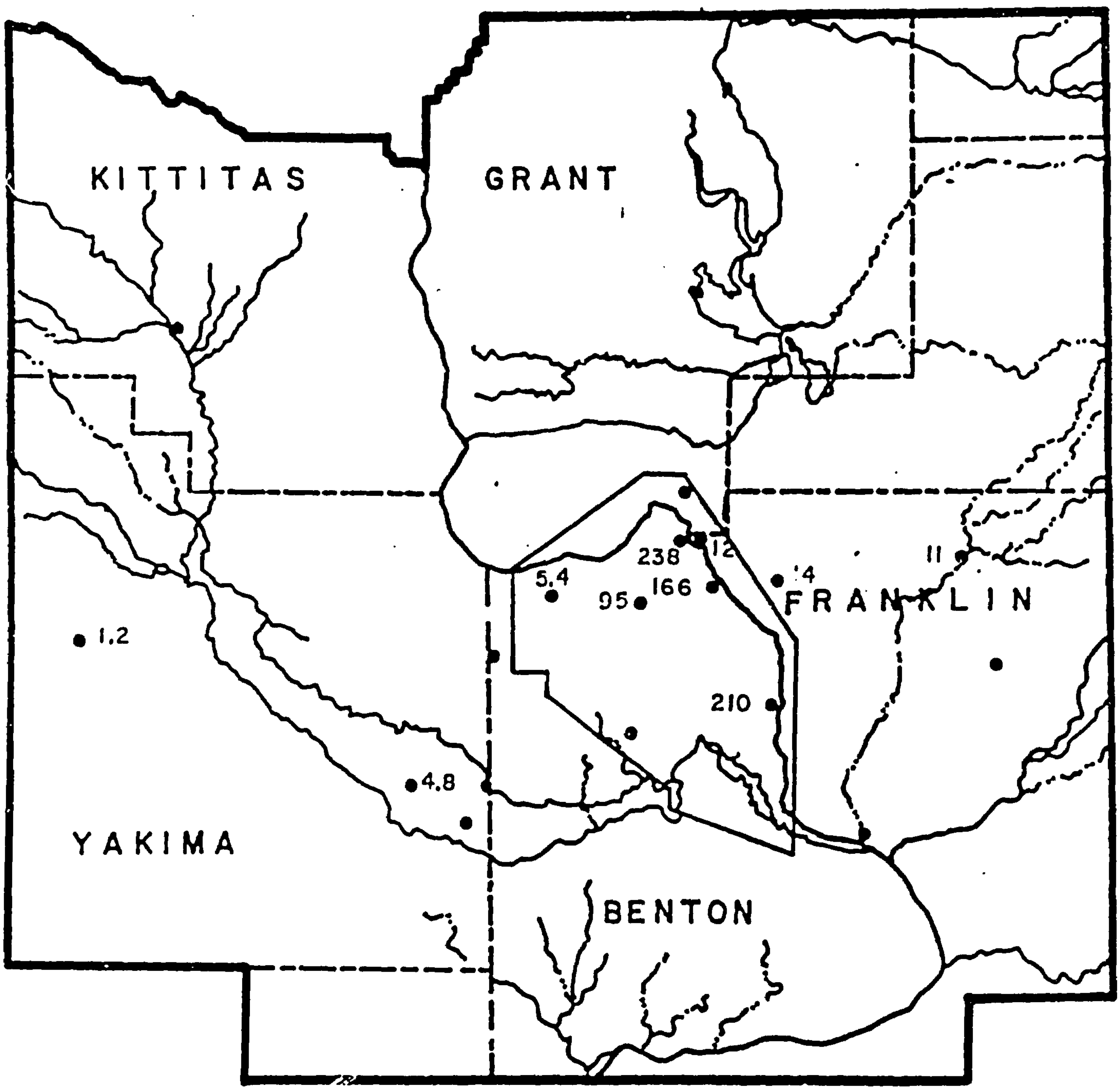


Figure 12

FLUORIDE - INTERMEDIATE WELLS

CONCENTRATION IN PPM

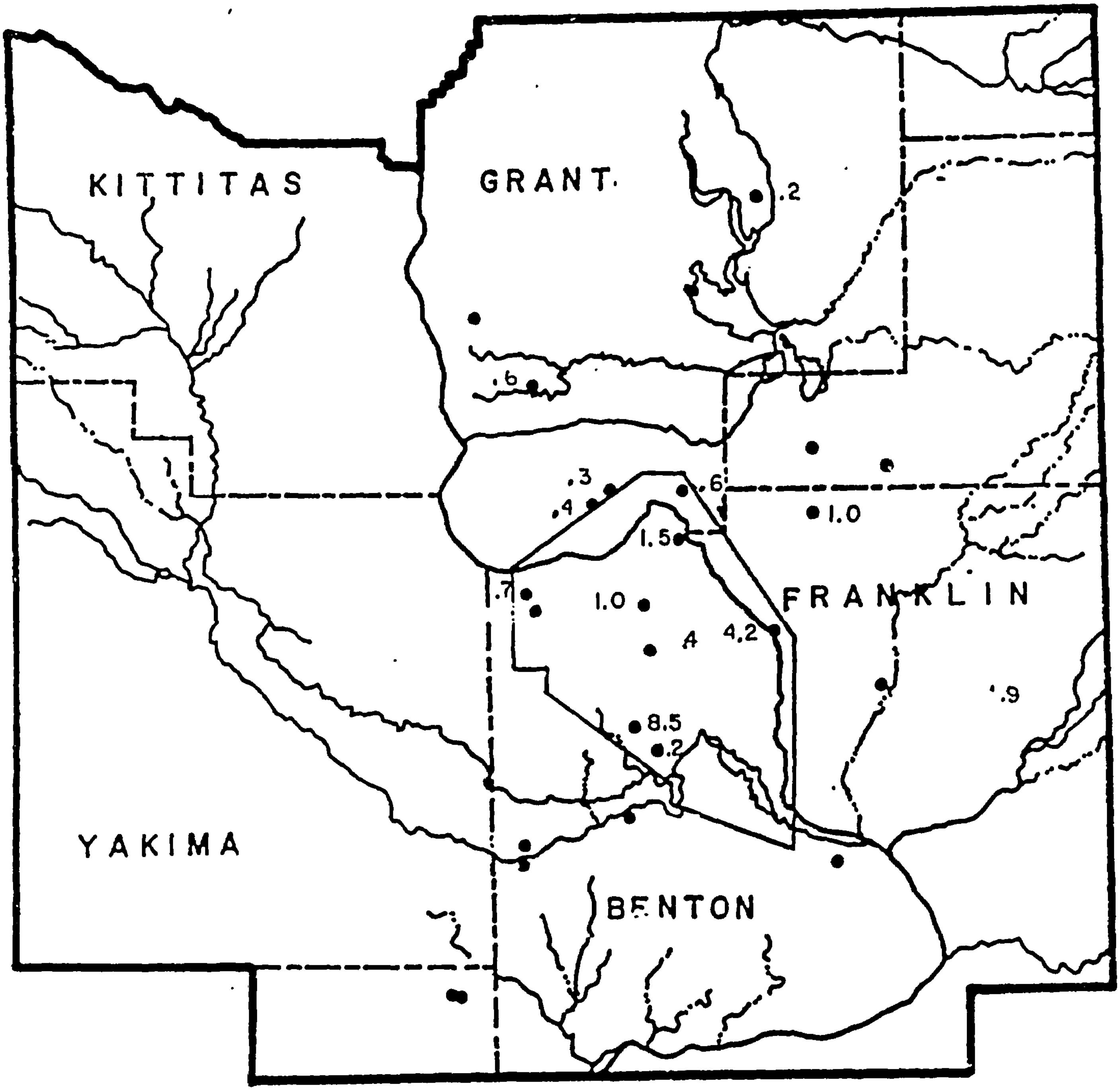


Figure 13

FLUORIDE DEEP WELLS

CONCENTRATION IN PPM

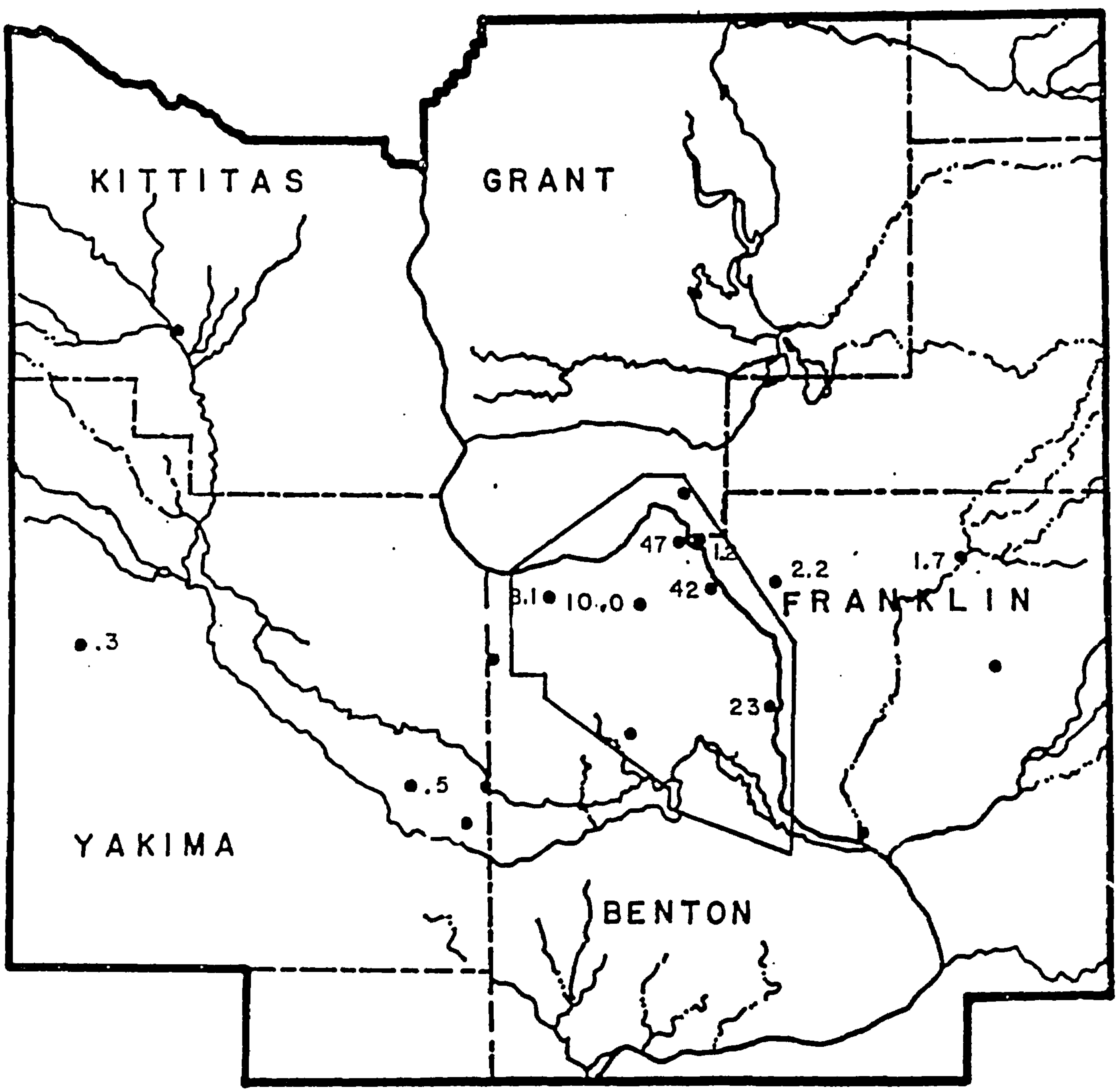


Figure 14

The control exerted on the rivers of the Columbia Plateau can be illustrated in the diagram used by Hooper and Camp (1981) to show locations of faults in the Lewiston Basin. The rivers are influenced by the structures in almost every place that the rivers intercept them. The river course is diverted sharply along fault lines and by uplifted anticlinal structures which may act as horizontal barriers to flow. Eleven such examples are circled in Figure 15. The Columbia River demonstrates this sort of behavioral pattern just north of its confluence with the Yakima and Snake Rivers.

Trimble (1950) has discussed structural control of channeling in the scablands regions of the Columbia Plateau and attributes control to regional joint systems in the basalt.

The regional groundwater patterns in the basalt are probably influenced as much by the structure as the surface water patterns. Flow may be diverted down synclines and around or through anticlines. Vertical fracturing in anticline structures may offer vertical conduits for recharging the groundwater systems, from above or from below as may be the case in the Pasco Basin since recharge estimates alone cannot account for the amount of discharge occuring there (Gephart, et. al, 1979). This water balance discrepancy supports recharge from interbasin flow and/or upwelling from a deeper system. Figure 16 shows zones of equal deformation associated with anticlinal and synclinal within the Pasco Basin (Dove, et. al, 1981). This highly deformed area may offer a pathway for upwelling from the deeper system.

Gravity maps of the Pasco Basin area show a linear trend along the Columbia River north of Richland. Both total gravity (Figure 17) and

STRUCTURAL MAP

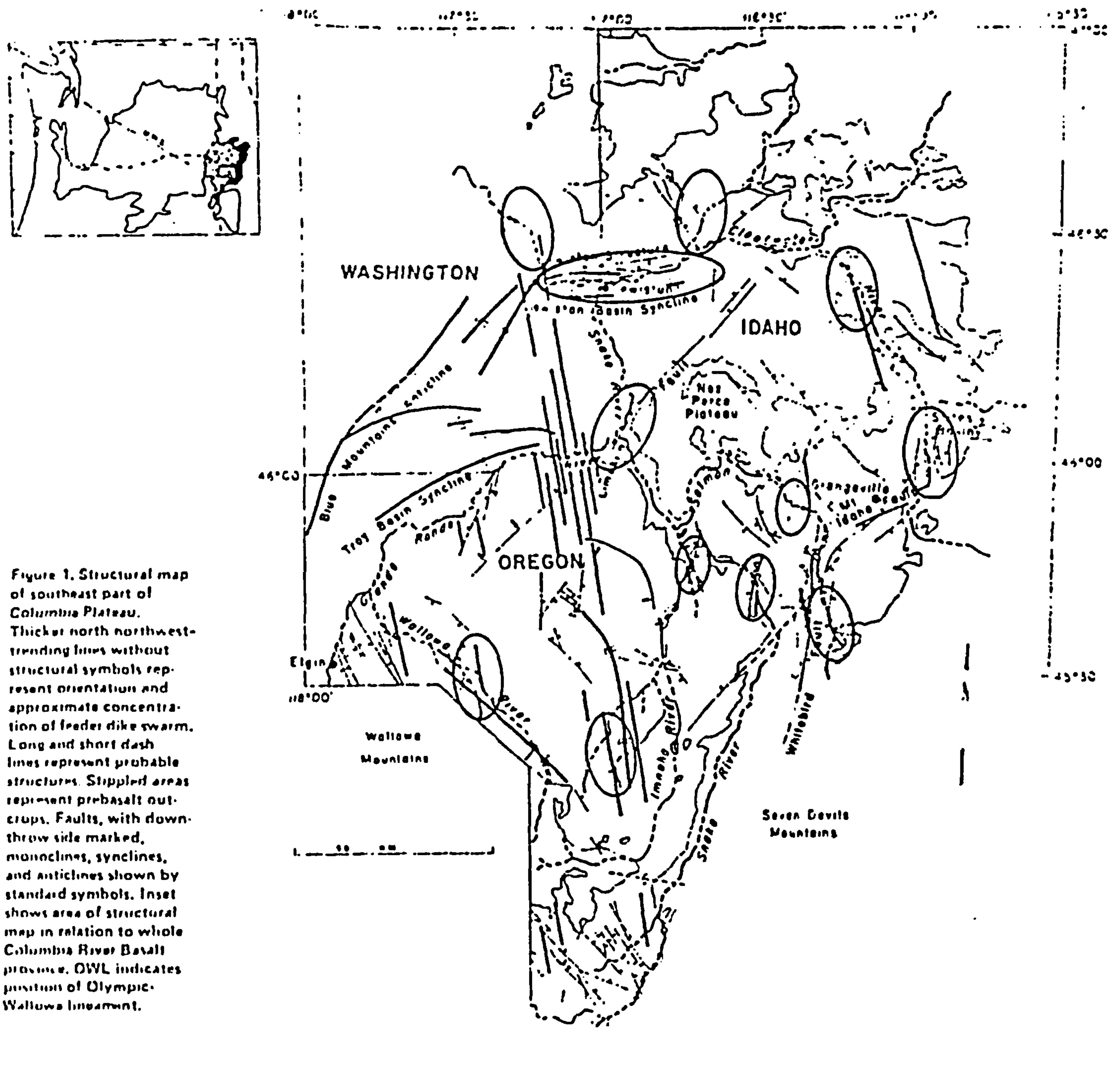
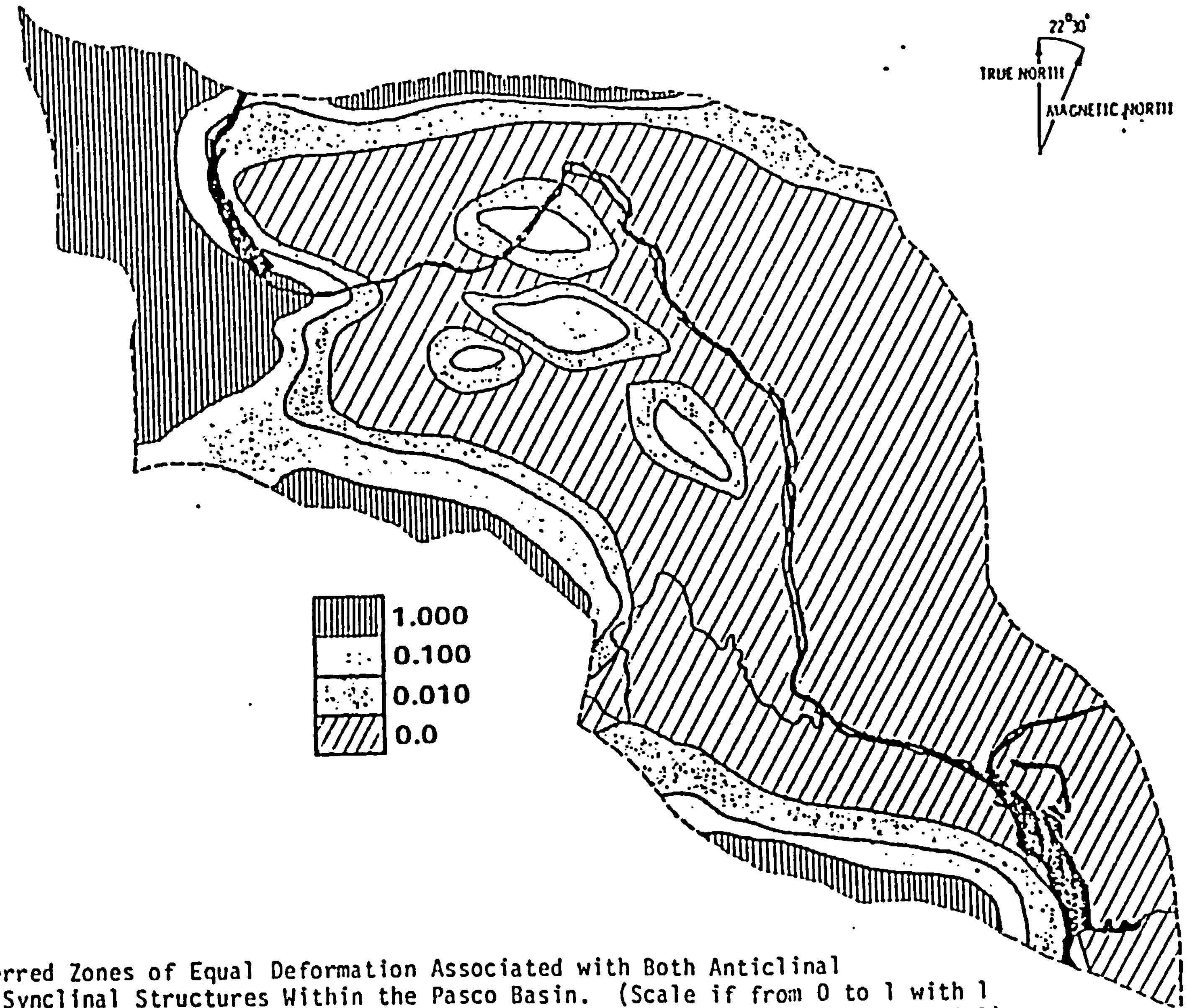


Figure 1. Structural map of southeast part of Columbia Plateau. Thicker north northwest-trending lines without structural symbols represent orientation and approximate concentration of feeder dike swarm. Long and short dash lines represent probable structures. Stippled areas represent prebasalt outcrops. Faults, with downthrow side marked, monoclines, synclines, and anticlines shown by standard symbols. Inset shows area of structural map in relation to whole Columbia River Basalt province. OWL indicates position of Olympic-Wallowa lineament.

ELLIPSES INDICATE AREAS WHERE STREAM COURSE IS CONTROLLED BY STRUCTURE. (After Hooper and Camp, 1981).

Figure 15

ZONES OF EQUAL DEFORMATION



Inferred Zones of Equal Deformation Associated with Both Anticlinal and Synclinal Structures Within the Pasco Basin. (Scale if from 0 to 1 with 1 representing areas of greatest inferred deformation.) (After Dove,et al, 1981).

Figure 16

TOTAL GRAVITY

(After Weston Geophysical for BWIP)
July 21, 1980

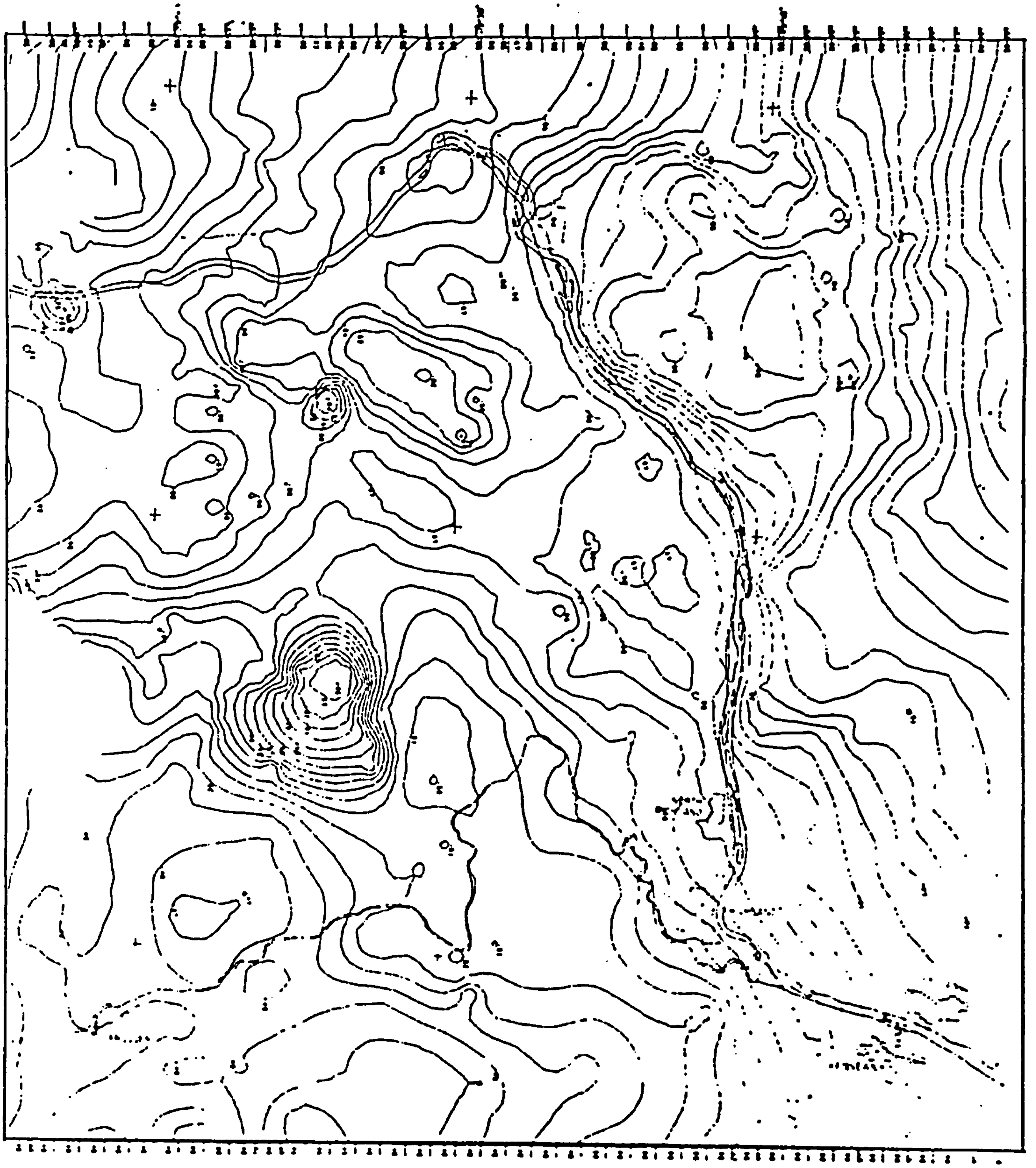


Figure 17

residual gravity maps show this same trend along the river between the horn and Richland (Total Gravity and Residual Gravity Maps, flown by Weston Teophysical for BWIP project, RHO, July 21, 1980). Structural control can be inferred in this area due to linearity and from the Bougier anomoly from one side of the river to the other (Ernst Zurflueh, personal communication).

Based on this structural evidence and the geochemical data, a conceptual model postulating structural control of discharge along the Columbia is proposed. In order to understand this mechanism a brief history of the pre-basalt stratigraphy and subsequent plateau development is useful.

Geologic and Tectonic History of the Columbia Plateau and its Influence on the Columbia River

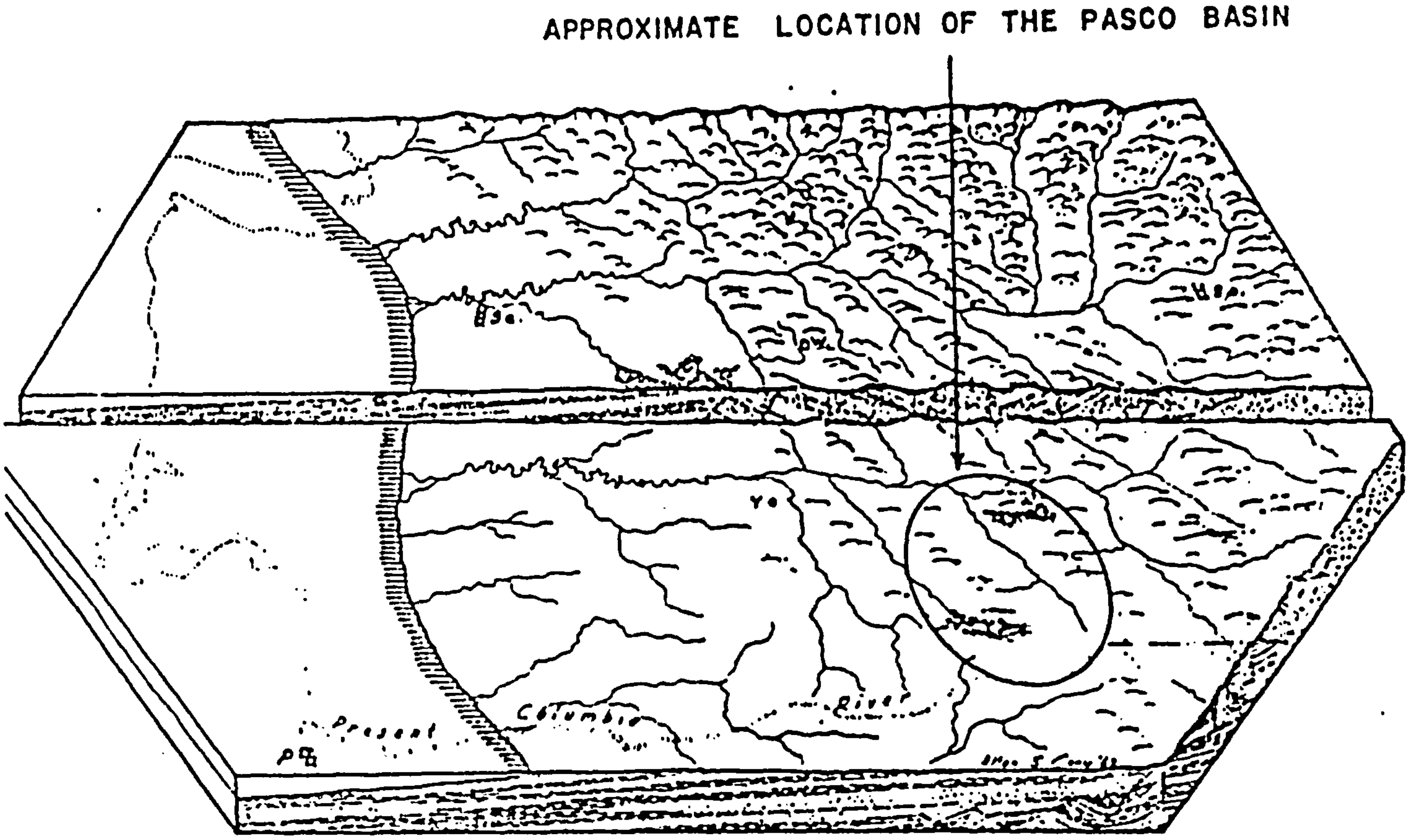
The Columbia Plateau is situated east of the northwest trending zone along which the Juan de Fuca Plate may be decending beneath the American Plate. This subduction is involved in the generation of the volcanic activity in the Cascade Range (Guzowski and Nimick, 1982), and may be responsible for the formation of the Plateau. The exact boundaries of the subduction zone are not yet known.

During the Eocene, the Pacific northwest was covered by a broad, deltaic lowland with numerous peat bogs, called the Weaver Plain. The climate was much wetter then and supported a forest made up of conifers, broad-leafed trees, palms, blooming vines and shrubs. The moist wet air from the Pacific Ocean was not blocked by the Cascade Range, since it had not yet formed (Mackin, 1965). The Oligocene epoch brought an era of compression to the area, which is expressed as northwest-southeast trending folds (Figure 18). The folding developed a low mountain range known as the Calkins Range, and created the general trend of modern drainage lines over the Columbia Plateau (Mackin, 1965). The Calkins Range was subsequently eroded and leveled before the time of the lava floods.

The outpouring of lava over this surface deflected the course of the ancestral Columbia River to the west, around the rim of the developing plateau until the uplift of the Cascades and subsequent outpouring of andesitic lava and the uplift of the Hog Ranch Axis, deflected the Columbia back eastward across the lava field at the location of the city of Wenatchee. The uplift of the Cascades caused folding to occur across the Columbia Plateau lava field, but the NW-SE trend of the folds reflected the direction of the basement upon which the flows rested, the Calkins Range remnants (Mackin, 1965).

The Yakima Fold Belt, specifically Gable Mountain-Gable Butte anticline has diverted the flow of the Columbia further eastward, possibly in two separate episodes, to its intersection with what appears to be a NW-SE trending fault line parallel to the Olympic - Wallowa Lineament and the Cold Creek Lineament (Ina Alterman, personal communication). It then intersects a more North South trending fault, or possibly a dyke (Phil Justus, personal communication) where it is deflected or entrenched until near its confluence with the Yakima and Snake Rivers at the nadir of the Columbia Plateau (Figure 19). If these proposed faults are controlled in the underlying sediments (Mackin, 1965), they cut through most, if not all of the Columbia River Group basalt, extending into the sediments. Earthquake swarms located at Wooded Island, in the center of Columbia River, indicate shallow focus for the most part (less than 1.8 miles) but

PRE-BASALT SURFACE



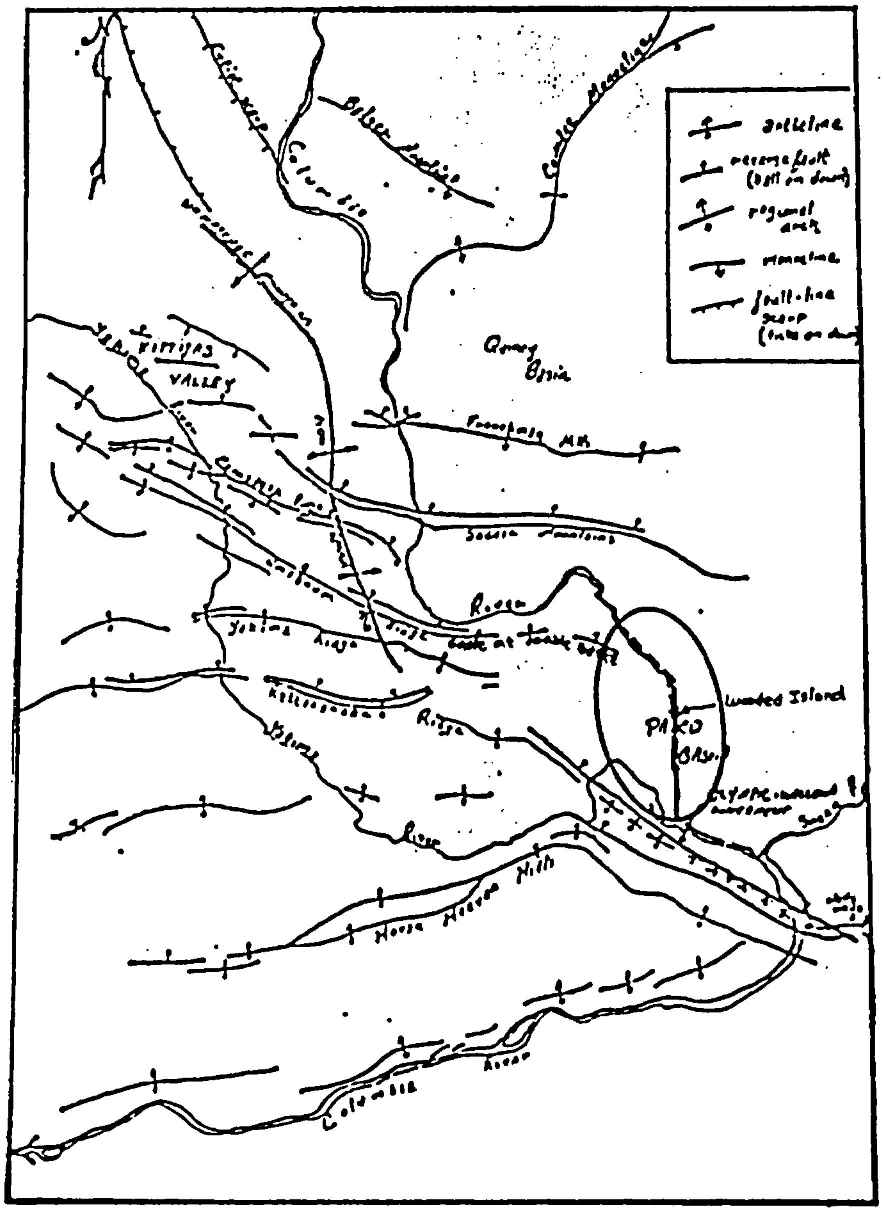
AN EOCENE GEOGRAPHIC PATTERN

The coal deposits of Washington were formed in peat bogs on broad deltaic lowlands, the Weaver Plain, which trended northwest across the site of the Cascades. The oscillating shoreline was sometimes west of the present position of Seattle, as shown, and sometimes to the east. The rivers that wandered on the Weaver Plain derived their loads of sediments from mountains in the northeastern half of the State. Volcanoes were active from time to time in places on the Plain.

(After Mackin, 1965).

Figure 18

TECTONIC MAP



ELLIPSE INDICATES AREA WHERE STRUCTURAL CONTROL IS PROPOSED. DASHED LINES WITHIN ELLIPSE INDICATE LOCATION OF PROPOSED FAULTS OR DYKES. (After Waitt, 1978).

Figure 19

activity has been measured much deeper (greater than 5.6 miles). If the fault does go into the underlying rock it would offer a mechanism for the deeper and shallower shocks.

A fault or dyke also may explain why some folds of the Yakima Fold Belt (Gable Mountain Gable Butte) end abruptly at this location along the river, while others such as the Saddle Mountains and Horse Heaven Hills continue across it. A pre-existing high angle fault or dyke could have acted as a shearing surface and allowed for the dragging of the folds as seen in the Pasco Basin without transmitting the folding to the other side of the basin. Evidence for this is also seen in the difference in elevation of the land surface from one side of the river to the other, approximately 500 ft. If some vertical displacement was occuring due to subsidence along the fault zone (possibly a graben structure), either present or past, it could explain this elevation difference.

An east-west cross-sectional view of the central Columbia Plateau from the Cascades to the Rocky Mountains (Figure 20), yields a picture of the postulated regional groundwater flow systems. Since the Pasco Basin is the structural low point of the Columbia Plateau, the basement structure may also reflect this low point (Waitt, 1978), and act as a discharge zone for the deeper sedimentary system. The basalt system is superimposed over this old regional system, with both systems discharging in the Pasco Basin. The discharge of the two systems becomes mixed as it migrates upward towards its discharge point. This upwelling may be attributed to structural control under and near the Columbia River. These structural features would create a zone of greater permeability and allow upwelling. While discharge probably continues south to Wallula Gap

CONCEPTUAL MODEL

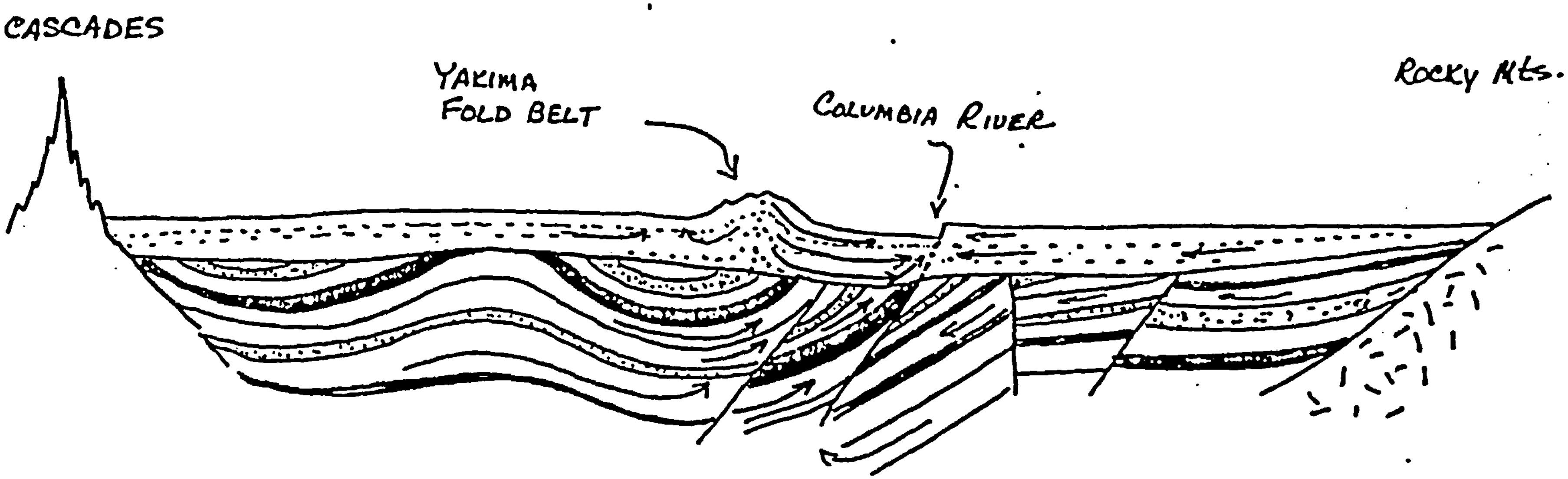


Figure 20

along the river the discharge from the lower system appears strongest near the horn of the Columbia River.

Summary

A hydrogeochemical model can be developed based on the distribution of the 3 factors derived from a factor analysis. The Pasco Basin is seen as a discharge area for the basalt system and for a portion of the underlying regional sedimentary system. Factor 3 is interpreted as representing water which has been recharged artifically from extensive irrigation practices of the region. Factor 2 distribution indicates a basalt equilibrated water and is fairly evenly distributed except for deep wells in the Pasco Basin indicating mixing with deeper upwelling Factor 1 water. Factor 1 is interpreted as water derived from a deeper and much older sedimentary system beneath the basalts, strongest upwelling exists at the horn of the Columbia and continues along the Columbia River towards Wallula Gap.

Factor scores drop off sharply from the river indicating that discharge is a localized phenomenon, taking place very close to the river. A proposed explanation for the localized discharge location is a dyke or faulting beneath the Columbia River and deformation associated with the anticlinal and synclinal structures.

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WELL #	WELL LOCATION	SILICA	IRON	ALUMINUM	MAGNESIUM	MANGANESE
1	6/2311P1	56.0	.03	0.0	2.4	.02
2	6/2315J1	57.0	.03	0.0	2.7	.02
3	8/242J2	47.0	0.05	0.0	6.2	.05
4	8/242Q1	45.0	0.05	0.00	10.0	0.08
5	8/2922A	53.0	0.27	0.02	72.0	0.20
6	8/3134H1	83.0	0.02	0.11	0.2	0.05
7	9/2323G1	52.0	0.03	0.0	15.0	0.02
8	9/2627K1	59.0	0.03	0.0	12.0	0.02
9	9/3018H1	54.0	0.04	0.03	0.5	0.02
10	10/2225F1	62.0	0.03	0.0	9.7	0.02
11	11/2414N1	45.0	0.03	0.0	8.3	0.02
12	11/2634R1	75.0	0.05	0.35	0.0	0.02

WELL #	SODIUM	BICARBONATE	POTASSIUM	CARBONATE	SULFATE	CHLORIDE
1	64.0	206.0	15.0	0.0	.20	9.1
2	64.0	205.0	13.0	0.0	.2	8.6
3	55.0	222.0	11.0	0.0	0.0	9.1
4	49.0	255.0	11.0	0.0	3.8	8.5
5	58.0	184.0	17.0	0.0	512.0	16.0
6	68.0	113.0	8.2	18.0	2.8	22.0
7	38.0	232.0	5.40	0.0	50.0	13.0
8	32.0	158.0	9.0	0.0	54.0	12.0
9	115.0	277.0	11.0	10.0	0.0	15.0
10	16.0	157.0	7.40	0.0	16.0	4.8
11	12.0	109.0	4.5	0.0	15.0	4.2
12	122.0	154.0	0.0	15.0	0.0	81.0

WELL #	FLUORIDE	NITRATE	PHOSPHATE	CALCIUM	BORON	CONDUCTIVITY
1	1.0	0.0	.09	6.2	.13	348.0
2	1.0	.2	.11	6.9	.07	345.0
3	0.9	0.0	.03	16.0	.15	380.0
4	.60	0.0	0.13	26.0	.15	429.0
5	0.40	0.40	0.00	103.0	0.03	1240.0
6	6.39	0.0	0.03	2.10	0.53	327.0
7	0.6	0.3	0.05	44.0	0.07	484.0
8	0.40	0.5	0.03	30.0	0.16	405.0
9	1.8	0.0	0.14	1.9	0.1	506.0
10	0.5	1.10	0.04	29.0	0.02	307.0
11	0.4	0.0	0.09	18.0	0.02	219.0
12	8.5	0.2	0.01	1.0	0.01	597.0

WELL #	PH	TEMPERATURE °F	WELL DEPTH (FT)	SAMPLE DEPTH (FT)
1	8.1	71.6	892.0	155
2	7.9	69.8	633.0	128.0
3	7.4	64.4	768.0	525.0
4	.999	62.24	744.0	493.0
5	7.3	73.4	802.0	295.0
6	9.0	77.72	385.0	130.0
7	7.9	60.8	1148.0	248.0
8	7.8	70.7	670.0	450.0
9	8.6	69.8	1033.0	194.0
10	7.6	68.0	1576.0	1203.0
11	7.5	59.0	407.0	.999
12	8.8	75.2	1000.0	739.0

WELL #	WELL LOCATION	SILICA	IRON	ALUMINUM	MAGNESIUM	MANGANESE
13	11/3011C1	45.0	0.02	0.0	39.0	0.02
14	12/2328Q1	36.0	0.02	0.02	7.9	0.02
15	12/2420N1	56.0	0.08	0.0	11.0	0.05
16	12/2824N1	56.0	0.05	0.14	0.7	0.10
17	13/2425E1	56.0	0.09	0.09	11.0	0.1
18	13/2530G1	56.0	0.07	0.08	8.9	0.05
19	13/2635H1	46.0	0.1	0.1	0.8	0.0
20	13/2813N1	67.0	0.04	0.04	0.4	0.02
21	14/251D1	56.0	0.14	0.02	8.6	0.02
22	14/3136J1	70.0	0.03	0.00	0.3	0.02
23	15/2628Q1	54.0	0.06	0.0	3.3	0.0
24	15/293J1	56.0	0.03	0.0	4.8	0.02
25	DC-2	153.0	0.022	0.050	42.0	0.004

WELL #	SODIUM	BICARBONATE	POTASSIUM	CARBONATE	SULFATE	CHLORIDE
13	21.0	210.0	4.6	0.0	158.0	51.0
14	9.0	93.0	1.8	0.0	11.0	5.1
15	21.0	170.0	7.7	0.0	0.20	3.8
16	94.0	170.0	11.0	8.0	29.0	29.0
17	26.0	180.0	7.3	0.0	0.2	4.4
18	30.0	175.0	8.6	0.0	0.0	4.4
19	79.0	199.0	7.8	10.0	0.0	4.2
20	78.0	182.0	17.0	1.0	19.0	14.0
21	17.0	141.0	11.0	0.0	24.0	5.0
22	72.0	139.0	9.0	10.0	27.0	11.0
23	4.1	139.0	17.0	3.0	24.0	4.3
24	70.0	184.0	13.0	0.0	19.0	14.0
25	181.0	73.0	18.0	26.9	17.4	95.0

WELL #	FLUORIDE	NITRATE	PHOSPHATE	CALCIUM	BORON	CONDUCTIVITY
13	0.04	33.0	0.02	90.0	0.0	843.0
14	0.4	4.1	0.18	18.0	0.06	201.0
15	0.6	0.0	0.02	18.0	0.02	276.0
16	4.2	0.0	0.13	3.7	0.09	468.0
17	0.7	0.0	0.03	18.0	0.09	295.0
18	0.7	0.0	0.03	16.0	0.11	287.0
19	1.0	0.1	0.11	2.1	0.06	344.0
20	2.2	0.0	0.26	0.8	0.12	386.0
21	0.4	0.0	0.03	24.0	0.03	291.0
22	1.7	0.0	0.03	3.1	0.03	352.0
23	0.3	0.2	0.04	3.3	0.04	303.0
24	1.8	0.2	0.06	7.6	0.06	406.0
25	21.0	.999	.999	0.26	.999	840.0

WELL #	PH	TEMPERATURE °F	WELL DEPTH (FT)	SAMPLE DEPTH (FT)
13	7.7	57.2	614.0	40.0
14	7.2	59.72	.999	.999
15	8.0	78.8	1200.0	400.0
16	8.7	66.2	755.0	.999
17	8.0	75.56	777.0	625.0
18	8.1	80.4	1110.0	.999
19	8.6	.999	5661.0	964.0
20	8.6	81.68	1119.0	1029.
21	8.1	79.52	938.0	891.0
22	8.8	77.0	1100.0	.999
23	8.4	.999	892.0	860.0
24	8.2	69.44	905.0	550.0
25	9.9	97.52	3273.0	2253.0

WELL #	WELL LOCATION	SILICA	IRON	ALUMINUM	MAGNESIUM	MANGANESE
26	DC-6	115.0	37.0	50.0	470.0	17.0
27	15/294A1	52.0	0.04	.999	3.50	.999
28	15/3023A1	38.0	0.4	.999	8.5	.999
29	15/321J1	66.0	0.07	.999	2.1	.999
30	17/32681	33.0	0.08	.999	12.0	.999
31	18/3123A1	30.0	0.11	.999	7.2	.999
32	19/3126D1	48.0	0.35	.999	7.3	.999
33	20/3122N1	31.0	2.4	.999	12.0	.999
34	8/242H	50.0	0.12	.999	6.1	.999
35	10/2611D1	51.0	0.68	.999	21.0	.999
36	13/2436D1	64.0	0.03	.999	11.0	.999
37	10/3930H	52.0	0.02	.999	10.0	.999
38	9/31-4N1	50.0	0.04	.999	12.0	.999

WELL #	SODIUM	BICARBONATE	POTASSIUM	CARBONATE	SULFATE	CHLORIDE
26	233.0	22.99	44.0	17.28	85.2	125.0
27	78.0	183.0	12.0	0.0	28.0	15.0
28	36.0	172.0	9.4	0.0	22.0	8.2
29	51.0	160.0	8.8	0.0	10.0	9.0
30	41.0	168.0	12.0	0.0	44.0	8.0
31	55.0	177.0	5.0	0.0	25.0	12.0
32	30.0	152.0	5.9	0.0	46.0	20.0
33	51.0	208.0	14.0	0.0	37.0	10.0
34	54.0	221.0	9.80	0.0	0.1	11.0
35	13.0	176.0	4.8	0.0	43.0	7.5
36	29.0	184.0	6.7	0.0	1.8	5.4
37	8.8	148.0	2.2	0.0	2.2	2.5
38	61.0	158.0	15.0	8.0	86.0	9.5

WELL #	FLUORIDE	NITRATE	PHOPHATE	CALCIUM	BORON	CONDUCTIVITY
26	41.0	.999	.999	1.3	.999	1060.0
27	2.6	0.1	0.0	3.6	.999	397.0
28	0.9	1.2	.999	18.0	.999	339.0
29	1.6	0.9	0.04	10.0	.999	297.0
30	0.5	0.0	.999	16.0	.999	385.0
31	1.6	0.3	.999	0.11	.999	376.0
32	0.50	2.2	.999	40.0	.999	409.0
33	0.5	0.3	.999	18.0	.999	438.0
34	0.9	0.20	0.08	17.0	.999	388.0
35	0.2	4.5	.999	38.0	.999	397.0
36	0.6	0.1	.999	18.0	.999	277.0
37	0.3	2.1	0.3	27.0	.999	247.0
38	0.9	0.1	.999	21.0	.999	480.0

WELL #	PH	TEMPERATURE °F	WELL DEPTH (FT)	SAMPLE DEPTH (FT)
26	10.1	114.8	4336.0	2260.5
27	.999	68.0	560.0	.999
28	8.1	54.0	850.0	414.0
29	8.2	59.0	353.0	334.0
30	8.0	57.0	424.0	.999
31	8.1	60.0	355.0	310.0
32	7.8	53.0	378.0	.999
33	7.9	54.0	500.0	.999
34	7.5	63.0	599.0	530.
35	7.7	74.0	1092.0	936.0
36	7.6	60.0	1250.0	1223.0
37	.999	57.0	343.0	320.0
38	.999	57.0	343.0	320.0

WELL #	WELL LOCATION	SILICA	IRON	ALUMINUM	MAGNESIUM	MANGANESE
39	12/2812H1	53.0	0.88	.999	1.9	.999
40	12/322881	70.0	0.03	.999	6.1	.999
41	13/3124R1	42.0	1.2	.999	12.0	.999
42	14/299A1	59.0	0.02	.999	10.0	.999
43	14/308G1	40.0	0.81	.999	106.0	.999
44	14/313682	45.0	0.04	.999	17.0	.999
45	14/2724C1	63.0	0.0	.999	0.4	.999
46	15/2732E1	54.0	0.29	.999	8.8	.999
47	16/241G1	51.0	0.26	.999	24.0	.999
48	17/2511E1	51.0	0.02	.999	25.0	.999
49	17/2633D1	56.0	0.01	.999	21.0	.999
50	18/2336H1	55.0	0.01	.999	25.0	.999

WELL #	SODIUM	BICARBONATE	POTASSIUM	CARBONATE	SULFATE	CHLORIDE
39	84.0	192.0	16.0	0.0	57.0	9.5
40	29.0	125.0	5.8	0.0	15.0	8.2
41	27.0	168.0	6.4	0.0	17.0	5.2
42	48.0	182.0	7.5	0.0	26.0	13.0
43	42.0	294.0	7.8	0.0	368.0	128.0
44	18.0	158.0	4.6	0.0	23.0	9.5
45	80.0	216.0	26.0	0.0	29.0	12.0
46	26.0	146.0	12.0	0.0	25.0	5.8
47	45.0	252.0	10.0	0.0	69.0	19.0
48	25.0	216.0	2.6	0.0	43.0	6.0
49	29.0	139.0	6.0	0.0	79.0	34.0
50	14.0	170.0	2.4	0.0	35.0	33.0

WELL #	FLUORIDE	NITRATE	PHOSPHATE	CALCIUM	BORON	CONDUCTIVITY
39	1.2	0.2	0.05	7.5	.999	456.0
40	0.9	0.7	.999	12.0	.999	256.0
41	0.5	3.8	.999	22.0	.999	322.0
42	1.0	0.7	.999	15.0	.999	373.0
43	0.3	99.0	.999	140.0	.999	1570.0
44	0.4	13.0	.999	28.0	.999	337.0
45	1.2	0.5	.999	7.0	.999	457.0
46	0.6	0.1	.999	21.0	.999	298.0
47	0.6	0.1	.999	40.0	.999	566.0
48	0.8	0.7	0.06	30.0	.999	432.0
49	0.5	22.0	0.03	45.0	.999	535.0
50	0.7	11.0	0.04	42.0	.999	462.0

WELL #	PH	TEMPERATURE	WELL DEPTH (FT)	SAMPLE DEPTH (FT)
39	8.2	66.0	450.0	450.0
40	8.0	67.0	1057.0	792.0
41	7.8	52.0	537.0	530.0
42	8.0	60.0	860.0	845.0
43	7.9	56.0	371.0	271.0
44	.999	60.0	286.0	286.0
45	8.0	86.0	1396.0	1371.0
46	7.9	62.0	1140.0	982.0
47	7.9	74.0	800.0	727.0
48	7.9	62.0	285.0	233.0
49	7.8	58.0	340.0	264.0
50	7.8	60.0	670.0	526.0

WELL #	WELL LOCATION	SILICA	IRON	ALUMINUM	MAGNESIUM	MANGANESE
51	18/283A1	54.0	0.04	.999	36.0	.999
52	19/247J1	42.0	.999	.999	22.0	.999
53	19/2428N1	55.0	0.03	.999	19.0	.999
54	19/2922C1	35.0	.98	.999	4.5	.999
55	20/2832C1	56.0	0.01	.999	16.0	.999
56	21/2431L1	50.0	0.08	.999	8.7	.999
57	22/2723R1	49.0	0.2	.999	8.1	.999
58	17/181B1	58.0	0.74	.999	9.2	.999
59	26/3132A	43.0	1.1	.999	16.0	.999
60	24/4022L1	.999	0.12	.999	11.0	.999
61	24/413N	51.0	0.02	.999	9.2	.999
62	25/4034	.999	0.04	.999	8.2	.999
63	25/4110G1	42.0	0.05	.999	11.0	.999

WELL #	FLUORIDE	NITRATE	PHOSPHATE	CALCIUM	BORON	CONDUCTIVITY
51	0.5	24.0	0.05	54.0	.999	612.0
52	.999	0.0	.999	34.0	.999	.999
53	0.4	9.6	.999	29.0	.999	340.0
54	0.4	0.3	0.07	11.0	.999	198.0
55	0.2	8.4	.999	26.0	.999	319.0
56	0.7	2.3	0.18	36.0	.999	323.0
57	0.9	0.0	.999	16.0	.999	316.0
58	0.2	0.8	0.25	18.0	.999	197.0
59	0.8	1.7	0.00	28.0	.999	391.0
60	0.2	0.4	.999	29.0	.999	284.0
61	0.2	0.1	.999	21.0	.999	220.0
62	0.3	12.0	.999	30.0	.999	283.0
63	0.3	34.0	.999	30.0	.999	291.0

WELL #	PH	TEMPERATURE °F	WELL DEPTH (FT)	SAMPLE DEPTH (FT)
51	7.8	60.0	126.0	100.0
52	.999	.999	502.0	167.0
53	7.9	.999	210.0	186.0
54	8.1	59.0	352.0	37.0
55	8.0	65.0	725.0	652.0
56	7.5	60.0	407.0	.999
57	8.1	.999	258.0	250.0
58	7.4	54.0	1208.0	232.0
59	7.8	56.0	208.0	.999
60	7.9	56.0	345.0	335.0
61	.999	59.0	410.0	.999
62	7.8	51.0	196.0	180.0
63	7.8	54.0	150.0	115.0

WELL #	WELL LOCATION	SILICA	IRON	ALUMINUM	MAGNESIUM	MANGANESE
64	26/4316F2	11.0	0.01	.999	14.0	.999
65	6/3510P1	72.0	0.03	.999	1.7	.999
66	6/369P1	60.0	0.09	.999	9.8	.999
67	7/3523M1	55.0	0.03	.999	2.1	.999
68	7/3718F1	56.0	0.03	.999	6.5	.999
69	15/4532N2	67.0	0.5	.999	15.0	.999
70	12/1613D1	54.0	0.06	.999	9.7	.999
71	12/1716R1	38.0	0.27	.999	6.6	.999
72	13/1931J1	39.0	0.02	.999	11.0	.999
73	14/1928NE	52.0	0.11	.999	10.0	.999
74	19/3523C1	43.0	0.01	.999	36.0	.999
75	13/3826	67.0	0.01	.999	8.8	.999
76	4623/1915	37.0	.999	.999	11.0	.999

WELL #	SODIUM	BICARBONATE	POTASSIUM	CARBONATE	SULFATE	CHLORIDE
64	3.5	137.0	2.2	0.0	13.0	14.0
65	32.0	126.0	8.6	0.0	3.2	6.5
66	.999	108.0	3.4	0.0	5.7	3.8
67	.999	125.0	7.8	0.0	3.8	3.6
68	9.3	106.0	2.6	0.0	2.5	1.0
69	25.0	207.0	4.4	0.0	4.9	2.0
70	10.0	116.0	1.8	0.0	4.4	3.0
71	7.2	85.0	3.1	0.0	4.4	1.2
72	12.0	116.0	4.8	0.0	21.0	26.0
73	22.0	154.0	4.5	0.0	1.2	4.3
74	23.0	238.0	6.1	0.0	42.0	56.0
75	9.4	140.0	5.8	0.0	2.8	2.0
76	22.0	.999	6.0	.999	41.0	24.0

WELL #	FLUORIDE	NITRATE	PHOSPHATE	CALCIUM	BORON	CONDUCTIVITY
64	0.0	5.0	0.05	34.0	.999	291.0
65	0.7	0.0	0.0	12.0	.999	226.0
66	0.6	0.4	.999	16.0	.999	186.0
67	0.6	0.1	.999	11.0	.999	214.0
68	0.2	0.2	.999	17.0	.999	169.0
69	0.4	0.1	0.05	22.0	.999	319.0
70	0.2	1.6	.999	16.0	.999	194.0
71	0.3	0.2	.999	12.0	.999	136.0
72	0.3	6.0	.999	34.0	.999	320.0
73	0.5	0.2	.999	17.0	.999	246.0
74	0.2	47.0	0.00	63.0	.999	694.0
75	0.5	1.0	.999	24.0	.999	227.0
76	0.4	.999	0.12	40.0	.999	395.0

WELL #	PH	TEMPERATURE °F	WELL DEPTH (FT)	SAMPLE DEPTH (FT)
64	8.1	53.0	268.0	238.0
65	8.2	75.0	1145.0	1135.0
66	.999	64.0	2061.0	.999
67	.999	68.0	515.0	463.0
68	8.0	56.0	1169.0	.999
69	7.7	58.0	954.0	.999
70	7.7	.999	146.0	130.0
71	7.9	63.0	1078.0	1035.0
72	7.3	.999	84.0	75.0
73	7.9	66.0	590.0	.999
74	8.2	60.0	460.0	.999
75	7.6	68.0	243.0	217.0
76	7.9	17.1	80.0	.999

WELL #	WELL LOCATION	SILICA	IRON	ALUMINUM	MAGNESIUM	MANGANESE
77	4630/1930	62.0	.999	.999	12.0	.999
78	4630/1932	46.0	.999	.999	12.0	.999
79	4631/1926	43.0	.999	.999	11.0	.999
80	4639/1934	31.0	.999	.999	9.6	.999
81	DC14M1	26.1	0.048	0.036	0.26	0.02
82	DC14GR	48.5	0.12	0.13	0.09	0.27
83	DC6GR	50.0	0.2	0.07	0.012	0.02
84	DC15GR	39.34	1.007	0.188	0.147	0.10
85	DC15LI	25.5	0.12	0.01	3.84	0.06
86	DC14EM	27.8	0.17	0.06	1.78	0.02

WELL #	SODIUM	BICARBONATE	POTASSIUM	CARBONATE	SULFATE	CHLORIDE
77	16.0	.999	6.0	.999	22.0	3.4
78	20.0	180.00	5.1	0.0	34.0	7.0
79	31.0	130.0	6.9	0.0	58.0	11.0
80	15.0	140.0	5.1	0.0	47.0	4.3
81	79.6	123.56	12.7	22.56	29.1	11.8
82	325.0	51.06	8.1	18.03	135.5	237.9
83	310.2	56.23	6.7	19.40	190.6	166.1
84	276 0	89.52	4.01	3.79	171.99	210.29
85	61.3	202.06	12.4	0.84	0.5	11.3
86	58.3	.999	9.95	.999	28.1	5.7

WELL #	FLUORIDE	NITRATE	PHOSPHATE	CALCIUM	BORON	CONDUCTIVITY
77	0.4	.999	0.03	32.0	.999	325.0
78	0.6	.999	0.15	40.0	.999	392.0
79	0.7	.999	0.12	37.0	.999	440.0
80	0.5	.999	0.09	35.0	.999	322.0
81	1.5	0.0	4.1	7.03	0.042	396.0
82	47.1	0.0	0.0	4.52	1.35	1543.0
83	42.2	0.5	0.5	1.66	1.21	1539.0
84	22.74	0.0	0.0	2.21	0.76	1340.0
85	1.2	0.5	0.5	10.7	0.05	364.1
86	1.0	0.5	0.5	9.0	0.05	.999

WELL #	PH	TEMPERATURE °F	WELL DEPTH (FT)	SAMPLE DEPTH (FT)
77	7.9	20.5	680.0	.999
78	8.0	18.1	308.0	.999
79	8.0	19.4	212.0	.999
80	8.1	16.5	164.0	.999
81	9.44	63.86	969.0	969.0
82	9.72	57.56	3180.0	3180.0
83	9.71	61.7	2992.0	2992.0
84	8.8	91.04	3301.0	3301.0
85	7.8	62.6	284.0	284.0
86	8.3	66.02	393.0	393.0

APPENDIX B

WELL #	FACTOR 1	FACTOR 2	FACTOR 3
1	-.211770	.403738	-.608809
2	-.258815	.304946	-.560237
3	-.399712	.019576	-.265459
4	999.000000	999.000000	999.000000
5	.337958	.001976	3.139688
6	.758580	.487525	-1.190757
7	-.210408	-.242975	.297179
8	-.337726	.137939	.017157
9	.628030	.106990	-.811169
10	-.578391	.138733	-.135892
11	-.579503	-.256693	-.231488
12	1.466692	-.198184	-.845783
13	-.056641	-.510599	2.386029
14	999.000000	999.000000	999.000000
15	-.466874	.286450	-.456455

WELL #	FACTOR 1	FACTOR 2	FACTOR 3
16	.654551	.060678	-.655289
17	-.423648	.219844	-.432108
18	-.394450	.328083	-.512302
19	999.000000	999.000000	999.000000
20	.077643	.712092	-.788164
21	-.452542	.389405	-.322080
22	.423934	.359635	-.901901
23	999.000000	999.000000	999.000000
24	-.046552	.265274	-.483347
25	999.000000	999.000000	999.000000
26	999.000000	999.000000	999.000000
27	999.000000	999.000000	999.000000
28	-.241775	-.204413	-.166941
29	-.191257	.119492	-.517397
30	-.217061	-.158901	-.102945
31	-.010563	-.431207	-.389807
32	-.260998	-.366659	.294125
33	-.249735	.009394	-.000363
34	-.355905	-.010528	-.256799

WELL #	FACTOR 1	FACTOR 2	FACTOR 3
35	999.000000	999.000000	999.000000
36	-.513304	.248577	-.412646
37	-.596650	-.244700	-.132396
38	999.000000	999.000000	999.000000
39	.013800	.309244	-.329956
40	-.370776	.176221	-.494371
41	-.427499	-.217319	-.017049
42	-.190069	-.015935	-.272697
43	.617431	-.430439	5.901627
44	999.000000	999.000000	999.000000
45	-.195226	1.027173	-.543170
46	-.442740	.182628	-.236704
47	-.156162	.123911	.324006
48	-.295909	-.224263	.104136
49	-.211060	-.191681	.979943
50	-.290490	-.257649	.543894
51	-.264522	-.213095	1.185614
52	999.000000	999.000000	999.000000
53	999.000000	999.000000	999.000000

WELL #	FACTOR 1	FACTOR 2	FACTOR 3
54	-.357398	-.350745	-.396643
55	-.442684	.003507	.009974
56	-.498776	-.304747	.159891
57	999.000000	999.000000	999.000000
58	-.683706	-.192621	-.266907
59	-.324022	-.300140	.079511
60	999.000000	999.000000	999.000000
61	999.000000	999.000000	999.000000
62	999.000000	999.000000	999.000000
63	-.583018	-.367889	.712295
64	-.326240	-.803243	.233474
65	-.376114	.415301	-.662572
66	999.000000	999.000000	999.000000
67	999.000000	999.000000	999.000000
68	-.502360	-.200840	-.419465
69	-.510130	.032947	-.246606
70	999.000000	999.000000	999.000000
71	-.530914	-.265613	-.439740
72	999.000000	999.000000	999.000000
73	-.451156	-.053691	-.386875