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DEPARTMENT OF ENERGY, MINES AND RESOURCES

GROUNDWATER GEOCHEMISTRY, UPPER NOTUKEU CREEK BASIN, SASKATCHEWAN

(Report and 7 figures)

M. L. Parsons

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ABSTRACT

Groundwater in the upper Notukeu Creek basin consists basically of four chemical types, which are correlated to sediments within the Upper Cretaceous, Tertiary, and Pleistocene strata. Depending on the predominant ions present, these chemical types are calcium-magnesium sulphate, calcium-magnesium bicarbonate, sodium bicarbonate, and sodium sulphate.

The significant geochemical processes are solution of carbonates and sulphates and cation exchange. The effect of these processes on the genesis of the chemical character of the groundwater is best understood by considering groundwater movement.

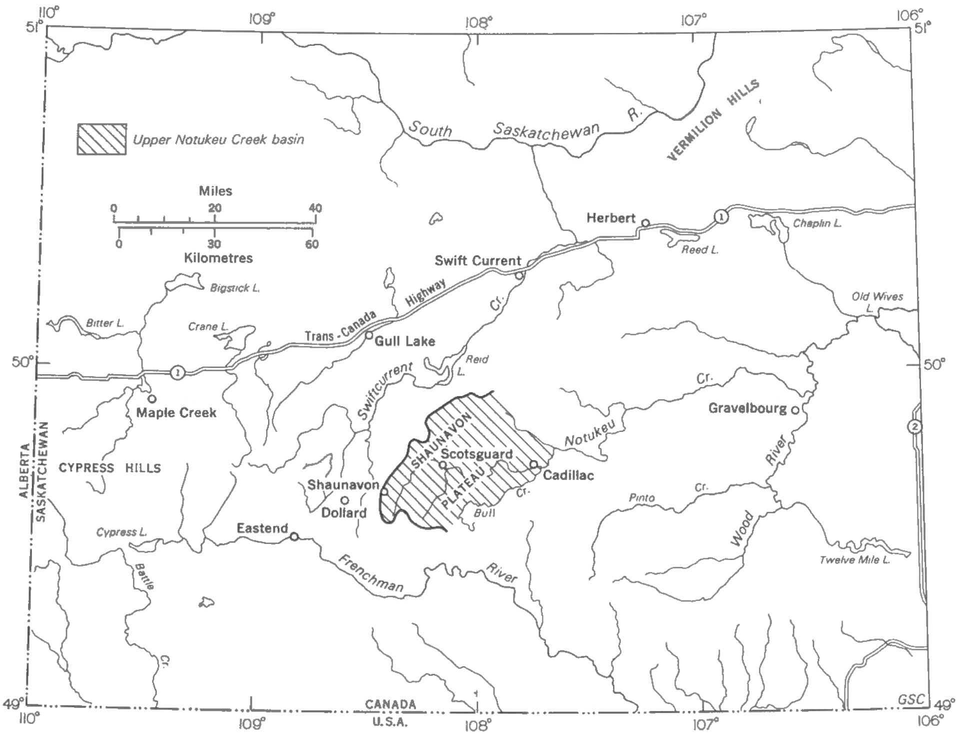

Figure 1. Location of upper Notukeu Creek basin, southwestern Saskatchewan.

GROUNDWATER GEOCHEMISTRY, UPPER NOTUKEU CREEK BASIN, SASKATCHEWAN

INTRODUCTION

Description of Area

The upper Notukeu Creek basin comprises the western part of the Old Wives Lake internal drainage basin in southwestern Saskatchewan (Fig. 1). The area lies within the bounds of townships 7 to 11, ranges 13 to 18, west of the 3rd meridian. The north and west boundaries of the irregularly shaped area are defined by the drainage divide between Notukeu Creek and Swift Current Creek; the southwest boundary is along the drainage divide between Notukeu Creek and Frenchman River. Bull Creek, a tributary of Notukeu Creek, was arbitrarily chosen as the southeast boundary and an unnamed tributary as the northeast boundary.

The area lies on the Shaunavon Plateau (Kupsch, 1955), which is situated in the eastern Cypress Hills Upland as defined by Acton et al. (1960). The Shaunavon Plateau has been dissected by Notukeu Creek and the resulting remnants form the main topographic features of the area. From an elevation of 3,350 feet south of Notukeu Creek the plateau slopes gently northeastward to 3,000 feet north of Notukeu Creek. The lowlands along Notukeu Creek reach a minimum elevation of less than 2,500 feet near the town of Cadillac (Fig. 1).

Drainage to the east is provided by Notukeu Creek and its tributaries, all of which are intermittent streams.

Present Study

The present study was initiated during the summer of 1963 while the writer was a member of a Geological Survey of Canada field party, under the supervision of R.A. Freeze, investigating the groundwater conditions of the Old Wives Lake drainage basin.

The purpose of the present study was to describe the chemistry of the groundwater of the upper Notukeu Creek basin in terms of the common anions and cations, to outline the geological factors and geochemical processes that influence the chemistry, and to consider the origin of the groundwater as reflected in its chemistry.

Field work consisted primarily of collecting water samples from wells throughout the area. Hach kit analyses and conductivity measurements, completed in the field, were used as a basis to select sixty representative samples for detailed chemical analysis.

The only previous investigation of the groundwater conditions in the upper Notukeu Creek basin was a water-well inventory compiled by the Geological Survey of Canada (MacKay, Beach, and Goodall, 1936a and 1936b; MacKay, Beach, and Johnson, 1936a and 1936b). The information of this inventory is available in mimeographed form as a water-supply paper for each municipality. Nine detailed chemical analyses contained in these papers (Water-Supply Papers 39, 89, and 118) are incorporated in the present study.

Acknowledgments

This paper presents the basic data and results of an M.Sc. thesis done by the writer while a graduate student at the University of Saskatchewan. Thanks is due to Professor T.E.W. Nind for his valuable supervision during the preparation of the thesis. Dr. W.O. Kupsch of the University of Saskatchewan offered helpful advice concerning the geology, and Mr. A. Rutherford of the Saskatchewan Research Council contributed to instructive discussions of various chemical problems.

STRATIGRAPHY

General Remarks

The aim of the following discussion of the stratigraphy is to outline the geological model in sufficient detail to determine, as satisfactorily as possible, the source of each of the groundwater samples, and to appraise those lithologic constituents that appear to contribute significantly to the chemistry of the groundwater.

Field study of the geology is possible only to a very limited degree, as outcrops are confined to a few roadcuts and valley bluffs where erosion has exposed the bedrock. Drillers' logs of water wells and water-well records compiled by the Geological Survey of Canada (MacKay, Beach, and Goodall, 1936a and 1936b; MacKay, Beach, and Johnson, 1936a and 1936b) were used as an aid in mapping the bedrock topography (Fig. 2), although these data have only limited value in a stratigraphic study. For these reasons the stratigraphy described below is based primarily on the previous geological work of others.

The bedrock geology is superimposed on the bedrock topography in Figure 2. Distribution of the bedrock formations was initially derived by extending eastward contacts that had previously been mapped in the Dollard area (Kupsch, 1956). Subsequent comparison of water analyses indicated an apparent correlation of chemical composition of the groundwater to the bedrock formations. On the basis of this correlation minor adjustments to the distribution of the formations shown on Figure 2 were made where it was felt that the need to account for the chemical composition of a groundwater sample could reasonably justify such adjustments.

The area is underlain by Upper Cretaceous and Tertiary strata, which appear to dip slightly to the northeast. Attitude determinations by Kupsch (1956, p. 28) on the Ferris coal seam indicated a dip of about 15 feet per mile in an easterly direction.

Upper Cretaceous Rocks

Bearpaw Formation

The Bearpaw Formation was defined by Furnival (1950, p. 39) as "the dark-coloured marine shales and minor intercalated marine and non-marine sandstones lying between the Oldman and Eastend formations". It is the oldest formation underlying the glacial drift in the upper Notukeu Creek basin and is exposed in a few places along creeks in the eastern part of the area.

The best exposure of the Bearpaw observed by the writer, lies 3 miles south of the town of Cadillac in N.E. 1/4 sec. 29, tp. 8, rge. 13, W 3rd meridian (Fig. 2). The outcrop comprises 45 feet of arenaceous shale, overlain by a bed of bentonite, 6 inches thick, and 10 feet of argillaceous, very fine, friable sandstone. Numerous, large (3 feet diameter), spherical sandstone concretions coated with gypsum crystals are present in the sandstone. The lower shale unit contains argillaceous carbonate lenses and nodules with numerous calcite-filled fractures. One such nodule contained Baculites, a characteristic Bearpaw fossil. Other small Bearpaw outcrops consist of rusty brown weathered, fractured, grey shale, which commonly contains abundant gypsum crystals.

In the Dollard area, the Bearpaw consists of dark grey shales with many large, round, calcareous, sideritic concretions, and the formation becomes sandy in the upper part (Kupsch, 1956, p. 6).

Clay mineral analyses of Bearpaw shale in the Swift Current area indicated a predominance of montmorillonite (Christiansen, 1959, p. 44). Unoxidized shale contained 75 per cent montmorillonite and 25 per

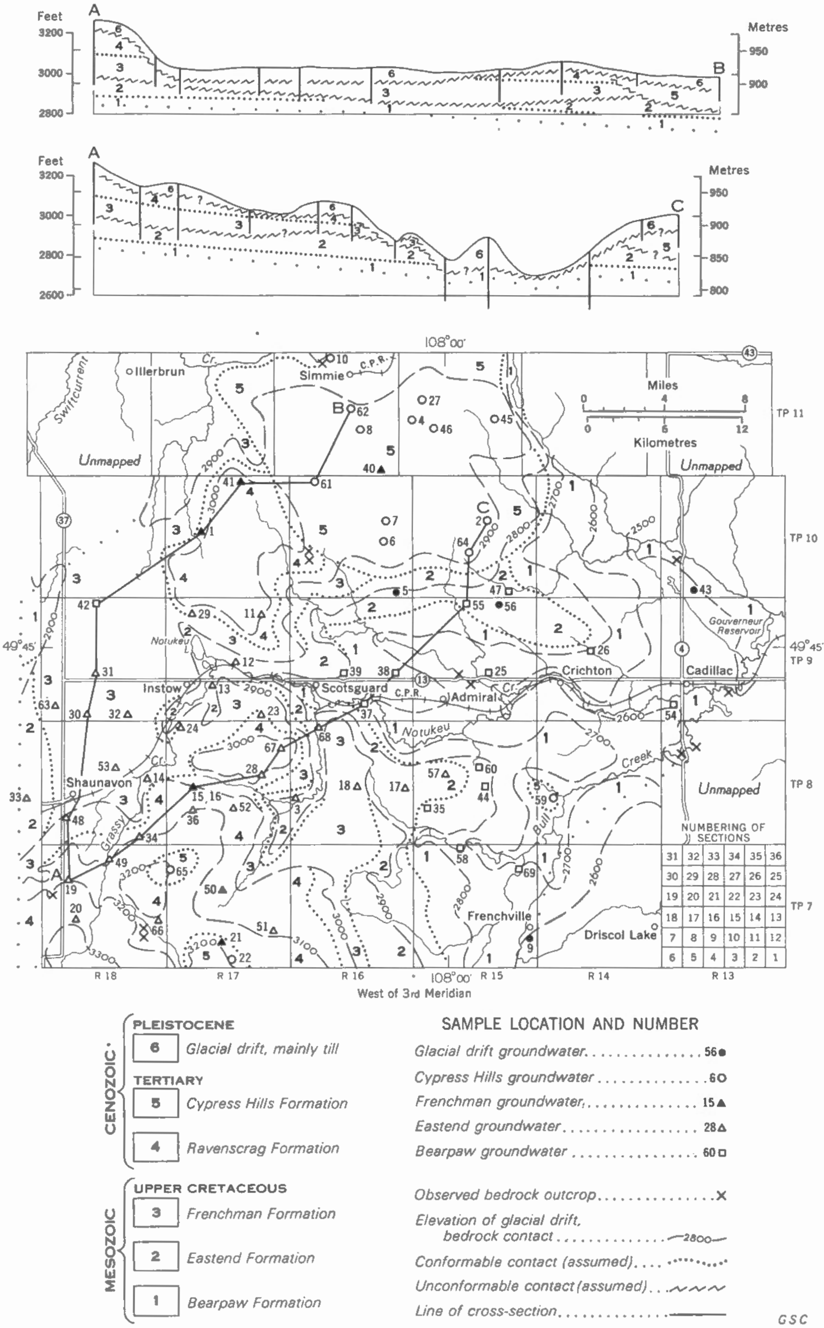

Figure 2. Bedrock geology of the upper Notukeu Creek area, southwestern Saskatchewan.

cent illite, and oxidized shale contained 85 per cent montmorillonite and 15 per cent illite. Hamilton (1962, p. 41) found that montmorillonite comprises the bulk of the clay minerals of Bearpaw sediments in the South Saskatchewan River valley. He attributed the dominance of montmorillonite to extensive volcanic activity in the source area of the Bearpaw sediments. Such volcanism may have contributed substantially to the sulphate content of the Bearpaw Formation.

The thickness of the Bearpaw is unknown in the upper Notukeu Creek basin, but in the Cypress Hills area it is estimated to be about 1,000 feet (Furnival, 1950, p. 40).

Eastend Formation

The type locality of the Eastend Formation is near the town of Eastend (Fig. 1). Kupsch (1956, p. 7) proposed as a type section an outcrop in Murphy's clay pit (Lsd. 6, sec. 25, tp. 6, rge. 22, W 3rd) southwest of the town of Eastend, where the formation is 80 feet thick. The formation consists of greyish yellow fine-grained sand with a high content of silt and clay. The sands are well sorted, commonly calcareous and low in carbonaceous material. No outcrop was observed in the upper Notukeu Creek basin, but reports of recovery of fine sand from many water wells suggest the presence of the sandy Eastend beds. It is assumed that the general lithological characteristics of the formation persist eastward from the type section in the Dollard area.

Only a few fossils have been collected from the formation and these indicate a marine origin (Kupsch, 1956, p. 7).

Both lower and upper contacts of the Eastend are transitional. The eastern edge of the Eastend Formation has been truncated by post-Paleocene and post-Oligocene erosion (Fig. 2). Truncation to the north and northwest is due, in part, to erosion prior to deposition of the overlying Frenchman Formation (Kupsch, 1956, Pl. 2).

Frenchman Formation

The Frenchman Formation in the eastern Cypress Hills comprises "all strata lying above the Whitemud and below the Ferris coal seam" (Kupsch, 1956, p. 19). The Whitemud appears to be absent in the upper Notukeu Creek basin, and the Frenchman unconformably overlies older Eastend and Bearpaw sediments (Fig. 2).

Two facies compose the Frenchman in the eastern Cypress Hills. The sand facies is a fine to medium grained 'salt and pepper' sand with local indurated masses, well cemented by calcium carbonate. Plant material, thin lignite stringers, and fossils of non-marine animals are common. The clay facies is described as greyish green and bluish bentonitic clay with some fine-grained sand beds. No outcrop of the Frenchman was observed in the upper Notukeu Creek basin, but it is assumed that the lithology is similar to that in the Cypress Hills.

The thickness of the Frenchman is expected to be variable owing to the unconformable nature of its lower contact. Kupsch (1956, p. 10) indicated a representative thickness of 200 feet. A maximum thickness of 130 feet is shown in the geologic cross section A-B (Fig. 2).

Post-Paleocene and post-Oligocene erosion has confined the Frenchman Formation to the western part of the upper Notukeu Creek basin (Fig. 2).

Tertiary Rocks

Ravenscrag Formation

The Ravenscrag Formation of Paleocene age was designated by Furnival (1950, p. 106) to include "the thick non-marine series of finely bedded and interbedded, grey and buff shales, silts, fine sands, lignitic laminae and coal seams that overlie the Frenchman formation and are overlain unconformably by the Cypress Hills formation". The lower boundary is placed at the bottom of the Ferris coal seam in the Dollard area (Kupsch, 1956, p. 22).

Fraser *et al.* (1935, p. 45) subdivided the Ravenscrag (which they referred to as the Upper Ravenscrag) into a lower grey facies and an upper buff facies. Kupsch (1956, p. 23) described a cyclic sedimentation in the lower grey facies consisting of very fine grained sand or silt, overlain in turn by underclay, a lignite seam, and interbedded clays and silts. The upper buff facies consists of silts or very fine grained sands.

Several outcrops believed to belong to the Ravenscrag Formation were observed by the writer in the upper Notukeu Creek basin (Fig. 2). In general they consist of brownish grey and grey shale with abundant carbonaceous plant fragments, and thin lignite stringers.

Kupsch (1956, p. 10) indicated a representative thickness of 310 feet for the Ravenscrag. Its maximum thickness in the upper Notukeu Creek basin is thought to be approximately 120 feet where it underlies the Shaunavon Plateau south of Notukeu Creek (Fig. 2).

Because coal is very common in the Ravenscrag, its presence as reported by many drillers and well owners, is a good indicator of this formation. The writer used this criterion in determining the areal extent of the formation.

Cypress Hills Formation

The Cypress Hills Formation of Oligocene age is the youngest bedrock formation in the upper Notukeu Creek basin. In the Dollard area it consists of hard conglomerates and sandstones, soft coarsely grained sands and some clays (Kupsch, 1956, p. 28). An outcrop on the south bluff of Swift Current Creek (N.E. 1/4, sec. 33, tp. 11, rge. 16, W 3rd) consists of hard, medium-grained, calcareous, light brown sandstone. Underlying this resistant bed is a conglomerate consisting of well rounded, oval-shaped pebbles and cobbles up to 6 inches, with a calcareous medium-grained sandstone matrix.

Fossils of non-marine animals are well preserved in the Cypress Hills sediments, which are believed to have been deposited in a freshwater fluviatile environment (Furnival, 1950, p. 120).

The thickness of the Cypress Hills Formation is unknown in the upper Notukeu Creek basin, but a thickness of 160 feet was measured by Kupsch (1956, p. 24) in the eastern Cypress Hills. At the base of the formation is an unconformity. Cypress Hills sediments appear to overlie all other formations in the area (Fig. 2).

The formation underlies the Shaunavon Plateau north of Notukeu Creek. Its presence in small patches on the bedrock upland south of Notukeu Creek and in the bedrock lowland on Bull Creek (sec. 18, tp. 8, rge. 14, W 3rd) is postulated on the observed chemical characteristics of the groundwater. Three samples (Nos. 22, 59, and 65, on Table I) collected from these areas are chemically similar to groundwater derived from the Cypress Hills Formation north of Notukeu Creek. While outliers of Cypress Hills Formation can be expected to occur on the bedrock uplands the same is not true for the lowlands. The gravel, which is reported to underlie the Bull Creek location at a depth of 35 feet, may therefore be a younger, preglacial stream deposit consisting of reworked Cypress Hills gravel. The writer does not wish to imply that the observed chemical composition is representative only of the Cypress Hills Formation; he does, however, suggest that in the upper Notukeu Creek basin it is reasonable to predict the presence of the Cypress Hills Formation on the basis of the chemical composition of the groundwater.

Pleistocene Sediments

The glacial geology was not studied, but an interpretation of soil maps (Mitchell et al., 1944) indicates that the glacial sediments are primarily till. In the Swift Current area Christiansen (1959, p. 31) described three till sheets of Wisconsin age. The tills are lithologically similar, being calcareous, montmorillonitic clay loam, and are separated by stratified drift. Production of water from the glacial drift is rare in areas underlain by bedrock aquifers, especially where the Cypress Hills and Eastend Formations are present. However, the fact that some water is produced from drift overlying the Bearpaw Formation suggests the presence of sand and gravel in the till.

The glacial drift is generally thin, probably not exceeding 100 feet, especially on uplands. The bedrock surface approximately parallels the present surface.

THE GROUNDWATER FLOW SYSTEM

General Remarks

The continuous movement of groundwater must necessarily result in progressive and related changes in its chemical composition. The variable composition of the flow medium and the duration and length of contact of groundwater with this medium influence the magnitude of these chemical changes. Several geologic formations consisting of a variety of lithologies are present in the upper Notukeu Creek basin, and so a knowledge of the flow system is essential to explain certain chemical changes of the groundwater there.

Groundwater flow systems may be of a local nature centred around depressions such as those of knob and kettle topography, or they may be of a regional type. Some local flow systems may be transitory, or occur only during certain months of the year (Meyboom, 1962, p. 11). Consideration of the significance of such transitory local flow systems on the chemical composition of groundwater is beyond the scope of this discussion, which is limited to an attempt to outline the general regional flow system on the basis of somewhat limited field observations and analogy to other areas.

Groundwater Discharge Areas

Regional groundwater discharge areas in the upper Notukeu Creek basin are characterized by the occurrence of alkali soils. Such soils have a distinctive white colour, due mainly to the concentration of sodium sulphate, which takes place at the surface in dry periods (Meyboom, 1962, p. 13). 'Black Alkali' soils also occur, owing to the presence of sodium carbonate (Mitchell et al., 1944, p. 177). No distinction between 'White Alkali' and 'Black Alkali' was made in mapping discharge areas of the upper Notukeu Creek basin. However, studies of the distribution of the two types of alkali soils should reveal an interesting correlation with the chemistry of the underlying groundwater.

Alkali soils may occur in well drained valleys such as Notukeu Creek, as well as in poorly drained, flat, topographically low areas such as that east of the town of Shaunavon (Fig. 3). The term 'playa' is applied to poorly drained alkaline areas ranging in size from the smallest depression to large topographically low areas covering many square miles (Meyboom, 1962, p. 13).

Distinctive alkali-tolerant vegetation is associated with alkali soils. Characteristic plants in this area were identified as Sarcobatus vermiculatus, Suaeda depressa, Distichlis stricta, and Salicornia rubera (John Hudson, personal communication). Meyboom (1962, p. 13) noted these species (except Sarcobatus vermiculatus) growing under similar conditions in south-central Saskatchewan.

The origin of alkali soils is due to ascending and evaporating groundwater rather than to the decomposition of saline parent material (Meyboom, 1962, p. 14). Their occurrence in both well drained and poorly drained areas indicates that the potential evapotranspiration is greater than the rate of groundwater discharge. Springs and seepages occur where the rate of groundwater discharge exceeds the potential evapotranspiration.

Description of the Flow System

It is suggested that the groundwater flow system of the upper Notukeu Creek basin is analogous to flow systems described by Meyboom (1962) in south-central Saskatchewan. Recharge of groundwater occurs in the uplands of the Shaunavon Plateau where groundwater movement is essentially downward through the low permeability glacial drift, the Ravenscrag, and parts of the Frenchman and Cypress Hills Formations. Since the Eastend sands, the sand facies of the Frenchman, and the coarse sediments

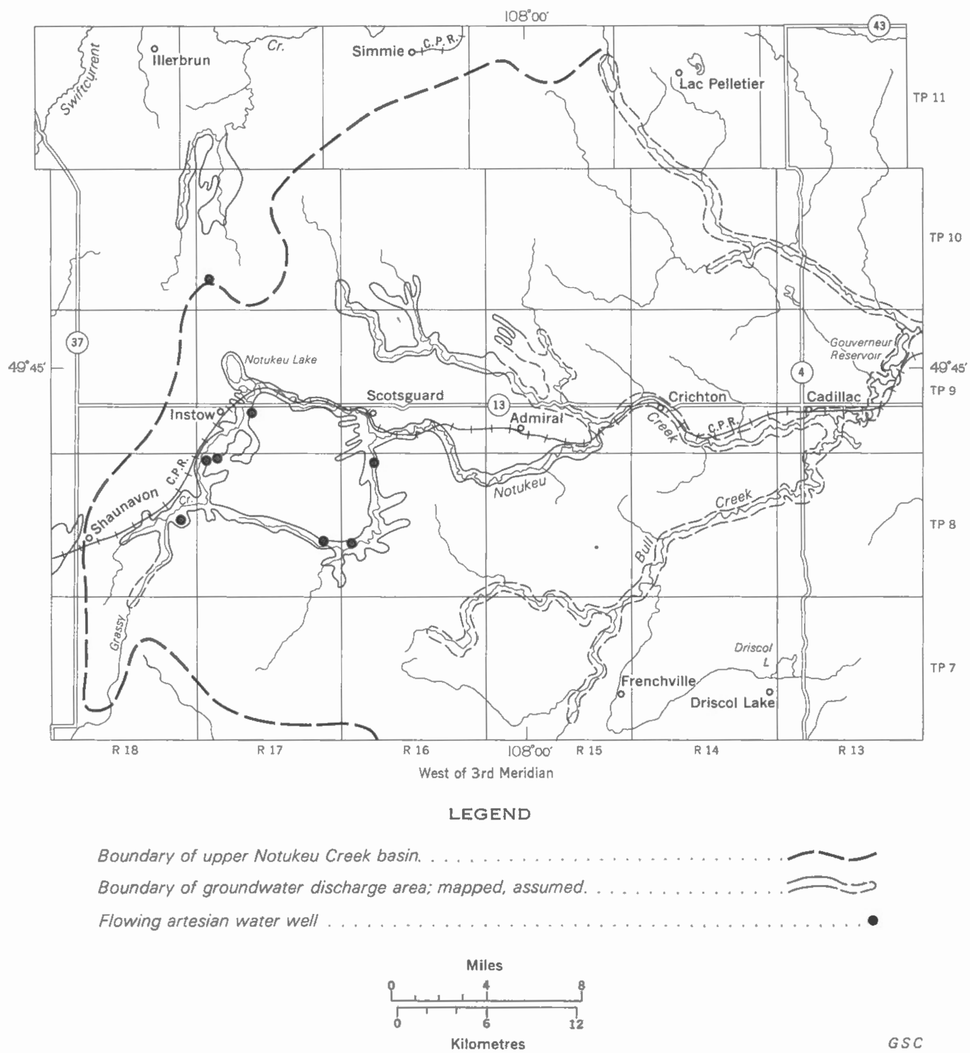

Figure 3. Major groundwater discharge areas, Notukeu Creek area, southwestern Saskatchewan.

of the Cypress Hills are relatively permeable, considerable refraction of the groundwater flow towards the horizontal undoubtedly takes place in the manner put forth by Hubbert (1940, p. 844). However, it is possible that the flow system of the upper Notukeu Creek basin penetrates deeply into the Bearpaw Formation, as suggested in Figure 4.

Lateral flow and upward leakage in permeable zones, primarily of the Eastend Formation, must occur near discharge areas underlain by these permeable zones. This is indicated by flowing water wells producing from the Eastend Formation in the discharge areas along Grassy Creek and along a Notukeu Creek tributary south of the village of Scotsguard (Fig. 3).

CHEMICAL DESCRIPTION OF GROUNDWATER IN THE UPPER NOTUKEU CREEK BASIN

General Remarks

The most common and abundant dissolved constituents of groundwater are the ions of sodium, potassium, calcium, magnesium, carbonate, bicarbonate, sulphate, and chloride. These constituents are present in varying amounts in groundwater of the upper Notukeu Creek basin area. In determining the origin of these constituents and the geochemical processes of mineralization, it is necessary to consider both absolute concentrations of ions and relative values.

Sampling of the groundwater was carried out with the aim of obtaining samples representative of the upper Notukeu Creek basin from the various geologic formations. The samples were obtained primarily from farmers' water wells, and therefore the distribution of the samples both areally and geologically is purely random. The location of the samples and their geologic source is shown in Figure 2.

Water samples were collected in glass or plastic quart-size containers. Two containers of water were obtained at each location, the contents of one being subjected to a hach kit analysis performed in the field, while the second container was stored for a possible future detailed chemical analysis. Sixty groundwater samples were selected for such detailed analyses and the results of the chemical analyses as well as the relevant data of each water well is set out in Table I.

Initial inspection and comparison of the water analyses was accomplished by means of chemical patterns similar to the method outlined by Stiff (1951). The chemical pattern of a water analysis is obtained by plotting the ionic concentrations expressed in equivalents per million (Table II) on a grid as illustrated in Figure 5.

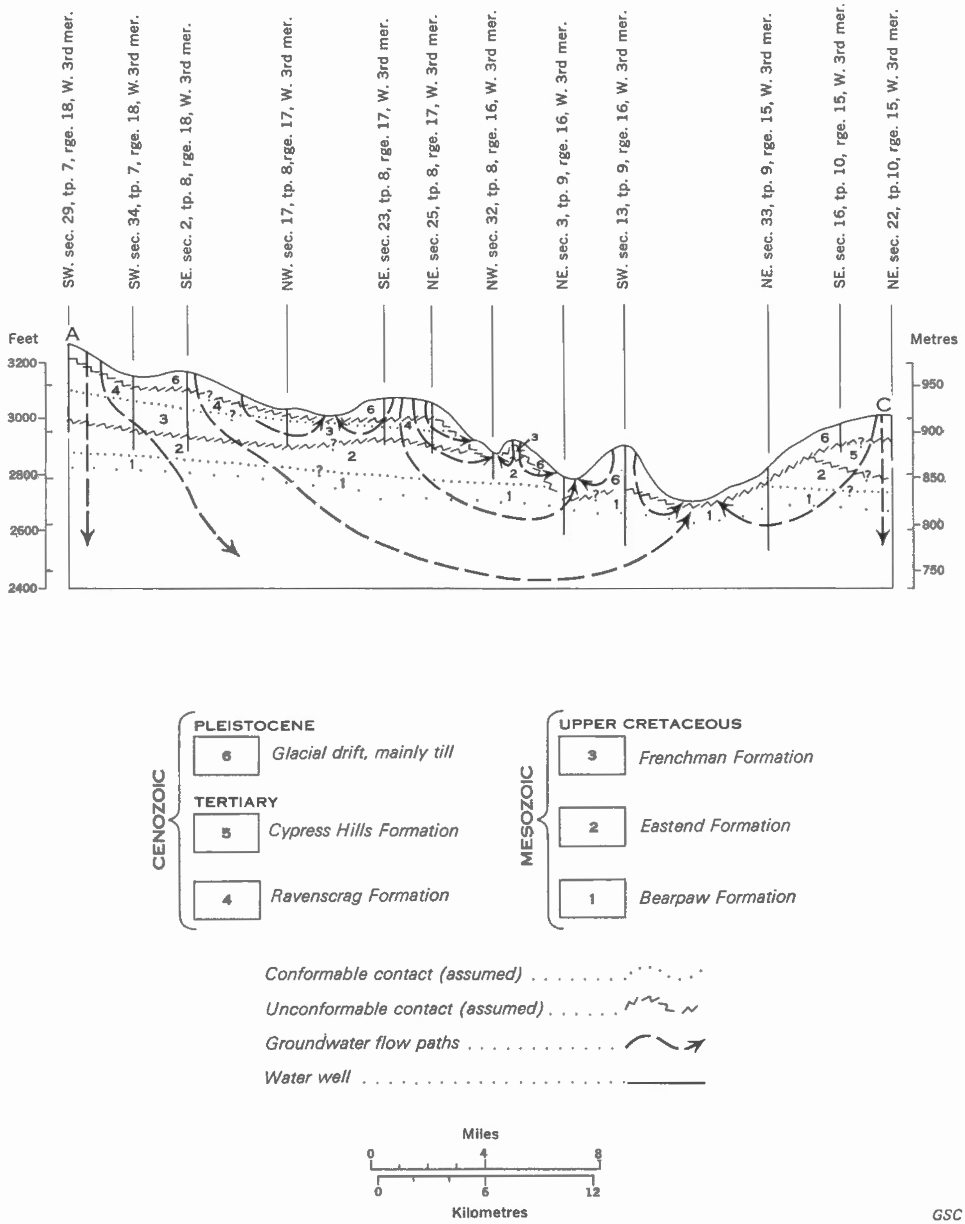

Figure 4. Geological cross-section showing generalized pattern of groundwater flow. For location of section see Figure 2.

TABLE I
CHEMICAL ANALYSES OF GROUNDWATER SAMPLES

Sample No.	Location* ¼ sec T. R.	Elevation of well	Depth of well (ft)	Source Formation	Chemical Constituents (ppm) Ca	Mg	Na	K	Cl	SO_4	HCO_3	CO_3	Alkalinity as ppm $CaCO_3$	Total Dissolved solids (ppm)
1	SE 20 10 17	3000	150	Frenchman?	43	17	175	-	0	165	484	0	395	655
2	NE 22 10 15	2995	150	Cypress Hills	38	23	9	-	0	8	248	0	195	215
3	SW 18 8 16	2935	65	Eastend	15	7	310	-	7	150	755	0	620	880
4	NE 18 11 15	3060	114	Cypress Hills	14	50	55	-	6	78	336	0	275	370
5	SW 1 10 16	2860	65	Drift	445	875	110	-	160	4080	390	0	320	5880
6	NE 14 10 16	3035	60	Cypress Hills	38	23	32	-	14	36	375	0	225	290
7	NE 23 10 16	3000	80	Cypress Hills	58	32	17	-	7	33	360	0	295	345
8	SW 14 11 16	3010	140	Cypress Hills	47	34	12	-	7	38	295	0	240	300
9	SE 12 7 15	2850	40	Drift	136	72	96	-	34	537	287	0	235	1140
10	NE 33 11 16	2675	0	Cypress Hills	43	25	13	-	7	27	270	0	220	265
11	SE 35 9 17	3045	260	Eastend	31	19	295	-	7	215	630	0	515	895
12	NW 15 9 17	2950	110	Eastend	7	3	345	-	14	210	655	0	535	920
13	NW 9 9 17	2940	105	Eastend	14	7	355	-	7	230	794	0	650	1030
14	SW 24 8 18	3000	55	Eastend	17	7	385	-	0	245	800	0	655	1070
15	NW 17 8 17	3035	130	Frenchman?	46	36	215	-	7	190	690	0	565	875
16	NW 17 8 17	3010	0	Frenchman?	92	54	140	-	0	215	675	0	555	850
17	NE 13 8 16	2965	90	Eastend	45	38	160	-	7	250	460	0	375	750
18	NW 15 8 16	2960	70	Eastend	48	21	90	-	7	85	425	0	350	475
19	SW 29 7 18	3255	305	Eastend	4	3	260	-	7	155	435	23	370	665
20	SE 17 7 18	3345	350	Eastend	8	4	320	-	7	190	575	12	475	835

Table I (cont.)

Sample No.	Location* ¼ sec T. R.	Elevation of well	Depth of well (ft)	Source Formation	Chemical Constituents (ppm) Ca	Mg	Na	K	Cl	SO_4	HCO_3	CO_3	Alkalinity as ppm $CaCO_3$	Total Dissolved solids (ppm)
21	SE 9 7 17	3230	200	French-man?	60	38	195	-	7	145	755	0	620	830
22	SE 3 7 17	3245	?	Cypress Hills?	64	48	42	-	7	25	535	0	440	460
23	SE 2 9 17	3005	120	Eastend	94	60	130	-	7	245	640	0	525	870
24	NE 31 8 17	2945	70	Eastend	16	6	345	-	7	285	625	13	520	985
25	SE 15 9 15	2690	65	Bearpaw	14	17	819	-	34	1080	885	0	725	2400
26	SE 21 9 14	2690	45	Bearpaw	173	168	1950	-	62	4400	860	0	705	7175
27	NW 20 11 15	3080	290	Cypress Hills	39	24	9	4	0	11	261	0	214	220
28	SE 23 8 17	3060	150	Eastend?	10	8	315	7	7	190	648	19	540	870
29	SE 32 9 17	3010	160	Eastend	23	13	330	7	11	290	592	0	485	985
30	SW 4 9 18	3040	155	Eastend	8	4	380	3	7	280	594	31	505	1000
31	SE 16 9 18	3020	165	Eastend	13	5	350	4	7	250	671	8	555	980
32	SW 2 9 18	3075	200	Eastend	11	4	330	5	7	210	545	43	475	855
33	SW 13 8 19	3000	70	Eastend	16	8	230	5	7	150	448	11	375	660
34	SE 2 8 18	3165	300	Eastend	7	5	270	5	7	95	590	8	490	700
35	NE 7 8 15	2900	63	Bearpaw	64	52	254	-	13	529	440	0	360	1140
36	NW 8 8 17	3095	195	Eastend	20	9	250	8	0	140	536	23	455	725
37	NE 3 9 16	2810	230	Bearpaw?	2	4	393	4	112	66	791	0	650	990
38	SW 13 9 16	2900	360	Bearpaw	284	157	1200	36	6	3180	933	0	750	5335
39	SE 16 9 16	2895	97	Bearpaw	48	40	465	17	5	800	559	0	460	1670
40	SW 1 11 16	2965	120	French-man?	39	30	100	6	3	127	380	0	310	510
41	NE 34 10 17	3050	170	French-man?	33	24	238	7	4	199	617	0	506	815
42	NE 33 9 18	3030	180	Bearpaw	6	10	333	4	5	389	462	0	380	995
43	SE 5 10 13	2550	40	Drift	85	123	132	54	33	491	560	0	460	1280
44	NE 15 8 15	2860	56	Bearpaw	64	32	532	-	23	750	787	0	645	1790
45	NE 14 11 15	3050	190	Cypress Hills	32	24	5	3	2	9	213	0	175	195

46	SE 17 11 15	3030	195	Cypress Hills	27	27	7	4	1	11	222	0	180	205
47	SE 2 10 15	2805	185	Bearpaw	72	46	425	14	6	845	543	0	445	1695
48	SW 8 8 18	3085	140	Eastend	30	16	276	3	3	270	578	0	475	915
49	SW 34 7 18	3145	265	Eastend	23	1	239	6	2	144	538	0	440	700
50	NE 21 7 17	3130	165	French-man?	21	26	163	13	1	110	513	0	420	605
51	NW 12 7 17	3080	137	Eastend	3	12	358	7	1	164	785	15	670	900
52	NW 10 8 17	3160	265	Eastend	2	7	339	7	1	157	750	0	615	895
53	NE 22 8 18	3030	120	Eastend	16	11	370	6	12	384	598	0	490	1115
54	NE 6 9 13	2635	45	Bearpaw	16	12	590	7	7	930	520	0	425	1840
55	NE 33 9 15	2785	260	Bearpaw?	2	4	380	4	105	80	742	11	630	985
56	NW 35 9 15	2875	70	Drift	273	148	182	13	48	1200	449	0	370	2175
57	SE 20 8 15	2870	60	Eastend	7	13	212	8	4	211	371	12	325	665
58	NW 33 7 15	2770	140	Bearpaw	28	16	587	8	18	675	823	0	675	1800
59	SE 18 8 14	2690	35	Cypress Hills?	93	64	27	1	9	76	563	0	460	570
60	NW 22 8 15	2825	35	Bearpaw	58	45	490	12	48	837	573	0	470	1790
61	NW 32 10 16	2980	45	Cypress Hills	45	41	12	2	5	32	328	0	270	315
62	SE 22 11 16	2975	130	Cypress Hills	33	25	24	5	0	16	281	0	230	255
63	NE 6 9 18	3010	128	Eastend	6	9	328	5	3	31	557	0	455	665
64	SE 16 10 15	2975	97	Cypress Hills	43	29	8	3	4	34	244	0	200	255
65	NW 30 7 17	3255	37	Cypress Hills?	70	68	13	11	10	82	466	0	380	515
66	SE 13 7 18	3225	200	French-man?	61	38	158	9	2	151	605	0	495	730
67	NE 25 8 17	3060	187	Eastend	7	15	376	-	14	328	660	0	540	1065
68	NW 32 8 16	2885	112	Eastend	14	6	330	-	12	230	616	0	505	915
69	NW 25 7 15	2775	60	Bearpaw	21	15	607	-	17	832	677	0	555	1825

(* All locations are West of 3rd meridian)

TABLE II
MILLIEQUIVALENTS OF IONS AND ION RATIOS

Sample No.	Chemical constituents (epm) Ca	Mg	Na	K	Cl	SO_4	HCO_3	CO_3	rCa* / rMg	$rHCO_3$ / rSO_4	rNa / rCa+rMg
1	2.2	1.4	7.6	-	0.0	3.4	7.9	0	1.6	2.3	2.1
2	1.9	1.9	.39	-	0.0	.17	4.1	0	1.0	24.0	.10
3	.75	.58	13.5	-	.2	3.1	12.4	0	1.3	4.0	10.1
4	.70	4.1	2.4	-	1.6	1.6	5.5	0	.17	3.4	.50
5	22.0	72.0	4.8	-	4.5	85.0	6.4	0	.31	.08	.05
6	1.9	1.9	1.4	-	.40	.75	4.5	0	1.0	6.0	.37
7	2.9	2.6	.74	-	.20	.70	5.9	0	1.1	8.4	.13
8	2.3	2.8	.52	-	.20	.79	4.8	0	.82	6.1	.10
9	6.8	5.9	4.2	-	.90	11.2	4.7	0	1.2	4.2	.33
10	2.2	2.1	.57	-	.20	.56	4.4	0	1.0	7.9	.13
11	1.6	1.6	12.8	-	.20	4.5	10.4	0	1.0	2.3	4.0
12	.35	.25	15.0	-	.40	4.4	10.8	0	1.4	2.5	25.0
13	.70	.58	15.5	-	.20	4.8	13.0	0	1.2	2.7	12.0
14	.85	.58	16.7	-	0.0	5.1	13.1	0	1.5	2.6	11.7
15	2.3	3.0	9.4	-	.20	4.0	11.3	0	.77	2.8	1.8
16	4.6	4.4	6.1	-	0.0	4.5	11.1	0	1.0	2.5	.68
17	2.2	3.1	7.0	-	.20	5.2	7.6	0	.71	1.5	1.3
18	2.4	1.7	3.9	-	.20	1.8	7.0	0	1.4	3.9	.95
19	.20	.25	11.3	-	.20	3.2	7.2	.77	.80	2.3	25.0
20	.40	.33	13.9	-	.20	4.0	9.5	.40	1.2	2.4	19.0
21	3.0	3.1	8.5	-	.20	3.0	12.4	0	.97	4.1	1.4
22	3.2	3.9	1.8	-	.20	.52	8.8	0	.82	17.0	.25
23	4.7	4.9	5.7	-	.20	5.2	10.5	0	.96	2.0	.59
24	.80	.49	15.0	-	.20	5.9	10.3	.43	1.6	1.7	11.6
25	.7	1.4	35.6	-	.90	22.4	14.5	0.0	.50	.65	17.0
26	8.6	13.8	85.0	-	1.7	92.0	14.1	0.0	.52	.15	3.8
27	2.0	2.0	.39	.10	0.0	.23	4.3	0.0	1.0	19.0	.10
28	.50	.66	13.7	.18	.20	4.0	10.6	.63	.76	2.7	11.8
29	1.2	1.1	14.4	.18	.31	6.0	9.7	0.0	1.1	1.6	6.3
30	.40	.33	16.5	.08	.20	5.8	9.7	1.0	1.2	1.7	22.6
31	.65	.41	15.2	.10	.20	5.2	11.0	.27	1.6	2.1	14.4
32	.55	.33	14.4	.13	.20	4.4	8.9	1.4	1.7	2.0	16.4
33	.80	.66	10.0	.13	.20	3.1	7.4	.37	1.2	2.4	6.9
34	.35	.41	11.7	.13	.20	2.0	9.7	.27	.85	4.9	15.4
35	3.2	4.3	11.1	-	.40	11.0	7.2	0.0	.74	.66	1.5
36	1.0	.74	10.9	.21	0.0	2.9	8.8	.77	1.4	3.0	6.3
37	.10	.30	17.1	.11	3.1	1.4	13.0	0.0	.33	9.3	43.0
38	14.2	12.9	52.2	.92	.17	66.0	15.3	0.0	1.1	.23	1.9
39	2.4	3.3	20.3	.42	.12	16.7	9.2	0.0	.73	.55	3.6
40	2.0	2.5	4.4	.15	.08	2.6	6.2	0.0	.80	2.4	.98
41	1.6	2.0	10.3	.18	.10	4.0	10.1	0.0	.80	2.5	2.9
42	.28	.78	14.5	.11	.15	8.1	7.6	0.0	.37	.94	13.7
43	4.2	10.1	5.7	1.4	.92	10.2	9.2	0.0	.42	.90	.40
44	3.2	2.6	23.2	-	.60	15.6	12.9	0.0	1.2	.83	4.0
45	1.8	2.0	.23	.08	.05	.19	3.5	0.0	.90	18.4	.06

Table II (cont.)

Sample No.	Chemical constituents (epm)								rCa* / rMg	rHCO3 / rSO4	rNa / rCa+rMg
	Ca	Mg	Na	K	Cl	SO_4	HCO_3	CO_3			
46	1.3	2.2	.31	.11	.03	.24	3.6	0.0	.59	15.0	.09
47	3.6	3.8	18.5	.35	.17	17.6	8.9	0.0	.95	.51	2.5
48	1.5	1.3	12.0	.08	.08	5.6	9.5	0.0	1.2	1.7	4.3
49	1.1	.07	10.4	.16	.05	3.0	8.8	0.0	1.6	2.9	8.9
50	1.1	2.1	7.1	.20	.03	2.3	8.4	0.0	.52	3.7	2.2
51	.15	.95	15.6	.18	.02	3.4	12.9	.50	.16	3.8	14.2
52	.10	.61	14.7	.18	.02	3.3	12.3	0.0	.16	3.7	20.7
53	.80	.93	16.1	.16	.34	8.0	9.8	0.0	.86	1.2	9.3
54	.80	1.0	25.7	.18	.20	19.4	8.5	0.0	.80	.44	14.3
55	.10	.29	16.5	.11	3.0	1.7	12.2	.38	.35	7.2	42.0
56	13.6	12.2	7.9	.30	1.3	25.0	7.4	0.0	1.1	.30	.31
57	.35	1.1	9.2	.20	.10	4.4	6.1	.41	.32	1.4	6.4
58	1.4	1.3	25.5	.20	.50	14.0	13.5	0.0	1.1	.96	9.5
59	4.6	5.3	1.2	.03	.26	1.6	9.2	0.0	.87	5.8	.12
60	2.9	3.7	21.3	.30	1.3	17.4	9.4	0.0	.78	.54	3.2
61	2.2	3.4	.52	.05	.15	.66	5.4	0.0	.65	8.2	.09
62	1.6	2.0	1.0	.13	0.0	.34	4.6	0.0	.80	13.5	.28
63	.30	.74	14.3	.13	.08	.65	9.1	0.0	.41	14.0	13.8
64	2.1	2.4	.36	.08	.10	.70	4.0	0.0	.88	5.7	.08
65	3.5	5.6	.57	.28	.29	1.7	7.6	0.0	.63	4.5	.06
66	3.0	3.1	6.9	.23	.06	3.1	9.9	0.0	.97	3.2	1.1
67	.35	1.2	16.4	-	.40	6.8	10.8	0.0	.29	1.6	10.5
68	.70	.50	14.4	-	.30	5.2	10.1	0.0	1.4	1.9	12.0
69	1.0	1.2	26.4	-	.50	17.3	11.1	0.0	.83	.64	12.0

(* "r" indicates element is expressed in milliequivalents)

TABLE III
SUMMARY OF CHEMICAL TYPES OF GROUNDWATER

Type	Predominant ions	Geologic source
A	calcium-magnesium sulphate	Glacial drift
B	calcium-magnesium bicarbonate	Cypress Hills Formation
C	sodium bicarbonate	Frenchman and Eastend Formations
D	sodium sulphate	Bearpaw Formation

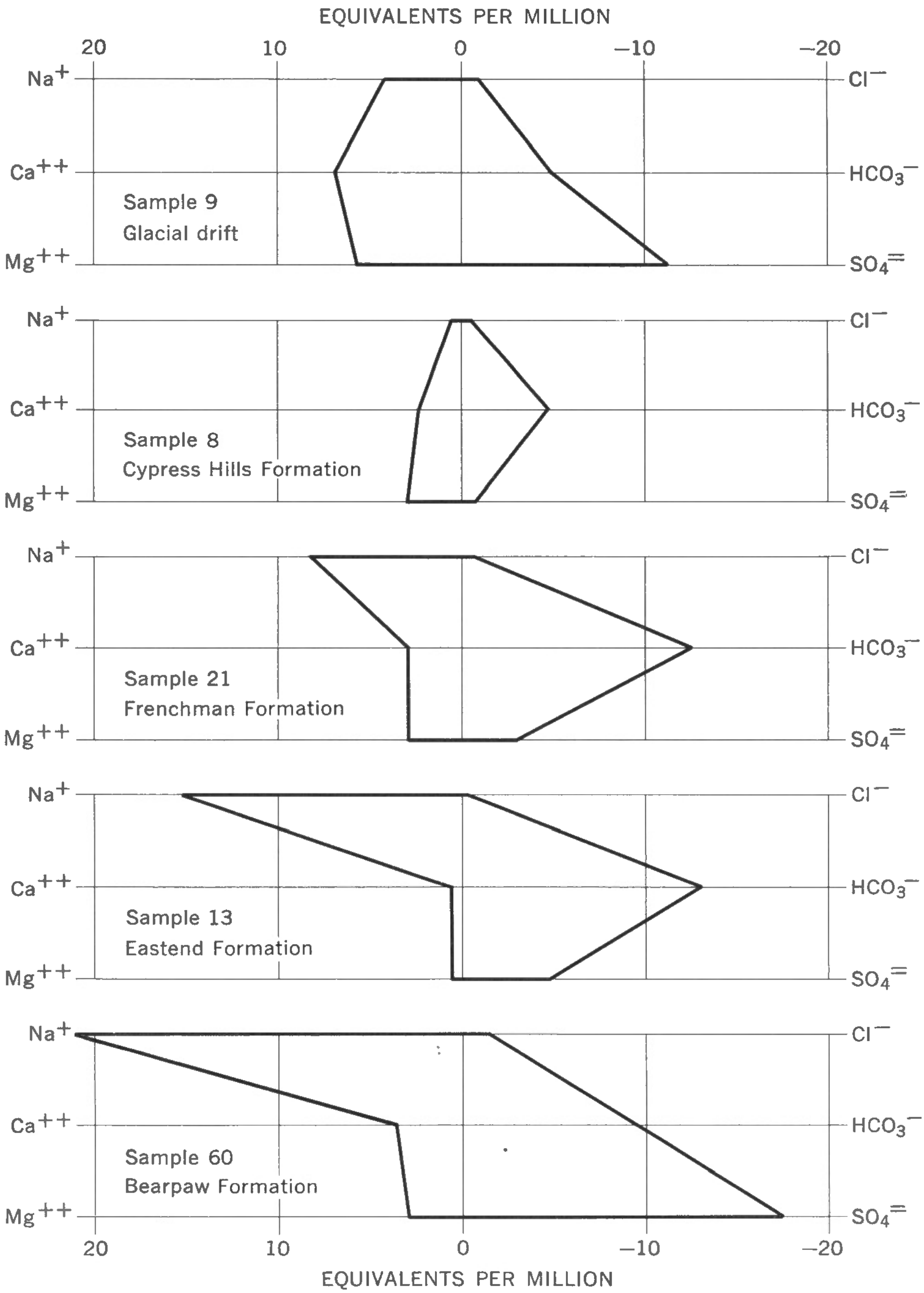

Figure 5. Chemical patterns of groundwater

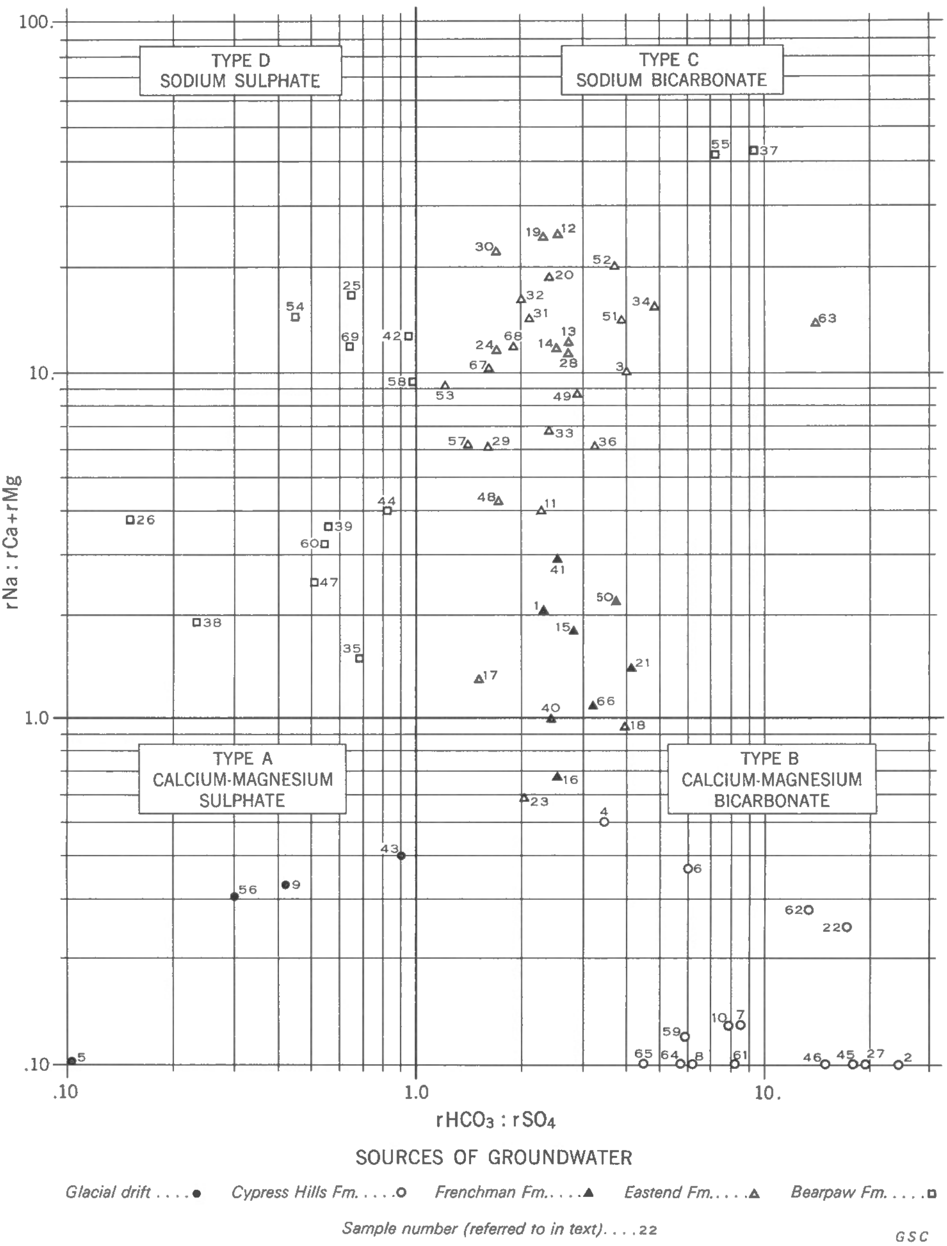

Figure 6. Chemical types of groundwater.

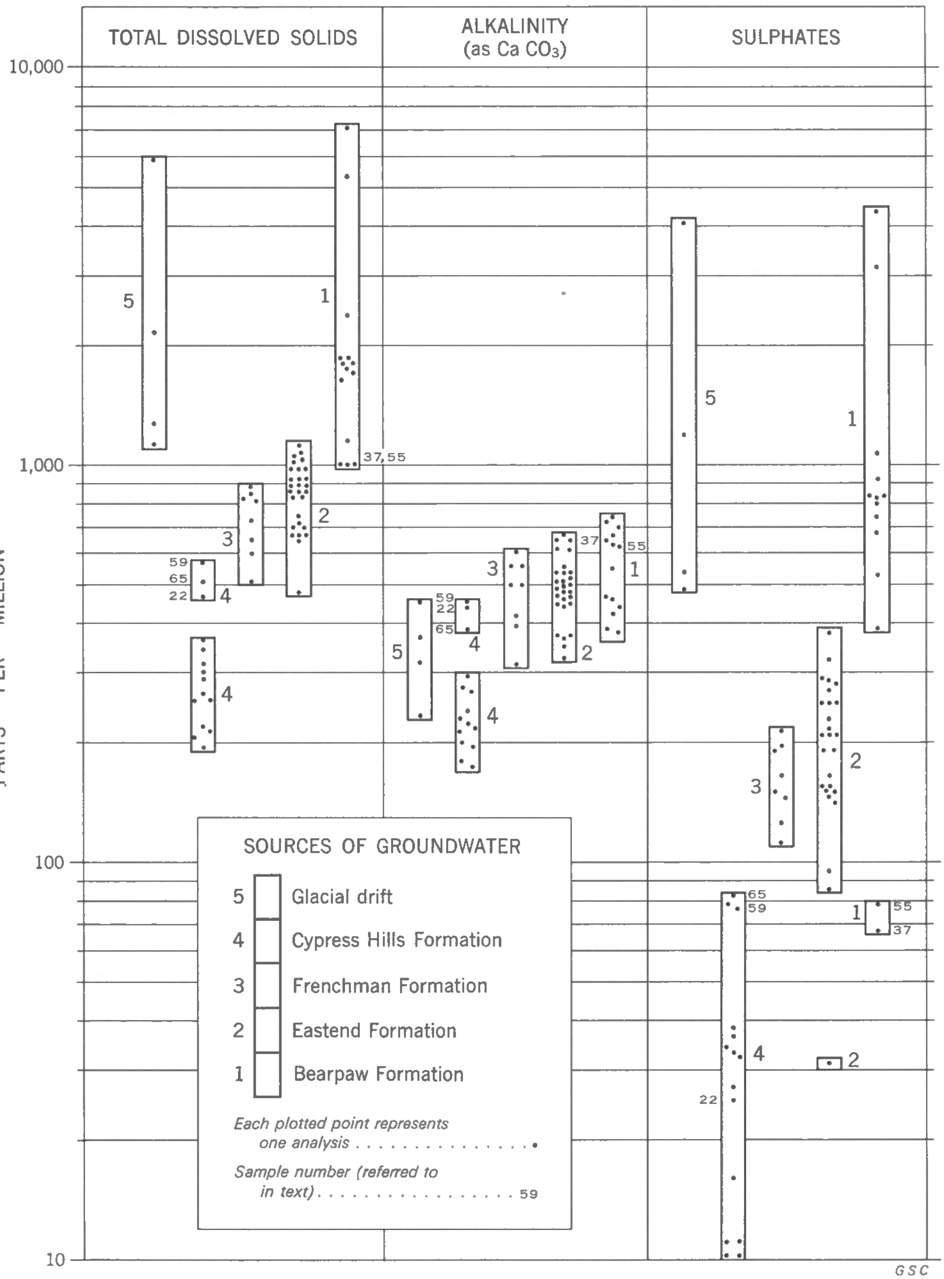

Figure 7. Bar graph comparing total dissolved solids, alkalinity and sulphates of groundwaters of the upper Notukeu Creek basin, southwestern Saskatchewan.

The patterns of Figure 5 are representative of groundwater derived from the glacial drift and the Cypress Hills, Frenchman, Eastend, and Bearpaw Formations. Comparison of water analyses by this method indicated that groundwater from each source is characterized by the predominance of certain ions, and that distinct differences in composition exist among groundwaters of the various sources. The term 'predominance' implies that the cation or anion to which is referred, with only few exceptions, constitutes more than 50 per cent of the total cations or anions respectively.

Classification

General remarks

The chemical types of groundwater are classified relative to one another, the criteria used consisting of a cation ratio and an anion ratio. In general the concentration of the monovalent Na ion contrasts with the sum of the concentrations of the bivalent Ca and Mg ions. These cations generally occur in concentrations of the same order of magnitude relative to the Na ion. The rCa:rMg ratio itself is erratic, varying between 0.16 and 1.6, and appears to have little or no significance (Table II). The K ion concentration was measured in only 38 of the groundwater samples. It is a minor constituent in the groundwater, present in amounts of less than 10 ppm in 30 of the 38 analyses.

Of the anions only SO_4 and HCO_3 are present in significant quantities. The Cl anion occurs in very small amounts in groundwater of the upper Notukeu Creek basin area, being present in quantities of less than 10 ppm in 50 of the 69 analyses.

Therefore the criteria of classification used were the cation ratio, rNa:r(Ca+Mg), and the anion ratio, $rHCO_3$:rSO_4, of each analysis (Table II). These ratios are plotted on a logarithmic graph (Fig. 6), from which four basic types of groundwater are distinguishable. To aid in the discussion of these types, the total dissolved solids, alkalinity, and sulphate content of each are plotted on Figure 7. Table III is a summary of suggested groundwater types, their predominant chemical constituents, and their geologic source.

Type A

Type A groundwater is represented by only four samples obtained from the glacial drift. The following characteristics are evident:

1. The cation ratio is less than 1 (Fig. 6). The Ca and Mg ions have a combined concentration ranging between 13 and 94 epm, while the Na ion is an important secondary constituent present in amounts ranging between 4.2 to 7.9 epm.

2. The anion ratio is less than 1 (Fig. 6). The SO_4 ion ranges in concentration from 10 to 85 epm. The HCO_3 ion varies in concentration from 4.7 to 9.2 epm.

3. Alkalinity, due primarily to the presence of HCO_3, ranges in concentration from 235 to 460 ppm expressed as $CaCO_3$ (Fig. 7).

4. The total dissolved solids widely range in concentration from 1140 to 5880 ppm (Fig. 7).

The wide range in the total dissolved solids probably is indicative of the degree of stagnation and the varying periods of time of contact of the groundwater with the glacial drift. Schoeller (1959, p. 68) stated that "the absolute value of chlorine is one of the most important pointers to the degree of stagnation of a body of groundwater, to its time of contact with the rock ...". Sample 5 has a high total mineral content of 5880 ppm and a Cl ion content of 160 ppm. The other type A samples have relatively less total mineral content and correspondingly less Cl ion content.

Type B

Type B groundwater is derived from the Cypress Hills Formation. The following characteristics, exclusive of samples 22, 59, and 65, which are discussed in a later paragraph, distinguish this type:

1. The cation ratio of 9 of the 12 samples is less than 0.15 (Fig. 6). The Ca and Mg ions range in total concentration from 3.5 to 5.5 epm. The Na ion concentration is generally less than 1 epm with a few exceptions.

2. The anion ratio varies between about 3.5 and 25 (Fig. 6). The SO_4 ion concentration is generally less than 1 epm. The HCO_3 ion ranges in concentration from 3.5 to 5.9 epm.

3. Alkalinity, due primarily to the presence of HCO_3, ranges in concentration from 175 to 295 ppm (Fig. 7).

4. The total dissolved solids range in concentration from 195 to 370 ppm (Fig. 7) and are the lowest of all groundwater in the Upper Notukeu Creek area.

Three water samples (Nos. 22, 59 and 65) of type B, collected south of Notukeu Creek (Fig. 2), differ in some respects from normal type B. Their ion ratios (Fig. 6) are comparable to those of other type B samples, but their absolute ion concentrations are approximately double the normal values. This is shown in the total dissolved solids and alkalinity graphs of Figure 7. The locations of these samples are in areas where Cypress Hills Formation has not been mapped. Their chemical composition may indicate the presence of erosional remnants of Cypress Hills, or in the case of sample 59, of preglacial stream deposits derived from Cypress Hills gravel. However, there is no obvious explanation of their higher ion concentrations.

Type C

Type C groundwater is derived primarily from the Frenchman and Eastend Formations. Excluding samples 37 and 55, which are discussed in a later paragraph, the following characteristics are evident:

1. With only few exceptions the cation ratio is greater than 1 and reaches a maximum of 25 (Fig. 6). Low values (less than 3) are characteristic of groundwater, from the Frenchman Formation, and high values are characteristic of groundwater, from the Eastend Formation. The Na ion ranges in concentration from 3.9 to 16.7 epm. The total content of Ca and Mg ions varies between 0.45 epm (sample 19) and 9.6 epm (sample 23). Increasing Na ion concentrations generally are accompanied by decreasing combined Ca and Mg ion concentrations and vice versa.

2. The anion ratio, with the exception of sample 63, varies between 1.2 and 4.8 (Fig. 6). The SO_4 content is distinctly greater than that of type B, ranging in concentration from 1.8 to 8.0 epm. This comparison, expressed in ppm, is demonstrated in Figure 7. The HCO_3 ion concentration varies between 6.2 and 13.1 epm.

3. Alkalinity, due primarily to the presence of HCO_3 as in other types, ranges in concentration from 310 to 670 ppm. This concentration is distinctly larger than those of types A and B as shown in Figure 7.

4. The total dissolved solids have a moderate concentration ranging essentially from 500 to 1100 ppm (Fig. 7).

It is noteworthy that regardless of the high Na ion concentrations, chloride is an insignificant constituent having a maximum concentration of only 0.4 epm.

Groundwater samples 37 and 55, thought to be derived from the Bearpaw Formation as shown on Figure 2, are included in type C, although their chemical compositions differ in some respects from normal type C. The chemical similarity of these two samples, as shown by Figures 6 and 7, is very pronounced. They have similar cation and anion ratios, which are both distinctly larger than those of normal type C samples. In addition they have significant Cl ion concentrations of 3.1 and 3.0 epm respectively. The writer has no explanation either for the similarity in composition of these samples or for their deviation from normal Bearpaw groundwater (type D).

Type D

Type D groundwater, derived from the Bearpaw Formation, has the following characteristics:

1. The cation ratio is greater than 1, varying up to a maximum of about 17 (Fig. 6). The Na ion content is greater than that of type C, ranging in concentration from 14.5 to 85 epm. The sum of Ca and Mg ion concentrations varies between 1.1 and 27.1 epm, but is mainly less than 7.5 epm.

2. The anion ratio varies between 0.15 and 0.95 (Fig. 6). The SO_4 ion content, which is comparable to that of type A, ranges in concentration between 8.0 and 92 epm. This comparison, expressed in ppm, is illustrated in Figure 7. The HCO_3 ion concentration is similar to that of type C and varies between 7.2 and 15.3 epm.

3. Alkalinity ranges in concentration from 360 to 750 ppm (Fig. 7) and is due primarily to the presence of HCO_3.

4. The total dissolved solids have a moderate to high concentration ranging from slightly less than 1000 ppm to greater than 7000 ppm (Fig. 7).

As with the other types, the chloride content is insignificant, being a maximum of 1.7 epm (sample 26) and commonly less than 0.3 epm.

Worthy of emphasis is the similarity in amounts of SO_4 ion and total dissolved solids of type A (glacial drift) groundwater and type D (Bearpaw) groundwater. The alkaline earths (Ca and Mg) predominate in type A, although the Na ion is a significant constituent. Sodium is the predominant cation in Type D. Type A samples are located near to (within 1 mile), or within, areas underlain by the Bearpaw Formation.

GENESIS OF THE GROUNDWATER CHEMISTRY - UPPER NOTUKEU CREEK BASIN

Bicarbonate

Normal concentration

Solution of carbonate minerals by water is influenced by the partial pressure of CO_2 in accordance with the following system:

$$CO_2 + H_2O \rightleftharpoons H^+ + HCO_3^-$$

$$Ca^+CO_3 \rightleftharpoons Ca^{++} + HCO_3^-$$

The initial source of CO_2 available to rain for attack on carbonate is the atmosphere, where the partial pressure of CO_2 is in the order of 0.0003 atmospheres. Such a CO_2 partial pressure at 16°C will allow solution of 63 ppm $CaCO_3$ (equivalent to 77 ppm HCO3). A much larger supply of CO_2 is available in the soil where various biological and chemical processes create partial pressures of 0.001 to 0.01 atmospheres (Schoeller, 1959, p. 55). This range of CO_2 partial pressures results in normal HCO_3 concentrations in groundwater commonly from 180 to 360 ppm and a maximum of 550 ppm (equivalent to 148, 295, and 450 ppm of $CaCO_3$ respectively).

The HCO_3 ion concentrations of types A and B groundwater, derived from the glacial drift and Cypress Hills Formation respectively, vary up to 563 ppm (9.2 epm) but are commonly less than 360 ppm (5.9 epm). Expressed in terms of $CaCO_3$ (alkalinity) these concentrations would be 460 and 300 ppm respectively (Fig. 7). It is significant that the ranges of alkalinity of these types are comparable, as carbonate concentrations of this magnitude are considered normal and correspond to typical CO_2 partial pressures in the soil.

Soil profiles in upper Notukeu Creek basin are characterized by zones (B horizon) of $CaCO_3$ accumulation. Since dissolved CO_2 quickly reaches its $CaCO_3$ saturation point, the HCO_3 content of types A and B groundwater is probably derived from the soil by infiltrating meteoric water.

High concentration

A notable increase in HCO_3 content, and therefore in alkalinity, occurs in groundwater of the Frenchman, Eastend, and Bearpaw Formations (Fig. 7). The HCO_3 ion concentrations range between 380 ppm (6.2 epm) and 933 ppm (15.3 epm) and are commonly greater than 550 ppm (9.0 epm). The corresponding alkalinity values range between 310 and 750 ppm, and are commonly greater than 450 ppm. In order that concentrations of this magnitude should occur, the water must contain a CO_2 concentration greater than that due solely to the CO_2 partial pressures in the atmosphere and soil.

Foster (1950, p. 40) outlined two hypotheses suggesting that carbonaceous material may be the source of the additional CO_2. The first of these was that reduction of sulphates by carbonaceous material because of chemical or biochemical action results in liberation of CO_2 and subsequent solution of $CaCO_3$. This process would result in very low SO_4 ion concentrations in the water, production of H_2S, and a rise in the amount of dissolved carbonate. However, the relative abundance of sulphate in type C groundwater in the upper Notukeu Creek basin and lack of a characteristic sulphurous odour in the water indicates that sulphate reduction has not occurred to any significant degree.

The second hypothesis suggested the generation of CO_2 by carbonaceous material without intervention of sulphates. Oxygen and carbon are important constituents of carbonaceous material. With burial, carbonaceous material undergoes alteration resulting in the loss of carbon dioxide, methane, and water (Foster, 1950, p. 40), all simple compounds of carbon, hydrogen, and oxygen. Foster favoured this hypothesis in explaining the origin of HCO_3 contents of greater than 800 ppm occurring in groundwater of the Atlantic and Gulf Coastal Plains.

Lignite seams and carbonaceous plant material are especially abundant in the Ravenscrag Formation and to a lesser extent in the Frenchman Formation. The Eastend Formation contains little carbonaceous material. It seems reasonable to postulate that CO_2 is generated by carbonaceous material in these sediments according to Foster's second hypothesis, although no data are available as to the content of the alteration products in the sediments or groundwater.

Not all groundwaters of type C or D in the upper Notukeu Creek basin have excessively high HCO_3 content. More precise definition of the areas of groundwater recharge and the flow system may account for these variations.

Sulphate

Water in contact with gypsum readily acquires a high content of $CaSO_4$. "The increase of SO_4 entails an increase not only of calcium but also of magnesium, of which gypsum always contains a fairly large proportion" (Schoeller, 1959, p. 57). It is here suggested that the sulphate ion concentration in groundwater of the upper Notukeu Creek basin is due to solution of alkaline-earth sulphate minerals, mainly gypsum. Varying sulphate ion concentrations of the different types of groundwater (Fig. 7) reflect mainly the supply of sulphate minerals available for solution, which in turn is a reflection of the nature and origin of the sediments.

The common occurrence of gypsum crystals in Bearpaw outcrops is indicative of a high sulphate mineral content in these sediments, which are predominantly marine shales. High SO_4 ion concentrations are characteristic of type D groundwater derived from this formation.

The predominantly sandy lithology of the Eastend Formation and part of the Frenchman Formation may account for the lower SO_4 ion concentration in type C groundwater. According to Rankama and Sahama (1950, p. 752) most sulphates are leached from resistate sediments. Type B (Cypress Hills) groundwater has the lowest SO_4 ion concentration of all groundwater in the upper Notukeu Creek basin. It may be speculated that the Cypress Hills sediments have a low sulphate mineral content because of their freshwater fluviatile origin, and because of leaching of the predominantly coarse resistate sediments mainly during pre-Pleistocene erosion.

The high SO_4 ion concentration of type A (glacial drift) groundwater combined with high Ca and Mg ion concentrations is indicative of the presence of gypsum in the drift. A large percentage of the glacial sediments is probably derived from the underlying Bearpaw Formation.

The high SO_4 ion concentration of type A groundwater in contrast to that of type B requires an explanation. The samples of type A are located in areas underlain by Upper Cretaceous sediments mainly of the Bearpaw Formation and therefore are a poor representation of the glacial drift as a whole. It is probable that the glacial drift overlying the Tertiary sediments is derived mainly from these sediments and not from the Bearpaw Formation. It is noteworthy that Mitchell _et al._ (1944, p. 102) made no mention of the presence of gypsum in the parent material of the soil of the Cypress Hills Association, which is developed on Tertiary sediments modified by glaciation. On the contrary, the parent material of the Haverhill Association, which is developed on glacial till, is described as calcareous "with streaks and concretions of lime carbonate and gypsum, ..." (Mitchell _et al._, 1944, p. 55). The low SO_4 ion concentration of type B groundwater indicates that any overlying glacial drift has a low gypsum content.

Modification by Cation Exchange

Solution, primarily of the alkaline-earth carbonates and sulphates, is considered the original process of mineralization of groundwater in the upper Notukeu Creek basin, hence the predominant cations of types A and B are Ca and Mg. Types C and D, however, have relatively low Ca and Mg ion concentrations compared to the concentration of Na (Fig. 6).

Remick (1924) described a similar occurrence in groundwater in the plains of Montana, and attributed the change in chemical composition to the presence of certain silicate minerals (clay minerals), which have the ability of ion exchange. This process also was observed by Meyboom (1960, p. 64) in southern Alberta.

The high Na content cannot be attributed to solution of NaCl or the presence of connate marine water because the Cl ion concentration is very small in all types of groundwater. Solution of $Na_2 SO_4$ is discounted as the main source of Na because the rNa far exceeds the rSO_4 in type C groundwater.

A possibility that should be considered is that clay minerals capable of cation exchange are present in the Frenchman and Eastend Formations, with the result that Ca and Mg ions in groundwater recharging these aquifers from the glacial drift and Cypress Hills Formation replace the Na ions in the exchanger substances. In this way Na could become the predominant cation in type C groundwater.

The degree of cation exchange is greater in the Eastend Formation than in the Frenchman Formation. This is indicated by the larger rNa:r(Ca+Mg) ratios (Fig. 6) of Eastend groundwater. This apparent difference in cation exchange capacity of the sediments may reflect the change from a marine to a non-marine environment toward the end of Late Cretaceous time. These changing conditions of sedimentation would be accompanied by a decline in the number of Na ions available for adsorption by clay minerals, and hence a decrease in the number of Na ions occupying exchange positions.

The concentration of Na ions is largest in type D groundwater derived from the Bearpaw Formation (Fig. 5). Montmorillonite, which has a high cation exchange capacity, is the predominant clay mineral of Bearpaw sediments. If it were assumed that exchange positions of clay minerals deposited in Late Cretaceous seas were saturated primarily with Na ions, then, although groundwater recharging the Bearpaw might have low concentrations of Ca and Mg ions, solution of gypsum in the Bearpaw Formation itself resulting in high concentrations of Ca and Mg ions would lead to almost immediate replacement of Na ions in the montmorillonite. Sample 26 (Table II) is an extreme example of increased concentration of the replacing cations (Ca and Mg) causing greater exchange. This highly mineralized sample contains 92 epm of SO_4 ion assumed derived from solution of Ca and Mg sulphate minerals. The combined Ca and Mg ion concentration, however, is only 22.4 epm in contrast to a Na ion concentration of 85 epm. In accordance with the law of mass action increased concentration of Ca and Mg ions in solution results in further release of Na ions by cation exchange (Hem, 1959, p. 221).

The significant concentrations of Na ions present in type A groundwater suggest that a small degree of cation exchange has occurred in the glacial drift. Since montmorillonite is an abundant clay mineral of the glacial sediments, it is possible that weathering of these sediments during and after glaciation may have resulted in displacement of the majority of the adsorbed Na ions by higher valence ions. This has resulted in only a small number of Na ions now occupying exchange positions in the clay minerals.

All of the Na content in type A groundwater cannot be attributed to cation exchange. Sample 5 (Table II) has a concentration of chloride (4.5 epm) that is almost equivalent to the Na ion concentration (4.8 epm), suggesting that solution of NaCl has occurred.

SUMMARY AND CONCLUSIONS

Groundwater of the upper Notukeu Creek basin is basically of four chemical types depending on the predominant ions present. The relative proportions of the constituents are roughly uniform for each type and each type is derived from, and is characteristic of a particular geologic formation or formations. Type A is a calcium-magnesium sulphate water derived from the glacial drift; type B is a calcium-magnesium bicarbonate water derived from the Cypress Hills Formation; type C is a sodium bicarbonate water derived primarily from the Frenchman and Eastend Formations; type D is a sodium sulphate water derived from the Bearpaw Formation.

The normal alkalinity of types A and B groundwater is caused by the presence of the bicarbonate ion obtained by solution of alkaline earth carbonates mainly in the soil horizon of carbonate accumulation. The distinctively higher bicarbonate concentration and hence alkalinity of types C and D groundwater requires a greater CO_2 partial pressure than that available in the soil. It is believed that carbon dioxide generated by alteration of carbonaceous material in the Ravenscrag and Frenchman Formations results in further solution of carbonate by downward percolating groundwater. The high bicarbonate concentration of type D groundwater may be an indication that the Bearpaw Formation is being recharged by groundwater from the overlying Eastend and Frenchman Formations. This characteristic may be a useful tracer in mapping the regional groundwater flow system of the Cypress Hills area.

The sulphate concentration is high in types A and D groundwater, low in type B groundwater, and moderate in type C groundwater. These varying concentrations reflect the supply of sulphate minerals, mainly gypsum, that are available for solution. The supply of sulphate minerals further reflects the nature and origin of the sediments.

Sodium ion concentrations are predominant in types C and D groundwater, whereas calcium and magnesium ions are present generally in relatively small and often insignificant amounts. This relationship is probably mainly a result of cation exchange by the clay minerals in the sediments. Calcium and magnesium ions in the groundwater replace sodium ions in the clay minerals.

The presence of chloride in only small and relatively insignificant concentrations is an indication of a lack of connate water in the marine sediments. It seems reasonable to suppose that the groundwater of the upper Notukeu Creek basin is of meteoric origin. Such an origin is indicated by the alkalinity relationships of the types of groundwater, and the apparent lack of connate water in the marine sediments.

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