

AN ABSTRACT OF THE THESIS OF

Gregory Stebbins Mack for the degree of Master of Science

in Geology presented on 3 June 1982

Title: Geology, Ground Water Chemistry, and Hydrogeology of

the Murphy Area, Josephine County, Oregon

Redacted for Privacy

Abstract approved: _____

E. J. Dasch

The Grants Pass Batholith of Cretaceous age has intruded the Triassic Applegate Group and metasedimentary rocks of the Jurassic Galice Formation in the Murphy area of Josephine County, southwest Oregon. The Applegate Group, mafic volcanic and sedimentary rock, has been partially (nonequilibrium) metamorphosed under greenschist facies conditions. The batholith, a hornblende-biotite granodiorite, has produced a contact aureole (hornblende-hornfels facies) in the country rocks.

Electrical conductance (EC), pH, temperature, and HCO_3^- were measured on 43 samples of well water and Applegate River water in the field. Analyses for Na^+ , K^+ , Mg^{++} , Ca^{++} , Cl^- , F^- , SO_4^{--} , total Fe, and SiO_2 (aq) were performed in the laboratory. Two water types based on EC are apparent. A low EC type ($< 500 \mu\text{mho/cm}$ @ 25°C) is characteristic of HCO_3^- waters; high EC is associated with Cl^- waters. Grus from the weathered pluton forms satisfactory aquifers with low EC. Applegate Group rocks form a clay-rich aquifer containing both high and low EC water. Wells located within the contact aureole in the Galice Formation yield high EC waters.

Low EC waters are associated with areas of high recharge equivalent to the "Local" zone, the shallowest zone of Toth's (1963) model.

Water quality enigmatically is characterized also by a molar Mg/Ca ratio of unity. High EC waters are associated with the emergence of deeper water along hydrogeologic boundaries.

Except for localized areas producing nonpotable water, aquifers can generally be described as suitable for domestic purposes. The ability of ground water resources to sustain development at recent rates is, however, severely limited.

Geology, Ground Water Chemistry, and Hydrogeology
of the Murphy Area, Josephine County, Oregon

by

Gregory Stebbins Mack

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Completed 3 June 1982

Commencement June 1983

APPROVED:

Redacted for Privacy

Associate Professor of Geology in charge of major

Redacted for Privacy

Chairperson of Department of Geology

Redacted for Privacy

Dean of Graduate School

Date thesis is presented 3 June 1982

Typed by Donna Lee Norvell-Race for Gregory Stebbins Mack

ACKNOWLEDGMENTS

I would like to acknowledge a number of people for their contributions to this project. I am grateful for both the technical and the personal support I have received.

Robert Almy, Hydrogeologist, Oregon Water Resources Department, suggested the topic and made data from his study available to me; I also appreciated the opportunity to discuss my procedures and findings with him. Robert Steimer, Watermaster, District #14, and his crew freely shared their data and their knowledge of the area with me. Len Ramp and Norman Peterson, Geologists, Oregon Department of Geology and Mineral Industries, who discussed with me their ideas about the geology of the area, were most helpful. I would like to thank Dr. Frank Spane and Dave Graham of Rockwell Hanford Operations, Basalt Waste Isolation Project, for making the computer program WATEQF available.

Dr. Alan Neim and Dr. Edward Taylor of the Department of Geology at O.S.U. provided equipment for water analysis. Ronald Senechal graciously contributed advice and assistance on the analysis. Dr. William Taubeneck helped with the interpretation of thin sections. Fellow graduate student Richard Mahood performed x-ray identification of a zeolite mineral.

Finally, I would like to extend my appreciation to my advisor, Dr. E. Julius Dasch, for his encouragement and patience throughout this project and his invaluable help with revision and editing of the manuscript. I would also like to thank my sweetheart, Carol, for her assistance with editing, typing, and proofreading.

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Geology, Ground Water Chemistry, and Hydrogeology
of the Murphy Area, Josephine County, Oregon

I. INTRODUCTION

Purpose

The purpose of this study is to investigate and describe the geology, ground water chemistry, and hydrogeology of the Murphy area, Josephine County, Oregon. Emphasis will be placed on the availability and quality of ground water. Waters high in dissolved material have been reported within the area. Two problems need to be solved: what is the source and extent of nonpotable water; and will the ground water resources support future development? The need arises from the increased demand placed upon the ground water system. Josephine County has increased in population by 65% in the last decade (1970-1980), with an 86% increase in unincorporated areas (Center for Population Research and Census, 1970 and 1980).

Location and Access

The thesis area is located in the northern Siskiyou Mountains, a subprovince of the Klamath Mountains, and is immediately south of the city of Grants Pass (Fig. 1). The area is accessible by many paved public and private roads. Portions of the U.S. Highway 199 and State Highway 238 transect the area. Because most of the land is privately owned, access and sampling are subject to the consent of the individual landowner. No access problems occurred during the study. Many ridgetops are publicly owned, including Bolt Mountain, Pickett Mountain, and Eagle Mountain.

Climate and Vegetation

The climate of the Murphy area is characterized by wet winters and hot, dry summers, with an annual normal rainfall of 82.3 cm/yr

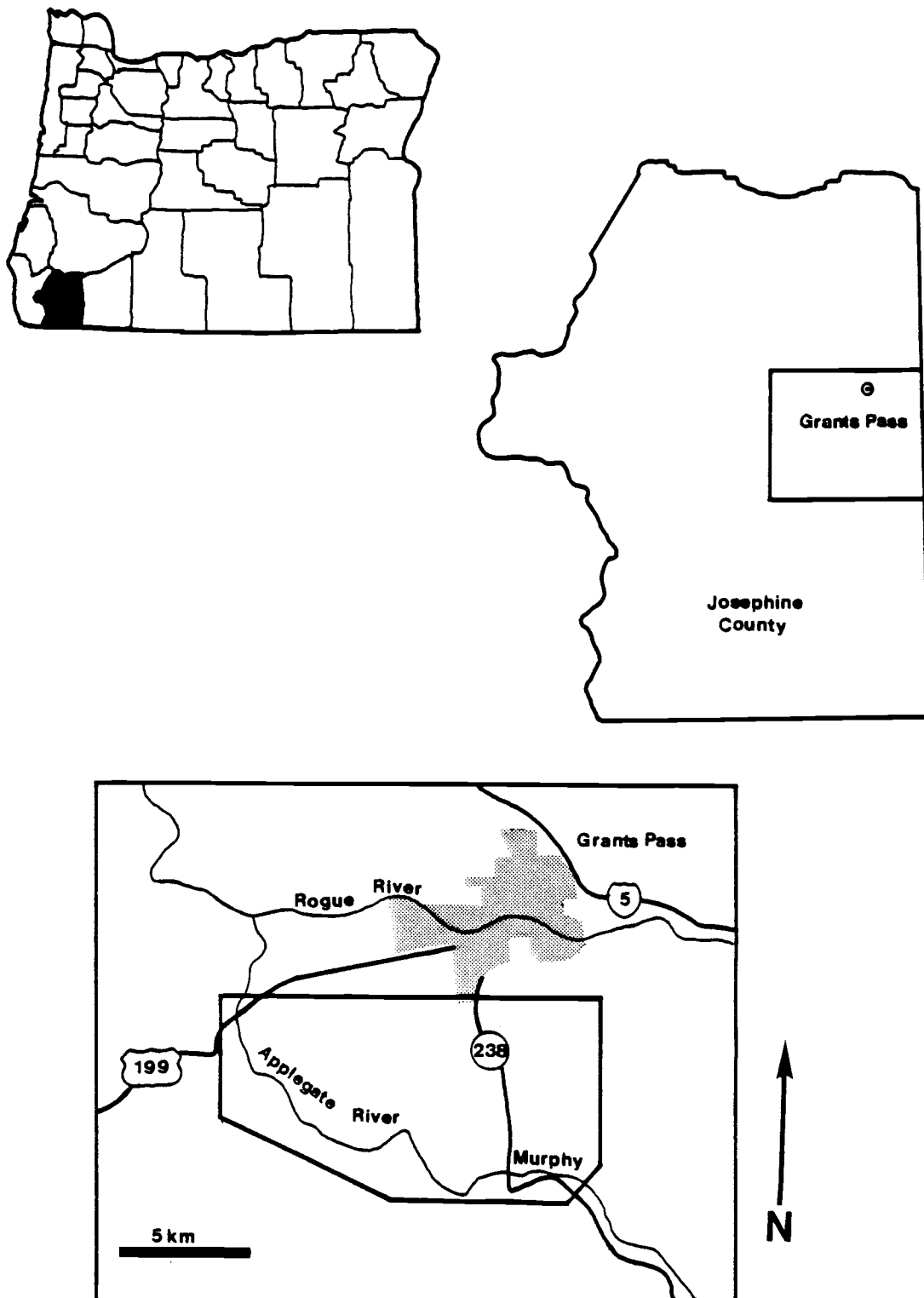


Figure 1. Location of Murphy area, Josephine County, Oregon.

(32.4 in/yr) (National Oceanic and Atmospheric Administration [NOAA], 1973) (Fig. 2). During the winter of 1978-1979, precipitation levels reached only 50% of normal. Over the five-year period 1975-1980, less than normal rainfall occurred in four of the years (NOAA, 1975 through 1980) (Fig. 3).

A thick soil supports the characteristic vegetation of the area--dense brushfields and mixed woodlands with heavy brush understory growth. Trees in the area include Jeffrey pine, sugar pine, Douglas fir, cedar, oak, maple, madrone, and alder. The chaparral is dominated by buckbrush ceanothus, shrub oak, and Pacific poison oak (Gratkowski, 1961).

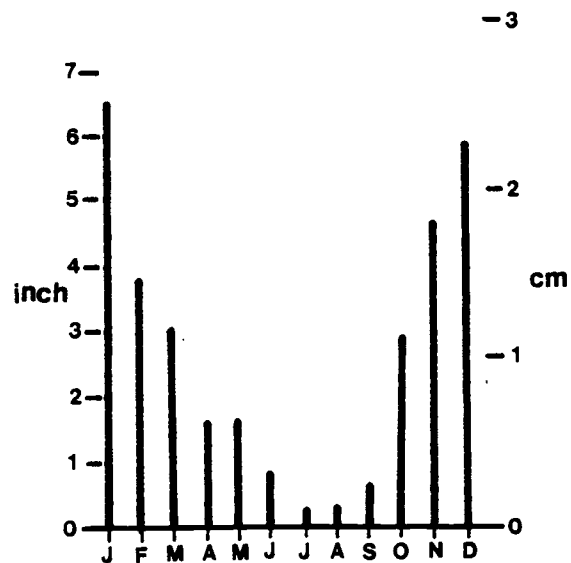


Figure 2. Monthly normal precipitation for Grants Pass (NOAA, 1973).

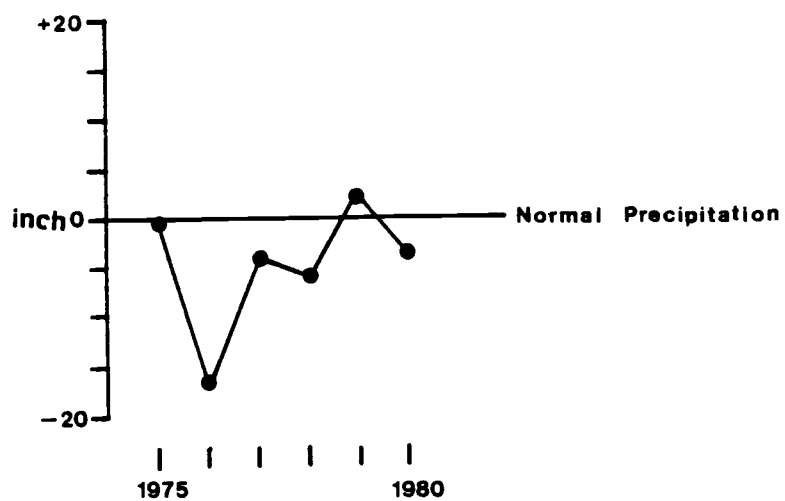


Figure 3. Rainfall deviation from normal annual precipitation (NOAA, 1975 through 1980).

II. GEOLOGY

The local geology was investigated on a reconnaissance level to understand and describe those features that pertain to water availability and quality. Emphasis was placed on extent of units, lithic character, and possible location of hydrogeologic boundaries. Field work consisted of geologic mapping (utilizing aerial photographs) (Plate I) and collection of rock samples. Minerals and textures were identified in thin section. Four systems of nomenclature based on rock type are used in this study: (1) sedimentary rocks (Pettijohn, 1975); (2) plutonic rocks (IUGS classification--Streckeisen, 1973 and 1976); (3) metamorphic rocks (Turner, 1968); and (4) volcanic rocks (Williams and others, 1954).

Klamath Mountains Province

The Klamath Mountains geologic province is an elongate north-south trending region in northwest California and southwest Oregon. It is bordered on the east by the Cascade Range and on the west and north by the Coast Range of Oregon and California. Irwin (1960) divided the Klamath Mountains into four allochthon belts (Fig. 4): (1) the Eastern Paleozoic Belt; (2) the Central Metamorphic Belt; (3) the Western Paleozoic and Triassic Belt; and (4) the Western Jurassic Belt. The four belts have been intruded by several granitic plutons (Fig. 5).

The Eastern Paleozoic Belt is situated in the southeast Klamath Mountains of California. The rocks range in age from early Paleozoic to Jurassic and are typically eugeosynclinal sedimentary and volcanic rocks.

The Central Metamorphic Belt is in the south-central Klamath Mountains. It consists chiefly of the Salmon Hornblende Schist and the Abrams Mica Schist. The age of the Abrams Mica Schist is 380 m.y. (Rb-Sr--muscovite; Lanphere and others, 1968).

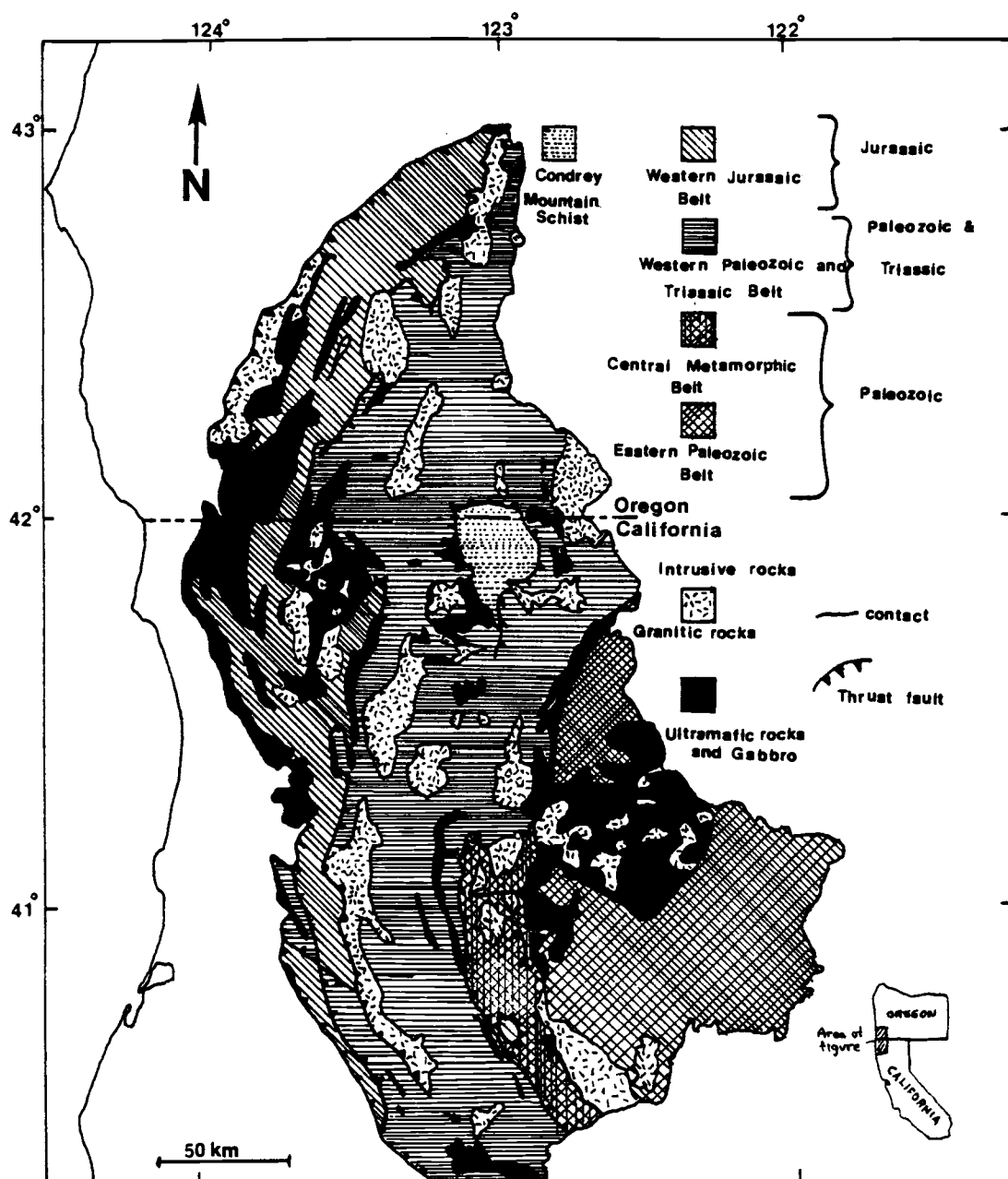


Figure 4. Generalized geology of the Klamath Mountains.

This diagram shows the four allochthon belts of Irwin, 1960 (after Hotz, 1971).

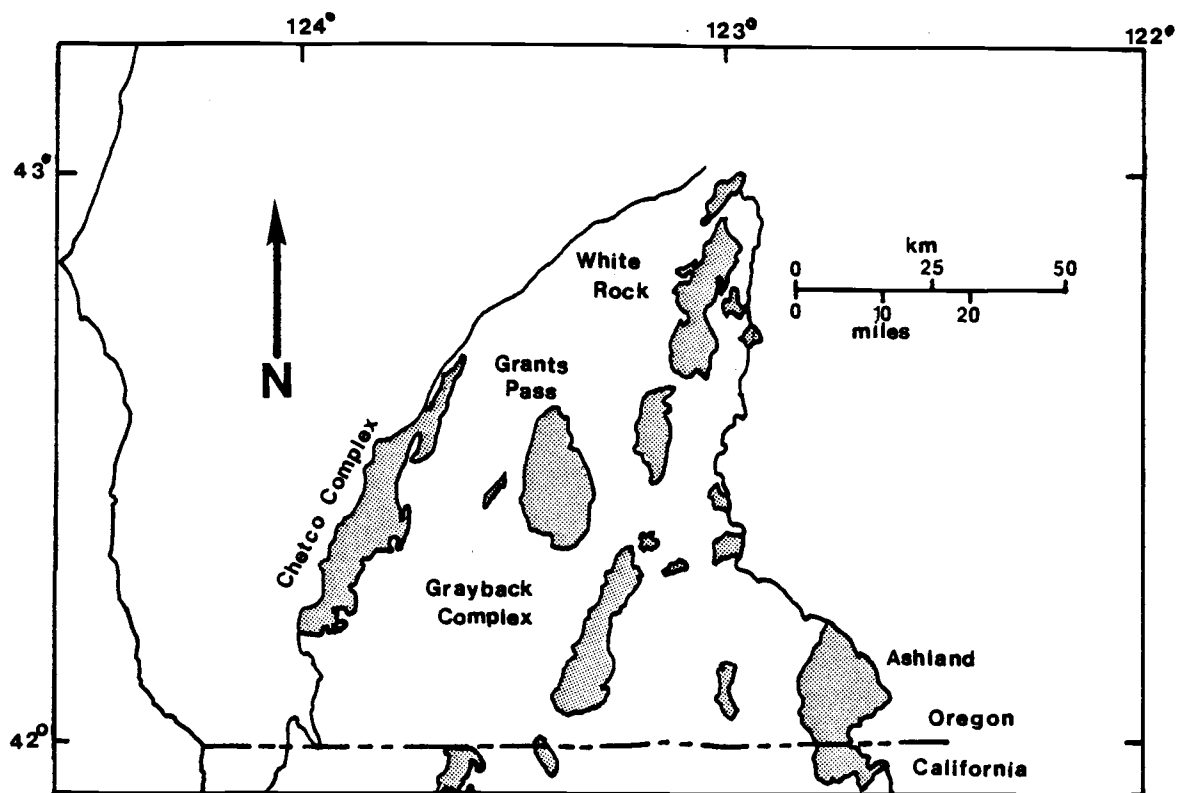


Figure 5. Plutonic rocks of the northern Klamath Mountains, Oregon (after Hotz, 1971).

The Western Paleozoic and Triassic Belt is the most extensive of the four belts. In Oregon it is represented by the Triassic Applegate Group of Wells (1956). Analyses of hornblende from two amphibolite samples north of Vesa Bluffs Pluton yielded K-Ar ages of 148 and 146 m.y. (Lanphere and others, 1968). Amphibolite gneisses from the Wrangle-Red Mountain area and the May Creek area yielded K-Ar ages (hornblende) of 144 and 150 m.y., respectively (Kays and others, 1977). These ages suggest that metamorphism ended during the Jurassic.

The Western Jurassic Belt extends over the western margin of the Klamath Mountains. An arcuate subprovince, it is composed of the Rogue and Galice Formations and the Josephine Peridotite. Middle Upper Jurassic pelecypods have been found in a sedimentary unit of the Galice Formation (Dott, 1971).

The four allochthon blocks are separated by thrust faults.

Nevadan Orogeny

The Nevadan Orogeny (Middle to Late Jurassic) had profound effects upon the rocks of the Klamath Mountains. During this period major thrusting, deformation of rock units, intrusion of mafic and felsic rock, and metamorphism occurred.

Earlier Work

Earliest work in this region was Diller's (1902) description of the development of the Klamath Mountains. He named the Galice Formation for outcrops along Galice Creek (Diller, 1907). Diller (1914, 1922) and Diller and Kay (1909, 1924) described the general geology and economic deposits. The mineral evaluation of the State of Oregon compiled by Brooks and Ramp (1968) included a section on the Klamath Mountains. Much of the early work was concerned with mining; indeed, southwest Oregon was first developed by the mining industry.

Wells and others (1940) compiled a geologic map of the Grants Pass Quadrangle. The most recent geologic map of the thesis area is that of Josephine County (Ramp and Peterson, 1979).

Early descriptions of the undifferentiated Applegate Group rocks were published by Wells (1939) and Wells and others (1949). The Galice Formation was described as slightly metamorphosed sedimentary and volcanic rocks by Wells (1939), Wells and others (1940, and Wells and Walker (1953). On the basis of their petrochemistry, the Galice and Rogue Formations have been identified as a Jurassic island arc sequence (Garcia, 1979).

Rock Units

Applegate Group

The Applegate Group rocks comprise a broad band of metavolcanic and metasedimentary units. Baldwin (1976) estimates that the formation may be several kilometers thick. A complex structural history has produced a series of rock layers which strike generally north to northeast and dip steeply to the east.

A variety of metavolcanic rocks has been mapped and reported, including basaltic and andesitic flow rocks, breccias, and pyroclastic rocks. Heinrich (1966) reports in addition rocks of the spilite-keratophyre association. A submarine origin is suggested by the presence of pillow structures (Heinrich, 1966). Not all the Applegate Group rocks are submarine in origin, however; Engelhardt (1966) describes relict pahoehoe lava structures which probably reflect sub-aerial cooling.

The metasedimentary rocks consist of a thick sequence of black, platy argillite, tuffaceous feldspathic and lithic graywacke with minor quartzite, recrystallized chert, and rare lenticular beds of marble. They are characteristically immature, poorly sorted, and contain subangular grains which indicate a relatively short transport

distance before deposition (Heinrich, 1966).

Metamorphic grade expressed by Applegate Group rocks appears to be highly variable over a relatively restricted area. Heinrich (1966), working in the Kinney Mountain area of Jackson County, reports nonequilibrium metamorphism ranging from the prehnite-pumpellyite metagraywacke facies to the quartz-albite-muscovite-chlorite subfacies of the greenschist facies. Kays and Ferns (1980) report rocks ranging from "feebly" metamorphosed greenschist facies to thoroughly recrystallized, medium-grade amphibolite facies schist and gneiss in the Condrey Mountain area. To complicate matters further, the Applegate Group has undergone a complex history of intrusion. Composition of plutons varies from gabbro to diorite to quartz monzonite (Hotz, 1971). The Applegate Group rocks can be viewed as highly variable in both original lithology and metamorphic grade.

Within the study area, the Applegate Group covers 27 km²; it ranks as the second largest unit of outcrop. Poor exposures, caused by thick vegetation and soil cover, are the rule, necessitating the collection of some samples as float.

Several samples of metavolcanic rocks were collected for petrographic work. The locations for these samples are Boardshanty Creek (BS-63), Pickett Mountain (P-80, P-86A), and Iron Creek (I-134). The mineralogy of the four samples is similar (Table 1). The amount of amphibole is about the same, with varying amounts of quartz, plagioclase, and epidote. The amphibole pleochroic colors are blue-green to green to light tan or pale yellow. Crystal varieties include fibrous, platy (with some crystals having ragged edges), and small needles. Many optical properties of the more iron-rich actinolite grains are commonly transitional with common hornblende (Deer and others, 1966). Based upon crystal form, the variety is most likely actinolite. The identification is important, as actinolite is a useful indication of metamorphic facies.

Sample BS-63 was collected as float on the east side of Pickett Mountain near Boardshanty Creek. A very crude mineral banding or

TABLE 1. Mineral composition of metavolcanic rocks of the Applegate Group.

Sample	Amphibole	Quartz	Epidote	Plagioclase	Sphene	Opaque Minerals
BS-63	50%	4%	4%	40%	--	2%
P-80	40%	40%	10%	10%	--	Tr
P-86A	50%	25%	5%	20%	Tr	Tr
I-134	55%	40%	Tr	--	5%	Tr

Other minerals:

BS-63: Chlorite

P-86A: Clay Minerals, Chlorite, Hematite

segregation can be seen in hand sample. Small plagioclase laths are set in a dark greenish gray matrix cut by a light yellowish green vein approximately 1 mm wide.

In thin section, relict labradorite laths in a matrix of actinolite and minor quartz, epidote, opaque minerals, chlorite, and biotite (?) display a blastoporphyrictic texture. Chlorite appears to have formed through the alteration of actinolite. Quartz occurs as xenoblastic groundmass and as veins and small stringers. Epidote also occurs in veins. Small veins appearing in hand sample appear to be segregated, with quartz toward the center and epidote toward the edges of the veins. Epidote is irregular in shape and intermixed with actinolite. At least three types of opaque minerals are in the sample: small disseminated blebs of pyrite (?), now altered to hematite; ilmenite altered to leucosene; and small octahedrons of magnetite. A few very small flakes appear to have the pleochroic colors and high birefringence of biotite. Based upon the plagioclase composition and relict textures, the parent rock was most likely a basalt.

Two samples were collected from Pickett Mountain (P-86A and P-80). Sample P-86A was collected on the east side of the mountain. A fresh surface of the sample reveals a light bluish gray surface having a greenish gray vein across it. Small (1 mm) white plagioclase laths can be seen in an aphanitic groundmass.

In thin section, the rock has a blastoporphyrictic texture. Relict plagioclase (An 50) laths are surrounded by a groundmass of actinolite, quartz, epidote, plagioclase, and minor sphene. Small clusters of actinolite appear as pseudomorphs of mafic phenocrysts such as pyroxene. Quartz is also found in small clusters of irregularly shaped blebs, suggesting a secondary filling of vesicles. Epidote occurs throughout the sample as small xenoblastic blebs associated in many places with plagioclase. In the groundmass, plagioclase is less than 0.1 mm in size, obviating composition identification. Sample P-86A lacks schistosity or even crude mineral banding.

The relict plagioclase composition and mineral textures suggest that the parent rock was an andesite. The high abundance of quartz would be caused by silica introduced during metamorphism.

Sample P-80 was collected at the top of Pickett Mountain. In the field, fine-grained, dark bluish gray aphanitic rock weathers to moderate brown. In thin section, a fine-grained mosaic of quartz, actinolite, epidote, plagioclase, and opaque minerals is observed. A uniform grain size and random mineral orientation create a granoblastic texture. Epidote is found as small xenoblastic blebs. Quartz occurs as xenoblastic filling of vesicles and in the matrix. Plagioclase occurs as xenoblastic grains showing faint twinning. Small grain size hampered identification of matrix phases. Opaque minerals occur as small irregular blebs. The abundance of amphibole suggests that the parent rock was an aphanitic mafic volcanic rock. Silica introduced during metamorphism would account for the high abundance of quartz.

From the south side of the Applegate River along South Side Road near Iron Creek, Sample I-134 was collected as float. This rock is fine-grained, dark greenish gray, with small (1-3 cm) whitish and greenish patches throughout. Small blebs of brass yellow sulfide minerals pepper the rock.

In thin section, the texture is blastoporphyritic; there are a very few relict phenocrysts. The whitish patches are microcrystalline, idiomorphic to xenoblastic quartz occurring in clusters, stringers, and as groundmass. Sphene is high in abundance (5%) and occurs as xenoblasts; typically, opaque minerals occur in the core of these xenoblasts. Blebs of opaque minerals appear throughout the slide. Epidote occurs in trace amounts. The rock appears to have a crude banding or mineral segregation. One relict phenocryst of plagioclase was found, although identification of composition was not possible. Abundances of actinolite and sphene suggest that the parent rock was a mafic volcanic rock. The abundance of quartz and

the crude banding suggest that silica was introduced or remobilized during metamorphism.

Determination of metamorphic facies for the four metavolcanic rocks has been complicated by the nonequilibrium nature of the metamorphism. Many relict phenocrysts and textures were found, suggesting that maximum temperature and pressure conditions were reached for only a relatively short time, preventing equilibration by diffusion. Based on the presence of actinolite and the absence of lower grade minerals, the area has experienced metamorphism to the greenschist facies. Biotite in Sample BS-63 indicates that metamorphism, at least locally, reached the biotite-chlorite subfacies.

Metasedimentary rocks are exposed on the western side of Bolt Mountain. To the east these rocks and the ultramafic rocks, with their complex hydration-dehydration history, are juxtaposed. To the west a regionally traceable thrust fault separates metasedimentary rock from granodiorite. It is evident that the geologic history of this locale is both interesting and complex; a detailed history was not attempted because it is not essential to the understanding of the local ground water chemistry. A variety of rocks is found in a relatively small area: (1) epidote rock with accessory sphene; (2) epidote rock with brown garnet, pumpellyite, sphene, and clay minerals; (3) actinolite-chlorite hornfels with plagioclase, spinel, clinozoisite, and opaque minerals; and (4) quartzite with veins of prehnite, radiating clusters of amphibole, clay minerals, and opaque minerals. Quartzites have been reported elsewhere in the Applegate Group (Wells and others, 1940).

A thin (0.5 m), sandy metasedimentary layer was found in the rock quarry 1 km west of Murphy. The layer is sandwiched between metavolcanic rocks. In the field, the sandy layer appears to be composed of quartz, plagioclase, and a green amphibole in a muddy matrix.

Weathering of the metavolcanic rocks was investigated by studying rock chips from a domestic water well located near Fruitdale Creek on Frankham Drive.

Rock sample LW-15 was collected at a drilling depth of 67 m. The rock is fine-grained with a whitish vein appearing in many of the rock cuttings. In thin section, the rock exhibits a high degree of alteration. Actinolite is altered to a rust-red stained clay-bearing material. Plagioclase has altered to clay minerals, epidote, and white mica. The whitish material was identified as laumontite by x-ray diffraction. Calcite occurs with laumontite.

Laumontite has been described as occurring in two types of deposit--buried diagenetic deposits and hydrothermal systems (Hay, 1966, 1978). Buried diagenetic processes result in a vertical zonation of zeolite minerals. These mineralogic zones record progressive dehydration resulting from increased temperature and pressure with burial. Laumontite and albite are representative of the deepest zone of zeolite formation; this zone grades into a deeper zone of prehnite-pumpellyite metagraywacke facies metamorphism. The open hydraulic system is within the shallowest zone of diagenetic zeolites; it is represented by clinoptilolite and mordenite assemblages. Zeolites are also widespread in areas of hydrothermal activity. A zonation similar to that developed in burial diagenesis environments may develop (Hay, 1978). Laumontite has also been associated with the deepest hydrothermal zone (Coombs and others, 1959; Hay, 1978). The proximity to the Grants Pass Batholith suggests that the Fruitdale Creek area may have been a site of hydrothermal activity. The occurrence of laumontite, in any case, is most likely a remnant of past plutonic or metamorphic events.

Galice Formation

The Jurassic Galice Formation consists of interstratified beds of volcanic and sedimentary rocks (Garcia, 1979). The volcanic rocks are basaltic to rhyolitic flow rocks, breccias, and tuffs. The sedimentary rocks, the bulk of the Galice Formation, consist of dark gray mudstones and graywackes. Thickness of the Galice Formation has

been reported as 4-5 km (McKee, 1972) to 8-9 km (Wells and others, 1940).

The Galice and Rogue Formations have been regionally metamorphosed under prehnite-pumpellyite metagraywacke to greenschist facies conditions (Garcia, 1979). Regional metamorphism has not modified the primary textures of the volcanic or sedimentary rocks except along shear zones. These rocks have been intruded by gabbroic to granodioritic plutons, and also by dikes and sills.

Within the study area, the Galice Formation occurs only along the western edge of the Grants Pass pluton. Exposures are rare because of thick vegetation and soil cover.

Sample C-13 was collected from the quarry on Chenny Creek, at the southern edge of the study area. The sample is two-toned--moderate yellowish brown and medium dark gray. Both rock types are well-cemented and fine-grained. In thin section the moderate yellowish brown rock contains clay, quartz, feldspar, mica, opaque minerals, and rock fragments. Grain size ranges from clay to very fine sand. Biotite and white mica are aligned parallel to bedding. Although the rock fragments have been altered, a few are still recognizable. Wells and others (1949) attribute the mica to metamorphic processes. The rock appears to be an arkosicwacke. The darker rock is also fine sand size and has a higher abundance of clay minerals. It is also an arkosicwacke. The clay matrix and cementation have greatly reduced the porosity of both rocks. In the study area, no volcanic rocks were found in the Galice Formation.

The contact with the Grants Pass Batholith is gradational. In the vicinity of the pluton, a distinct contact aureole has formed. The Galice Formation is in thrust fault contact with the Applegate Group.

Ultramafic Rocks

Ultramafic rocks are widely distributed throughout the Klamath

Mountains. Serpentinite and partially serpentinized peridotite occur as highly sheared stringers and as plates. The largest such mass in Oregon is the Josephine Peridotite. Vail (1977), among others, recognized this unit as an ophiolite sequence that formed in a marginal basin environment during Jurassic time. Many ultramafic rocks have been intruded by gabbro and diorite, thus predating mafic rock intrusion (Ramp and Peterson, 1979).

The composition of the ultramafic rocks varies from dunite to pyroxenite, the most common variety being harzburgite. Most of these rocks show at least minor serpentinization; intensity of alteration varies considerably within short distances.

In the study area serpentinite crops out in two localities, one on Bolt Mountain and one on the ridge 3 km south of Newhope. The Bolt Mountain location consists of three separate bodies. The main body is on Bolt Mountain; there are smaller exposures to the east and to the west. The western outcrop is in contact with the Galice Formation and the granodiorite, whereas the eastern body is in contact with gabbro. Total outcrop for all the ultramafic rocks in the study area is about 2.5 km^2 , one of the smallest units mapped.

In outcrop the serpentinite is well exposed, with thin or no soil. Vegetation consists of sparse stands of madrone and Jeffrey pine with abundant buckbrush and poison oak! This is in sharp contrast to the lush vegetation of adjoining regions with different kinds of bedrock. Serpentinite forms appreciable slopes which are typically unstable and rubbly.

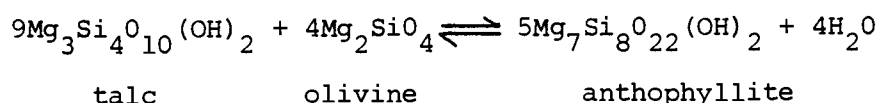
Variations within the serpentinite bodies are recognizable in the field. They are caused by varying degrees of serpentinization and subsequent alteration of the serpentine to talc. Rocks containing the most serpentine are fibrous and dark greenish gray, commonly with patches of dark orange, whereas light greenish white rock is composed of talc and actinolite. Two talc prospects occur--one on the south side of Bolt Mountain and the other on the ridge crest

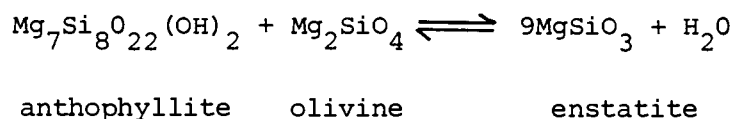
south of Newhope (Plate I).

Petrographic sections were prepared from two rock samples collected on Bolt Mountain. Sample B-30 is composed of olivine (40%), tremolite (30%), and serpentine (25%), with minor talc and opaque minerals. Small blebs of optically continuous olivine, having a web texture, are surrounded by veinlets of serpentine. The olivine has partly altered to slender prismatic crystals of tremolite. The serpentine minerals occur as both antigorite flakes and fibrous chrysotile. The serpentine has dehydrated to form talc and olivine. Thus, olivine occurs as both a relict mineral and a recrystallized mineral.

In sample B-43, olivine is less abundant (20%) and smaller in grain size. The amount of talc is much higher (45%); it occurs as highly birefringent groundmass. Tremolite was not found. Serpentine is low in abundance (1%). Idioblastic enstatite (10%), with small prismatic crystals (1 mm), lacks alteration, and thus has a fresh appearance. Anthophyllite (20%) occurs as idioblastic to xenoblastic bladed crystals and radiating clusters. Opaque minerals (4%) and minor brucite also occur.

The original rock composition of either sample can only be inferred. The texture and abundance of olivine suggest an olivine-rich peridotite. Most of the original minerals have been serpentinized. The association of anthophyllite and enstatite along with a lack of tremolite and serpentine suggest that these rocks have undergone subsequent dehydration. Radiating clusters of anthophyllite is a texture consistent with ensuing metamorphism of serpentinite (Moore and Qvale, 1977). The following equations from Turner (1968, p. 163) describe possible dehydration reactions:





Anthophyllite thus may have formed from talc, and enstatite from anthophyllite. The temperature and water pressure necessary for these reactions to occur are 600°C to 700°C and 1 kb to 10 kb (Turner, 1968). Loss of water could have been caused either by contact with the contiguous granodiorite or, perhaps more likely, by a regional metamorphism as found elsewhere in the Klamath Mountains. Kays and Ferns (1980) and Ferns (1979) have described the regional metamorphism of serpentinite in the Wrangle Gap-Red Mountain area.

Contacts with neighboring units are not well exposed; on many slopes they are covered by talus. Serpentinite outcrops are at least partly bounded by faults, as seen by lineations apparent in the field and on aerial photographs. Thus these rocks are exposed as a result of tectonism.

Gabbroic Rocks

Gabbroic rocks crop out throughout the Klamath Mountains and comprise major lithic units. Compositions reported include olivine gabbro, gabbronorite, hornblende gabbro, metagabbro, and epidiorite. Godchaux (1969) describes gabbro-pyroxenite and garnetiferous gabbro associated with the Grayback Complex.

Metagabbro or gabbronorite occurs in four locations within the study area and crops out over a total of 5 km² (Plate I). Two of the locations are on the north and south ends of Pickett Mountain. The largest outcrop is to the southeast of Bolt Mountain and is transected by the Applegate River.

The fourth location is just inside the western edge of the granodiorite. A small isolated body of gabbronorite (Sample A-35) is situated on a small ridge approximately 2 km east of Wilderville. In the

field, plagioclase, a black pyroxene, and a light brown pyroxene can be seen. In thin section, Sample A-35 is an allotriomorphic-granular, fine-grained rock. The anhedral pyroxenes are augite (15%) and hypersthene (25%), which have been uralitized to a rim of amphibole (10%) having pleochroic colors of light green to mud green to brown. Anhedral plagioclase (An 55; 50%) is not zoned, shows straining, and has only slight alteration. Apatite occurs as an accessory mineral.

The petrologic significance of the gabbro-norite is not clear. Godchaux (1969) proposed two mechanisms for the associated mafic and ultramafic rocks within the interior of the nearby Grayback Complex. In the first, gabbroic and ultramafic rocks occur as an early cumulate phase related to the intermediate rocks through magma genesis. For the second mechanism, two independent magmatic phases may have been emplaced along a common zone of weakness. Godchaux favored the latter possibility.

Identification of the metagabbro in the field is hindered by its resemblance to the metavolcanic rocks because both are composed of actinolite and plagioclase. Although most samples of metagabbro have phenocrysts, a few samples are fine-grained.

Two slides of metagabbro were prepared: Sample SM-128, collected from the large outcrop south of the Applegate River; and Sample NR-163, collected at the south end of Pickett Mountain.

Rock sample SM-128 was collected 1.5 km south of the Applegate River along the southern edge of the study area. In outcrop, white laths of plagioclase are seen in a dusky blue-green matrix with minor pyrite. In thin section the rock is a medium-grained cumulate. Zoned plagioclase (An 70-An 35; 55%) appears with adcumulate growth rings. The anhedral to euhedral plagioclase has been saussuritized to white mica, clay minerals, and minor epidote. Alteration coincides with adcumulate growth. Augite (15%) has been altered to actinolite. The actinolite (30%) occurs as felty masses, blades, and needle-shaped grains. Optically opaque minerals have altered to hematite. The rock is a mesocumulate with the intercumulate altered

to actinolite and clay minerals.

Rock Sample NR-163 was collected at the south end of Pickett Mountain 0.5 km east of Murphy. In hand specimen, white laths of plagioclase are set in a dusky blue-green matrix. In thin section Sample NR-163 is a medium-grained mesocumulate rock. Plagioclase (An 54-An 47; 40%) appears as subhedral to euhedral laths that have inclusions of actinolite needles. Other alteration products of plagioclase include minor epidote and clay minerals. Pyroxene and perhaps olivine have been completely altered to actinolite and chlorite. Anhedral-bladed pseudomorphs of hornblende are now actinolite, although a few grains of hornblende remain. Actinolite (55%) occurs as rounded grains, idiomorphic prisms, needles, and fibers. Optically opaque minerals occur interstitially. Veinlets of quartz, opaque minerals, and actinolite crosscut the sample.

Sample NR-163 also appears to have a mesocumulate premetamorphic texture, although much of the original texture has been obscured. The cumulate phase appears to be plagioclase, hornblende, and possibly pyroxene. Intercumulate material has altered to actinolite, chlorite, and clay minerals. The parent rock was apparently a hornblende gabbro.

Both samples SM-128 and NR-163 appear to have undergone non-equilibrium or partial metamorphism. The metamorphic event has left the plagioclase unaltered, whereas the more mafic minerals, such as augite and hornblende, and the groundmass have recrystallized. The formation of actinolite and chlorite suggests that conditions equivalent to the chlorite subfacies (greenschist facies) were reached.

Grants Pass Batholith

Granitic plutonic rocks occur throughout the Klamath Mountains province (Fig. 5); they intrude rocks of each of the four lithic belts. Plutons are most common in the Central Metamorphic and Western Paleozoic and Triassic Belts, and range in size from stocks

less than 1.5 km in diameter to outcrops of batholithic dimensions. They are typically elongated with long axes parallel to the north-south trend of the lithic belts. Within the Klamaths Hotz (1971) found compositions ranging from quartz diorite to diorite to granite. In addition, compositional similarities were found between Klamath Mountains province plutonic rocks and rocks of the western Sierra Nevada.

The Grants Pass Batholith (K-Ar age = 136 m.y.; hornblende; Hotz, 1971) is a major lithic unit in the Klamath Mountains. The egg-shaped batholith outcrop has a length of 27 km and a maximum width of 14 km. The Rogue River transects the pluton north of the study area. Fresh exposures are difficult to find; most of the pluton is covered by a thick weathering zone. Fresh samples can be found in road cuts and along stream and river channels.

The Grants Pass Batholith has been described as a quartz monzonite (Hotz, 1971) and as a quartz diorite (Wells and others, 1940; Ramp and Peterson, 1979). Using the IUGS system of classification (Streckeisen, 1976), the sample of Hotz (1971) is a granite (Fig. 6). Sample JP-144 was collected in a road cut on Demary Drive near the northern border of the study area. The sample appears to be essentially unweathered; there is relatively minor alteration of plagioclase and potassium feldspar. A slab of the sample was stained for easier identification of plagioclase and potassium feldspar and point-counted ($\Sigma = 1000$); Table 2 displays the pointcount data. The sample is a hornblende-biotite granodiorite.

In hand specimen, milky white plagioclase laths, milky white potassium feldspar, clear quartz, black biotite, and hornblende are observable, with minor apatite and sphene. Microscopically, the rock is medium-grained, hypidiomorphic-granular in texture. Laths of subhedral to euhedral plagioclase show slight saussuritization. Plagioclase shows normal zoning (An 60-An 35), with some zones saussuritized. Orthoclase is anhedral, having some myrmekitic

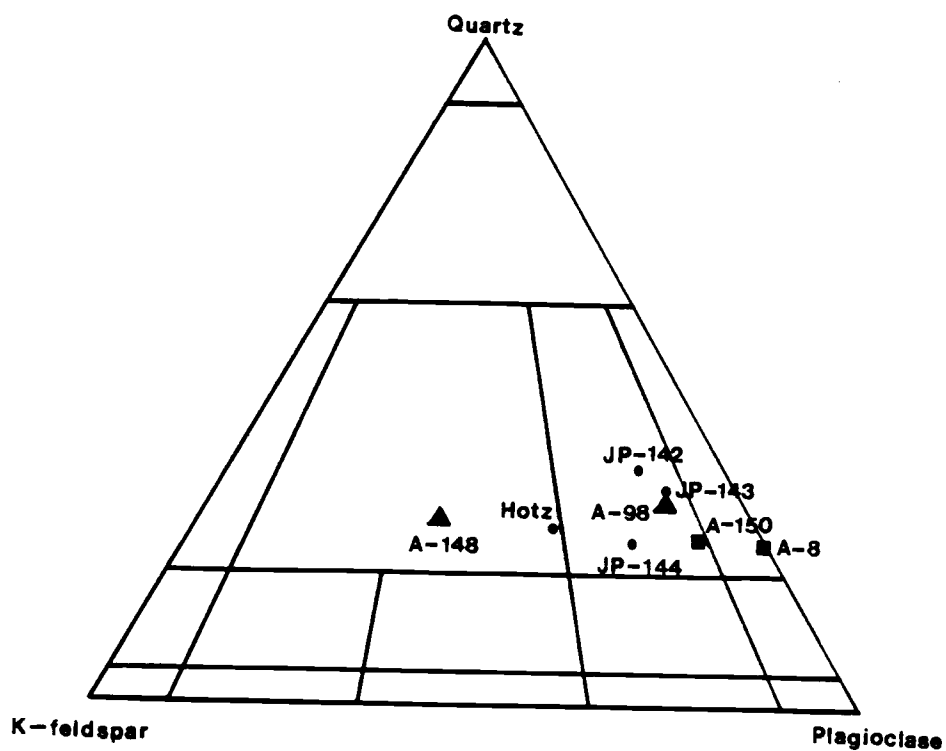


Figure 6. Plutonic rock classification of the IUGS system (Streckeisen, 1976).

Marginal plutonic rocks, A-8 and A-150, were collected in the riverbed of the Applegate River. Central plutonic rocks were collected at an outcrop on Demary Drive. Sample "Hotz" is from Hotz, 1971.

TABLE 2. Pointcount data

Sample No.	Quartz	K-feldspar Percent	Plagioclase	Dark Minerals	Total Counts	Rock Name
JP-144	21(25)	14(17)	46(58)	19	1188	granodiorite
JP-143	30(33)	8(9)	52(58)	10	1041	granodiorite
JP-142	34(36)	10(11)	53(50)	6	1018	granodiorite
A-8	16(25)	0(0)	50(75)	34	1006	tonalite
A-98	30(31)	10(10)	58(59)	2	993	leucogranodiorite
A-150	20(25)	52(66)	7(8)	20	530	granodiorite
A-148	28(28)	41(41)	30(31)	1	855	leucogranite
(quartz + plagioclase + K-feldspar = 100%)						

intergrowths. Orthoclase and quartz form large poikilitic crystals enclosing plagioclase, quartz, and accessory minerals; both minerals also show strain features. Biotite (11%) and hornblende (8%) are anhedral to euhedral, and both show late stage alteration to chlorite. Accessory minerals include anhedral to euhedral sphene (1%), apatite, zircon, and opaque minerals.

At the location where JP-144 was obtained two samples of weathered rock were also collected; JP-143 is a consolidated rock and JP-142 is unconsolidated grus.

The slightly weathered sample (JP-143) can be contrasted with the sample of unweathered pluton (JP-144). The plagioclase has similar composition, but more saussuritization has occurred. The weathered sample shows more fracturing of quartz and orthoclase.

In Sample JP-142, the plagioclase shows considerable saussuritization, some minerals having been completely replaced. Small veinlets of fractured orthoclase are present. Quartz shows signs of fracturing. Small veinlets of brecciated hornblende, biotite, plagioclase, quartz, and clay minerals are also present. The point-count data indicate that the weathered samples have lost orthoclase and some plagioclase relative to quartz (Fig. 6).

The weathered zone, with a maximum thickness of 45 m, forms a thick blanket of grus over most of the pluton. The maximum particle size of the grus is 28 mm, but most particles range from 0.5 to 1.0 mm. This corresponds to a coarse sand size. The particles are angular and brittle.

Although the composition of the Grants Pass Batholith appears to be fairly uniform, some variation occurs near the contacts. At some locations, potassium feldspar is less abundant and ferromagnesian minerals are more abundant. Sample A-8 was collected close to the western edge of the granodiorite near the overpass of U.S. Highway 199 over the Applegate River. This rock is a tonalite. Along with a significant increase in the color index (34), dark minerals form a distinct lineation. This compositional variation

does not occur in some locations, as demonstrated by Sample A-150 (Fig. 6). This rock, a granodiorite, was collected 1.5 km north of the Wilderville School, next to the Applegate River. Sample A-150 shows a lineation of dark minerals.

Contact with host rock is gradational. Xenoliths of host rock have been partly assimilated by the granodiorite, as found in the field at the U.S. Highway 199 overpass of the Applegate River. Blocks of the Galice Formation have been incorporated into the granodiorite. A similar situation occurs at a road cut on Jaynes Drive near the eastern contact with the metavolcanic rocks. Blocks of varying shades of gray are found surrounded by lighter-colored material (Fig. 7). A later phase of feldspar intrusion (small stringers) took place.

Several felsic dikes occur within the pluton. Sample A-148 is an example of such a dike; it was collected next to the Applegate River north of Wilderville School. The dike is granitic in composition with biotite and apatite as accessory minerals.

Outside the batholith, a small, simple pegmatite dike is located on South Side Road in a road cut approximately 1.3 km southwest of Newhope. The dike is 2.4 m thick and cuts metagabbroic rock. In the field, Sample A-98 appears white with pale yellowish orange stain. Quartz, feldspar, and plagioclase have a graphic texture. Small biotite flakes are seen. In thin section, the primary minerals have a fine-grained, hypidiomorphic-granular texture. Plagioclase (An 69) is subhedral to anhedral. Quartz is anhedral, and orthoclase is subhedral to anhedral. Accessory minerals are sphene, biotite, and opaque minerals. Epidote occurs as small, interstitial, anhedral grains. Opaque minerals have altered to hematite and limonite; plagioclase has altered to white mica. Pointcount data indicate the rock is a biotite leucogranodiorite (Table 2).

Using Buddington's (1959) classification of zones of emplacement, the Grants Pass Batholith was formed in the mesozone. A number of factors contributed to this determination: (1) the surrounding host rock is metamorphosed to the greenschist facies; (2)

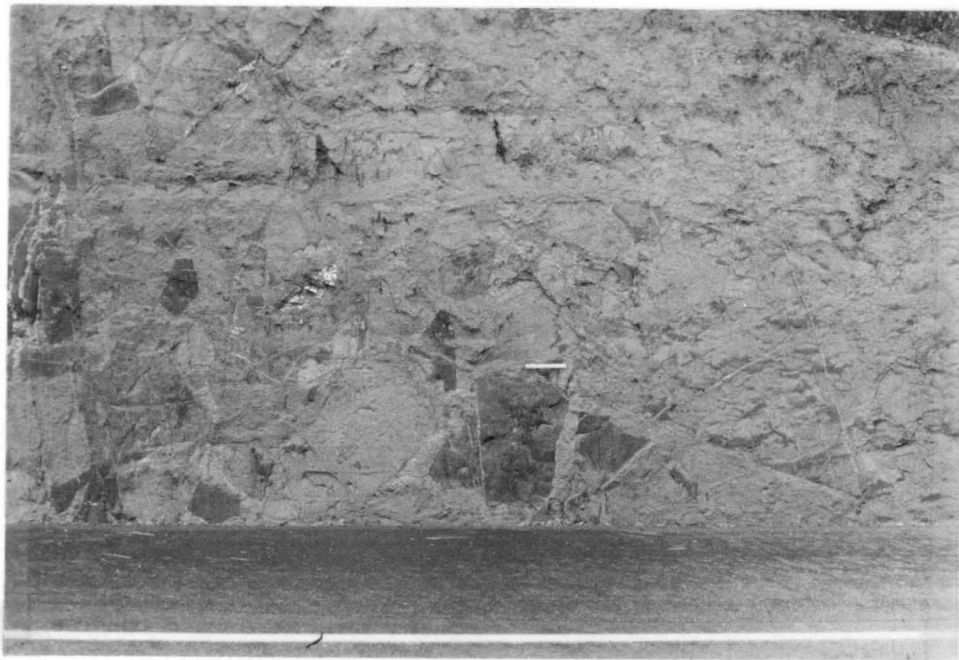


Figure 7. Photograph of the gradational contact between the Grants Pass Batholith and rocks of the Applegate Group (Jaynes Drive near Cloverlawn Drive).

Ruler directly above largest xenolith is about 30 cm (12") in length.

there is a well-developed contact aureole; (3) foliation within the pluton occurs only at the edges; (4) there has been a substantial length of time (136 m.y.) for erosion to expose the batholith; (5) no direct relation to volcanic rock of the same age, and no ring dike complexes or other shallow level features were found; and (6) assimilation of country rock in the form of xenoliths took place. Mesozonal plutons are thought to form at depths of 4 to 10 km.

Contact Aureole

A contact aureole completely circles the granodiorite. Several rock samples were collected and studied petrographically to learn more about the aureole, although mineral isograds were not mapped.

The entire study area is located on the southern end of the Grants Pass Batholith. Representative samples were collected from the Galice Formation (A-32 and A-151) and the Applegate Group (J-105). The samples of the Galice Formation were collected along the north side of the Applegate River west of Wilderville. Sample A-32 was taken on the western flank of the small outcrop of gabbro-norite. Sample A-151 was collected about 800 m southeast of A-32 (Plate I).

Sample A-32 is a cordierite-biotite-quartz-garnet-muscovite spotted slate. Slight schistosity is observable in outcrop, owing to the alignment of mica. Porphyroblasts give the rock its spotted appearance. In thin section, fine-grained lepidoblastic texture is dominated by the alignment of xenoblastic brown biotite (30%) and xenoblastic muscovite (5%). Most of the cordierite (50%) is xenoblastic and riddled with inclusions. A few grains show characteristic pseudo-hexagonal crystal form. Quartz (10%) occurs throughout the slide as indiscrete, colorless, xenoblastic grains. Porphyroblasts of xenoblastic garnet (5%) are colorless, isotropic grains. Minor minerals include optically opaque minerals and zircon.

Sample A-151 is a cordierite-biotite-quartz spotted slate.

Dusky red biotite is set in a medium dark gray groundmass. Petrographically, Sample A-151 is a lepidoblastic rock dominated by the alignment of mica. Cordierite (50%) is seen as pseudo-hexagonal porphyroblasts. Biotite (40%) is xenoblastic and brown. Quartz (10%) occurs as xenoblastic grains. Accessory minerals include opaque minerals and zircon. Alteration products include muscovite, chlorite, and clay minerals.

The abundance of biotite suggests that these rocks belong to the hornblende-hornfels facies. In both samples, the aluminum phase is cordierite. The pyroxene-hornfels facies of pelitic rocks is characterized by sillimanite or andalusite associated with cordierite (Turner, 1968). Since these minerals were not found, the higher temperature conditions probably were not reached.

The contact between the granodiorite and the metavolcanic rocks is a veined, gradational contact. Sample J-105 was collected on the eastern edge of the contact zone, west of Pickett Mountain. In the field, the sample has a medium gray to dark gray crude, gneissic banding with small white veinlets throughout.

In thin section, a fine-grained mosaic of diopside, amphibole, plagioclase, and quartz occurs. Diopside (35%) is xenoblastic. The amphibole (35%) is hornblende with pleochroic colors of olive green to green to light tan. Occurring as small, irregular blebs to prismatic crystals, it appears to have partly replaced diopside. Plagioclase (An 45; 20%) is also present as xenoblastic crystals, and shows minor alteration to white mica and epidote. Quartz (10%) is also xenoblastic. Accessory minerals include apatite and brass yellow pyrite (?). Crude banding results from a segregation of quartz-feldspar and diopside-amphibole layers.

This rock is characteristic of the hornblende-hornfels facies. The principal phases are hornblende, plagioclase, and diopside. In the pyroxene-hornfels facies, hypersthene should form from mafic rocks (Turner, 1968). It seems likely that the higher pressure and temperature conditions were not reached.

South of the Grants Pass Batholith, the Grayback Igneous Complex was studied by Godchaux (1969). The aureole was described as thermal and isochemical. A wide aureole developed on the eastern side of the complex and a very narrow one on the west. The highest metamorphic grade achieved was pyroxene-hornfels facies. Hornblende-hornfels was well developed with "basification" of plagioclase and transformation of actinolite to hornblende. An outer zone of actinolite schist was also described. Godchaux (1969) recognized the complexity of contact metamorphic events in these regional metamorphic rocks.

The contact aureole at the southern edge of the Grants Pass Batholith does not appear to be as well developed as the Grayback Complex. The thickness of the aureole on the western side is less than 0.5 km. The eastern aureole is structurally more complex because of a high angle fault located in the area. Talus from Pickett Mountain has obscured the contact. Most likely, this aureole is less than 1 km thick, but somewhat thicker than that along the western boundary.

Alluvium

Two alluvial units were distinguishable in the field: bench gravels or terrace deposits, and recent river alluvium (Plate I). The bench gravels lie above a 3-5 m high embankment. Relatively minor in occurrence, they are the remnants of an early erosional cycle. Clasts range in size from 700 mm to 3 mm and are set in a muddy matrix.

The recent river alluvium was and is being deposited by the Applegate River. The clasts are principally gabbro and metavolcanic rocks. The river alluvium varies from clay, silt, and sand size to cobble size. Normally, little stratification is found, but clay and mud layers occur locally at depth. Deposits of considerable thickness are found in the Murphy Creek area and the Wilderville School

area. Maximum depths reported by drillers are 49 m near the Murphy Creek area, and 37 m north of Wilderville School.

Structure

The locations of faults and fracture zones are important not only for structural interpretation but for hydrogeologic interpretation as well. The study area is dominated by two major structural features: the thrust fault separating the Applegate Group and the Galice Formation; and a series of north to northeast-trending high angle faults. Thrust faults are a major structural feature of the Klamath Mountains. Irwin (1964) recognized these features as divisions between regional subprovinces. In the study area, the thrust fault is located on Bolt Mountain (Plate I).

Four north to northeast-trending high angle faults occur in the study area. The most prominent fault occurs from Murphy Creek along the eastern contact of the Grants Pass Batholith to the Fruitdale Creek area. Its northern continuation apparently is covered by alluvium. This fault is recognizable by lineation on aerial photographs and by the occurrence of a major topographic low. A second high angle fault is adjacent to the serpentinite outcrop south of Newhope. The third is obscured by alluvial material. These three were recognized by Ramp and Peterson (1979). A fourth fault is located in Boardshanty Creek and was recognized by lineations on aerial photographs, lineation in the field, and a topographic low area.

Two east-west-trending faults located near Bolt Mountain were recognized by lineations on aerial photographs and by linear contacts in the field.

Displacement on all the faults was not determined, owing to a scarcity of good outcrops. Vail (1977) estimated that high angle faults in the Oregon Mountain area could have displacements of several thousand meters. Displacements of thrust faults were estimated by Vail (1977) to be several kilometers.

Summary

Applegate Group rocks were metamorphosed under nonequilibrium conditions to the greenschist facies; at least locally, they reached the biotite-chlorite subfacies. Most likely, silica was introduced into some of the Applegate Group rocks during metamorphism. The ultramafic rocks are characterized by serpentized olivine-rich peridotites which have undergone a complex hydration-dehydration history. Two types of gabbroic rocks were found in the area--metagabbro and gabbro-norite. The Grants Pass Batholith, a hornblende-biotite granodiorite, weathers to a gray layer in its upper portions. The Batholith has produced a contact aureole (hornblende-hornfels facies) in the country rocks. Structurally, the geology is dominated by north-northeast and east-west trending high angle faults and by a regional thrust fault.

III. GROUND WATER CHEMISTRY

Water chemistry obviously is an integral part of a ground water investigation. The purposes of chemical analysis in this report are two-fold: a practical description of water chemistry; and an interpretation of origin of composition. Description of water quality consists of a listing of analyses, classification of waters, a statement of suitability for irrigation purposes, and a water chemistry map with Stiff patterns. Species analyzed include Na^+ , K^+ , Ca^{++} , Mg^{++} , HCO_3^- , CO_3^{--} , SO_4^{--} , F^- , Cl^- , SiO_2 , and total Fe. Laboratory methods for the analysis of dissolved constituents are briefly described in the Appendix.

Field Methods and Procedures

Water quality was investigated by sampling 41 domestic water wells and two samples of the Applegate River. The fieldwork was completed in summer, 1979. The river samples were collected prior to the completion of the Applegate Dam. Techniques in the sampling of well waters can be critical in assuring a representative analysis of the aquifer. Within most well bores, water is commonly in contact with the well casing, pump parts, and the atmosphere. Chemical reactions with these materials can change the composition of the waters. Pumping a well prior to sampling can remove much of the affected water. Methods of water well sampling used in this study were suggested by Wood (1976).

To obtain a representative sample, a well must be pumped until the temperature, electrical conductance, and pH are constant. This minimum requirement does not, however, guarantee a representative sample. There is no minimum pumping time past which the parameters listed will not vary. Wells in constant use require only a few minutes of pumping, whereas little-used wells may require a day or more. Well samples should be excluded if stabilization of these

parameters cannot be obtained within a practicable time.

Potential contamination, precipitation of solutes, and loss of dissolved gasses can be minimized by sampling as close to the well head as possible. This practice was followed. After ten minutes of pumping, temperature was monitored with a laboratory grade thermometer. Once thermal stabilization occurred, electrical conductance was monitored with a Lab-line Portable Lectro MHO-meter. After replicate readings, pH was monitored with an Orion model 407A specific ion meter and an Orion combination pH electrode, model 91-0500.

When these parameters stabilized, two one-quart samples were collected. One of the one-quart samples was acidified to prevent algae growth and inhibit redox reactions of easily reduced metals such as Fe. The other one-quart samples were refrigerated.

Analyses of HCO_3^- and CO_3^{--} were performed in the field using a potentiometric titration technique (see Appendix). The necessity of field analyses arises from the rapid exchange of CO_2 between atmosphere and sample, which can alter the carbonate equilibrium and pH values relatively quickly (Roberson and others, 1963). Wood (1976) warns that these parameters are particularly variable if samples are collected and stored in certain types of plastic containers, since many kinds of plastic are permeable to CO_2 . To help insure representative analysis, samples were analyzed within four hours of collection.

Previous Work

A brief study of ground water in the Grants Pass area was done by Robison (1973). This study included a total of 15 water analyses, eight of which were sampled within the area described herein. Wells completed in alluvium or in granitic rock commonly yielded Ca-Mg- HCO_3 type water. High total Fe was found in some waters from the granitic rocks. Applegate Group metavolcanic rocks tend to produce Ca-Mg- HCO_3

waters, with some producing NaCl waters. Excessive SO_4^{--} and Cl^- tend to occur in waters having high total dissolved solids.

Water Quality Data

Table 3 was prepared as a summary of water quality data. For the purpose of this study, water chemistry samples are listed by field number. Well location numbers have been included, since several governmental agencies use them for well records (Fig. 8).

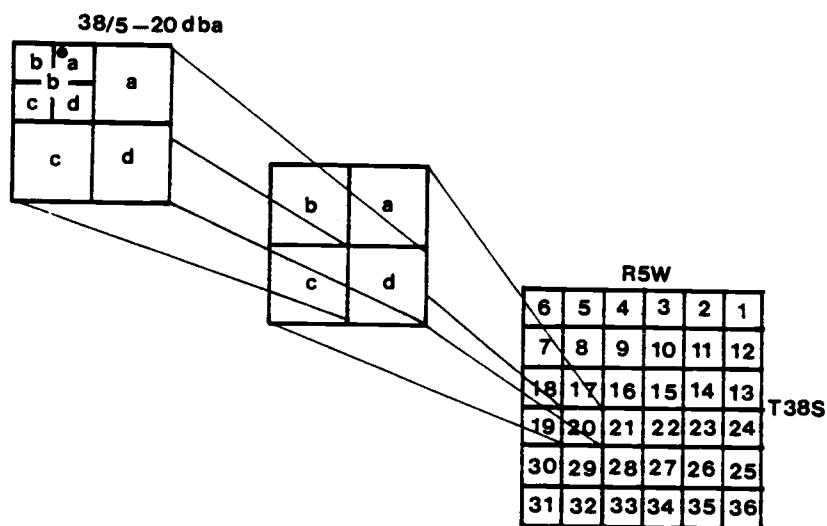
Two samples of the Applegate River were collected; Sample 101 was collected in early summer and Sample 133r was collected in September at low river flow. Sample 131s was collected from an air-rotary drill rig at the time of drilling. The nonpotability of the water was immediately apparent, and the well was abandoned. Since contamination by the drilling process was unavoidable, analysis of HCO_3^- was not performed. Sample 131 is from a second well located on the same property. After sampling, it was learned that the well had not been sufficiently developed. Cement grout was still in the casing and was, consequently, collected along with Sample 131; the measurement of HCO_3^- for this sample is therefore invalid. Analyses of Samples 131 and 131s have been included only for purposes of rough comparison.

Temperature, pH, and Electrical Conductance

Temperature, pH, and electrical conductance (EC) were measured in the field at time of sampling. Temperature was measured in degrees Celsius and pH in conventional pH units. Electrical conductance is a measure of the ease with which an electrical current will flow through a material. The unit of measure is the inverse ohm (mho), the reciprocal of the resistance. The units of EC used in this study are $\mu\text{mho/cm}$ @ 25°C or μmho @ 25°C . The SI units equivalent to μmho 's are microsiemens (μS). Electrical conductance has

TABLE 3. Water analysis data.

Field No.	Well Location No.	Name	Field Data				mg/l								µg/l	mg/l		Total Hardness	% Error
			Date	Temp. °C	pH	EC µmho/cm	Na ⁺	K ⁺	Ca ⁺⁺	Mg ⁺⁺	HCO ₃ ⁻ /CO ₃ ²⁻	Cl ⁻	F ⁻	SO ₄ ²⁻	Total Fe	SiO ₂	TDS		
101		Applegate River	6/21	18.3	7.66	241	2.3	1.0	17	8.7	101	1.7	.09	9	60	14	54	81	5.7
102	37/6-12aba	Wharten, M.H.	7/19	14	7.1	280	12	1.1	27	9.8	158	1.5	.2	11	0	43	160	108	3.0
103	36/5-33cba1	Paliani	7/27	15	6.78	172	6.7	0.2	12	9.9	105	1.4	.06	7	80	37	130	73	5.5
104	37/5-16dcc	Intihar, J.D.	7/28	16.9	7.19	320	12	0.4	28	16	197	3.0	.1	8	60	40	200	136	3.6
105	37/5-16dab	Atkin, J.	7/29	19.7	6.98	324	10	0.5	29	18	203	3.9	.1	9	30	62	230	146	3.6
106	36/5-33cbd	Broffle, W.	7/31	19.9	7.63	2990	530	0.5	100	3.5	150	860	.2	120	80	30	1700	264	1.5
107	36/5-33cba2	Skjerseth, H.	7/31	13.8	7.52	2120	220	0.1	150	34	163	590	.2	67	190	21	1160	514	2.1
108	37/6-12bbc	Olen, J.	7/31	13.8	7.49	288	10	2.1	26	12	170	1.6	.2	6	30	32	170	117	3.4
109	36/5-32dab	Willfoung, B.	8/1	15.2	6.99	329	15	0.7	29	14	151	17	.2	12	0	43	210	130	.8
110	36/5-33ccc	Baker, H.	8/1	14.0	6.82	291	29	0.2	18	8.5	138	10	.09	7	20	44	180	80	-3.1
111	36/5-32dbb	Houser, J.	8/2	12.8	7.09	197	7.6	1.7	18	9.3	131	2.2	.2	4	10	40	150	86	6.1
112	37/5-16acc	Morgan, R.	8/2	13.8	7.49	394	18	0.3	30	20	196	14	.1	12	20	45	240	157	.9
113	37/6-12bad	Summers, J.	8/2	16.9	7.08	200	12	1.6	17	7.1	126	.4	.2	4	260	48	150	72	4.2
114	37/5-8abb	Ellsworth	8/8	15.1	7.12	338	20	0.6	29	13	193	3.9	.2	10	40	49	220	126	1.3
115	36/5-33bad	Manon, T.	8/8	15.0	7.42	343	30	0.3	25	11	176	29	.09	6	50	35	220	108	4.9
116	36/6-33ddd	Ruda, S.	8/9	15.2	7.11	232	8.7	1.2	24	9.0	244	2.6	.2	4	100	38	210	99	28
117	37/5-7daa	Duff, J.B.	8/9	16.8	6.78	340	13	0.7	33	15	202	3.4	.1	6	20	56	230	144	1.0
118	36/6-32add	Bolten, A.M.	8/9	14.1	7.38	282	14	1.6	28	11	172	2.9	.2	5	80	42	190	118	1.1
119	37/6-6dda	Heglin, C.	8/11	14/8	7.38	4060	1100	1.4	140	1.1	59	2000	.7	4	790	19	3300	350	2.3
120	37/6-5ccb	Goodell, B.	8/11	18.0	6.79	5000	1000	3.6	440	5.4	104	2700	.3	100	250	24	4300	1100	9.6
121	36/5-32daa	Sybrant, F.	8/11	15.9	6.64	1010	160	0.2	41	4.6	149	230	.1	33	70	32	570	121	1.2
122	37/6-6acb	Runstetler, L.	8/12	14.1	6.53	124	7.6	1.5	11	5.8	70	3.2	.06	4	190	14	120	51	-2.6
123	37/5-7dab	Cutlett, H.	8/12	16.8	6.78	369	5.8	0.2	38	20	196	9.3	.09	7	40	54	230	177	-2.3
124	37/5-19adc	Boyke, W.R.	8/13	12.4	8.58	4480	950	1.1	490	1.6	22.3/3.9	2600	.08	160	200	20	4200	1230	7.9
125	37/5-19acd	Campbell, J.A.	8/13	15.2	8.01	558	66	0.3	25	.5	121	100	.1	14	70	19	280	64	10.1
126	37/5-19aca	Firestone	8/13	14.0	8.21	208	15	0.1	27	.9	108	6.2	.06	4	30	23	130	71	-1.1
127	37/5-15bbd	Tuck, R.	8/14	14.9	7.17	492	7.3	0.7	62	28	276	1.3	.06	38	160	34	310	270	-3.4
128	37/6-15bba	McCloud	8/14	14.9	6.98	425	4.3	0.2	44	31	270	2.9	0	8	50	52	270	240	-2.8
129	37/5-8bda	Trevett, D.	8/14	13.8	7.71	339	22	0.1	29	12	161	1.7	.1	33	80	37	210	123	-0.2
130	36/5-33bba3	Whittaker, A.	9/8	12.8	7.91	1535	220	0.2	130	6.5	90	620	.3	73	560	29	1100	351	10.5
131	36/5-33bba2	Latham, J.	9/8	13.2	8.39	3710	610	1.0	390	4.3	--	1800	.2	214	3700	.8	--	991	--
131s	36/5-33bba1	Latham, J.				20000	2100	3.4	2000	15	--	10000	0	775	68000	7	--	4990	--
132	37/6-5cca	Taglier, L.	9/9	12.8	6.31	178	8.5	2.8	16	8.1	106	1.3	.1	5	40	40	130	73	.6
133	36/5-32ddb	Breshears, D.	9/10	15.1	7.79	442	21	0.2	42	22	236	4.2	.2	29	50	43	280	195	-2.4
133r		Applegate River	9/9	21.2	8.44	221	6.2	1.6	24	10	123	6.4	.06	7	260	15	130	101	.3
134	36/5-32aba	Norby, O.	9/10	15.8	7.09	780	120	0.1	16	2.7	170	130	.2	31	740	35	420	51	6.5
135	37/5-5dbb	Child, L.	9/10	13.8	6.92	348	13	0.3	37	5.7	172	3.3	.2	33	60	48	220	118	11
136	37/5-19dac	Gibson, C.	9/11	12.8	7.58	280	14	0.6	32	11	185	2.0	.08	4	80	26	180	125	.8
137	37/6-14abb	Simmons, G.E.	9/11	13.8	6.83	372	4.4	0.2	40	24	239	2.4	0	6	40	58	250	168	.7
138	37/6-8dcb	Gorden, L.	9/11	13.4	6.09	150	7.3	1.9	14	5.7	61	2.2	.06	6	80	36	100	134	-13
139	37/6-6ddb	Ravencroft, S.	9/12	14.2	6.63	342	31	1.1	23	8.5	101	86	.05	6	580	0	210	92	13
140	37/6-6bba	Tetherow, V.	9/12	13.7	6.97	330	18	0.3	41	9.3	201	8.9	.1	4	660	42	220	141	.4
141	36/6-26ccc	Aguilera, J.	9/14	13.9	6.70	188	13	0.8	17	6.8	110	1.0	.2	3	310	52	150	70	-2.3



For well location number 38/5-20dba:

Township: T38S
 Range: R5W
 Section: 20
 Subsection: dba

Well location numbers with a number after the last subsection indicate separate wells located in a common subsection.

Figure 8. Well location numbering system.

also been called specific conductance or specific electrical conductance.

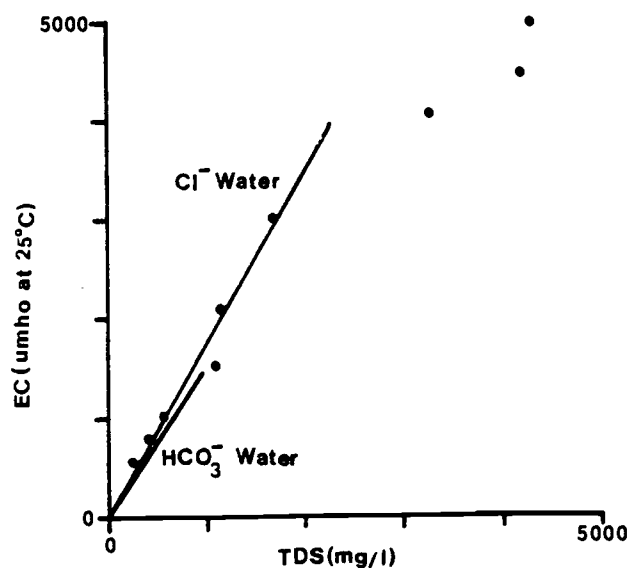
Electrical conductance is a function of total dissolved ions and ionic speciation. The relation between ionic concentration and EC is linear for a dilute solution of a single salt. As ionic concentration of the single salt increases, the linear relation does not hold. Both the slope of the linear portion and the deviation at higher concentrations are dependent on the ionic components present. From a plot of EC vs. total dissolved solids (TDS) (Fig. 9), two linear trends for lower EC values can be observed--one for HCO_3^- waters, the other for Cl^- waters. This diagram also shows deviation from linearity at higher concentrations.

Dissolved Species

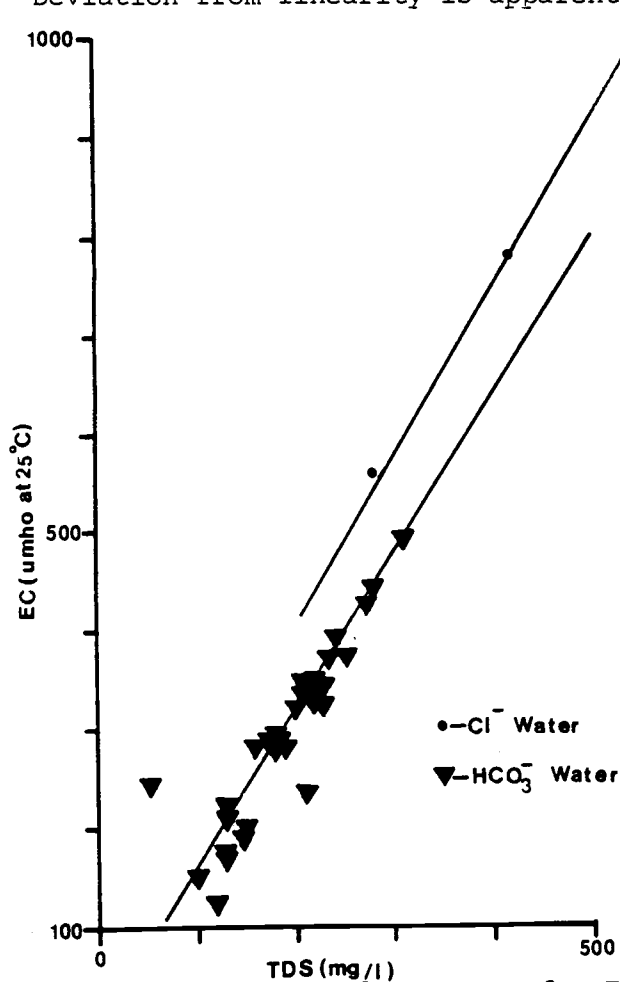
The values obtained from the analyses represent dissolved species concentrations (Table 3). The units reported are mg/l and $\mu\text{g/l}$, corresponding to ppm and ppb. In places, equivalents per liter (eq/l) are used in calculations. To convert from mg/l to meq/l, divide by the gram-formula weight and multiply by the charge.

The Fe values represent total dissolved Fe. The samples were pretreated with a reducing agent to reduce any Fe^{+++} to Fe^{++} .

Total dissolved solids (TDS) values approximate the absolute quantity of material in solution. Generally, one of two methods is used to determine TDS: (1) weight of residue after evaporation; or (2) computed value from chemical analysis. The first method involves weighing the dry residue remaining after evaporation of the volatile portion of an aliquot of sample. A final drying at either 103°C or 180°C for one hour is commonly part of the process. The main objection to this method is that volatile dissolved material of course is not measured. For example, the bicarbonate system becomes unstable at 100°C; half reacts to form water and CO_2 , and half forms CO_3^{--} (Hem, 1970). Certain organic constituents and other species such



(a) EC vs. TDS values plotted are for EC above 500 μmho @ 25°C . Deviation from linearity is apparent at higher TDS values.



(b) EC vs. TDS values plotted are for EC below 1000 μmho @ 25°C . Separate trends can be seen for Cl^- waters and for HCO_3^- waters.

Figure 9. EC vs. TDS.

as NO_3^- are also lost during the drying process.

To compare the evaporation method with the second method, computation from the chemical analyses, the convention is to convert HCO_3^- by a gravimetric factor which assumes half of the HCO_3^- is volatilized as CO_2 . This value is then summed with the other values in the chemical analysis. In this study, the TDS were computed from the chemical analysis using the HCO_3^- correction. Recently, a second computational method has appeared in the literature. Computed by direct summation of all constituents in mg/l, the value is commonly described as "TDS as reported" (Hem, 1970).

"Hardness" is a term ingrained in ground water literature. Several definitions have been proposed, most of which center around hardness as associated with effects observed in the use of soap or with precipitate formed when a solution is heated. A practical definition involves the effect of the water in question on the alkaline-earth cations (Hem, 1970, p. 224). The value of hardness is computed by multiplying the sum of Ca^{++} and Mg^{++} by 50. This value is expressed as CaCO_3 and called total hardness or Ca-Mg hardness. Since Ca and Mg analyses are more specific and useful, hardness has very limited geochemical significance. Owing to the common use of the term and the variety of people who may read this study, values for hardness are included in Table 3.

Percent Error

As a check of the precision of the analyses, percent error was calculated. This is a measure of the charge balance.

$$\text{Percent Error} = \frac{\text{anions} - \text{cations}}{\text{anions} + \text{cations}} \times 100, \text{ expressed in meq/l}$$

Ideally, of course, percent error should be zero; deviation from zero is then a cumulative indication of the precision. A

histogram of the percent error shows a distribution with a slightly positive mean (2.1) and a standard deviation of 4.9 (Fig. 10). A positive mean indicates that, on the average, resulting anion values were greater than cation values. The samples with EC above 500 μmho @ 25°C are all positive with five of the nine samples having more than 6% error. This has resulted in a definite positive influence on the mean. Of the total 41 samples, 27, or 66%, have a positive percent error. The causes of the error are not clear. Several possible mechanisms, alone or in concert, could account for the error: systematically biased techniques; sorption of cations on the plastic container; interference in the method of analysis; or incomplete analysis.

To qualify the error in the anion-cation balance, the data have been divided into four groups based on an ideal error of zero and a quasistatistical division of five (Fig. 11). Since values of precision were not measured, few conclusions can be based on these divisions. The precision could be greatly increased by replicate analyses; owing to cost and time considerations, however, only one analysis of each sample was performed.

Major ion chemistry controls the percent error in each analysis. Errors involved in the analysis of each species can cancel. The magnitudes of secondary or minor constituents are too small to affect the calculation. Therefore, the percent error does not adequately evaluate the precision of all the constituent measurements.

Classification of Ground Water

Classification of ground water types is a convenient method for describing composition in terms of identifiable groups or categories. Many different schemes have been devised for this purpose, although only minor attention has been given to the subject in the U.S. literature. Hem (1970) suggests using the dominant ions for classification only when their relative abundances exceed half of

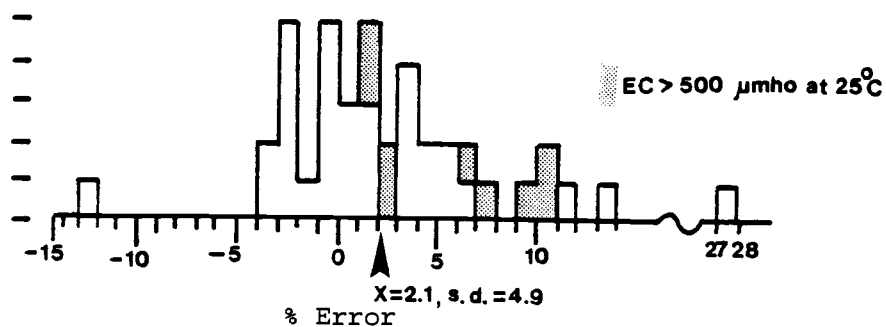


Figure 10. Histogram of percent error in water analyses.

% Error			
0	5	10	15
least chance for error	chance of error--data should be considered with caution	most likely a chance of error--data should be considered with doubt	very doubtful

Figure 11. Qualification of data by percent error divisions.

the total anions or cations. A NaCl water thus would have over half the cations as Na^+ and over half the anions as Cl^- . Waters in which no cation or anion constitutes as much as half of the totals should be recognized as mixed types and identified by the names of all the important cations and anions.

Two additional schemes in use in the literature are based on TDS. Both are simple and convenient methods for classification. For this study, the U.S. Geological Survey method is used (Table 4). The other scheme is included for reference (Table 5).

Drinking Water Standards

As an indication of the overall water quality for human consumption, or potability, the well samples are compared to federal guidelines for drinking water. Table 6 is a brief summary of the federal recommendations for drinking water and the rationale for selection of limits. Comparing the well samples with the recommended limits, it is apparent that wells with high TDS also show high values for hardness, Na^+ , and Cl^- . Samples high in total Fe do not appear to follow this trend; they seem to be fairly localized. Hardness appears to be related to type of source rock. All the wells located in gabbroic rocks (127, 128, and 137) have hard water, and there are localized occurrences of hardness in samples from the Applegate Group rocks.

Suitability of Waters for Irrigation

Chemical quality is the most important water characteristic in evaluating its usefulness for irrigation. Features that need to be considered are relative proportion of Na^+ to other cations and TDS values. Whether a particular water could successfully be used for irrigation also depends on many factors not directly associated with water quality, such as soil composition, drainage, and rainfall.

TABLE 4. Classification based on TDS used by U.S. Geological Survey (Hem, 1970).

Name	TDS (mg/l)
Slightly saline	1,000 - 3,000
Moderately saline	3,000 - 10,000
Very saline	10,000 - 35,000
Briny	More than 35,000

TABLE 5. Classification based on TDS (Davis and DeWiest, 1966; Freeze and Cherry, 1979).

Name	TDS (mg/l)
Fresh water	0 - 1,000
Brackish water	1,000 - 10,000
Saline water	10,000 - 100,000
Brine water	More than 100,000

TABLE 6. Summary of recommendations on the limits to drinking water quality.

Species	Recommendation-Rationale
Na ⁺	20 mg/l - restricted Na-diet 270 mg/l - moderately restricted Na-diet 270 mg/l - usually unacceptable on taste preference
K ⁺	no recommendations - usually low in concentration
Ca ⁺⁺	recommendations as total hardness
Mg ⁺⁺	recommendations as total hardness
HCO ₃ ⁻	no recommendations - usually considered as alkalinity
Cl ⁻	250 mg/l based on taste preference
F ⁻	1.2 mg/l adverse physiological effects
B	750 µg/l for long-term irrigation on sensitive crops
SO ₄ ⁻⁻	250 mg/l taste and laxative effects
Total-Fe	0.300 mg/l objectionable taste or laundry staining
SiO ₂	no recommendations
TDS	no recommendation for domestic water supplies, although waters with over 500 mg/l TDS will most likely be objectionable on taste preference or one of the other standards
Hardness--Concentrations have not yet been proven to be health-related.	
0-75 mg/l as CaCO ₃	soft
75-150 mg/l	moderate hard
150-300 mg/l	hard
300 mg/l and up	very hard

Ion exchange processes occurring in irrigated soils may influence soil properties, especially where concentrations of solutes are high. Water high in Na^+ relative to total cations tends to fill exchange positions on the soil particle with Na^+ ; water high in divalent cations tends to reverse this process. Strongly hydrated Na^+ replacing less hydrated Ca^{++} and Mg^{++} results in an increase in hydration and swelling of the soil particles. This swelling can of course significantly reduce permeability (Stumm and Morgan, 1981). Water high in Na^+ relative to total cations is classified as a high sodium hazard. In an attempt to describe this quantitatively, the U.S. Salinity Laboratory Staff (1954) defined the sodium adsorption ratio (SAR).

$$\text{SAR} = \frac{[\text{Na}^+]}{\left[\frac{[\text{Ca}^{++}] + [\text{Mg}^{++}]}{2} \right]^{1/2}} \quad \text{(all concentrations expressed in meq/l)}$$

This expression is a reasonable prediction of the degree to which water enters the ion exchange process. Other than for classification of irrigation waters, SAR values have limited geochemical significance; they are included in this report because of the importance of agriculture in southern Oregon.

Total dissolved solids influence a water's suitability for irrigation. Osmotic processes enable plants to take up water and nutrients selectively while excluding many undesirable constituents. By consuming water but not its dissolved material, plants concentrate soluble salts in the soil zone. The usability of a water for irrigation can thus be classified according to the amount of dissolved material in solution. For this purpose, TDS can be adequately expressed in terms of electrical conductance. High electrical conductance corresponds to a high salinity hazard.

A system of classification of irrigation waters is based on a plot of log electrical conductance vs. SAR (U.S. Salinity Laboratory

Staff, 1954). With a total of 16 classes, the classification ranges from Low Sodium Hazard-Low Salinity Hazard (C1-S1) to Very High Sodium Hazard-Very High Salinity Hazard (C4-S4).

The 38 well samples and two river samples are plotted on Figure 12. Samples 131s and 134 plot off the diagram. The majority of the samples plot in the C1-S1 to C2-S1 fields, with most SAR values less than two. The waters which present a medium to very high sodium hazard also have a relatively high salinity hazard.

Interpretation of Ground Water Data

Water Chemistry Map

Stiff's (1951) method of visually displaying water chemistry data involves plotting the analysis on a bar graph and connecting the points to form a polygon (Fig. 13). The chemical unit used is milliequivalents per liter. High TDS samples naturally will have a larger area pattern than low TDS samples. A Na-Cl type water has a pattern that is distinct from that of a Ca-Mg-HCO₃ type water. The patterns make possible quick visual comparisons of water types. The Stiff diagram is the most accepted method of displaying water chemistry data in ground water studies in the United States.

A water quality map using Stiff diagrams was prepared (Plate II). The Stiff patterns show a relation between water quality and geology (see Plate I for geology). In the Fruitdale Creek area, an abrupt change in water quality may be seen in the contact-fault area. Since the contact is buried at this location, the relation of the contact to the high angle fault running through the area is obscured. Wells on the eastern side of the creek tend to be higher in Na⁺ and Cl⁻, and some wells are high in Ca⁺⁺. Wells on the western side have water qualities that are characteristic of the granodiorite, including low TDS values. The contact, or fault, thus separates two hydrochemical systems.

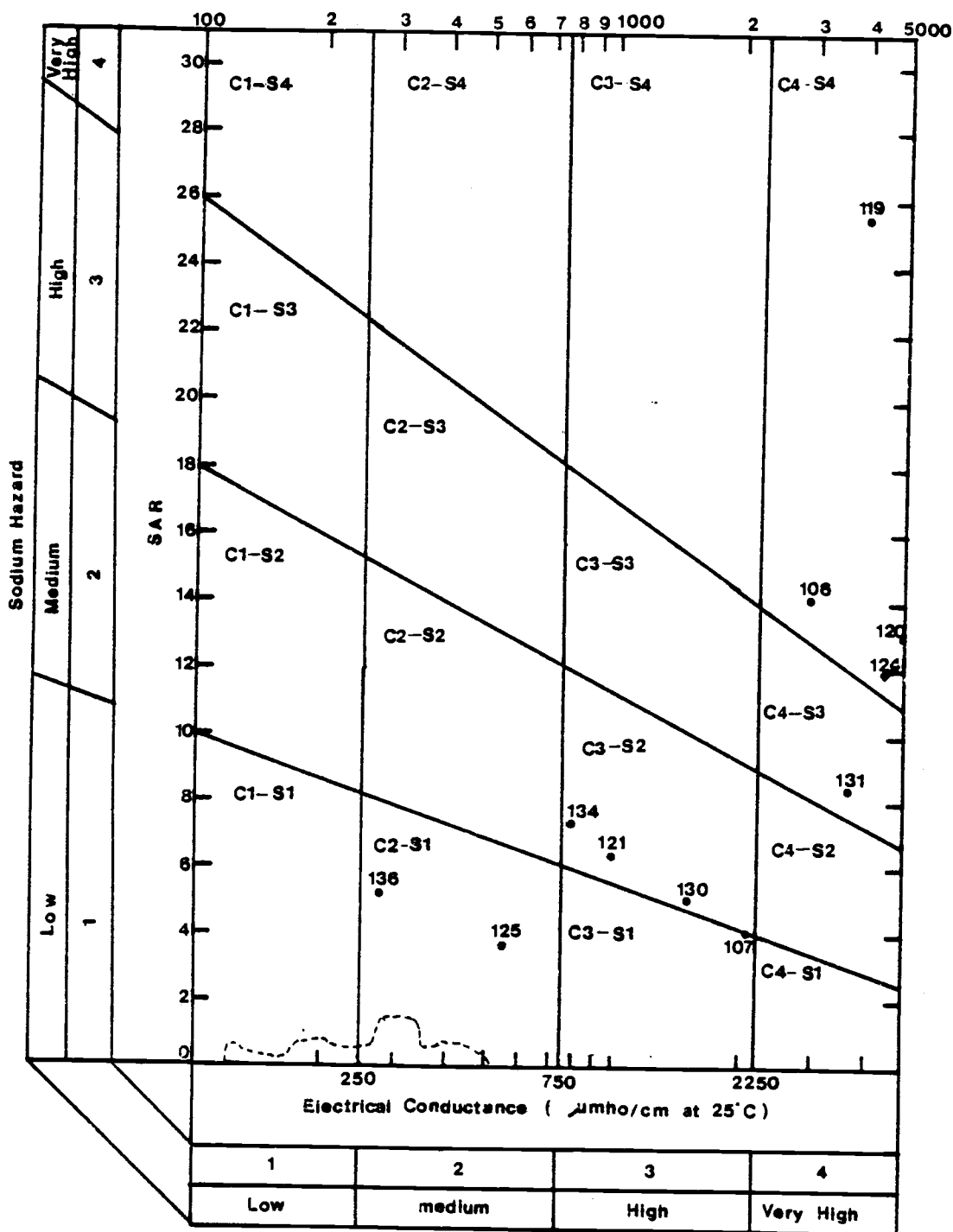


Figure 12. Classification of irrigation waters.

Data consist of 41 samples from this study. Sample 131s, 134 plot off the diagram. Dashed line represents field where most of the samples plot (from U.S. Salinity Laboratory Staff, 1954).

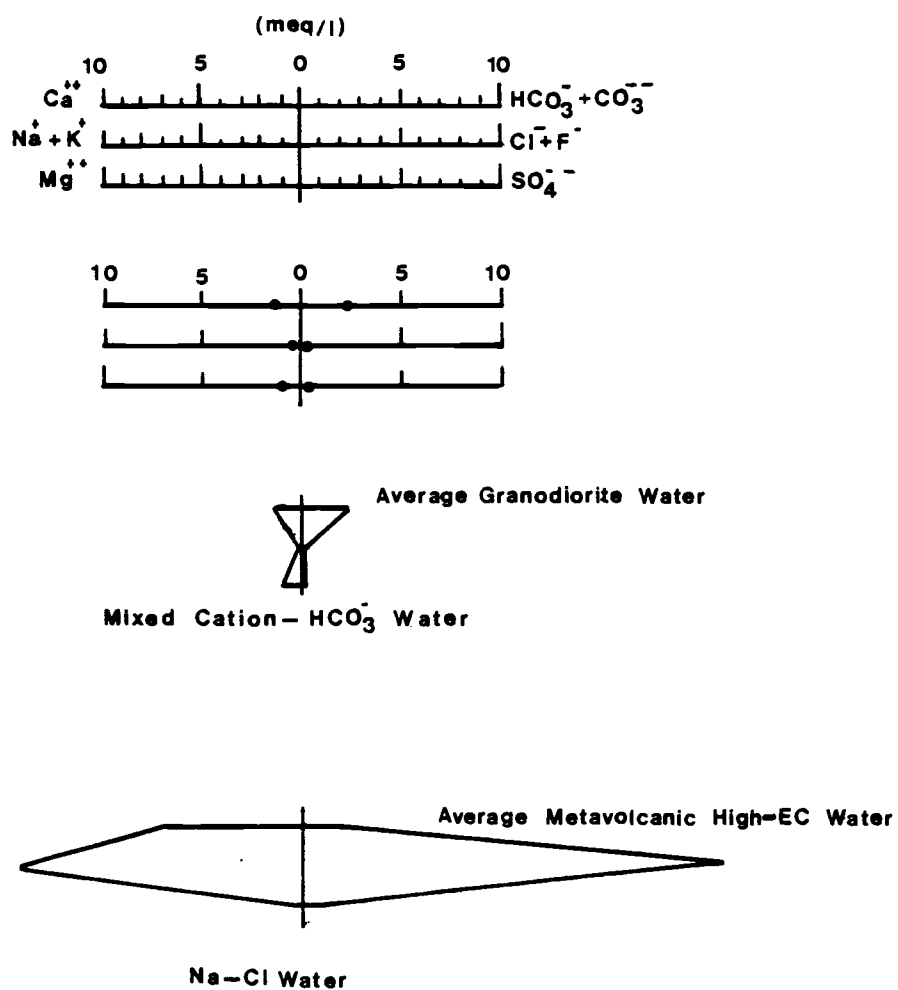


Figure 13. Stiff diagrams.

To make a Stiff diagram, water analyses are plotted in meq/l on the bar diagram above. The data are connected to form a polygon. The size of the pattern depends upon the amount of TDS. The shape of the pattern shows chemical type.

The abrupt change in water quality is not found to the south in the Onion Creek area. Wells sampled in the area of the contact and fault are similar to wells away from that area. The Onion Creek wells are similar to the Boardshanty Creek wells, which are on the other side of Pickett Mountain. Both areas have waters relatively high in Ca^{++} , Mg^{++} , and HCO_3^- . The mechanism affecting water quality in other areas apparently is not operating here.

In the Murphy area, four wells to the east of the fault were sampled. An abrupt change in water quality occurs within a relatively short distance with no observable geologic changes. Well 126 is producing from a shallower zone. Wells 125 and 124 are both producing in bedrock and still show a large difference in water quality. This variation is believed to result from the fractured bedrock and the junction of the intermediate or regional flow systems and the local flow system (see Hydrogeology).

To the east of Bolt Mountain, Wells 127, 128, and 137 produce from the metagabbro. In the area, gabbroic rocks are rarely usable as an aquifer owing to the rugged nature of the terrain they form. The water quality appears to be fairly uniform, but only a limited number of samples is available.

In the Sleepy Hollow Loop-Applegate River area (SHL-AR), an abrupt change in water quality occurs across a lithic contact (Fig. 14). Well 132 is producing from the granodiorite, whereas Wells 119 and 120 produce from within the contact aureole in the Galice Formation. Well 120 is located on the contact. Well 139 has been shown to have a significant component of water coming from the river.

The granodiorite hosts water lowest in TDS. The good quality is the result of the relatively permeable grus layer, which forms aquifers with a higher recharge rate. The waters have equal amounts of Ca^{++} and Mg^{++} , and the dominant anion in all samples is HCO_3^- .

In summary, waters high in TDS are associated with the contact of the granodiorite in the Fruitdale Creek and SHL-AR areas. The

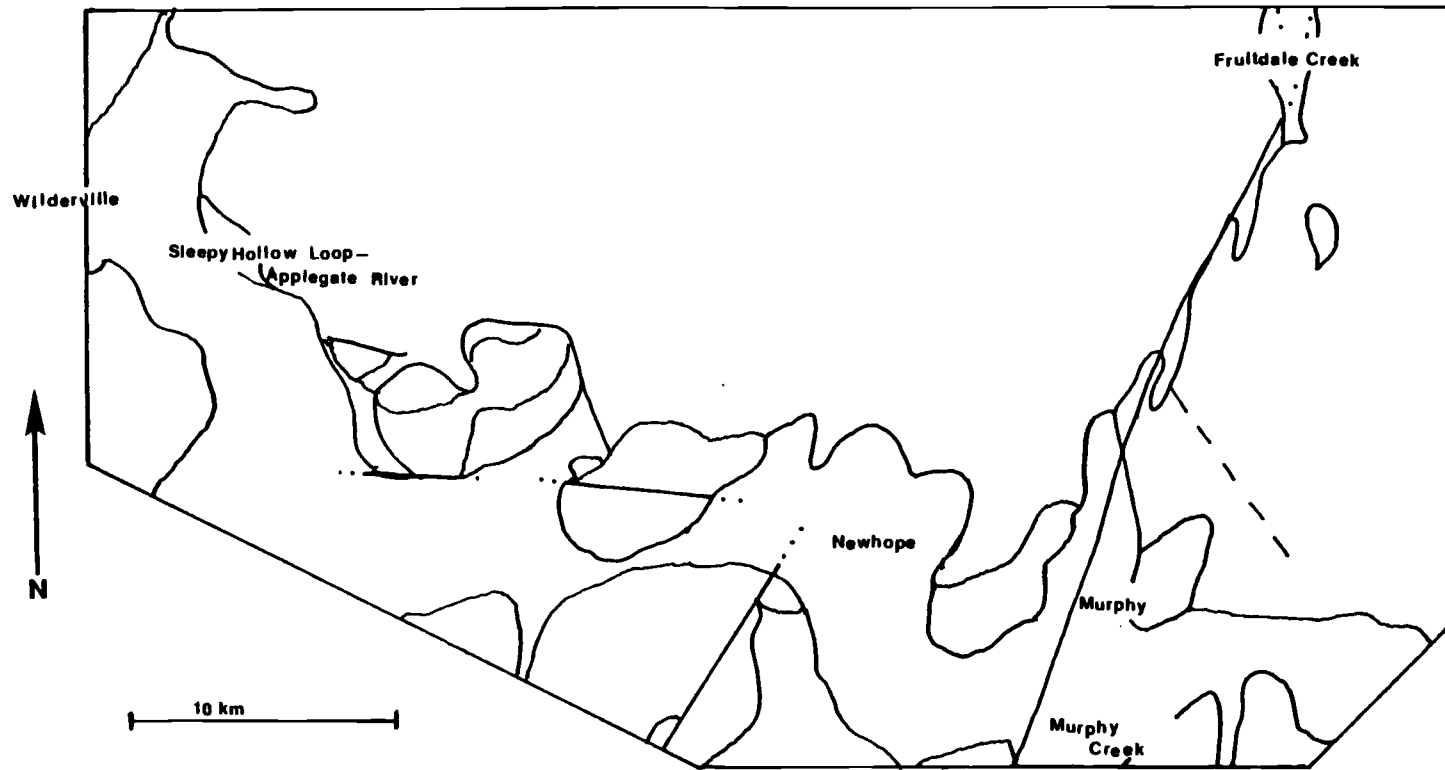


Figure 14. Location of areas reporting nonpotable waters.

Generalized geology is included. Areas of nonpotable water are the Fruitdale Creek area, the Murphy Creek area, and the Sleepy Hollow Loop-Applegate River area.

high TDS waters are attributed to the restricted nature of the regional flow system and the fractured nature of the rocks. The abrupt change in water quality at the contact of the granodiorite suggests that the contact is a hydrochemical boundary.

Relative Abundances of the Major Ions

A useful graphical method for visually displaying major chemical similarities and differences among a series of water samples is the trilinear diagram developed by Hill (1940) and Piper (1944). This kind of plot can clearly display many data; it is also a convenient way to show the effects of water mixing.

The trilinear diagram (Fig. 15) combines three distinct fields for plotting--two triangular fields for cations and anions and a diamond-shaped field for overall chemical character. In most waters, the most abundant cations are the two alkaline earth metals, Ca^{++} and Mg^{++} , and one alkali metal, Na^+ . Generally having an abundance much less than Na^+ , K^+ is plotted with Na^+ . The most abundant anions are HCO_3^- , SO_4^{--} , and Cl^- ; less abundant CO_3^{--} is plotted with HCO_3^- .

The method for plotting is similar to that of conventional trilinear diagrams. Relative concentrations in eq/l are plotted on the cation and anion triangles. The diamond-shaped field is plotted by recording the intersection of two rays, one from each of the two points representing relative cations and anions (Fig. 15).

A disadvantage is that relative and not total concentrations are plotted. Because each analysis is represented by a single point, waters with very different total concentrations of dissolved material can plot at the same point. This type of diagram, while it is by no means a universal solution to all ground water problems, can nonetheless be helpful in understanding some kinds of chemical problems.

To use as a mixing model, two criteria must be satisfied, one graphical and one graphical-algebraic (Piper, 1944). The graphical

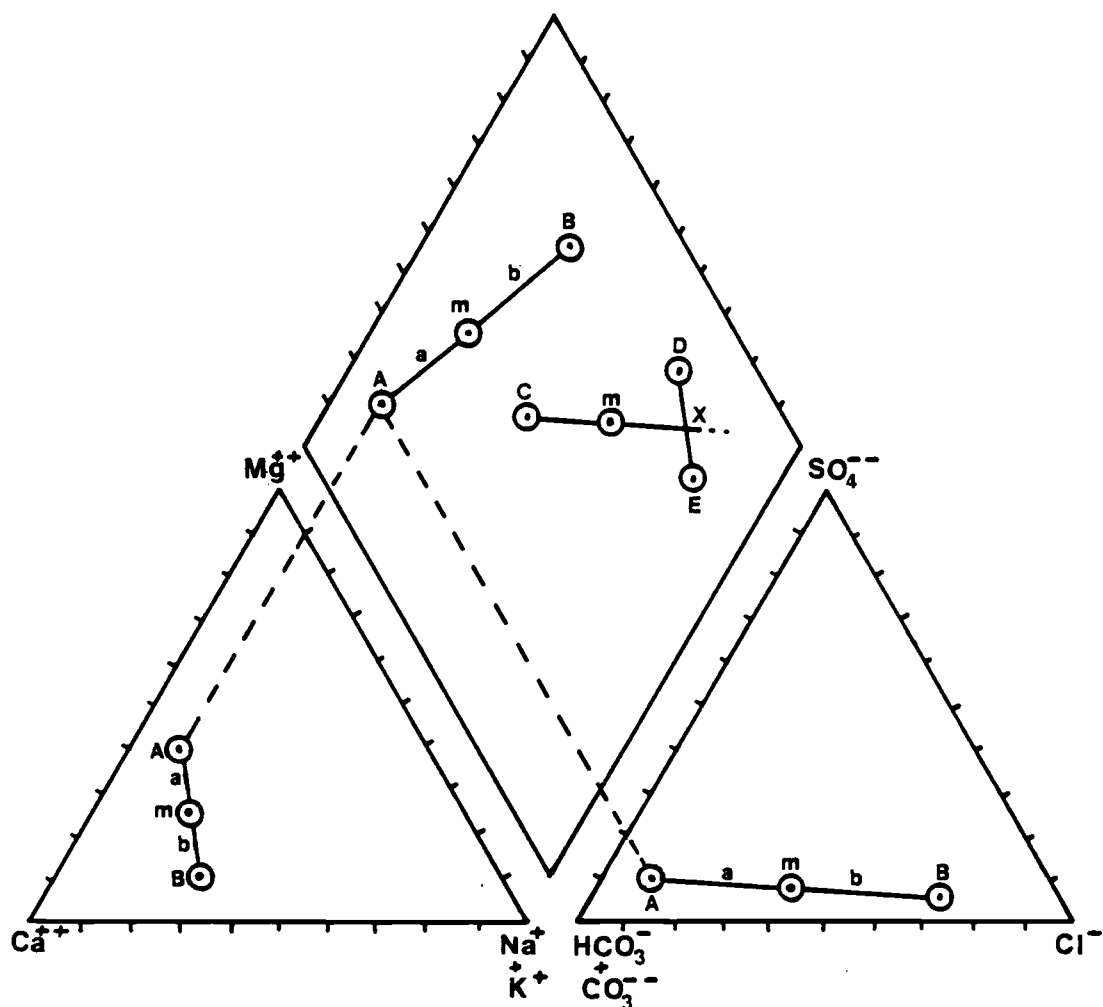


Figure 15. Trilinear diagrams.

Shown here are simple binary and tertiary mixing models. To plot data in the central diamond-shaped field, first plot relative abundances in meq/l in both the cation, lower left, and anion, lower right triangles. Two rays are then projected into the diamond-shaped field, as with point A. The line A-m-B represents a binary mixing model. Point m will always lie on line AB in all three fields. Used in the algebraic criterion, parameters a and b are measured in any of the three fields. Points C, D, E, and m represent a three component mixing model. A line is projected through C and m to point X. D-X-E is treated as a binary model to calculate the hypothetical concentrations of solution X with the same proportion solution D and E mixed with C to form m. The system C-m-X is then treated as a binary model (Piper, 1944).

criterion considers only relative abundances of different water types. In a simple binary mixing model (A and B, Fig. 15), the mixture (m) must fall on a straight line between A and B in all three fields on the diagram. This criterion will allow a large number of data to be examined before applying the more rigorous graphical-algebraic criterion.

The second criterion uses total concentrations in several algebraic expressions and is more decisive in determining mixing models. Most of the values are taken from the chemical analysis, except two (a and b) which are measured directly from the plot.

Graphical-algebraic procedure:

- 1) $E_m = [E_a \cdot E_b(a+b)] / (aE_a + bE_b)$; $E_m(\text{calc.}) = E_m(\text{meas.})$
- 2) $V_a = bE_b / (aE_a + bE_b)$; $V_b = aE_a / (aE_a + bE_b)$
- 3) $C_m = (C_a \cdot V_a) + (C_b \cdot V_b)$; for each component, $C_m(\text{calc.}) = C_m(\text{meas.})$

E_m : total concentrations in eq/l of major ions in mixture

E_a : " " " " " in A

E_b : " " " " " in B

a: length of intercept on plot, from any one of the three fields

b: length of intercept on plot, from any one of the three fields

V_a : proportionate volume of component A in mixture m

V_b : " " component B " " "

C_a : concentration of each component in solution A

C_b : " " " " solution B

C_m : " " " " solution mixture

These mixing model solutions are similar to center of gravity solutions. A three or more component system can be involved with all the algebraic equations, but simplification is possible. Consider a three component system (C, D, and E, Fig. 15) where m represents water formed by mixing C, D, and E. First, project a straight

line through C and m to intersect a line between D and E at point X; this represents the chemical composition of a hypothetical mixture of waters D and E in the same proportions they mixed with water C to form m. From the above equations (1, 2, and 3) the theoretical composition of water X can be determined. Then treat water m as a presumed mixture of waters X and C. This procedure can be adapted to systems of more than three components.

Within the study area, water high in TDS has been reported in three subareas--Fruitdale Creek, Murphy Creek, and the Sleepy Hollow Loop-Applegate River area (Fig. 14) (Mack, 1982). By comparing the trilinear plots of wells producing from these areas with plots from areas with potable water, a better understanding of the ground water flow system can be obtained.

Waters from wells producing within the pluton are plotted in Figure 16. These well samples are from varied locations throughout the granodiorite, yet they form a tight cluster. This is the result of the relatively uniform composition of the pluton. In comparison, data of water samples from wells located in the Applegate Group meta-volcanic rocks produce more scatter (Fig. 17). Reasons for scatter are the more varied compositions of the host rocks and the fractured nature of the aquifers.

A composite plot of the data from this study and additional data from the U.S. Geological Survey-Water Resources study (Almy, in press) indicates that relative abundances correlate with electrical conductance (EC) (Fig. 18). The data plot into three rather separable groups according to an artificial division of EC (500 μmho @ 25°C): low EC; high EC-low Na^+ ; and high EC-high Na^+ . The segregation into low or high EC is the result of the progressive geochemical alteration of ground water. The clustering of all low EC samples in one part of the plot suggests that a few weathering or pedogenic reactions are controlling the relative abundances in most of the samples.

In the diamond-shaped field of Figure 18, the two high EC

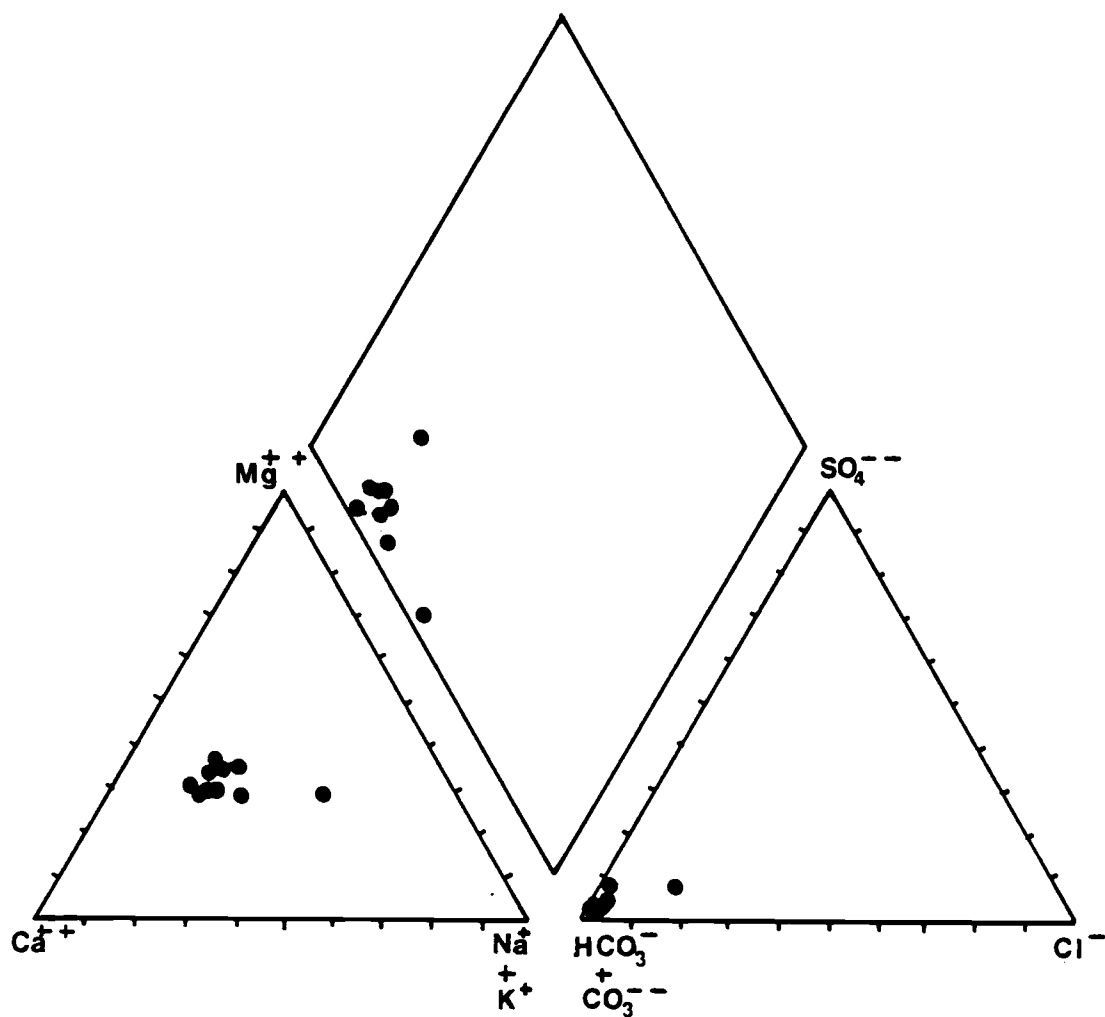


Figure 16. Trilinear plot-waters from granodiorite.

Trilinear plot of water data from well samples located within the granodiorite. Samples plotted are 102, 108, 109, 111, 113, 118, 132, and 141 from this study and GS-7 and GS-4 from Almy (in press).

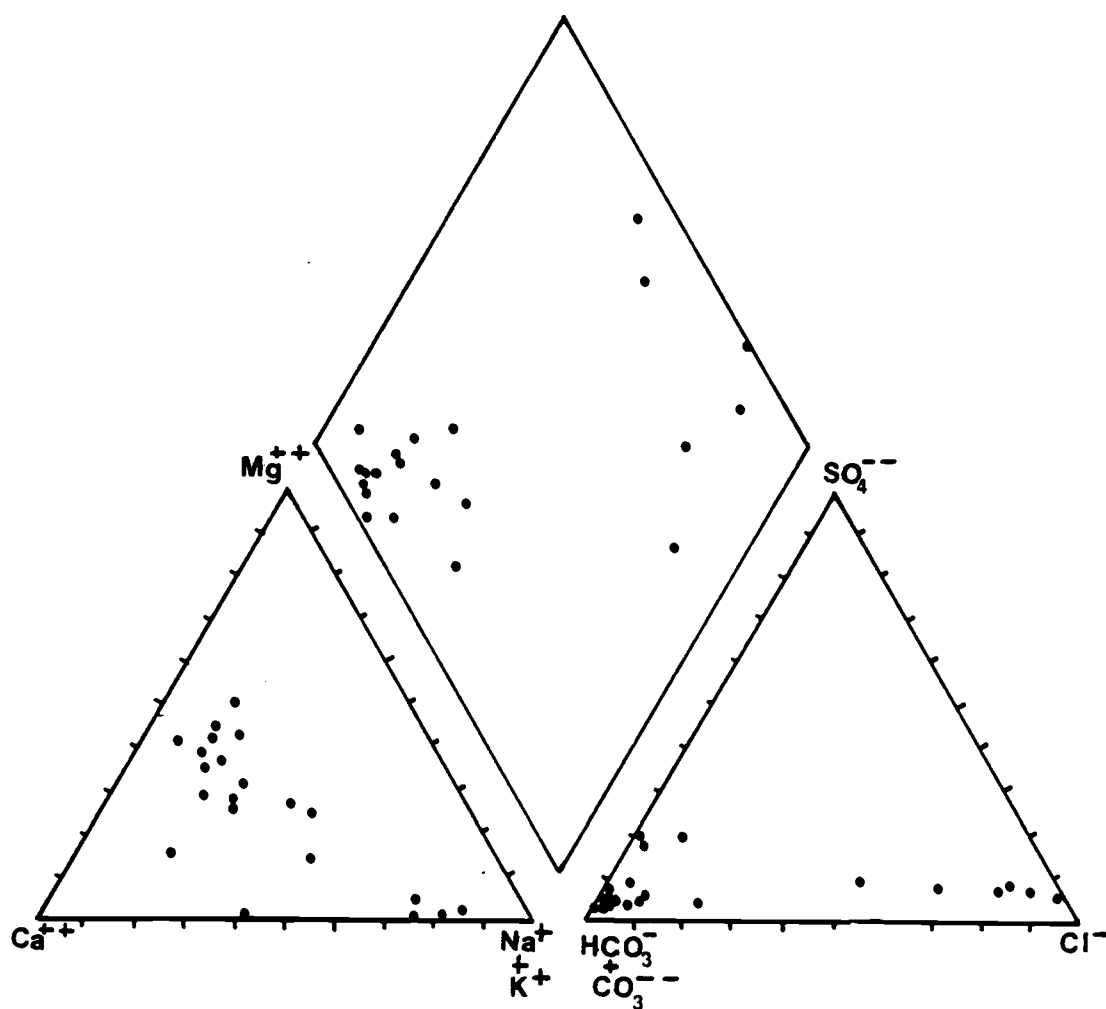


Figure 17. Trilinear plot-waters from Applegate Group metavolcanic rock.

Trilinear plot of water data from wells located within the Applegate Group metavolcanic rocks. Samples plotted are 103, 104, 105, 106, 107, 112, 114, 115, 117, 121, 123, 129, 130, 133, 134, 135, 136, and 110 from this study. Also plotted are GS-5, GS-6, and GS-36 from Almy (in press).

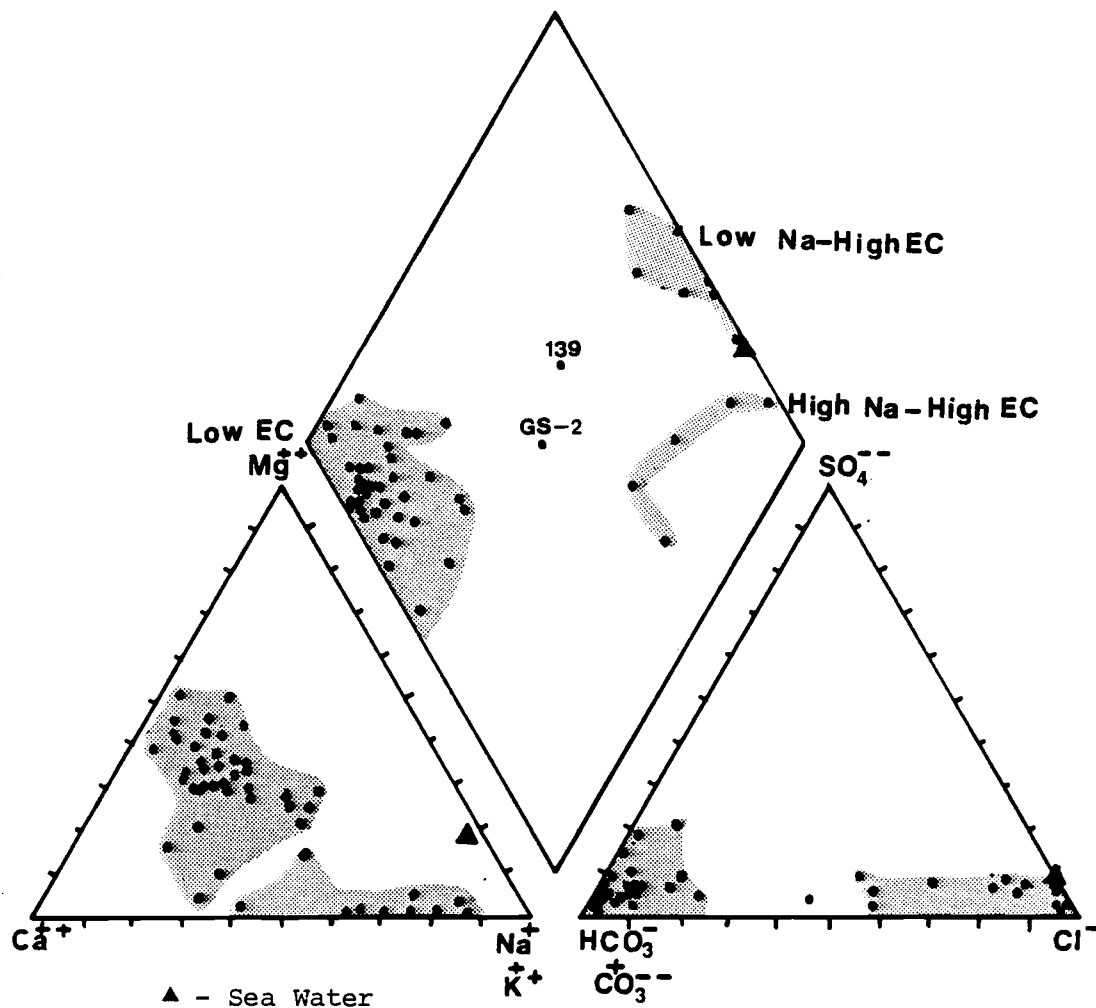


Figure 18. Trilinear plot-composite plot of 42 water samples.

Composite plot of 42 water samples from this study, 8 from Almy (in press), and average sea water. Three groups stand out--one low EC (<500 μmho @ 25°C) and two high EC. The high EC groups are further divided into a low Na group and a high Na group.

groups are separated by a point representing sea water. In the cation field, however, sea water plots outside all three groups; the possibility that the nonpotable, more saline waters are a mixture of unmodified sea water and low EC ground water thus seems remote. If the more saline waters are related to older sea water trapped between grains of the host rock, they have undergone considerable chemical modification.

Data for the Fruitdale Creek area are plotted in Figure 19. Samples 131 and 131s are plotted assuming a HCO_3^- value of 244 mg/l. Analytical data for this species are not available. This value is probably high, since this is a maximum value from all the samples analyzed. The range of HCO_3^- values for samples with over 100 mg/l Cl^- is 22 mg/l to 170 mg/l. The high Cl^- values of these samples dominate the relative anion abundances.

Within the two high EC groups, EC decreases away from GS-6 (Fig. 19), with the exception of 131s. This general trend suggests that the higher saline water will have a similar chemical composition to GS-6. Chemical processes could then modify these waters to produce the two trends. The low Na^+ trend appears to result from a removal of Na^+ relative to Ca^{++} , a result that can take place in ion exchange reactions. The high Na^+ trend has Cl^- removed relative to HCO_3^- . Addition of HCO_3^- through soil processes is possible.

Data from Murphy Creek (Fig. 20) and the Sleepy Hollow Loop-Applegate River area (Fig. 21) are insufficient to establish similar trends.

Simple three component mixing apparently occurs on a local scale within the Sleepy Hollow Loop-Applegate River area. Sample 139 appears to be a mixture of river water (101) and a more saline water intermediate in composition between Samples 119 and 120 (Fig. 21). A straight line was projected through 101 and 139 to the intercept of 119 and 120 at point X. The graphical alignment is close.

For the graphical-algebraic criterion, values used in the calculation are presented in Table 7. The hypothetical concentration of

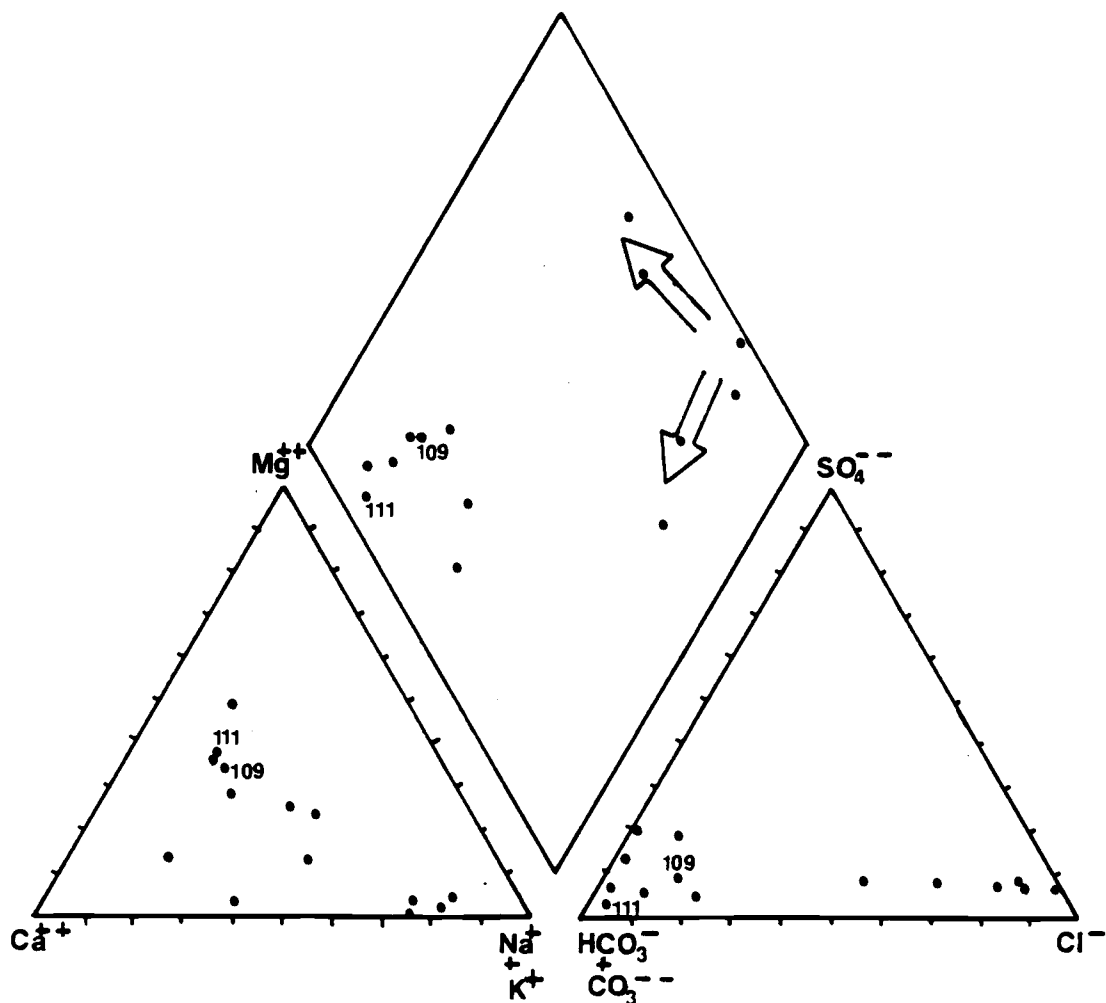


Figure 19. Trilinear plot-waters from Fruitdale Creek area.

Trilinear plot of wells located within the Fruitdale Creek area. Arrows in the high EC groups show trends of decreasing EC. Samples 111 and 109 are located within the granodiorite; other points represent water collected from Applegate Group metavolcanic rocks.

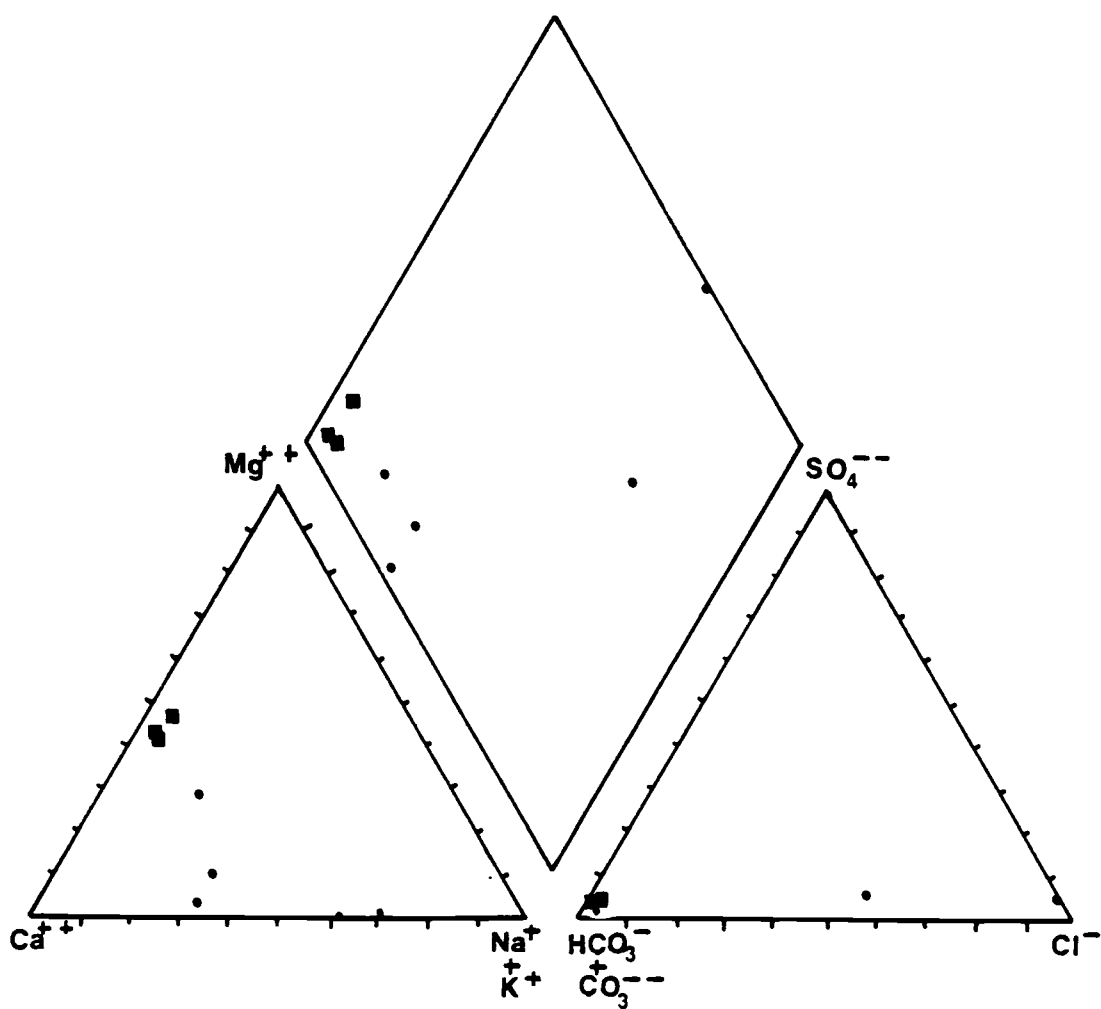


Figure 20. Trilinear plot-waters from Murphy Creek area.

Trilinear plot of water from wells located in the Murphy Creek area and from wells located within gabbroic rocks. Samples from:

- Murphy Creek area--124, 125, 126, 136, and GS-2
- Wells located in gabbroic aquifers--127, 128, and 137.

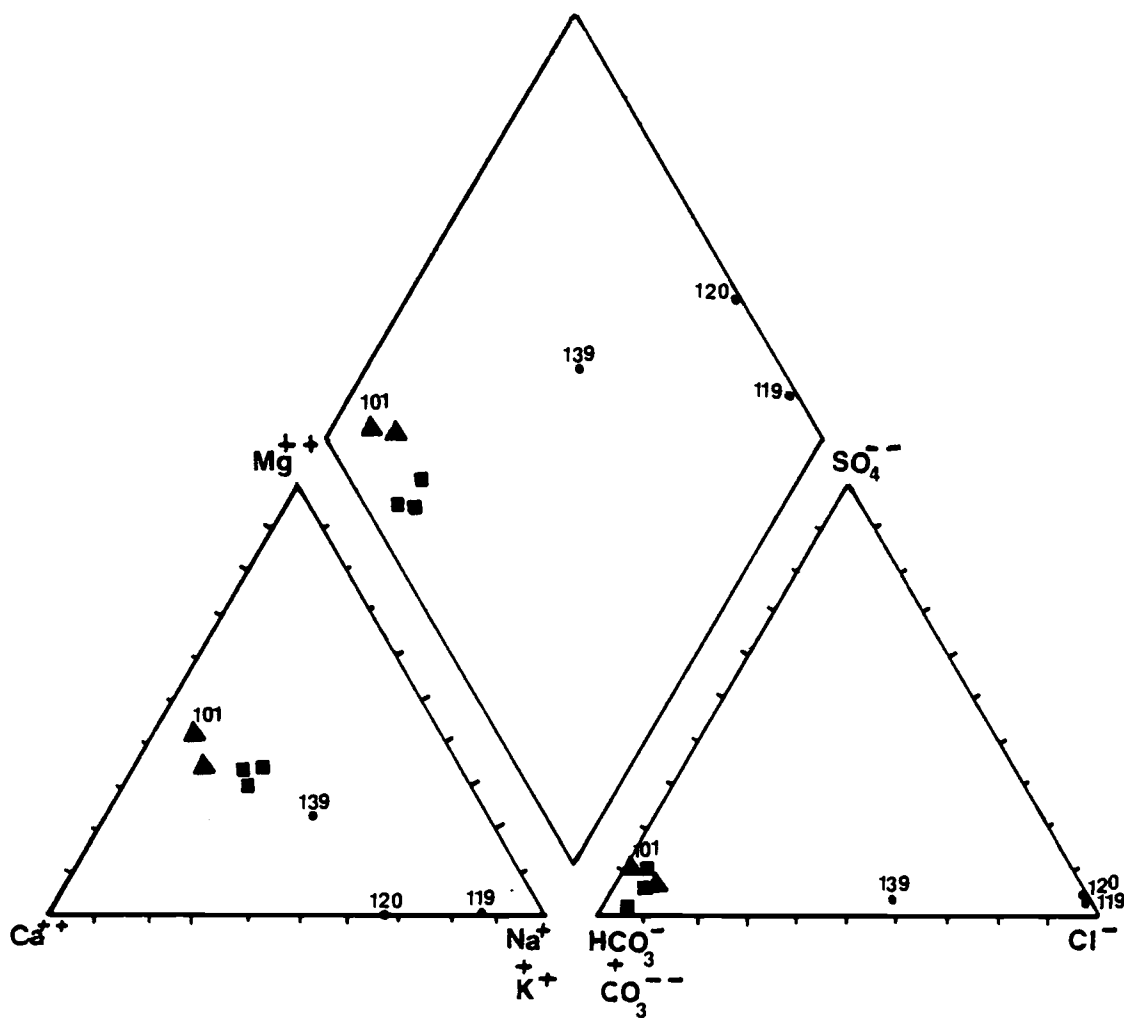


Figure 21. Trilinear plot-waters from Sleepy Hollow Loop-Applegate River area.

Trilinear plot of water data from wells located in the Sleepy Hollow Loop-Applegate River area. A three component mixing model was applied to Samples 101, 119, 120, and 139. Reasonable alignment occurs in all three fields.

TABLE 7a. Values used in three component mixing model.

	a	b	Ea	Eb	Va	Vb
To form solution X	0.5	2.2	112	144	.89	.11
To form solution 139	3.5	4.3	141	3.57	.97	.03

TABLE 7b. Concentrations used in three component mixing model.
(meq/l)

	Ca^{++}	Mg^{++}	$\text{Na}^+ + \text{K}^+$	HCO_3^-	Cl^-	SO_4^{--}	Em
Cx	20.35	0.41	43.97	1.62	74.0	0.36	141
Cm (calc.)	1.43	0.71	1.42	1.66	2.27	0.19	7.72
Sample 139 (meas.)	1.1	0.70	1.38	1.66	2.4	0.125	7.36
% difference	30	1	3	0	1	52	5

Cx -- Hypothetical mixture of Samples 119 and 120 in proportions equivalent to their mixture with Sample 101 to form Sample 139

Cm -- Calculated hypothetical mixture of Sample 101 and Cx corresponding to Sample 139

% difference -- $(\text{Cm} - \text{Sample 139}) \times 100$

each of the major constituents was calculated for solution X. A binary model was then applied to solution X and Sample 101. This included the calculation of a set of theoretical concentrations for Sample 139, which were compared to the measured values. The percent difference values indicate a fairly good correlation, although Ca^{++} and SO_4^{--} concentrations appear high.

The results suggest that Sample 139 is a mixture of a water intermediate in composition between Samples 119 and 120 and river water. From the volume calculation (V_a and V_b), most of the water apparently is coming from the river. The TDS values for 119 and 120 are high enough to render these more saline waters nonpotable. The large percentage of river water in Sample 139 apparently maintains its potability.

A plot of water data from well samples from the Applegate River alluvium (Fig. 22) does not indicate contamination from deeper aquifers. Simple mixing of waters appears to have occurred in the case of Sample 139 only.

Hydrochemical Modeling

Hydrochemical modeling of natural waters offers insight in understanding processes regulating aqueous chemistry. In their analysis of chemical species distribution in sea water, Garrels and Thompson (1962) were the first to use the method of successive iterations to understand equilibrium in natural waters. The approach influenced an entire generation of computer models. One of the first programs, WATEQ, calculates equilibrium distribution of inorganic species and compares ion activity products and equilibrium constants (Truesdell and Jones, 1974). An updated Fortran IV version, WATEQF, contains several modifications, including data for 14 additional ionic species, new thermodynamic data, and an option for calculating the activity coefficient (Plummer and others, 1976). The program WATEQ2, the most recent version, contains several additional trace elements

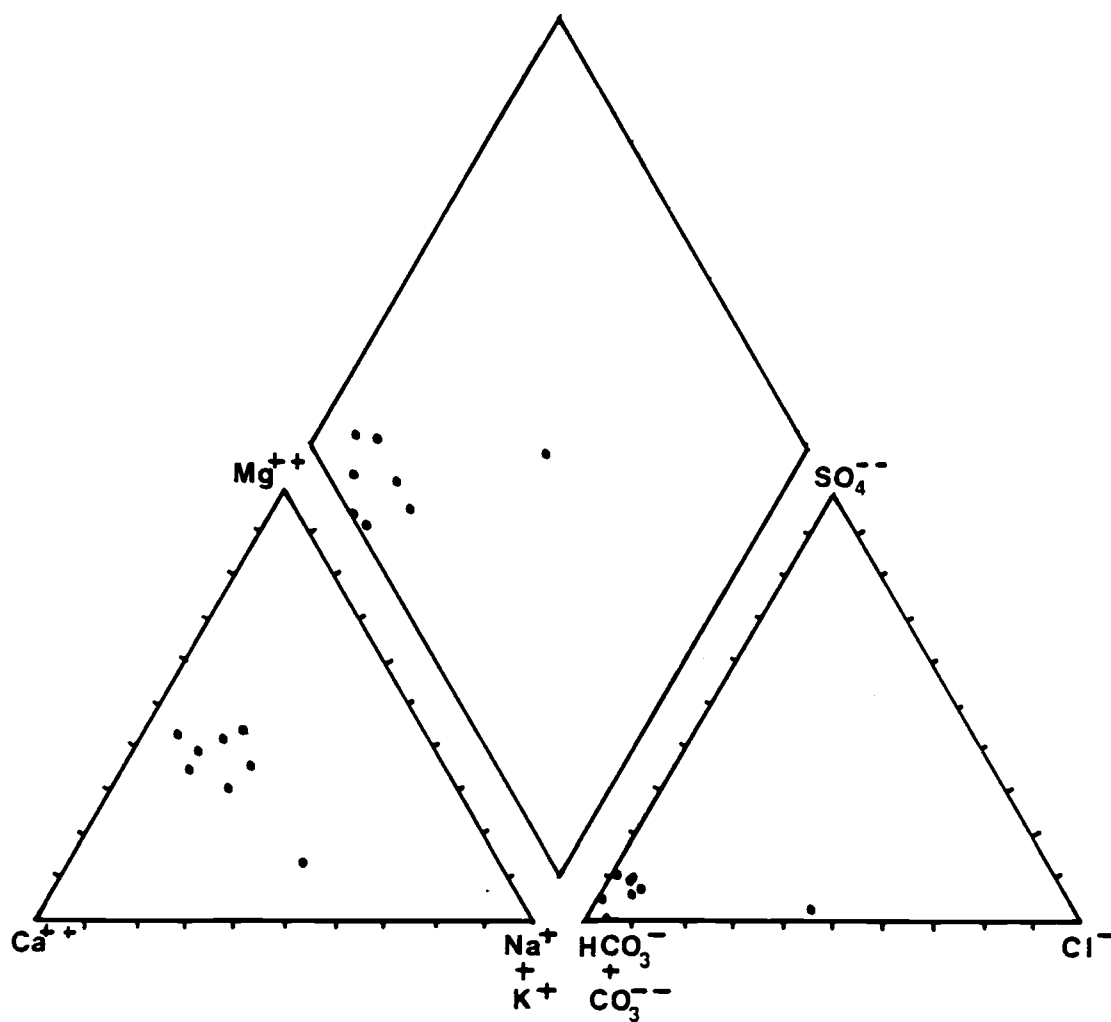


Figure 22. Trilinear plot-waters from Applegate River alluvium.

Trilinear plot of data from water samples from wells located in Applegate River alluvium. Plot does not include data for water samples located near Murphy Creek.

(Ball and others, 1979).

For this study WATEQF was used. This program became available through Rockwell Hanford Operations, Basalt Waste Isolation Project, Hydrology Group. The program WATEQ2 was not used because the additional elements it contains were not analyzed in this study.

As with nearly all aqueous chemical models, WATEQF is based on ion association theory. Two assumptions are therefore basic: that there exist complexes whose formation can be described by equilibrium expressions; and that activity coefficients can be described by equations depending only upon temperature and ionic strength. The program WATEQF calculates equilibrium distribution by an iteration technique whereby a series of simultaneous mass balance and equilibrium equations is solved. Activity coefficients are calculated using either the Debye-Hückel or the Davies equation (Table 8). The Davies equation can be used for solutions with higher ionic strength ($.1 < I < .5$).

Equilibrium constants are corrected for temperature using either an algebraic equilibrium expression or the van't Hoff relation.

van't Hoff expression:

$$\frac{d \ln K}{dT} = \frac{\Delta H_r}{RT^2} \quad (\text{Lewis and others, 1961})$$

By assuming H_r is independent of temperature, and integrating, the form used in WATEQF is obtained:

$$\ln K_t = \ln K_t^\circ - \frac{\Delta H_r}{R} \left[\frac{1}{T} - \frac{1}{T_r} \right] \quad (\text{Plummer and others, 1976})$$

Where: R = Gas constant

T = Absolute Temperature ($^{\circ}\text{K}$)

T° = Reference Temperature (25°C ; 298.16°K)

K_t = Equilibrium constant at Temperature T

K_t° = Equilibrium constant at Temperature T°

H_r = Enthalpy of reaction

TABLE 8. Thermodynamic terms used in this study.

1) Activity

$$\{i\} = \gamma_i [i]$$

$\{i\}$ = activity of i

γ_i = activity coefficient of i

$[i]$ = molality of i

2) Ionic Strength, I

$$I = \frac{1}{2} \sum_i^n [i] z_i^2$$

z = charge of i

3) Extended Debye-Hückel

$$\log \gamma_i = \frac{-Az^2 \sqrt{I}}{1 + Ba \sqrt{I}}$$

for $I < 0.1$

From Stumm and Morgan (1981)

A and B are constants that depend upon temperature and dielectric constant; a is size of hydrated ion

4) Davies Equation

$$\log \gamma_i = -Az^2 \left(\frac{\sqrt{I}}{1 + \sqrt{I}} - 0.2I \right)$$

for $I < 0.5$

From Stumm and Morgan (1981)

5) van't Hoff expression

$$\frac{d \ln K_t}{dT} = \frac{\Delta H_r^\circ}{RT^2}$$

From Lewis and others (1961)

ΔH_r° = enthalpy of reaction

R = gas constant

T = absolute temperature

K_t = equilibrium constant at temperature T

An algebraic equilibrium expression is an empirical equation describing the temperature dependence of a reaction. Reactions covered by this approach include the dissociation of carbonic acid, silicic acid, boric acid, calcite, dolomite, sulfuric acid, and hydrogen sulfide. An algebraic expression is considered more reliable than the van't Hoff expression because temperature dependence of ΔH_r causes deviation in the equation, especially at high temperatures. Using either expression, the reaction equilibrium constants are valid for most ground water temperatures. Calculations of WATEQF are considered reliable in the temperature range 0°-100°C (Nordstrom and others, 1979). The temperature correction allows the measured field temperature and pH to be used in equilibrium calculations. The pH and temperature are assumed to be representative of the aquifer, provided that proper sampling techniques are employed.

Several qualifications must be made concerning the results of this study. Redox potentials were not measured at the time of sampling and no redox equilibria are considered, including all Fe-bearing phases. Unfortunately, Al_2O_3 was omitted from the chemical analysis, thereby excluding aluminosilicate mineral equilibria; the opportunity to employ chemical modeling techniques occurred after field and laboratory work for this study had been completed. Even with these restrictions placed upon the results, the calculations done with WATEQF are valid and useful.

The ion distribution for aqueous species was calculated for all samples except 116, 131, and 131s (Table 9). The analysis for Sample 116 is suspect owing to large analytical error. Alkalinity determinations were not made for Samples 131 and 131s because neither well was properly sampled. The activity values listed can be used in equilibrium calculations such as those of WATEQF and as graphical aids in considering mineral stability relations.

The computer model compares the analyses to a total of 193 reversible congruent dissolution reactions. Exclusion of Al_2O_3 , Fe,

TABLE 9. Ionic distribution of aqueous species calculated from WATEQF. (Units are in terms of molar activity. Thus activity of Ca^{++} for Sample 101 is 0.33×10^{-3} M.

Sample No.	Ca^{++} $\times 10^{-3}$	Mg^{++} $\times 10^{-4}$	Na^+ $\times 10^{-3}$	K^+ $\times 10^{-5}$	Cl^- $\times 10^{-4}$	SO_4^{--} $\times 10^{-4}$	HCO_3^- $\times 10^{-3}$	CO_3^{--} $\times 10^{-6}$	H_2CO_3^* $\times 10^{-4}$	H^+ $\times 10^{-8}$	OH^- $\times 10^{-7}$	F^- $\times 10^{-6}$	MgOH^+ $\times 10^{-8}$	MgSO_4^* $\times 10^{-6}$	MgHCO_3^+ $\times 10^{-6}$	MgCO_3^* $\times 10^{-7}$	MgF^+ $\times 10^{-7}$	CaOH^+ $\times 10^{-9}$
101	.33	2.8	.095	2.4	.45	.69	1.55	2.86	.84	2.2	2.7	4.4	2.8	3.7	2.5	6.9	.69	2.2
102	.51	3.1	.49	2.6	.40	.79	2.41	1.10	5.1	7.9	.53	9.7	.57	4.4	3.2	2.7	1.4	.63
103	.24	3.2	.28	.48	.37	.54	1.62	.36	7.1	17	.28	2.9	.32	3.2	2.4	.97	.48	.15
104	.51	4.9	.48	.95	.79	.55	3.0	1.8	4.9	6.6	.83	4.8	1.4	5.0	7.5	7.4	1.2	1.0
105	.52	5.4	.40	1.2	1.0	.61	3.1	1.2	7.6	13	.64	4.7	1.3	6.3	10	5.8	1.5	.81
106	1.2	.73	20	1.1	200	5.6	2.0	3.6	3.6	2.3	2.9	8.8	.79	7.8	.93	2.3	3.7	8.7
107	2.0	7.7	8.2	.22	140	3.0	2.2	2.7	1.8	3.0	1.4	8.7	3.7	42	7.4	17	3.2	6.5
108	.49	3.7	.41	5.0	.42	.43	2.6	2.9	2.2	3.2	1.3	9.7	1.7	2.9	4.1	8.6	1.8	1.5
109	.53	4.3	.61	1.7	.45	.83	2.3	.84	6.1	10	.46	9.6	.69	6.6	4.6	2.9	2.1	.57
110	.34	2.7	1.2	.48	2.6	.52	2.1	.51	8.6	15	.28	4.4	.26	2.6	2.5	1.1	.57	.22
111	.35	3.0	.31	4.1	.58	.30	2.0	.87	4.5	8.1	.47	9.9	.48	1.7	2.4	2.1	1.4	.38
112	.54	6.0	.72	.71	3.7	.80	2.9	3.3	2.6	3.2	1.3	4.7	2.7	8.7	7.5	16	1.4	1.6
113	.33	2.3	.49	3.9	.11	.31	1.9	.91	4.1	8.3	.64	9.8	.53	1.3	2.3	1.8	1.2	.51
114	.53	4.0	.81	1.4	1.0	.69	2.9	1.4	5.8	7.6	.61	9.6	.85	5.1	5.4	4.7	1.9	.76
115	.46	3.4	1.2	.71	7.5	.42	2.7	2.6	2.7	3.8	1.2	4.3	1.4	2.6	4.1	7.2	.73	1.3
117	.60	4.5	.52	1.7	.89	.41	3.1	.72	13	17	.32	4.8	.52	3.5	7.2	2.7	1.1	.46
118	.52	3.4	.57	3.8	.76	.35	2.6	2.3	2.9	4.2	1.0	9.7	1.2	2.3	3.9	6.3	1.6	1.2
119	1.6	.21	39	2.9	450	.15	.77	.68	.84	4.2	1.1	30	8.0	.060	.074	.12	.31	4.0
120	4.4	.93	35	7.2	600	3.0	1.3	.32	5.2	16	.36	12	.12	5.2	.67	.26	.62	3.8
121	.65	1.2	6.3	.46	58	2.1	2.2	3.6	13	23	.22	4.7	.094	4.7	1.3	.37	.30	.33
122	.22	2.0	.31	3.7	.86	.32	1.1	.13	8.6	29	.14	3.0	.098	1.2	.93	.21	.29	.076
123	.68	6.0	.23	.47	2.4	.46	2.9	.69	12	17	.32	4.2	.69	5.1	9.1	3.5	1.3	.52
124	4.9	.27	33	2.2	570	4.8	.29	3.8	.021	.26	14	3.3	1.3	2.4	.031	.82	.042	160
125	.45	.15	2.7	.71	26	1.0	1.8	6.9	.46	.98	4.8	4.9	.25	.28	.13	.84	.037	5.0
126	.53	.29	.62	.24	1.7	.31	1.6	9.6	.27	.62	.69	3.0	.70	.16	.21	2.2	.043	8.4
127	1.0	7.7	.29	1.6	.33	2.2	4.1	2.2	7.2	6.8	.67	2.8	1.8	32	14	14	1.1	16
128	.76	8.9	.17	.47	.75	.49	4.0	1.4	11	10	.43	--	1.4	8.0	16	10	--	.77
129	.52	3.6	.89	.24	.44	2.3	2.4	4.5	1.3	1.9	2.1	4.8	2.6	15	3.7	13	.83	2.6
130	1.8	1.5	8.3	.44	150	3.6	1.2	3.5	.42	1.2	3.1	14	1.6	9.9	.75	4.2	.96	13
132	.32	2.7	.35	6.8	.35	.39	1.6	.12	4.9	49	.078	4.9	.071	1.9	1.7	.25	.62	.057
133	.72	6.3	.84	.47	1.1	1.8	3.5	8.0	1.5	1.6	2.9	9.4	6.3	21	10	41	3.0	4.8
133r	.45	3.1	.25	3.8	1.7	.51	1.8	21	.15	.36	21	2.9	24	3.1	3.8	60	.54	23
134	.27	.76	4.5	.23	34	2.2	2.6	1.2	5.3	8.1	.60	9.6	.16	3.1	.94	.75	.37	.38
135	.67	1.7	.53	.71	.87	2.3	2.6	.78	8.4	12	.35	9.7	.20	7.3	1.9	1.1	.80	.54
136	.59	3.4	.57	1.4	.53	.28	2.8	3.7	2.0	2.6	1.5	3.9	1.7	1.7	3.8	10	.62	2.0
137	.71	7.1	.18	.47	.62	.38	3.6	.87	14	15	.28	--	.69	5.0	11	5.0	--	.46
138	.28	1.9	.30	4.6	.59	.48	.95	.042	21	81	.049	3.0	.033	1.7	.76	.064	.27	.033
139	.43	2.6	1.3	2.6	.23	.42	1.5	.23	9.6	23	.18	2.4	.17	2.1	1.8	.50	.31	.18
140	.75	2.8	.73	.71	2.3	.27	3.0	1.0	8.8	11	3.9	4.8	.38	1.4	3.7	2.3	.66	.67
141	.34	2.2	.53	1.9	.27	.23	1.7	.31	9.1	20	.21	9.8	.16	.95	1.6	.55	1.1	.16

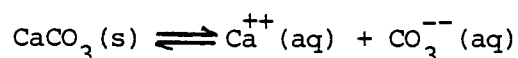
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TABLE 9 (continued)

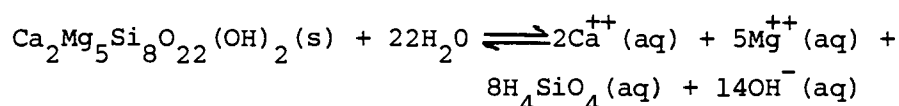
Sample No.	CaSO ₄ x10 ⁻⁵	CaHCO ₃ ⁺ x10 ⁻⁵	CaCO ₃ x10 ⁻⁶	NaSO ₄ x10 ⁻⁷	Na ₂ SO ₄ x10 ⁻⁸	NaHCO ₃ x10 ⁻⁶	NaCO ₃ x10 ⁻⁸	Na ₂ CO ₃ x10 ⁻¹¹	NaCl° x10 ⁻⁷	KSO ₄ x10 ⁻⁸	KCl° x10 ⁻⁹	H ₂ SO ₄ x10 ⁻¹⁰	H ₂ SO ₄ x10 ⁻²⁰	HCl° x10 ⁻¹⁷	H ₄ SiO ₄ x10 ⁻⁴	H ₃ SiO ₄ x10 ⁻⁷	H ₂ SiO ₄ x10 ⁻¹¹
101	.43	.44	1.2	.21	.0023	.076	.19	.012	.0011	1.0	.028	1.2	.33	.038	2.3	8.8	3.6
102	.72	.90	.64	.83	.078	.62	.30	.12	.0048	1.2	.027	4.5	5.0	.075	7.2	5.9	.38
103	.23	.29	.10	.35	.017	.24	6.0	.013	.0026	.15	.0047	.066	15	.16	6.2	2.6	9.0
104	.52	1.2	1.1	.74	.050	.76	.76	.20	.0095	.32	.019	2.8	2.3	.17	6.7	7.9	.92
105	.60	1.4	.81	.87	.036	.65	.37	.093	.010	.46	.031	5.3	6.6	.48	10	8.8	.91
106	13	2.2	5.8	390	770	21	55	650	100	3.8	5.7	11	3.0	22	5.0	19	9.1
107	11	3.3	6.3	53	85	9.7	12	86	29	.38	.81	6.5	2.7	10	3.5	7.5	1.2
108	.38	.92	1.6	.37	.029	.55	.65	.22	.0043	1.2	.055	.99	.45	.032	5.2	11	1.6
109	.81	.94	.52	1.2	.12	.73	.30	.14	.068	.81	.19	6.3	8.7	1.2	7.2	4.9	.29
110	.32	.54	.20	1.3	.30	1.3	.34	.33	.078	.14	.033	5.6	12	.95	7.3	3.1	.11
111	.19	.50	.35	.18	.012	.33	.14	.040	.0045	.67	.062	1.7	2.0	.099	6.7	5.0	.26
112	.77	1.2	2.0	1.2	.17	1.1	1.3	.81	.066	.32	.067	1.8	.84	.27	7.5	15	2.3
113	.19	.52	.37	.42	.029	.50	.29	.10	.0013	.72	.011	2.0	2.1	.029	8.0	7.4	.66
114	.67	1.2	.89	1.3	.18	1.2	.69	.44	.021	.58	.038	3.9	4.0	.21	8.2	7.5	.58
115	.35	.93	1.4	1.2	.25	1.7	1.9	1.8	.23	.18	.14	1.2	.61	.76	5.8	10	1.6
117	.45	1.5	.52	.59	.042	.84	.25	.093	.012	.41	.038	5.2	11	.48	9.3	4.3	.19
118	.34	1.0	1.4	4.4	.047	.78	.73	.35	.011	.78	.076	1.1	.62	.077	7.0	11	1.4
119	.45	.93	1.3	14	95	16	16	490	440	.26	34	.47	.27	.49	3.2	5.2	.71
120	25	4.8	1.8	320	1300	240	77	180	510	13	110	38	78	360	4.1	2.1	11
121	2.5	1.1	.28	33	32	7.2	1.4	6.7	9.1	.56	.70	36	110	39	5.3	1.7	.049
122	.13	.18	.035	.22	.013	.18	.024	.0063	.0068	.69	.082	6.9	28	.61	2.3	.52	.0091
123	.58	1.6	.57	.30	.0096	.36	.10	.017	.014	.13	.030	5.9	13	1.3	9.0	4.1	.18
124	42	1.0	21	300	2200	5.0	65	1900	470	5.9	33	.87	.033	3.0	3.3	75	120
125	.83	.62	3.6	6.5	2.9	2.5	11	23	1.7	.42	.48	.73	.096	.70	3.1	22	14
126	.29	.63	5.8	.41	.048	.53	3.3	1.7	.025	.043	.010	.14	.012	.024	3.8	40	33
127	4.2	3.2	2.7	1.5	.075	.62	.38	.088	.024	2.1	.014	11	10	.059	5.7	5.7	.49
128	.67	2.3	1.3	.20	.0058	.36	.14	.020	.0032	.13	.0091	3.7	5.3	.21	8.7	5.7	.31
129	2.2	.92	2.7	4.3	.75	1.1	2.2	1.7	.0099	.31	.0027	3.2	.88	.020	6.1	20	5.2
130	12	1.6	7.2	58	100	5.4	15	110	31	.90	1.7	3.1	.55	3.9	4.9	24	8.4
132	.23	.37	.042	.26	.020	.30	.022	.0067	.0030	1.5	.061	13	92	.35	6.7	.83	.0073
133	2.4	1.9	6.7	3.7	.52	1.5	4.0	2.6	.023	.51	.013	2.2	.48	.048	7.1	30	11
133r	.44	.74	13	.53	.012	.24	4.4	.64	.011	1.3	.17	.16	.0067	.033	2.4	65	230
134	1.1	.54	.38	26	19	6.4	3.5	13	4.0	.30	.20	13	14	7.9	5.8	5.2	.41
135	2.8	1.3	.60	2.6	2.7	.72	.23	.10	.011	.95	.016	20	34	.24	8.0	4.3	.18
136	.30	1.2	2.5	.31	.038	.83	1.1	.57	.0075	.22	.020	.51	.19	.029	4.3	10	1.6
137	.49	1.9	.71	.14	.0049	.33	.086	.013	.0027	.10	.0076	4.0	8.4	.21	9.7	4.2	.14
138	.25	.20	.014	.30	.018	.15	.0069	.0018	.0045	1.3	.071	29	320	1.1	6.0	.46	.0027
139	.33	.49	.12	1.2	.28	1.0	.17	.18	.71	.65	1.5	7.3	.24	.13	--	--	--
140	.37	1.7	.88	.41	.060	1.2	.41	.25	.042	.11	.043	2.1	3.1	.57	7.0	4.2	.19
141	.14	.42	.12	.27	.027	.48	.092	.041	.0036	.26	.013	3.3	9.2	.12	8.7	2.8	.071

and redox potentials of course reduce the number of reactions. Examples are the dissolution of calcite and tremolite:

Calcite:



Tremolite:



For equilibrium constant expressions to be calculated, the reactions are assumed to be reversible. For calcite or other minerals of simple structure, this assumption is in most cases valid. For more complicated minerals such as tremolite, reversibility is not as clearly assumable. Many weathering reactions of mafic and feldspar minerals have been shown in the laboratory to be complex. Originally, weathering reactions were considered incongruent, whereby a solid phase formed (Wollast, 1965; Busenberg and Clemency, 1976). Holdren and Berner (1979) and Berner and Holdren (1979) found that although feldspar dissolution occurs stoichiometrically, $\text{Al}^{+++}(\text{aq})$ will form a fine-grained precipitate. The Al precipitation not only prevents buildup of Al in solution but it forms fairly quickly.

A useful term, saturation index (SI), can be defined as the ratio ion activity product/equilibrium constant; thus $\text{SI} = 1$ is an indication of equilibrium. Table 10 is a listing of log SI values for selected mineral reactions. The samples in this study are nearly all saturated with respect to quartz, cristobolite- α , and chalcedony. All samples are undersaturated with respect to amorphous silica. Several samples are supersaturated with respect to talc, tremolite, aragonite, calcite, dolomite, and even sepiolite.

Histograms of log SI are used as graphical aids in interpretation of equilibrium conditions. It was determined from the

TABLE 10. Log SI (saturation index) for selected reactions.

Sample No.	Quartz	Cristobalite- α	Amorphous silica	Calcite	Dolomite	Magnesite	Talc	Tremolite	Aragonite	Sepiolite
101	0.45	-0.18	-0.85	-0.58	-1.26	-4.30	-1.32	-3.83		
102	1.01	0.37	-0.31	-0.84	-1.95	-4.75	-3.01	-8.31		
103	0.93	0.29	-0.39	-1.64	-3.20	-5.18	-5.02	-13.59		
104	0.93	0.30	-0.37	-0.61	-1.26	-4.28	-1.73	-5.55		
105	1.08	0.45	-0.22	-0.75	-1.49	-4.36	-1.83	-6.02		
106	0.76	0.13	-0.53	0.10	-1.03	-4.75	-1.78	-2.97		
107	0.70	0.06	-0.62	0.15	-0.18	-3.96	-0.54	-1.75		
108	0.88	0.24	-0.04	-0.44	-1.05	-4.25	-0.94	-3.53		
109	0.99	0.35	-0.32	-0.93	-2.00	-4.70	-3.12	-8.77		
110	1.02	0.38	-0.30	-1.34	-2.85	-5.14	-4.82	-12.77		
111	1.00	0.35	-0.33	-1.10	-2.34	-4.87	-3.33	-9.37		
112	1.03	0.39	-0.29	-0.34	-0.69	-3.99	0.26	-1.25		
113	1.01	0.38	-0.30	-1.09	-2.37	-4.90	-3.04	-8.46		
114	1.05	0.41	-0.27	0.41	-1.57	-4.50	-2.23	-6.70		
115	0.90	0.27	-0.41	-0.50	-1.19	-4.32	-1.23	-4.18		
117	1.08	0.44	-0.23	-0.94	-2.03	-4.71	-3.70	-10.15		
118	1.00	0.36	-0.32	-0.50	-1.26	-4.38	-1.22	-4.18		
119	0.65	0.01	-0.67	-0.54	-3.02	-6.10	-6.13	-11.77		
120	0.70	0.07	-0.60	0.20	-2.52	-5.73	-7.03	-14.28		
121	0.85	0.21	-0.46	-1.20	-3.17	-5.59	-7.30	-17.05		
122	0.52	-0.12	-0.80	-2.10	-4.32	-5.85	-8.95	-21.83		
123	1.06	0.42	-0.24	-0.90	-1.88	-4.61	-3.40	-9.57		
124	0.70	0.06	-0.62	0.67	-0.96	-5.28	1.24	6.07	0.48	
125	0.63	-0.01	-0.68	-0.09	-1.70	-5.24	-2.81	-4.79		
126	0.73	0.09	-0.59	0.12	-1.08	-4.83	-0.52	-0.05		
127	0.89	0.25	-0.42	-0.22	-0.61	-4.02	-1.71	-5.29		
128	1.08	0.44	-0.24	0.57	-1.07	-4.15	-1.92	-6.42		
129	0.95	0.31	-0.37	-0.22	-0.66	-4.07	0.57	0.01		
130	0.86	0.22	-0.47	0.22	-0.72	-4.57	0.13	0.92	0.01	
132	1.00	0.36	-0.33	-2.02	-4.18	-5.80	-8.17	-20.65		
133	0.99	0.35	-0.32	0.18	0.25	-3.55	2.16	3.48		
133r	0.42	-0.20	-0.86	0.43	0.72	-3.34	3.83	8.43	0.25	0.29
134	0.89	0.25	-0.42	-1.07	-2.73	-5.29	-5.08	-12.27		
135	1.06	0.42	-0.26	-0.86	-2.39	-5.15	-4.68	-11.53		
136	0.81	0.17	-0.52	-0.24	-0.80	-4.19	-0.98	-3.28		
137	1.14	0.50	-0.18	-0.79	-1.65	-4.48	-3.03	-8.99		
138	0.94	0.30	-0.38	-2.51	-6.38	-6.38	-10.04	-24.73		
139	--	--	--	-1.57	-3.42	-5.47	--	--		
140	1.00	0.36	-0.32	-0.70	-1.89	-4.82	-3.96	-10.12		
141	1.09	0.45	-0.23	-1.57	-3.38	-5.44	-5.50	-14.32		

relative abundances that a few weathering reactions appear to be controlling the composition of the low EC waters. A histogram of these reactions would be expected to have both limited variability of SI values, and a clustering of these values around one. If the thermodynamic data used are not accurate, the histogram would show a cluster about some value other than one, because of an incorrect equilibrium constant. Therefore, in the interpretation of these histograms, the value of the standard deviation and the frequency at the mode, as well as the magnitude of the SI values, should be considered.

Three carbonate minerals are used for reference--calcite, magnesite, and dolomite (Fig. 23). The dolomite is assumed to have a molar ratio $\text{Ca/Mg} = 1$. Seven samples are supersaturated with calcite. The range of SI values covers four orders of magnitude. Dolomite SI values have a range of six orders of magnitude. For magnesite, the range is smaller, three orders of magnitude, and all samples are undersaturated with respect to this phase. Three critical observations can be made: few samples are supersaturated with carbonate minerals; the frequency at the mode is small in all three cases; and the standard deviations are large. These observations suggest that the three carbonates are not controlling the concentrations of Ca^{++} , Mg^{++} , and CO_3^{--} in many of the samples. Calcite could be precipitating in some waters; in the petrographic investigation of rock chips from Well 131s, calcite was found.

A close examination of tremolite and talc equilibrium calculations reveals similar results (Fig. 24). The histograms have broad ranges, large standard deviations, and small frequencies at the mode. These two dissolution reactions are most likely not controlling the concentrations of the relevant dissolved constituents. Values of SI greater than one thus are considered coincidental. Talc and tremolite are metamorphic minerals, and low temperature equilibrium is unlikely (Deer and others, 1966).

Solubility data for SiO_2 show a marked contrast to the above

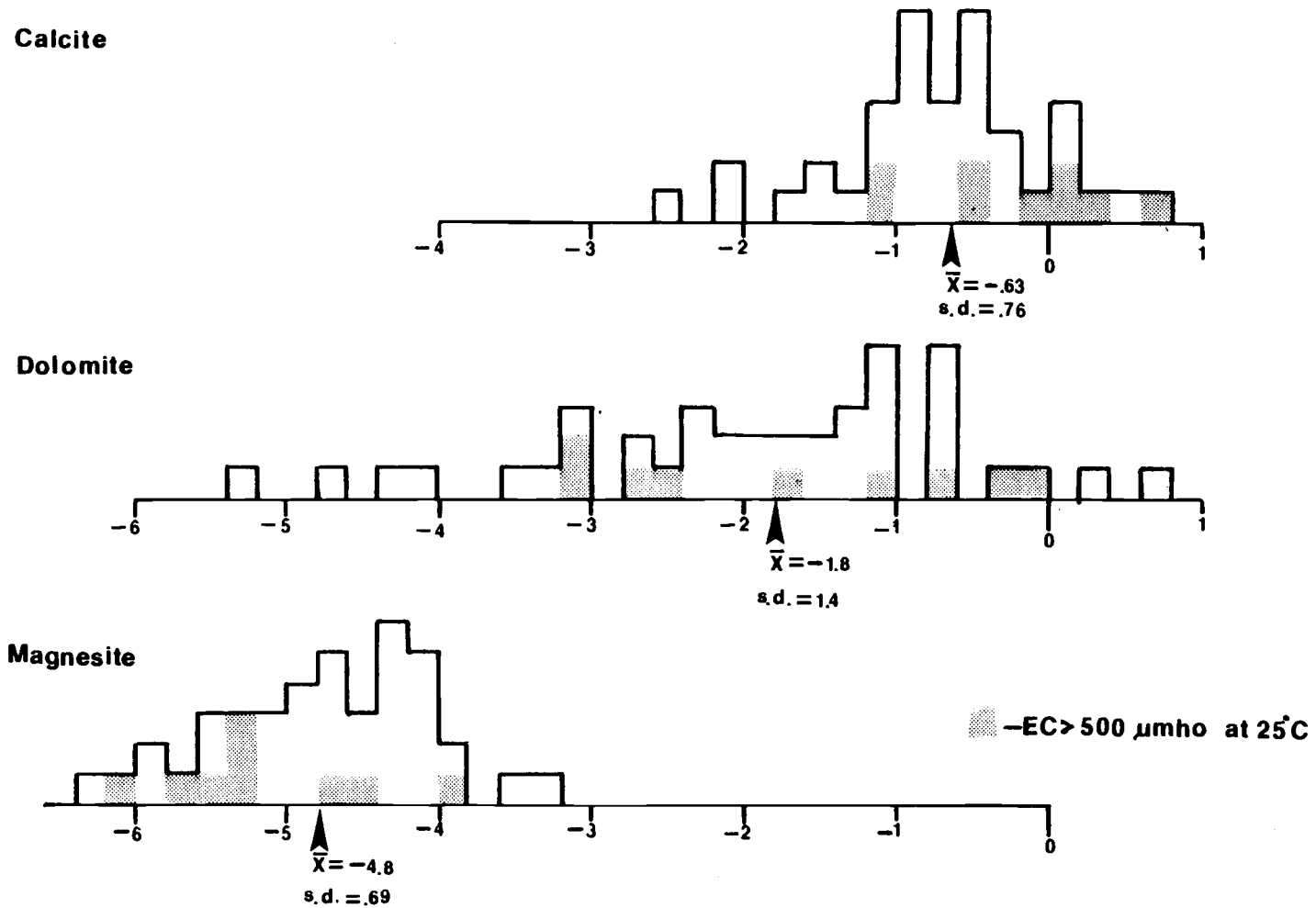


Figure 23. Histograms of log SI results for calcite, dolomite, and magnesite.

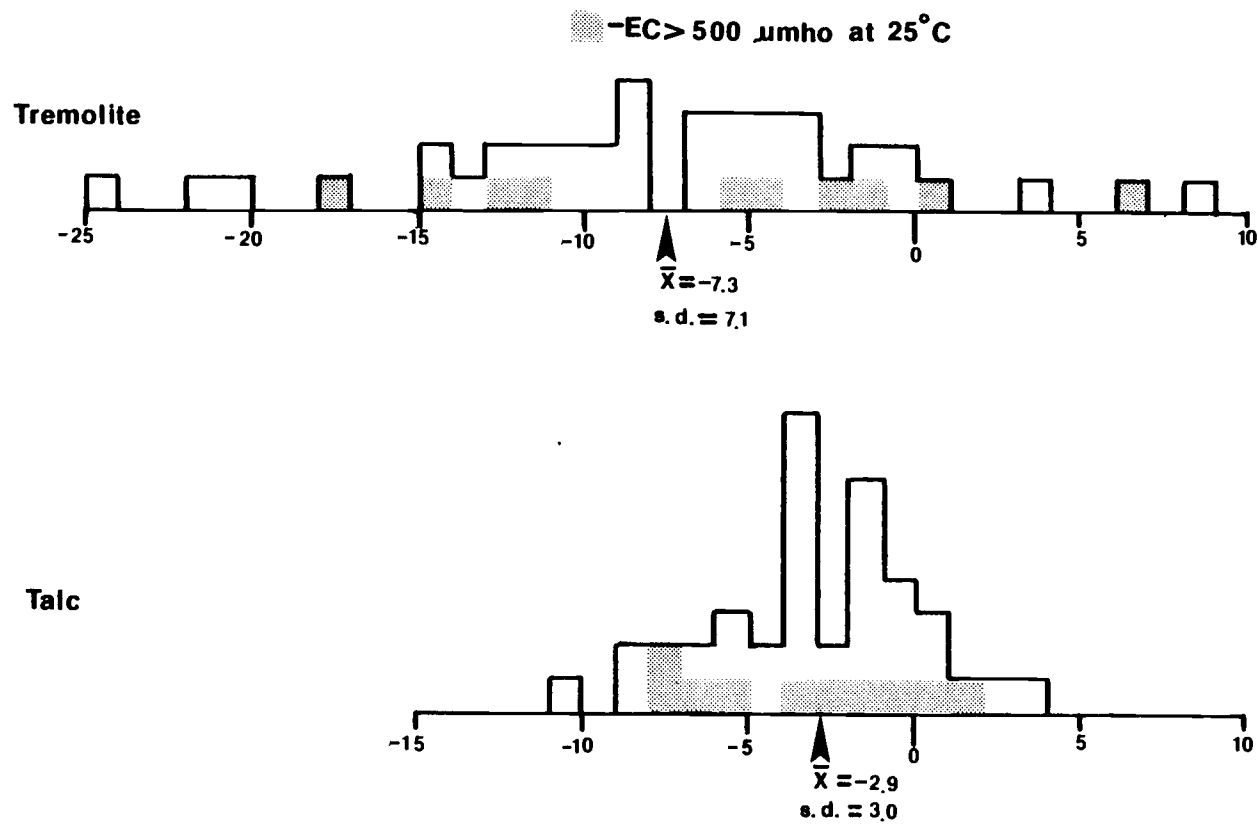


Figure 24. Histograms of log SI results for tremolite and talc.

The data are from this study. This is a composite of all samples.

reactions. Histograms were made for the SiO_2 phase of quartz, cristobolite- α , and amorphous silica (Fig. 25). Since the ion activity products are the same for all three, the differences in the histograms result from differences in K_t values. The standard deviation is the same for all three reactions and, most importantly, its value is small. The range in value is also small and the frequency at the mode is high. All three factors suggest some type of solubility reaction is controlling SiO_2 concentrations.

The controlling reactions are most likely not quartz, cristobolite, or amorphous silica dissolution. Both quartz and cristobolite appear to be saturated, but precipitation of either phase seems unlikely because the reactions are very slow at ground water temperatures (Morey and others, 1962). Of the three, amorphous silica is most likely to precipitate in an aqueous solution. The SI values, however, indicate it is undersaturated.

Experimental work has shown that SiO_2 is solubilized from feldspar and mafic minerals during weathering (Wollast, 1965; Busenberg and Clemency, 1976; Siever and Woodford, 1979). The concentrations of SiO_2 from these weathering processes can exceed quartz solubility. Some type of weathering of feldspar or mafic minerals is believed to be controlling SiO_2 concentrations in the ground water of this study.

The two river samples show marked changes in geochemistry during the summer. Sample 101 was taken early in the summer (June) when the river was at higher flow rates. At the end of summer (September) Sample 133r was taken. Flow rates were then very low. Sample 101 is supersaturated only with quartz. By late summer, supersaturation occurs with calcite, aragonite, dolomite, sepiolite, tremolite, and talc. From the trilinear diagram (Fig. 21) the relative concentrations of major constituents appear very similar. The low concentrations thus result mainly from dilution.

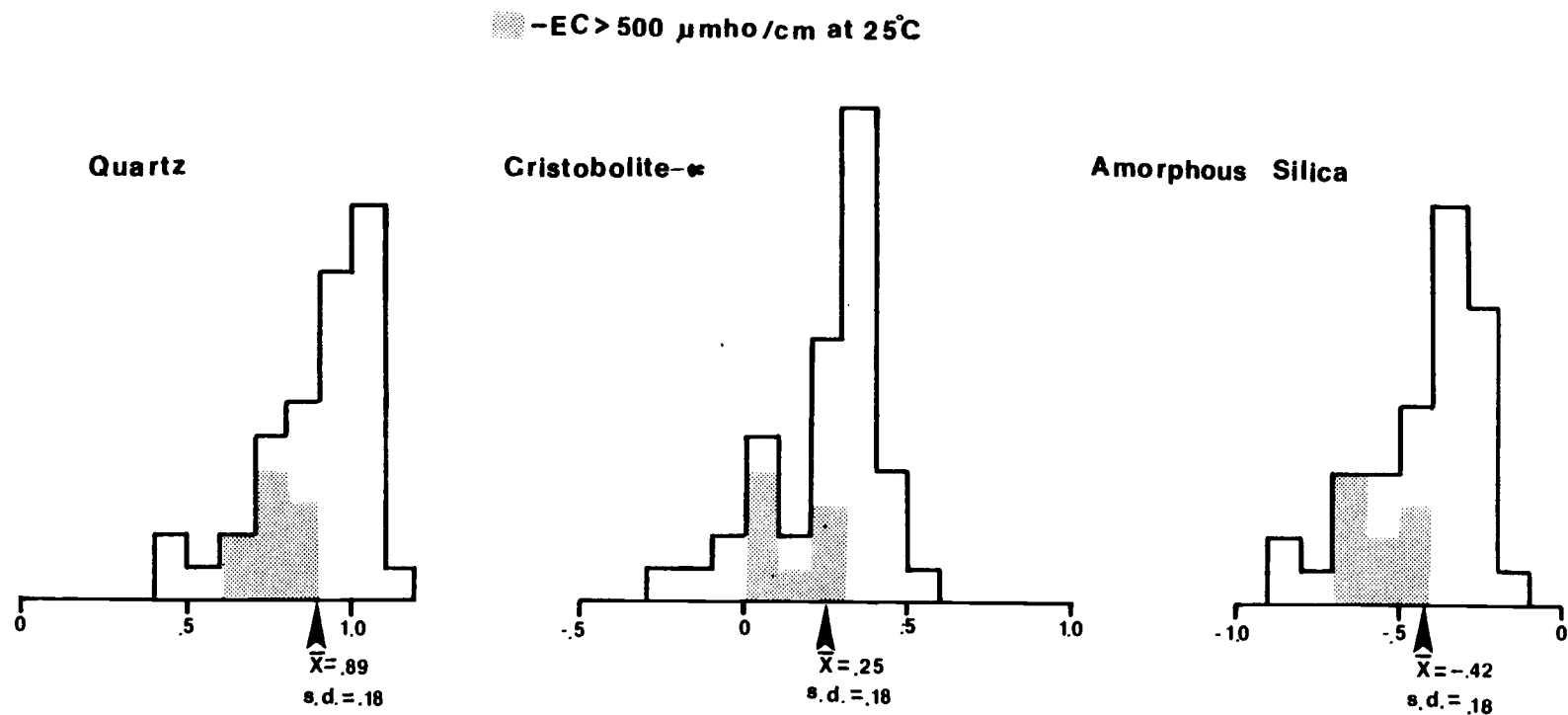


Figure 25. Histograms of log SI results for quartz, cristobolite- α , and amorphous silica.

Mineral Stability

In tracing the chemical evolution of ground water, departure from equilibrium is a reality that must be addressed. One method to illustrate this feature is to plot selected dissolved species on a diagram showing theoretical stable phases. In the literature these diagrams are called stability diagrams, theoretical ion activity diagrams, and ion predominance diagrams. Feth and others (1964) used this type of diagram effectively in the interpretation of waters from the granitic rocks of the Sierra Nevada.

Unfortunately, many problems exist with the construction and interpretation of stability diagrams. Their use, ultimately, is dependent upon the quality of basic thermodynamic data. The uncertainty of much of the relevant thermodynamic data results in poorly defined stability fields. This limitation restricts systematic interpretation of the diagrams. The plots are useful, however, for comparison of data with that of other studies.

Six stability diagrams are included herein (Figs. 26 to 31). The diagrams are from Helgeson and others (1969); updated SiO_2 data are included. The diagrams have been plotted for samples at 25°C, whereas the field samples ranged in temperature from 12.4° to 21.2°C. Naturally, since the basic thermodynamic relations are temperature dependent, deviation from 25°C will correspond to a shifting of the stability fields. In this case, however, the magnitude of this temperature shift would be small when compared with the uncertainties of the thermodynamic data.

Data for the two primary alkali metals from waters of this study plot in or near the kaolinite field, except for Sample 124, which plots in the low albite field (Figs. 26 and 27). Data for the alkaline earth metals are not easily interpreted. In Figure 28, these data cluster near the kaolinite-Mg-montmorillonite phase boundary. Unfortunately, the location of the phase boundary is too

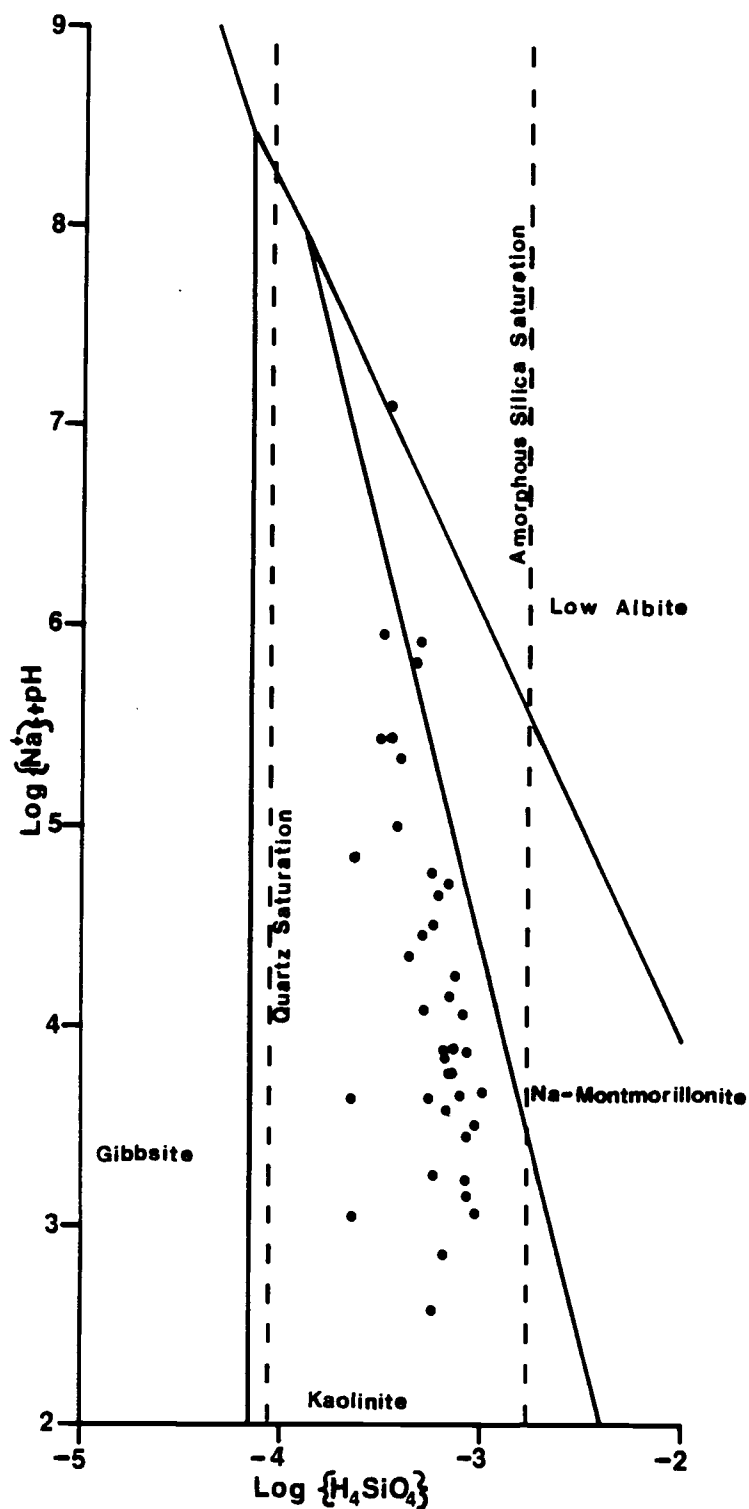


Figure 26. Stability diagram for the system $\text{HCl-H}_2\text{O-Al}_2\text{O}_3\text{-Na}_2\text{O-SiO}_2$ at 25°C and 1 atm .

Data plotted are from this study. Most of the data plot in the kaolinite field (from Helgeson and others, 1969).

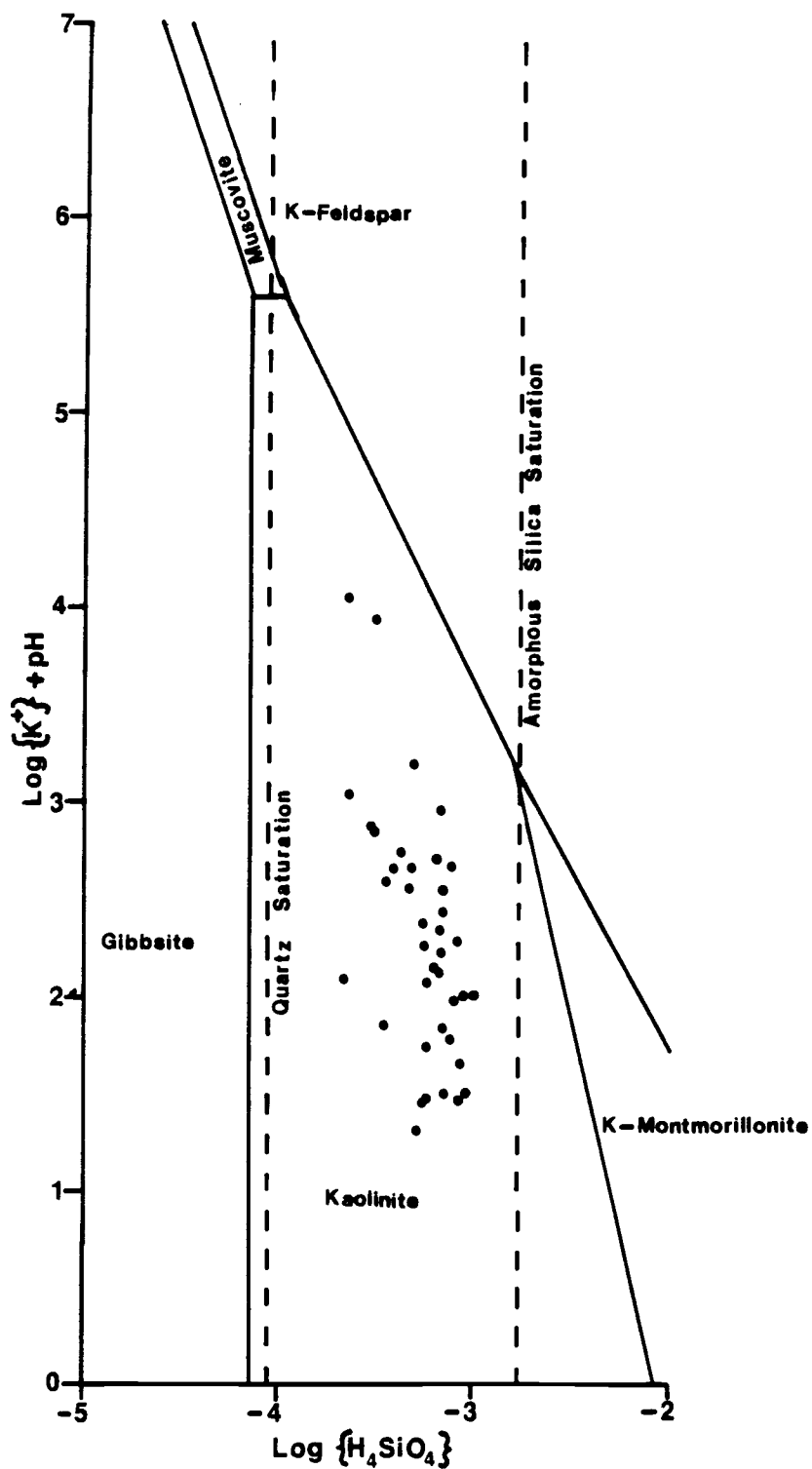


Figure 27. Stability diagram for system $\text{HCl-H}_2\text{O-Al}_2\text{O}_3\text{-K}_2\text{O-SiO}_2$ at 25°C and 1 atm .

Data are from this study and plot in the kaolinite field (from Helgeson and others, 1969).

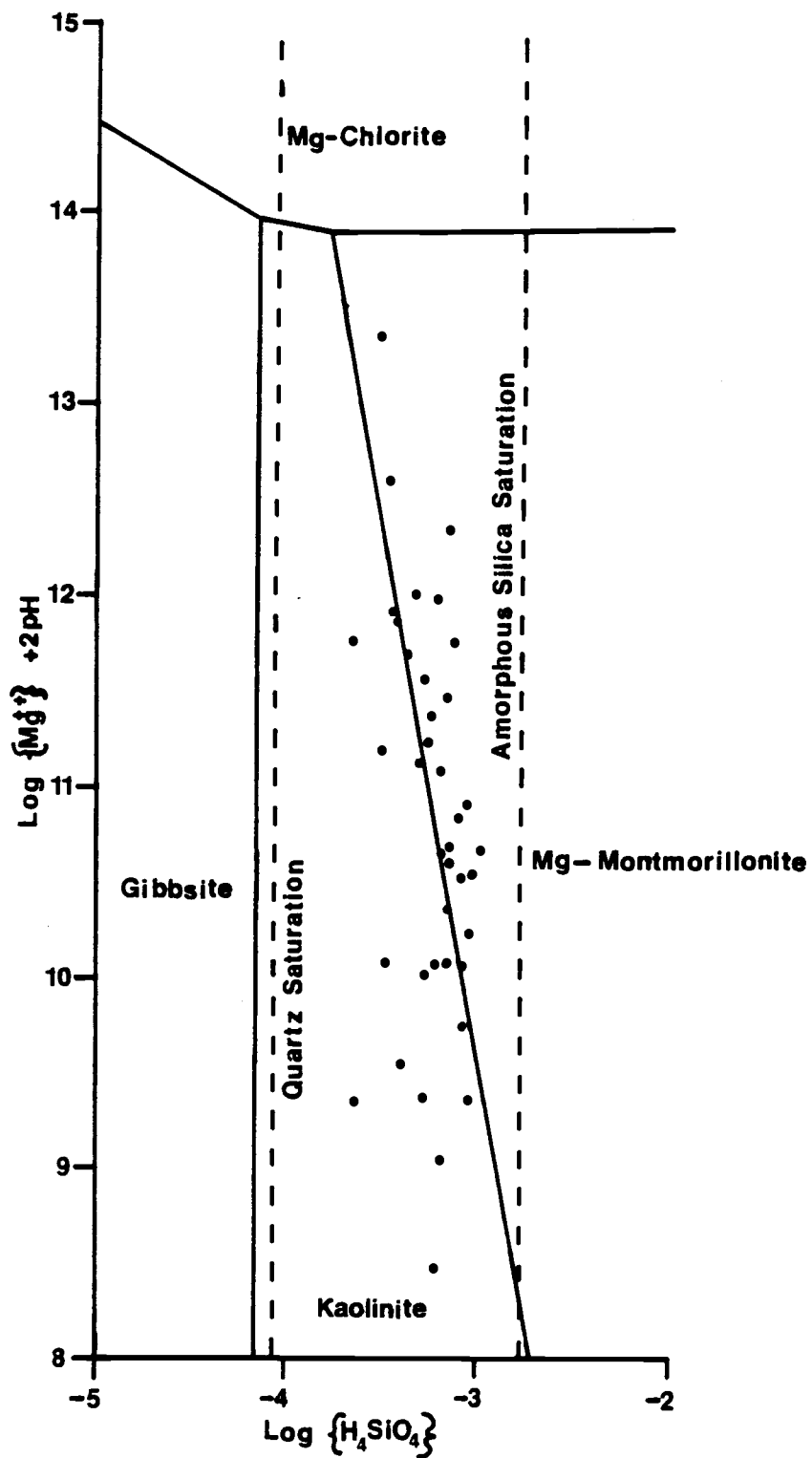


Figure 28. Stability diagram for system $\text{HCl-H}_2\text{O-Al}_2\text{O}_3\text{-CO}_2\text{-MgO-SiO}_2$ at 25°C and 1 atm .

Data are from this study (from Helgeson and others, 1969).

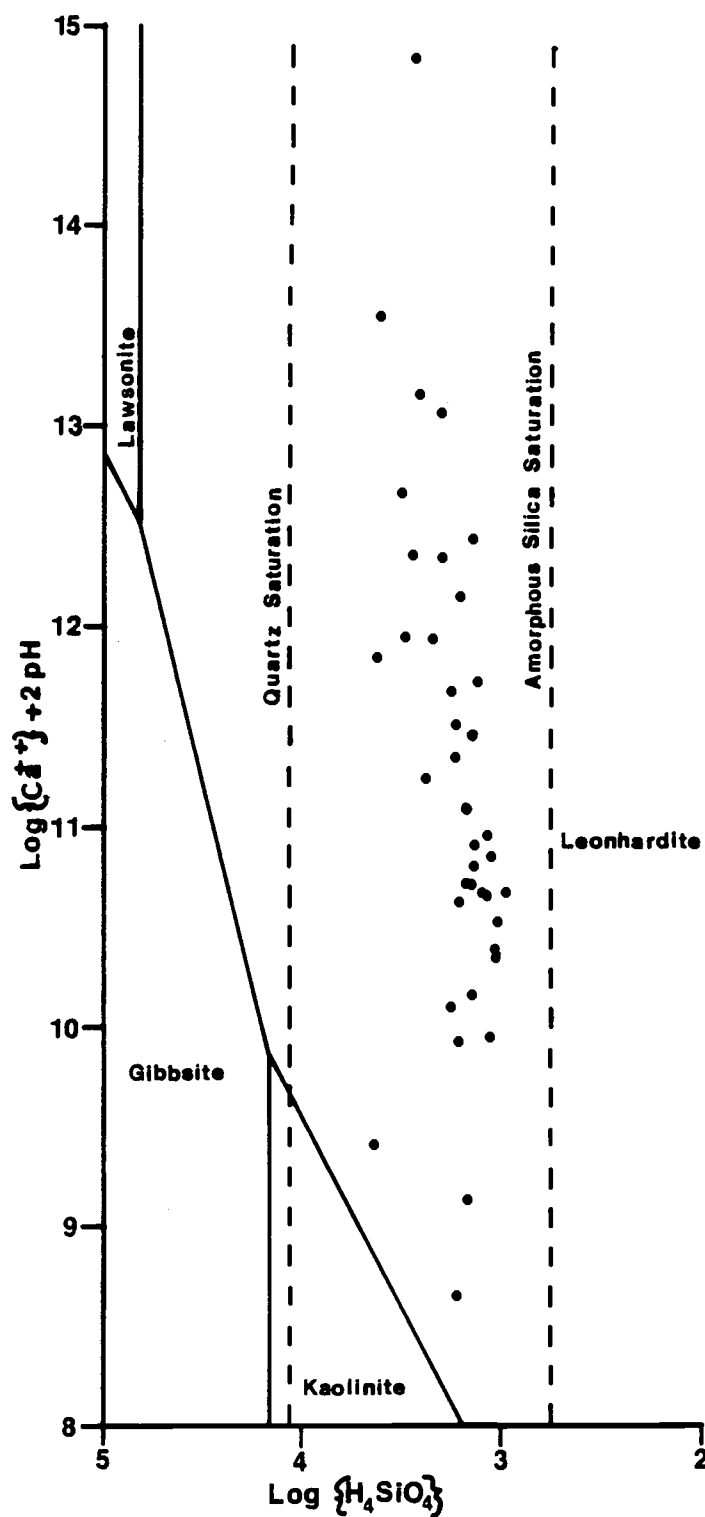


Figure 29. Stability diagram for system $\text{HCl-H}_2\text{O-Al}_2\text{O}_3\text{-CaO-CO}_2\text{-SiO}_2$ at 25°C and 1 atm .

Data are from this study and plot in the leonhardite field (from Helgeson and others, 1969).

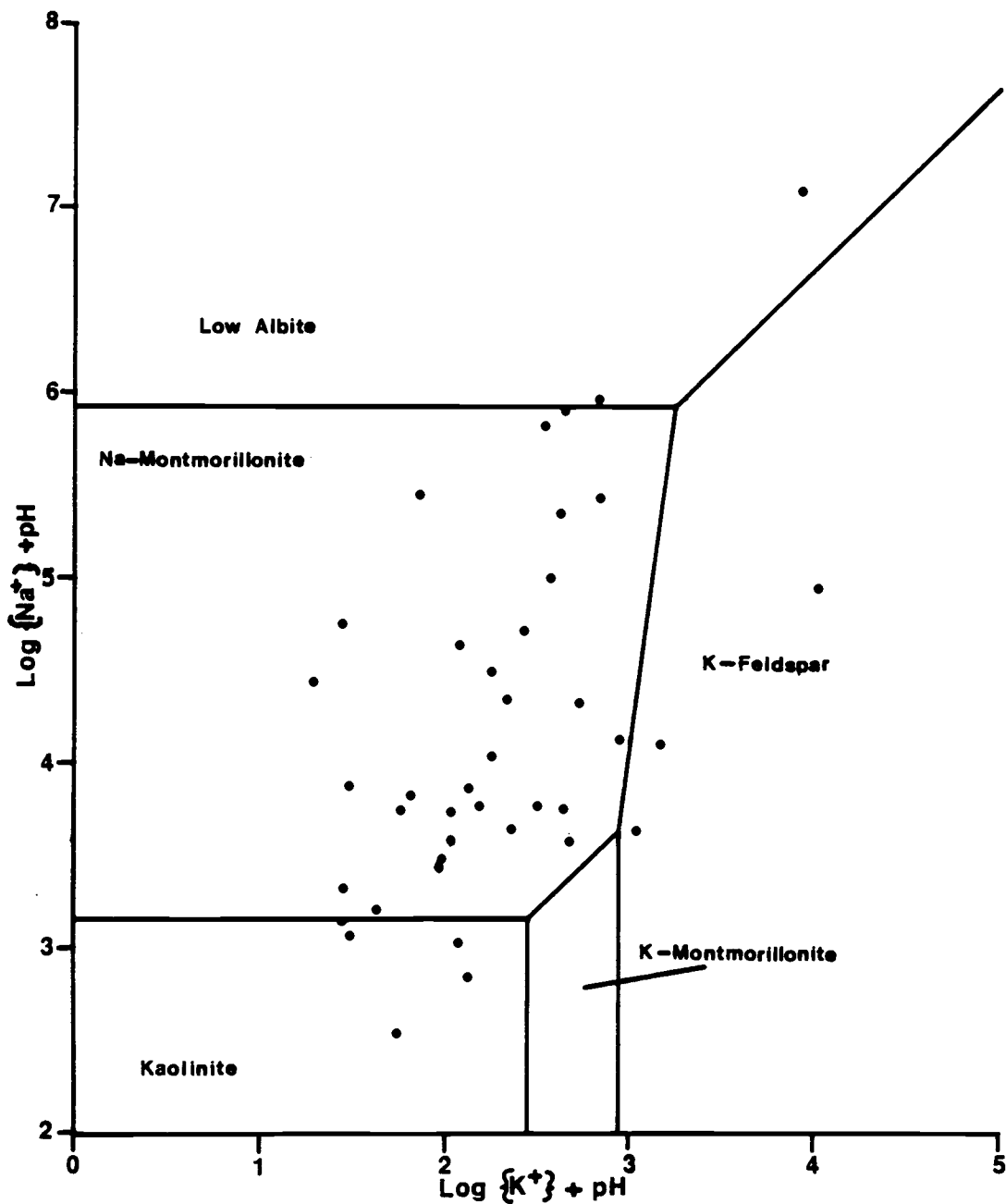


Figure 30. Stability diagram for the system $\text{HCl-H}_2\text{O-Al}_2\text{O}_3\text{-K}_2\text{O-Na}_2\text{O-SiO}_2$ at 25°C , 1 atm, and amorphous silica saturation.

$\text{Log } \text{H}_4\text{SiO}_4 = -2.70$; since most of the samples are undersaturated with respect to amorphous silica, the data plot in the kaolinite field (from Helgeson and others, 1969).

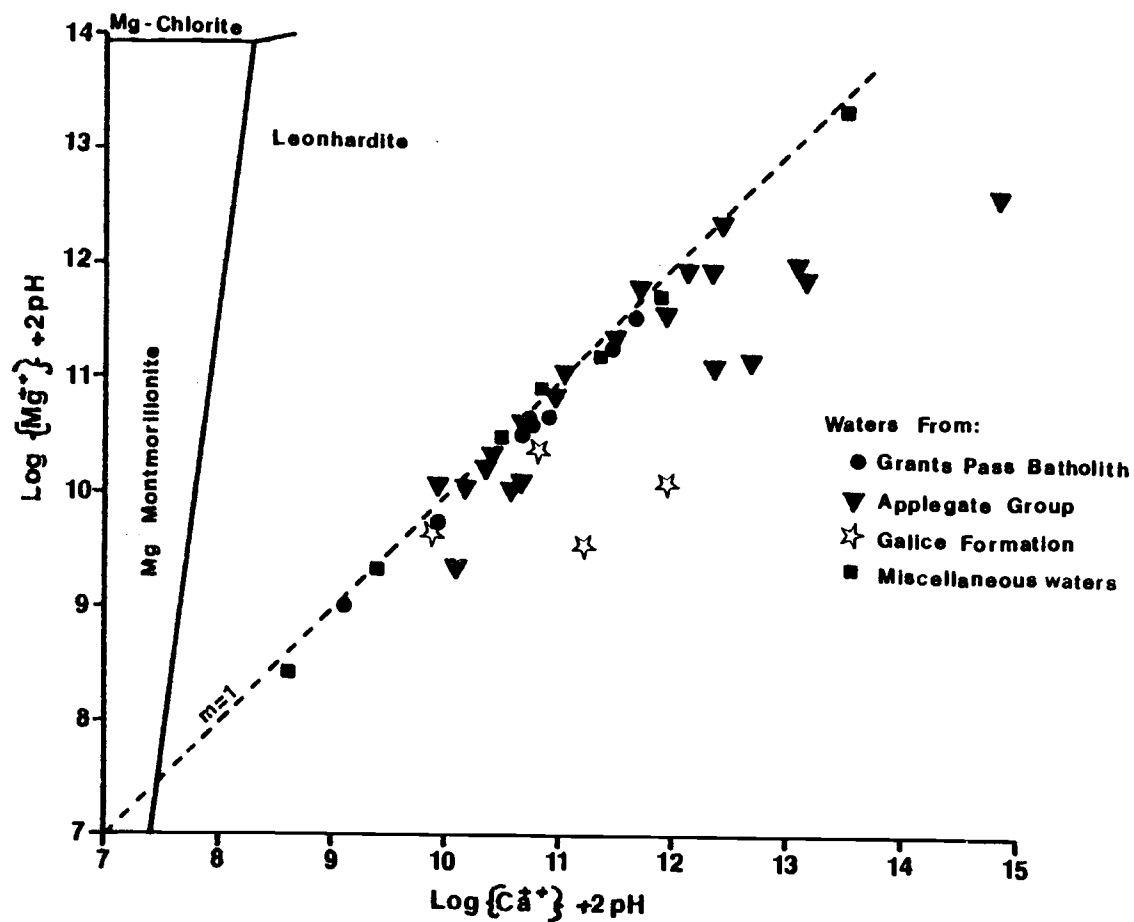


Figure 31. Stability diagram for the system $\text{HCl-H}_2\text{O-MgO-Al}_2\text{O}_3\text{-CaO-CO}_2\text{-SiO}_2$ at 25°C, 1 atm, and amorphous silica saturation.

The data represent waters sampled from various geologic units within the study area. Concentrations (mole/l) expressed in terms of activity (from Helgeson and others, 1969).

uncertain to warrant a definite conclusion concerning equilibrium. Calcium ion data plot in the leonhardite field (Fig. 29). Leonhardite ($\text{Ca}_2\text{Al}_4\text{Si}_8\text{O}_{24} \cdot 7\text{H}_2\text{O}$) is a zeolite, a partially dehydrated variant of laumontite ($\text{Ca}_2\text{Al}_4\text{Si}_8\text{O}_{24} \cdot 8\text{H}_2\text{O}$) (Deer and others, 1966).

The other stability diagrams (Figs. 30 and 31) show the relation of the two alkali metals to each other and the relation of the two alkaline earth metals to each other. In both Figures 30 and 31, amorphous silica saturation ($\log \text{H}_4\text{SiO}_4 = -2.70$; Helgeson and others, 1969) is used in the construction of the diagrams. In Figure 30, the data plot mostly in the Na-montmorillonite field. This figure can be used with Figures 26 and 27 to form a three-dimensional diagram. The data of Figure 30 plot within the kaolinite field, as most of the samples are undersaturated with respect to SiO_2 .

On the diagram of alkaline earth metals (Figure 31), the data plot in the leonhardite field and have a very striking linearity ($r \doteq 0.9$). This clustering of data occurs on the Ca side of a reference line with positive slope of one and an intercept of zero. The high EC samples are generally higher in Ca relative to Mg, subsequently plotting to the right of the line. To show this relation more clearly, a plot of $\log \text{Ca/Mg}$ vs. TDS (Fig. 32) was constructed. Samples with low TDS values cluster around a Ca/Mg ratio of one, while samples with high TDS values have higher Ca/Mg ratios.

To determine if this rather striking trend is unusual, data representative of similar rock types from other locations were plotted on a similar diagram (Fig. 33). White and others (1963) report chemical analyses of subsurface waters from a variety of rock types. Their data, though not extensive, offer a selection of representative water analyses. Waters selected for Figure 33 have TDS values less than 1000 mg/l and were produced from rocks similar to those of this study. The data of White and others (1963) follow the same trend, plotting on the Ca side of a line with unit slope.

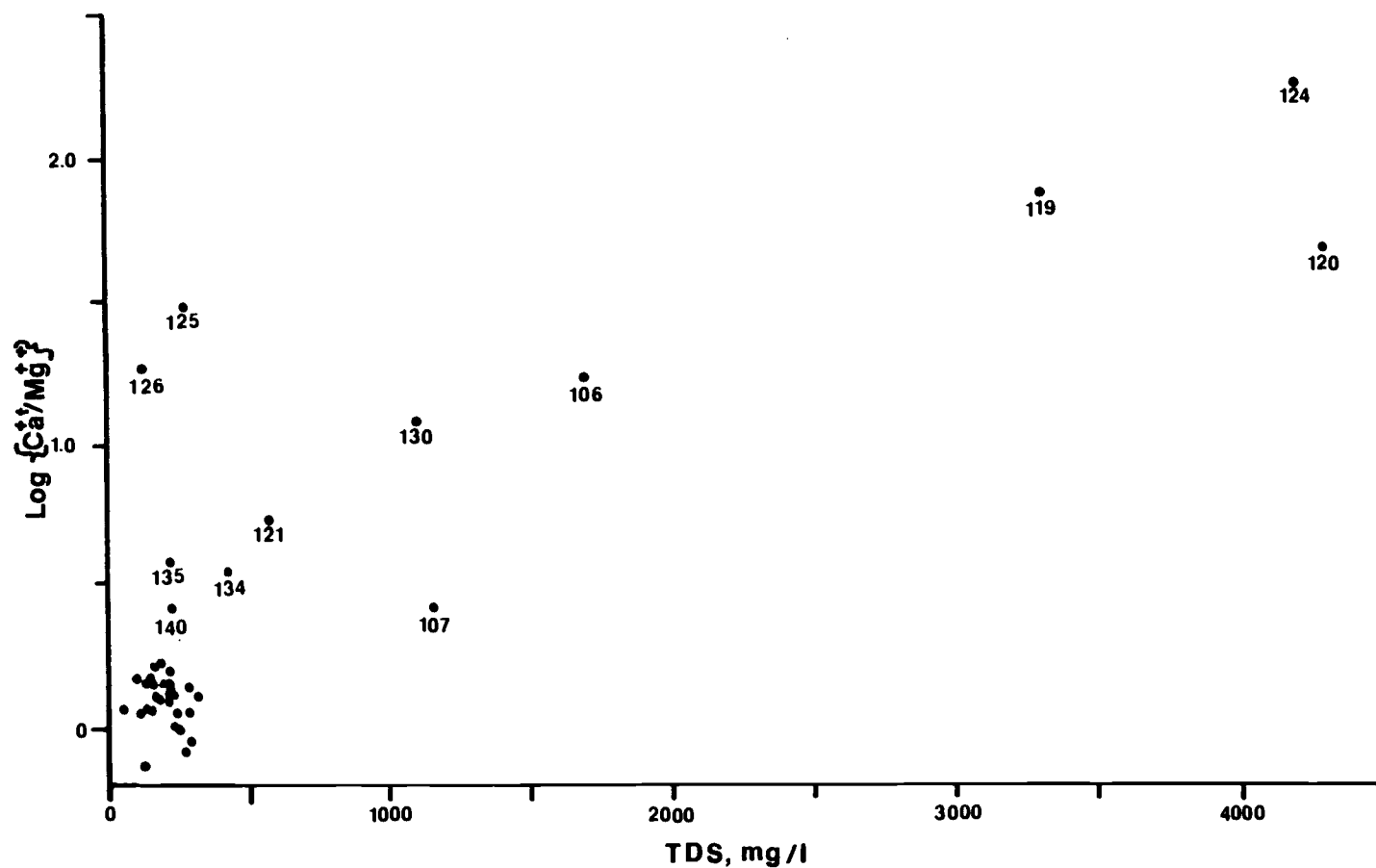


Figure 32. Plot of $\text{Log } \{ \text{Ca}^{++}/\text{Mg}^{++} \}$ vs. TDS.

This diagram shows the relation of Ca and Mg to TDS. Most of the data with low TDS plot in the lower left corner. The samples with high TDS generally have a higher Ca/Mg ratio.

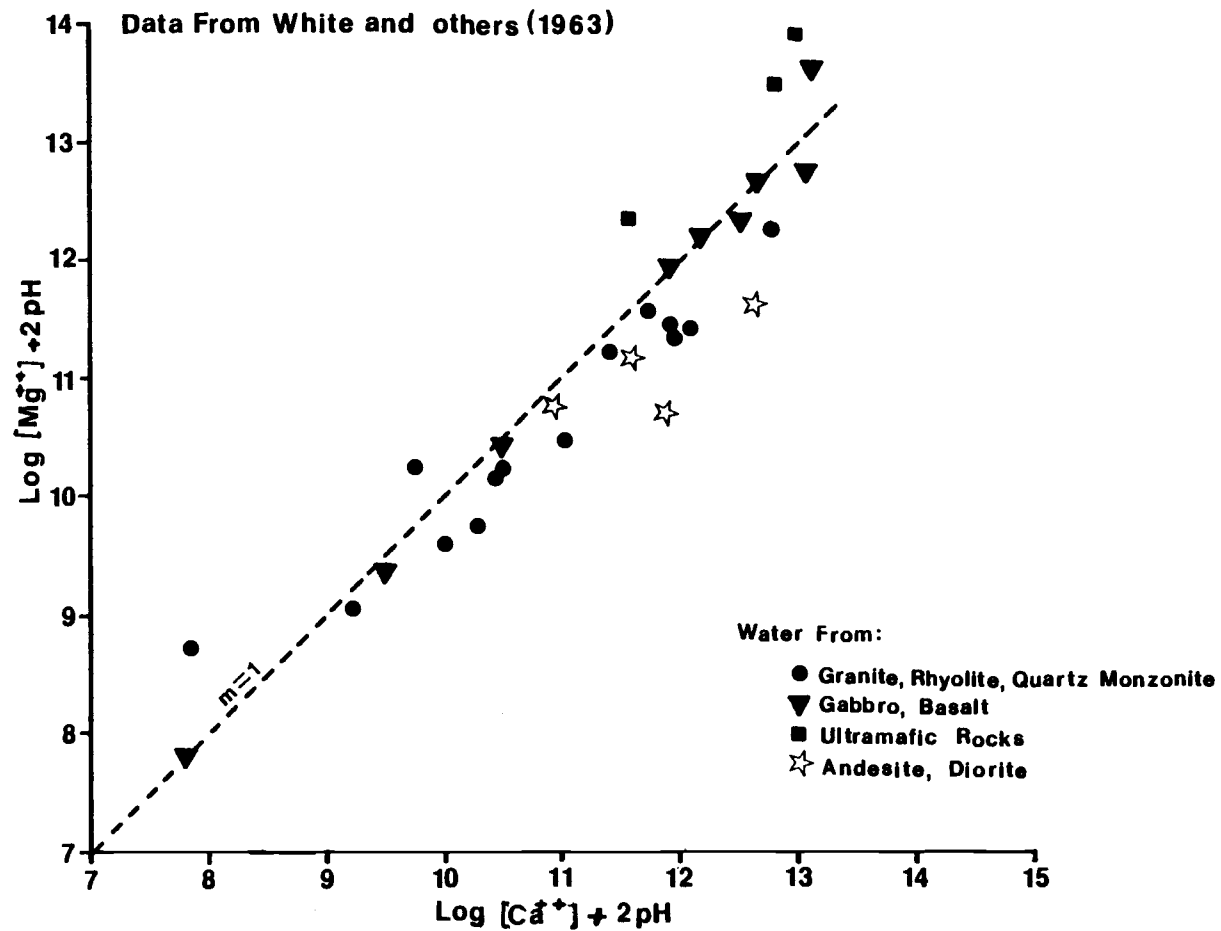


Figure 33. Plot of $\text{Log } [\text{Mg}^{++}] + 2 \text{ pH}$ vs. $\text{Log } [\text{Ca}^{++}] + 2 \text{ pH}$.

Data are from White and others (1963) and have TDS values less than 1000 mg/l.

Although six samples do plot on the Mg side of the reference line, three are from aquifers composed of ultramafic rocks. Trends in both sets of data suggest that leaching of Ca^{++} and Mg^{++} into ground water is independent of rock type and geographic location. Evidently the leaching reaction must involve common mineral phases such as feldspar, mica, and amphibole. Weathering of these minerals would then contribute Ca^{++} and Mg^{++} to solution. Ultimately, the Ca/Mg ratio will depend on weathering of solid phases, ion exchange, and the precipitation of secondary weathering products.

Garrels (1967) reported a general qualitative summary of the genesis of the chemical constituents of ground water in igneous rocks. The most active agent in the weathering of aluminosilicate rocks is $\text{H}_2\text{CO}_3(\text{aq})$. The principal complex ion at normal pH values, HCO_3^- , can thus be used as a general indication of degree of weathering. Plagioclase and mafic minerals such as biotite and hornblende are attacked much more readily than potassium feldspar or quartz (Goldich, 1938; Jackson and others, 1948; Stumm and Morgan, 1981). Dissolved Na^+ and Ca^{++} thus are attributed mainly to the weathering of plagioclase. For the metavolcanic rocks, actinolite and to some degree laumontite probably are contributing Ca^{++} to solution. Dissolved K^+ and Mg^{++} may be attributed to dark minerals. Little K^+ or other dissolved species are derived from potassium feldspar.

The main weathering product and the first to form is commonly kaolinite (Garrels, 1967). However, other minerals can also form, including smectite, chlorite, illite, and a variety of essentially x-ray-amorphous, or very poorly crystalline aluminosilicates.

Analyses were divided into four groups according to rock type and an arbitrary EC value of 500 μmho @ 25°C: (1) low EC waters from granodiorite; (2) low EC waters from metavolcanic rocks; (3) high EC waters from metavolcanic rocks; and (4) high EC waters from the Galice Formation within the contact aureole.

Water analyses within each of these groups were averaged (Table 11). The granodiorite waters are the lowest in dissolved constituents.

TABLE 11. Average concentrations of dissolved species. (The chemical groups are separable by rock type and by an EC value of 500 μmho @ 25°C.)

Rock Type	EC Group	No. of Samples	mmoles/l							mg/l		
			Na ⁺	K ⁺	Ca ⁺⁺	Mg ⁺⁺	HCO ₃ ⁻	Cl ⁻	SO ₄ ⁻⁻	SiO ₂	TDS	pH
Granodiorite	low	8	.5	.038	.55	.40	2.30	.098	.07	.71	164	7.02
Metavolcanic rock	low	14	.71	.009	.73	.54	2.89	.19	.13	.71	207	7.26
Metavolcanic rock	high	7	14	.009	3.4	.31	2.03	21	.74	.44	1350	7.63
Galice	high	2	46	.064	7.2	.13	1.30	65	.59	.37	3800	7.09
Applegate River water	low	2	.18	.033	.5	.38	1.84	.11	.083	.23	92	8.05
Sea Water	high	456	10	9.7	54.2	2.3	535	27.6	.1		34000	8.1

The metavolcanic waters have a slightly higher TDS, possibly suggesting a slower recharge rate. Waters from metavolcanic rocks are divided according to EC values. As EC increases, TDS values also rise. Associated with these increases is a large increase in dissolved Na^+ , Ca^{++} , and Cl^- , and a slight increase in SO_4^{--} . Concentrations of Mg^{++} , HCO_3^- , and $\text{SiO}_2(\text{aq})$ actually show a slight decrease. The concentrations of K^+ are variable; apparently they are primarily a function of rock type. Both the granodiorite and contact aureole rocks in the Galice Formation have abundant biotite, whereas the metavolcanic rocks have very little. Biotite is most likely the main source of dissolved K^+ . Chebotarev (1955) recognized similar changes in absolute and relative concentrations when comparing Cl^- waters to HCO_3^- waters. The decrease in HCO_3^- suggests that mechanisms other than weathering by $\text{H}_2\text{CO}_3(\text{aq})$ are contributing to TDS. Both Na^+ and Ca^{++} occur in common rock forming minerals. Minerals containing Cl^- , on the other hand, are not sufficiently abundant in most igneous rocks to account for Cl^- in solution (Hem, 1970). The mechanism which supplies Cl^- probably is also responsible for the increased Na^+ and Ca^{++} , but the nature of this mechanism is not known.

Summary

Ground water quality in the area ranges from good to nonpotable. Waters high in TDS are reported in the Fruitdale Creek area, the Murphy Creek area, and the Sleepy Hollow Loop-Applegate River area. Abrupt changes in water quality occur at the contact of the granodiorite with the Galice Formation and with the Applegate Group metavolcanic rocks. The contact of the Grants Pass Batholith and the host country rock has been interpreted as a hydrogeologic boundary.

Ground waters can be grouped into chemical types based on EC; the dividing point is a value of 500 $\mu\text{mho}/\text{cm}$ @ 25°C. Low EC values are characteristic of HCO_3^- waters; high EC is associated with Cl^- waters. Simple mixing occurs in only one case. For the most part,

the low EC waters do not appear to be a simple dilution of high EC waters. Although the high EC waters are typically NaCl waters, the relative abundances indicate that they are not a mixture of sea water and low EC waters.

Computer modeling of chemical equilibria suggests that most reversible, congruent, dissolution reactions are undersaturated. Equilibria with calcite, dolomite, and magnesite were found to be undersaturated in most cases, although calcite may be precipitating locally. Reactions involving dissolution of quartz, a silica phase, were found to be supersaturated. Dissolved silica is believed to be controlled by weathering of mafic and feldspar minerals.

Stability diagrams indicate that the stable weathering product is kaolinite, although the thermodynamic data are uncertain for many of the phases involved. On a plot of $\log [\text{Mg}] + 2\text{pH}$ vs. $\log [\text{Ca}] + 2\text{pH}$, a striking trend appeared--data plotted to the Ca side of a reference line of unit slope. This trend was found not to be unique to this area; it is believed to be caused by the weathering of common mineral phases.

Qualitatively, sources of dissolved constituents in the low TDS samples can be attributed simply to weathering of minerals. The granodiorite is composed of potassium feldspar, quartz, plagioclase, hornblende, and biotite. The Applegate Group metavolcanic rocks are composed of actinolite, quartz, plagioclase, epidote, minor sphene, and, in the Fruitdale Creek area, laumontite. Gabbroic rocks have a similar mineralogy consisting of actinolite, epidote, and plagioclase. The primary weathering agent is dissolved H_2CO_3 . Dissolved Na^+ and Ca^{++} are attributed to the weathering of plagioclase; additional Ca^{++} is supplied by actinolite and laumontite. Both Mg^{++} and Ca^{++} occur in actinolite, although the ratio Mg/Ca is unknown. The source of dissolved K^+ is biotite, as indicated by the higher concentrations of K^+ in waters from biotite-rich rocks. The concentrations of Cl^- and SO_4^{--} are low enough to be attributed to atmospheric transport, although oxidation of S^- minerals could account for some SO_4^{--} .

IV. HYDROGEOLOGY

The purposes of this hydrogeologic investigation are to describe the physical ground water systems and to evaluate their potential for development. For description, the study area is divided according to rock unit; subareas reporting nonpotable water are described separately. Commonly used aquifers are found in four rock units: Applegate Group; Galice Formation; Grants Pass Batholith; and alluvium. Mafic and ultramafic units are mainly located in areas of high topographic relief and thus do not provide useful aquifers. Nonpotable water has been reported from along Fruitdale Creek, from along Murphy Creek, and from the Sleepy Hollow Loop-Applegate River area (Fig. 14).

The hydrology of the area was first described by Robison (1973). Included in his report is a brief description of the aquifers and their characteristics. A U.S. Geological Survey-Oregon Water Resources Department study on the hydrologic character of the Rogue River Basin has been partially completed. The Oregon Water Resources portion of the joint project included the middle and lower Rogue Basin (Almy, in press). Many of the water level measurements and aquifer test results discussed in the following paragraphs are derived from this study.

Aquifer and Subarea Descriptions

Applegate Group

Wells located within rocks of the Applegate Group yield water that is variable in both quality and quantity. In the Fruitdale Creek area, rock cuttings from Well 131s were logged at the time of drilling (Fig. 34). The weathering profile was divided into four zones: upper soil zone; upper weathered zone; lower weathered zone; and fractured zone.

Depth below land surface, m

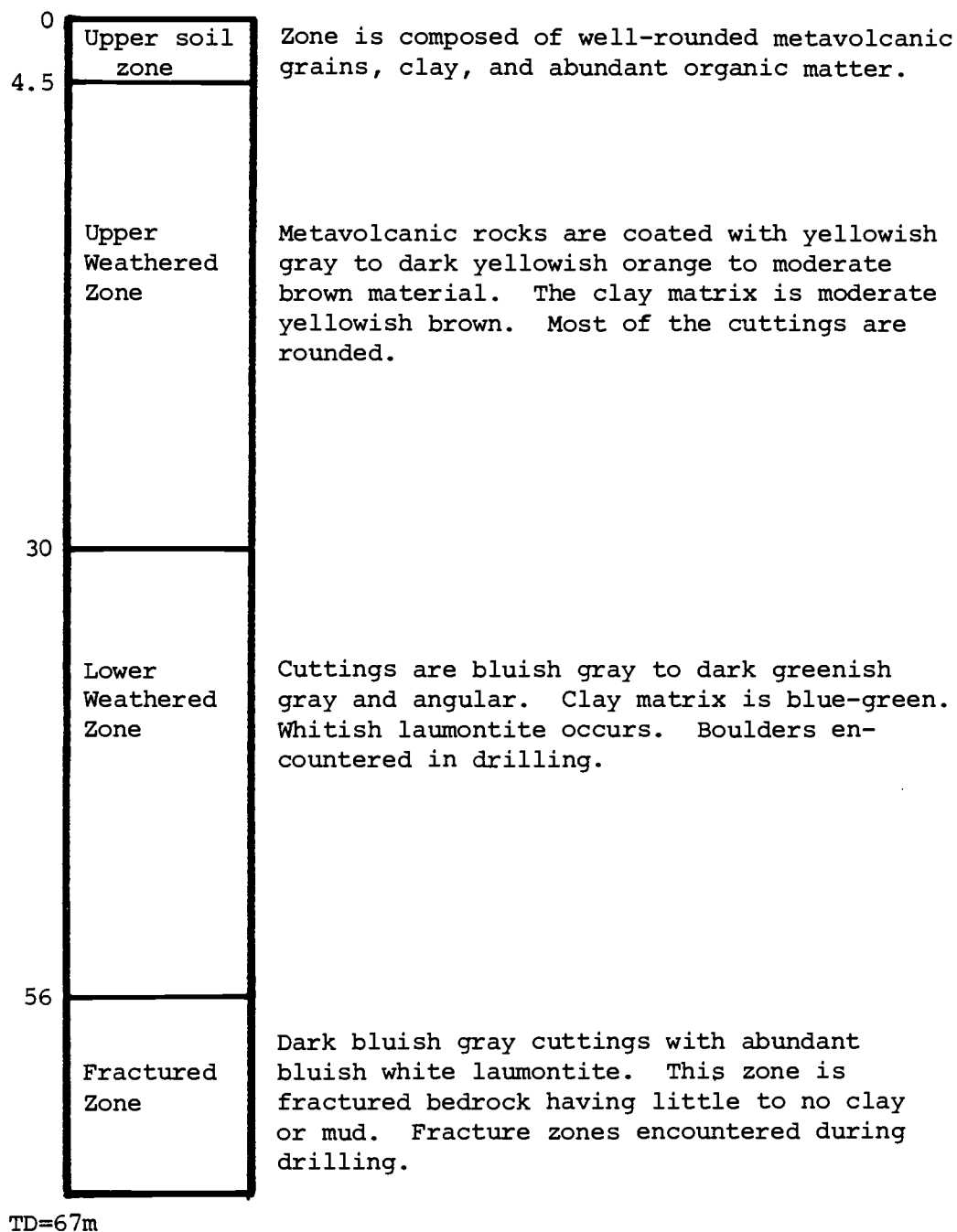


Figure 34. Well log for Well 131s.

Water samples from two depths in Well 131s were collected for EC measurements. A shallow sample (47 m depth) had an EC value of 620 $\mu\text{mho}/\text{cm}$ @ 25°C. A second, deeper sample (67 m) had a much higher EC value of 20,000 $\mu\text{mho}/\text{cm}$ @ 25°C; this water is nonpotable. This second sample, labeled 131s, was analyzed for major element composition. As the well was not cased at the time of sampling, the samples probably represent to an unknown degree a composite of waters from the open borehole. The large difference in EC measurements suggests, however, that the two waters were not well mixed.

Well capacity in the Applegate Group rocks varies from very good at 150 gal/min (820 m^3/day) to values that are insufficient for domestic use. The wide range in capacities is the result of a fracture-dominated flow system. Aquifers of the Applegate Group rocks have had nonpotable water reported in two areas--the Fruitdale Creek area, and the Murphy Creek area.

Galice Formation

The Galice Formation does not form appreciable aquifers within the study area, although there are some low-yield (domestic) wells within the unit. These rocks form areas of high relief along the western edge of the area. Water from wells located near the contact aureole of the granodiorite reportedly has high TDS.

Grants Pass Batholith

The granodiorite of the Grants Pass Batholith forms the most satisfactory aquifer found in the study area. Water quality in this unit is generally good, although high Fe has been reported. The upper weathered section (grus) forms aquifers that are fairly uniform in chemical composition. Waters in this zone are under a slight confining pressure, probably because they are partially supporting a lithostatic load. The grus is underlain by slightly altered,

fractured granodiorite, which is in turn underlain by fractured but reasonably fresh granodiorite. This freshest rock is referred to by many drillers as "tombstone."

Well yields from the granodiorite range from 2 gal/min to 20 gal/min (11 to 110 m³/day). The best yields are found in areas where grus is especially thick. Near the western and southern edge of the pluton there is no grus. In these areas, ground water is confined to fractures.

Alluvium

Alluvial material of sufficient thickness to form aquifers occurs along Murphy Creek and along the Applegate River. In the Murphy Creek area, nonpotable saline water has been reported. For the most part, waters from the alluvium are potable, although pollution from septic tanks can be a local problem. Properly constructed wells will, of course, prevent this kind of contamination.

Fruitdale Creek

The contact between the Applegate Group and the granodiorite is buried under alluvium in the Fruitdale Creek area. The west side of the drainage basin is composed of granodiorite and grus and forms relatively satisfactory aquifers. The eastern side is composed of metavolcanic rocks of the Applegate Group. Variable water quality is associated with these rocks.

Chemical quality of the ground water changes abruptly across the contact. Well 109 is located within the granodiorite and has a relatively low TDS value of 210 mg/l, whereas Well 121 (only 180 m from Well 109) is located within the metavolcanic rocks and has a high TDS value of 570 mg/l (Plate II). The waters with high TDS appear to be areally restricted. A cross section through this area shows an abrupt change in lithology (Fig. 35).

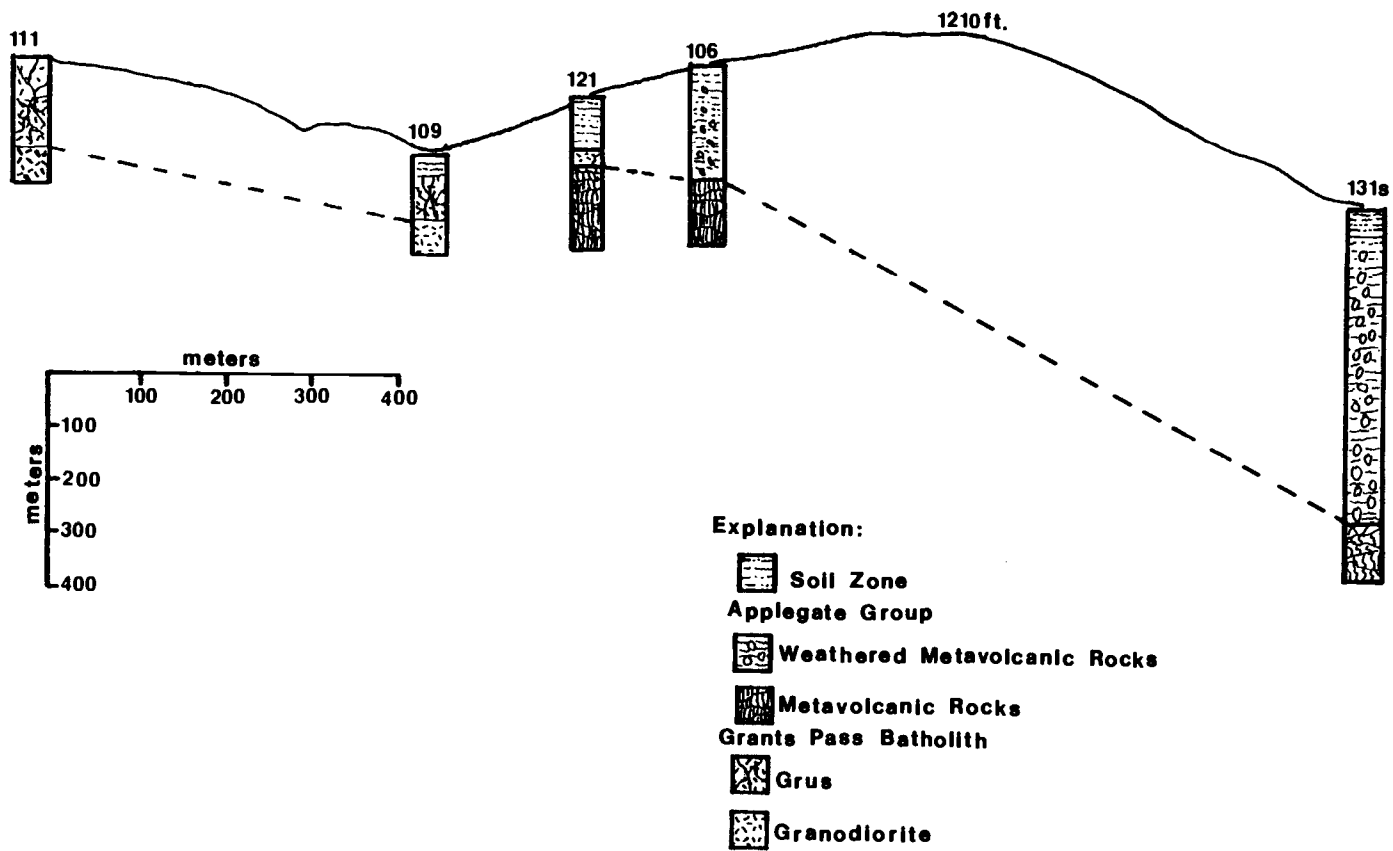


Figure 35. Cross section of Fruitdale Creek area.

Murphy Creek

The aquifers in the Murphy Creek area consist of gravel underlain by fractured metavolcanic rocks. In drillers' logs, granite has been reported at depth. Since no granite outcrops occur in this subarea, these reports are difficult to interpret. Most likely, the granite reported is derived from a small dike. The alluvium in this subarea reaches a maximum depth of 49 m.

Water quality problems in the Murphy Creek area are similar to those of the Fruitdale Creek area. Highly saline water is associated with the fractured metavolcanic rock. Change in water quality is geographically abrupt, as seen in Wells 124, 125, and 126 (Plate II).

Sleepy Hollow Loop-Applegate River

The Sleepy Hollow Loop-Applegate River (SHL-AR) area is composed of granodiorite and contact metasedimentary rocks of the Galice Formation. Both rock types have little intergranular porosity and are dominated by fracture flow, especially near the contact. Wells located within the contact aureole produce waters high in TDS; poor quality waters appear to be restricted to this geologic feature.

Chemical quality changes abruptly between Wells 120 (4300 mg/l TDS) and 132 (130 mg/l TDS), which are located adjacent to each other (Plate II). Well 120 is located within 2 m of the contact of the Galice Formation and the granodiorite. Well 132 is located within the granodiorite.

Aquifer Tests

A useful technique to determine transmission and storage properties is the aquifer test. The theory of aquifer tests is widely known and will not be covered here. Table 12 contains a list of symbols that will be used in discussing the tests reported herein.

TABLE 12. Hydrogeologic symbols

Symbol	Description	Remarks	Units
Q	Flow rate		gal/min
T	Transmissivity	$T = Kb$	ft^2/day
b	Aquifer thickness		ft
K	Hydraulic conductivity		ft/day
s	Drawdown during pumping		ft
s'	Residual drawdown during recovery		ft
s*	Calculated recovery	$s^* = (s - s')$	ft
t	Time of pumping		min
t'	Time since pumping stopped		min

English units rather than metric units are commonly used in ground water literature and in the field. In this section, English units will be used and metric equivalents will be included where practicable.

Parameters of most interest are transmissivity (T) and storativity (S or Sya). The values of T vary from 100 ft²/day (10 m²/day), suitable for domestic wells, to 10⁵ ft²/day (10⁴ m²/day), suitable for most municipal, industrial, or irrigation purposes (Johnson Division, 1975). Storativity varies with the type of aquifer; in unconfined aquifers, Sya ranges from 0.01 to 0.35, and in confined aquifers S is usually between 10⁻³ and 10⁻⁵ (Johnson Division, 1975).

No aquifer tests were performed on Applegate Group rocks. Generally, an aquifer rich in clay such as the upper weathered zone of the metavolcanic rocks has limited values of T and S (Sya).

Rogue Community College

An aquifer test was performed May 24-25, 1980, on the Rogue Community College (RCC) campus, which is adjacent to the north side of the study area. The unit tested was the granodiorite aquifer, with large outcrop area and relatively homogeneous composition. The test was performed by R. B. Almy, Hydrologist, Oregon Water Resources Department; he was assisted by the author, U.S. Geological Survey personnel, and District 14 Watermaster's Office personnel.

The RCC site offers minimal hydrologic interference from adjoining wells. The test utilized four observation wells and one pumped well (Fig. 36). The pumped well, RCC-2, and two observation wells, RCC-1 and RCC-3, were located on the RCC campus; the other two observation wells, Nipps-1 and Nipps-2, were located across Highway 199 at Nipps Nursery. Figure 37 is a summary of the geological well logs obtained from the driller reports. Well constructions are summarized in Table 13.

During the test, water levels were monitored using calibrated electric sounders placed in the wells at least 12 hours prior to

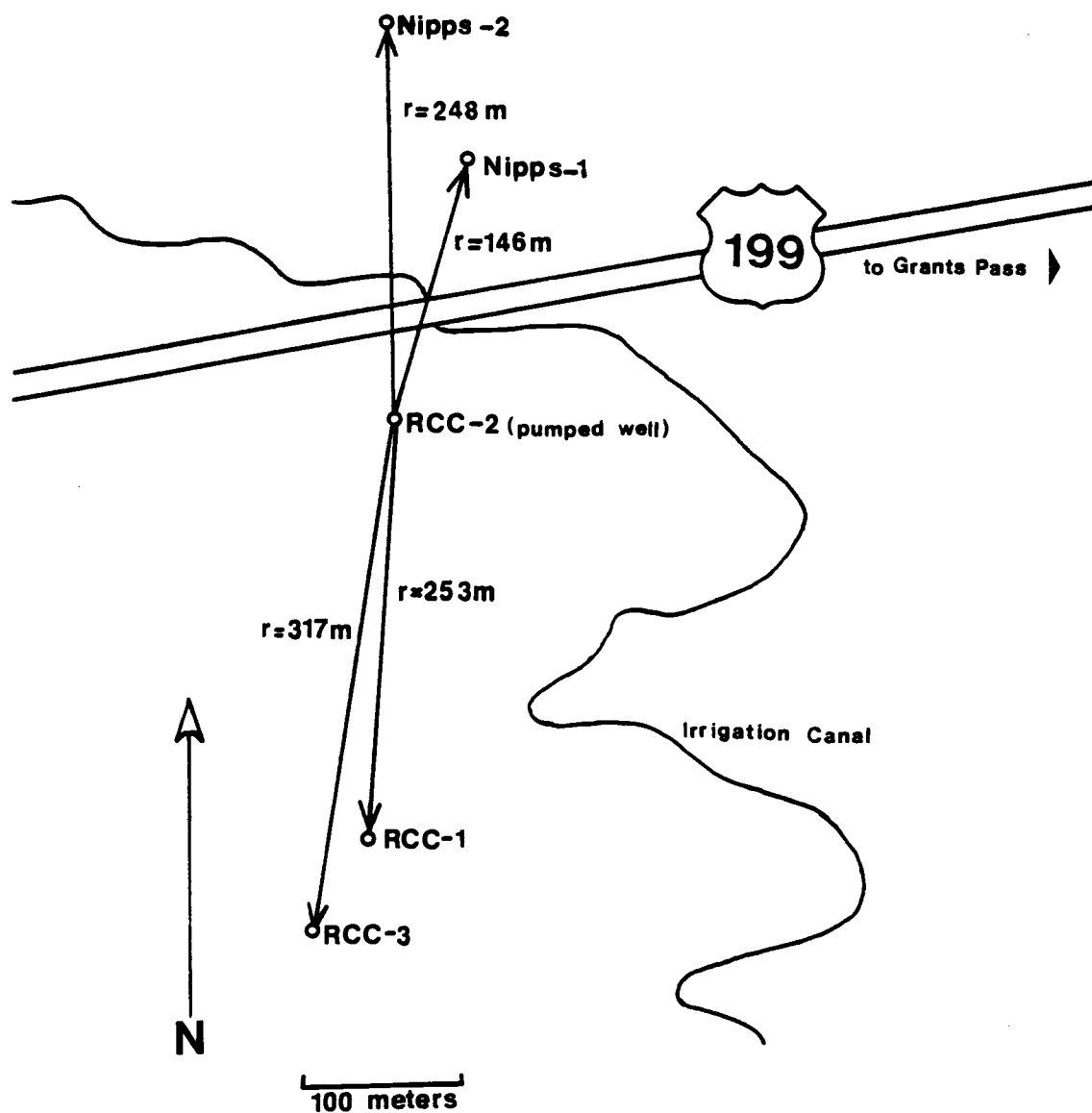


Figure 36. Well layout for aquifer test.

Test of 24-25 May 1980 at Rogue Community College, Josephine County, Oregon. The pumped well is RCC-2; the observation wells are RCC-1, RCC-3, Nipps-1, and Nipps-2.

Depth, feet below land surface

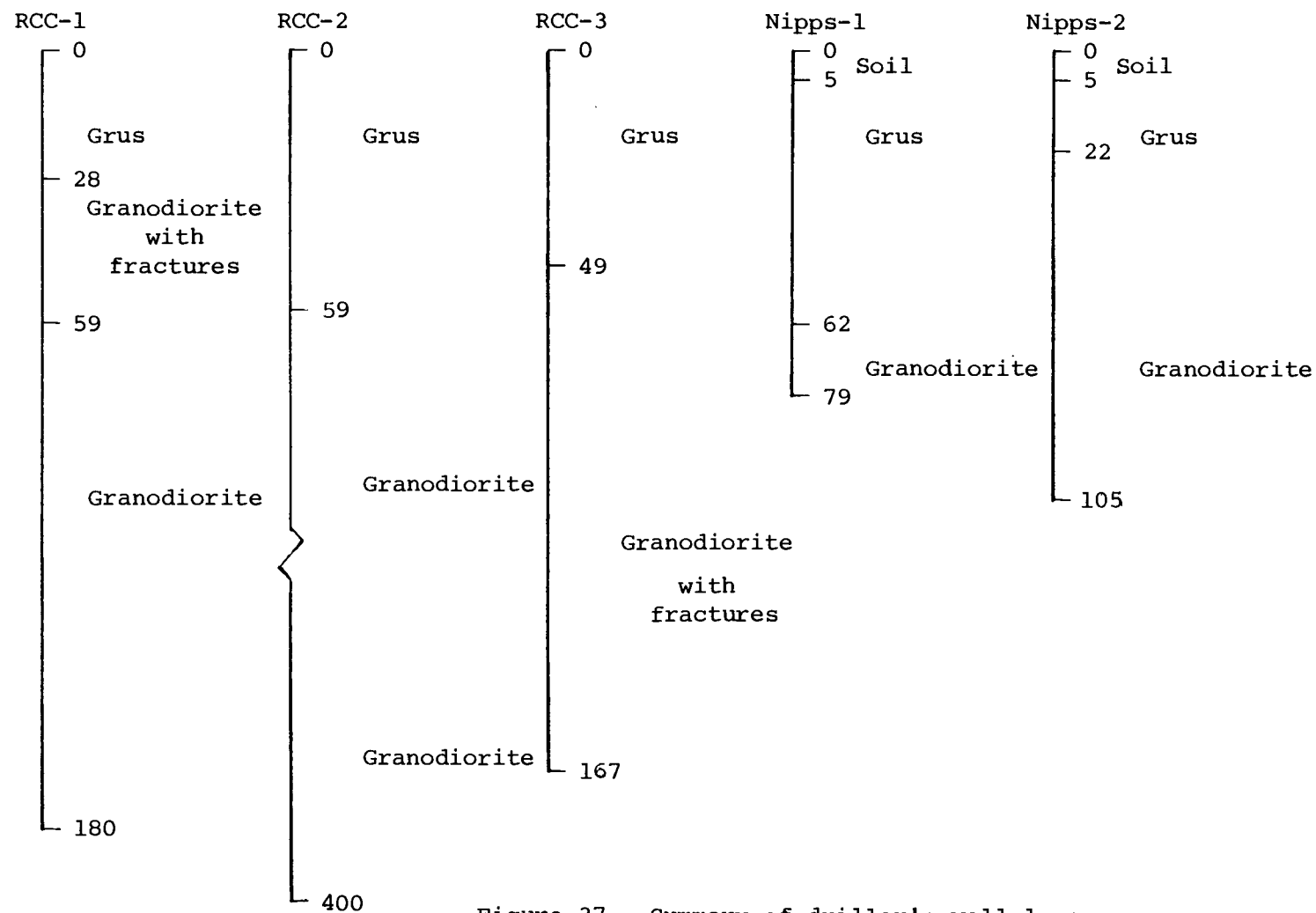


Figure 37. Summary of driller's well logs.

TABLE 13. Well construction for aquifer test.

Well	Total depth	Diameter of well	Depth of casing	Development
RCC-1	181' (53 m)	12" (30 cm)	57' (17 m)	Slotted
RCC-2	400' (122 m)	12" (30 cm)	72' (22 m)	Slotted
RCC-3	166' (51 m)	6" (15 cm)	54' (16 m)	Open hole
Nipps-1	80' (24 m)	6" (15 cm)	65' (20 m)	Open hole
Nipps-2	104' (32 m)	6" (15 cm)	60' (18 m)	Open hole

pumping. Water discharge was measured using an orifice bucket as described in Johnson Division (1975, p. 87).

The test was a 24-hour, constant discharge test (flow rate = 14.5 gal/min; $79 \text{ m}^3/\text{day}$) and recovery test. As the well was pumped, flow rate (Q) and depth to water in all five wells were measured. After pumping, depth to water was monitored as the system recovered. The first part of the aquifer test is referred to as a constant discharge test; the second phase is the recovery test. They are analyzed separately.

The analysis of the constant discharge test generally employs the use of the Theis Well Function, requiring a response in at least one observation well. Although water levels were monitored in all the wells, no significant drop in water levels was recorded in any of the four observation wells. Since the well function cannot be used, the method employed was the straight line method of Cooper and Jacob (1946). This is a linear approximation to the well function; it is considered valid for long pumping times.

Before the data are interpreted, well bore storage must be considered. Once pumping has started, an initial phase of dewatering takes place within the well bore. Since this is not an aquifer response, deviation in drawdown (s) data will occur. If well bore storage is significant, a plot of $\log(s)$ vs. $\log \text{ time}(t)$ will be a straight line with positive, unit slope (Ramey, 1970). In the absence of significant well bore storage, the plot will show curvature. The data for this test plot in a straight line with a slope of 2.8 (Fig. 38), indicating possible well bore storage. To account for this deviation, one of three methods can be used: an algebraic expression to correct the flow rate; matching of type curves; or calculation of the critical time (t_c) at which well bore storage becomes insignificant. The last approach is used here. For an approximation of t_c , the values of flow rate (Q) and s are substituted into the following equation:

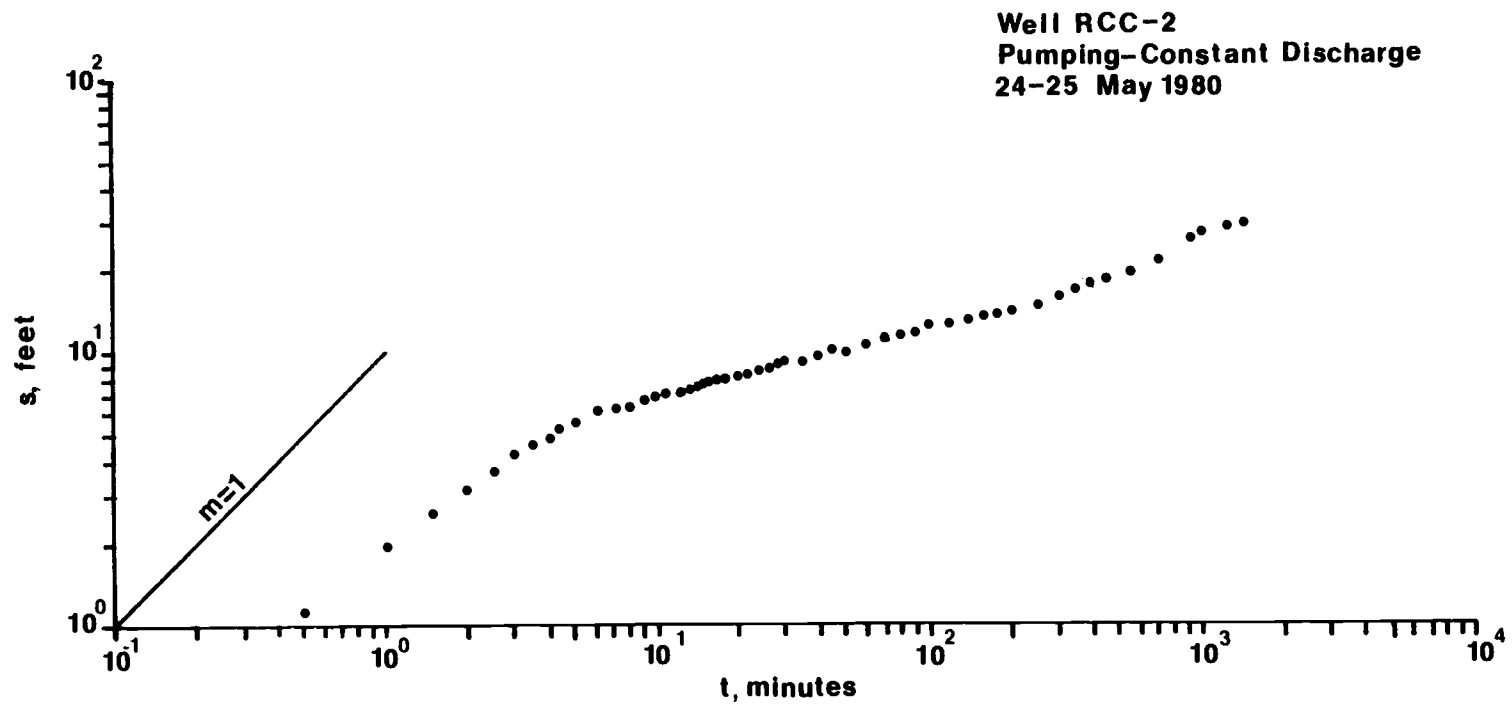


Figure 38. Logarithmic plot of drawdown vs. time.

The early time data plot in a straight line with a slope greater than one, indicating well bore storage is affecting drawdown data.

$$t_c = \frac{0.6(d_c^2 - d_p^2)}{(Q/s)_c} \quad (\text{Schafer, 1978})$$

t_c = time well bore storage insignificant (minutes)

d_c = inside diameter of well casing (inches)

d_p = outside diameter of pump connecting pipe (inches)

$(Q/s)_c$ = specific capacity at time t_c (gal/min-ft)

At first glance, this formulation appears to be an equation with two unknowns, t_c and $(Q/s)_c$. A second equation is represented by the measured values of t and (Q/s) from the pumping data. Successive iterations are used until the value of t_c calculated from measured (Q/s) corresponds to measured t . The value of t_c is the minimum time that the drawdown data should be analyzed. For the pumping phase of the RCC test, a t_c value of 60 minutes was calculated.

In applying the straight line method, a plot of s vs. $\log(t)$ shows two linear trends intersecting at about 250 minutes (Fig. 39). This decrease in T can be explained as either delayed yield from storage, perturbation caused by an impervious hydrologic boundary, or perhaps both.

Delayed yield from storage is an explanation for situations in which an unconfined aquifer initially displays characteristics of a confined aquifer. After a short time, the response reverts to one representative of an unconfined aquifer (Lohman, 1979). The incipient water movement has a significant vertical component, violating a basic assumption. On a plot of $\log(s)$ vs. $\log(t)$, the Theis Well Function shows a noticeable shift, as do the data for this test (Fig. 38). If a response occurs in an observation well at large radial distance, the phenomenon will be less pronounced (McWhorter and Sunada, 1977). Other aquifer tests conducted in the Merlin area by the Oregon Water Resources Department also suggest delayed yield from storage (Almy, 1980a; 1980b; personal communication).

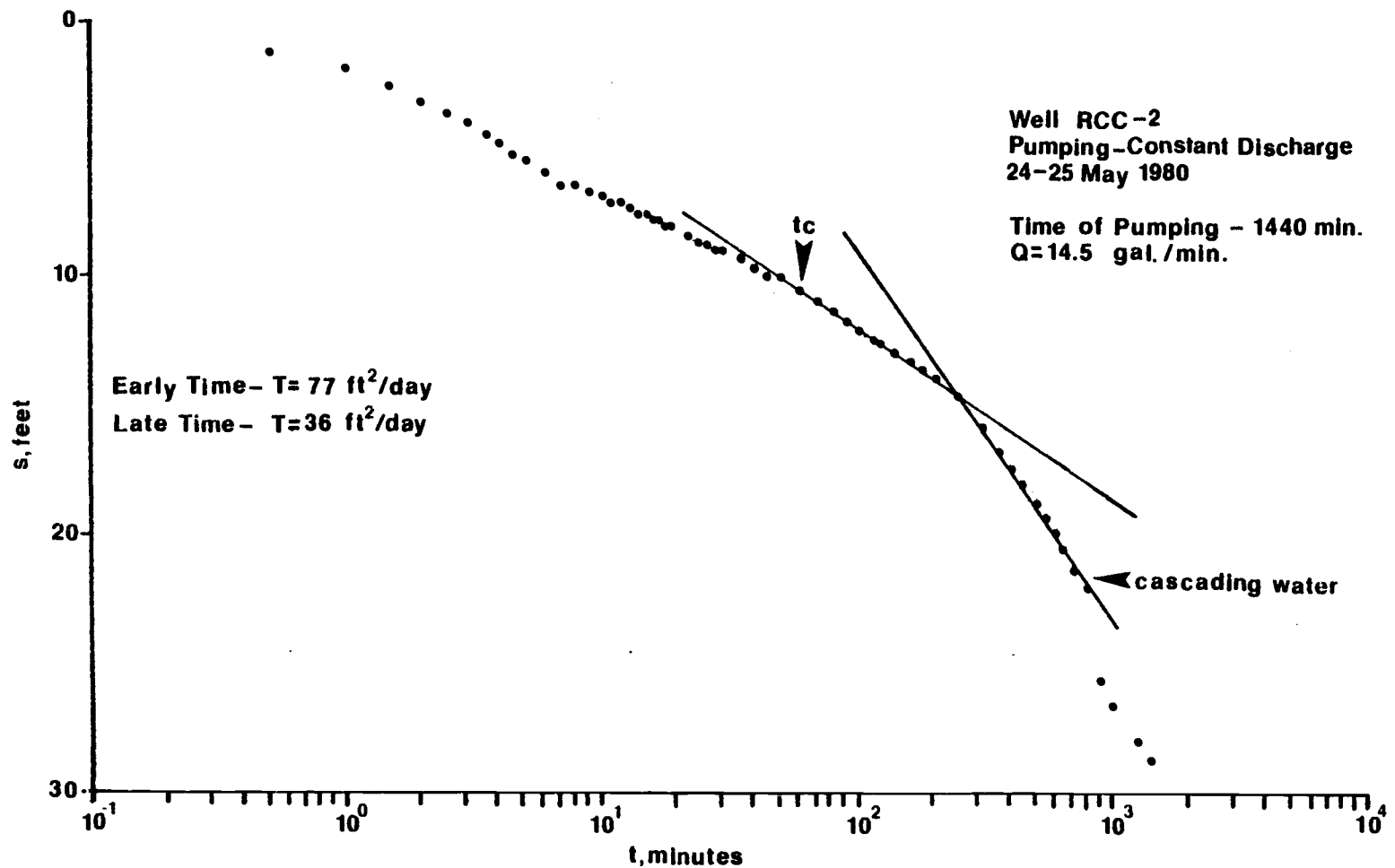


Figure 39. Semilogarithmic plot of drawdown vs. log t, time.

The data form two linear trends. The change in slope occurs at 250 min. The critical time, t_c , is the minimum time the data should be analyzed. Cascading water was detected at 22 feet of drawdown.

The linear trends in Figure 39 can be analyzed for two T values. A linear regression of early time data yields a value of $77 \text{ ft}^2/\text{day}$ ($7.2 \text{ m}^2/\text{day}$); late time data correspond to a value of $36 \text{ ft}^2/\text{day}$ ($3.3 \text{ m}^2/\text{day}$) (Table 14).

During pumping, cascading water was detected inside the well bore beginning at a drawdown of 66 ft (20 m). The free-falling water was evidenced by splashing sounds from within the well bore and by responses on the electric sounder. This suggests that a significant portion of the water flowing to the well is being supplied through the upper grus layer.

The recovery test offers a more reliable estimate of T. The recovery test began 1440 minutes after pumping began and lasted 400 minutes, which is correlative with 80% of calculated recovery. During the recovery phase, cascading water in the borehole continued until a residual drawdown of 66 ft (20 m) was reached. A plot of log calculated recovery (s^*) vs. log time since pumping stopped (t') shows the same linear trend as the pumping data (Fig. 40). The conditions for well bore storage correspond to the variables s^* and t' when in the recovery phase. A t_c value was calculated using the Schafer (1978) equation. Since the recovery data are plotted as t/t' , a t_c value was calculated corresponding to a t/t' value of 14. On the recovery plot, the irregularities at early recovery time (large t/t') undoubtedly are caused by inhomogeneities in aquifer permeability and by vertical leakage (Fig. 41). Linear regression on the linear portion of low t/t' values produces a T value of $59 \text{ ft}^2/\text{day}$ ($5.5 \text{ m}^2/\text{day}$) (Table 14).

In summary, values of T were measured for the granodiorite using straight line approximation on both constant discharge pumping and recovery tests. No values of storage were calculated because no response occurred in the observation wells. The recovery data offer the most reliable value of transmissivity (T) at $59 \text{ ft}^2/\text{day}$. The magnitude of T suggests the aquifer is suitable for single

TABLE 14. Summary of aquifer test results.

Test	Transmissivity		Remarks
	m^2/day	ft^2/day	
<u>RCC-2</u>			
constant discharge	7.2	77	$\log(t)$ vs. s , Cooper and Jacob (1946) straight line method early time data
$Q = 79 \text{ m}^3/\text{day}$ $= 14.5 \text{ gal/min}$	3.3	36	same as above--late time data
recovery	5.5	59	$\log(t/t')$ vs. s' , Cooper and Jacob (1946) straight line method
<u>Hidden Valley School</u>			
average transmissivity: $4.6 \text{ m}^2/\text{day}$			
average storage coefficient: 3×10^{-5}			

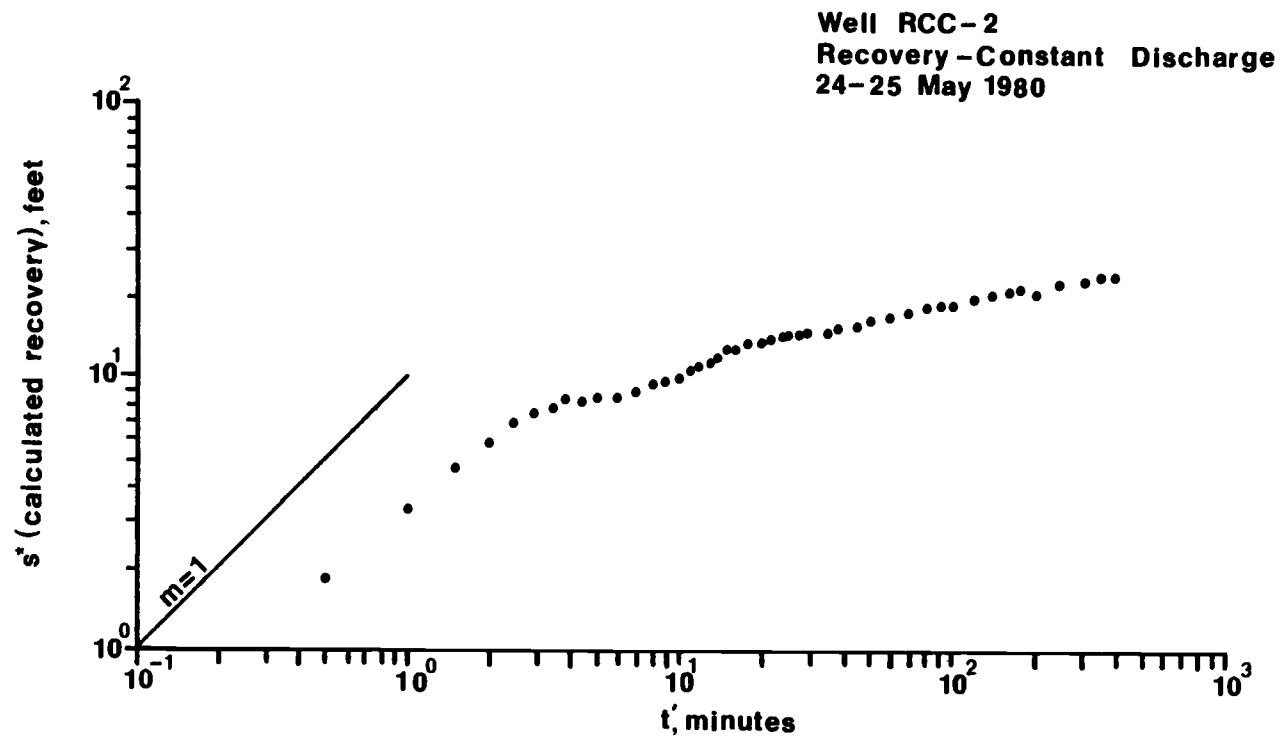


Figure 40. Logarithmic plot of calculated recovery vs. time since pumping stopped.

The early time data plot in a linear fashion with a slope close to one, indicating well bore storage is affecting recovery data.

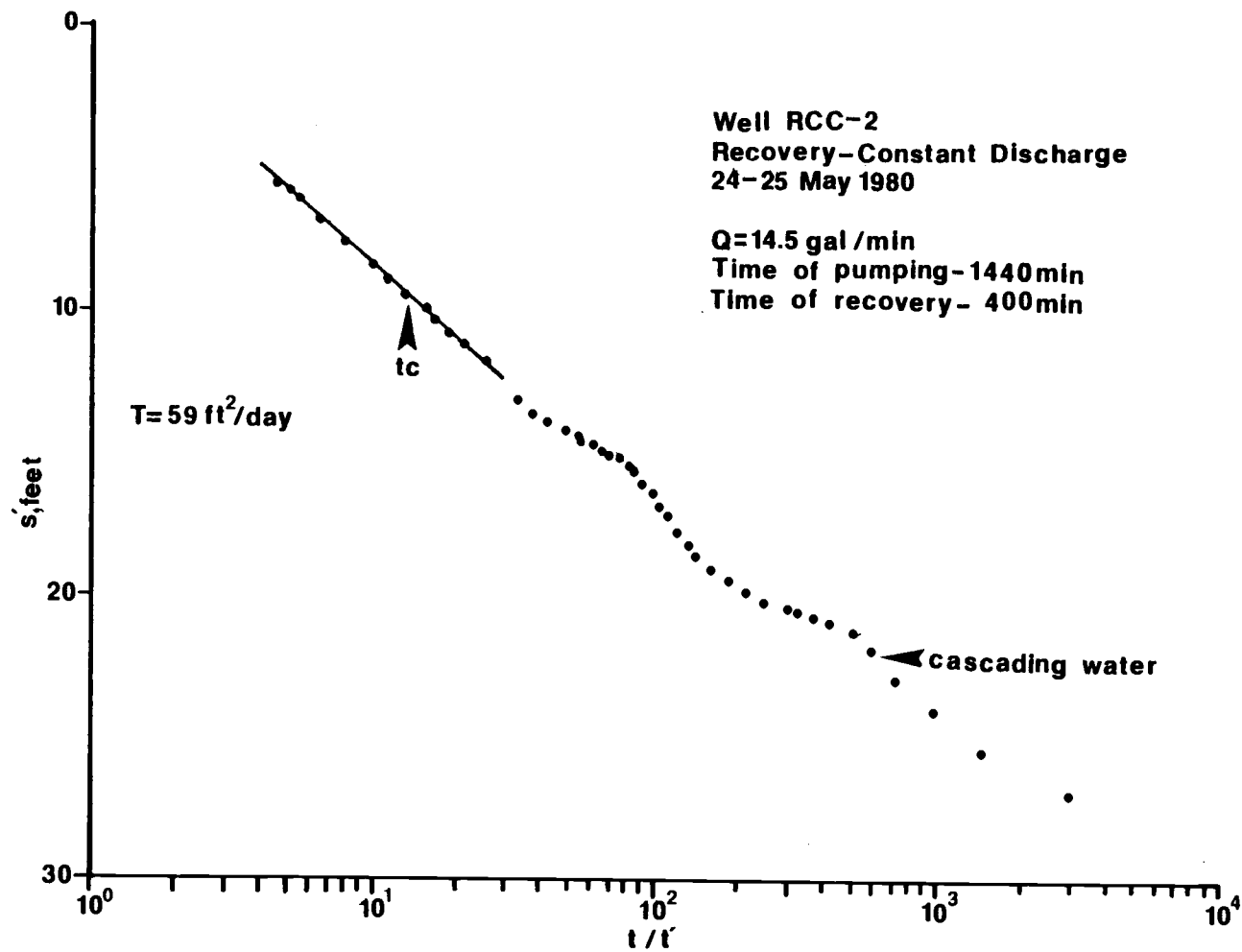


Figure 41. Semilogarithmic plot of residual drawdown vs. dimensionless time.

This method offers the most reliable value of transmissivity.

family uses, but would be of marginal value for higher water capacity needs.

Murphy Creek

An aquifer test was performed on September 5, 1980 by the Oregon Water Resources Department at Hidden Valley High School, located near the lower portion of Murphy Creek south of the study area (Almy, 1980b). The unit tested was the alluvial gravels. The aquifer is composed in places of unconsolidated sand and gravel and is confined by overlying clay and clayey gravel zones. Drillers' reports indicate that neither the primary water-producing zone nor the confining zones are horizontally continuous. The test data are consistent with these reports. An average transmissivity of $50 \text{ ft}^2/\text{day}$ ($4.6 \text{ m}^2/\text{day}$) and an average storage coefficient of 3.0×10^{-5} were calculated (Almy, 1980b). This test indicated that transmissivity is suitable for most single family use. The storage coefficient determined is low. It should be noted that the thicknesses and areal extents of this type of aquifer are limited.

Small Drainage Basins

Toth (1963) used a mathematical model in his theoretical analysis of ground water flow within small drainage basins. In an idealized situation, three flow systems can be identified: local; intermediate; and regional (Fig. 42). The local flow system is characterized simply by recharge at topographic highs and discharge at topographic lows. Local flow systems thus are dependent upon relief, with high relief corresponding to deeper flow systems. In relatively flat terrain, the local system may not develop. Located at shallower depths, this system is most affected by seasonal recharge.

In the intermediate system, recharge and discharge do not necessarily occur at the highest and lowest areas in the basin. Regional

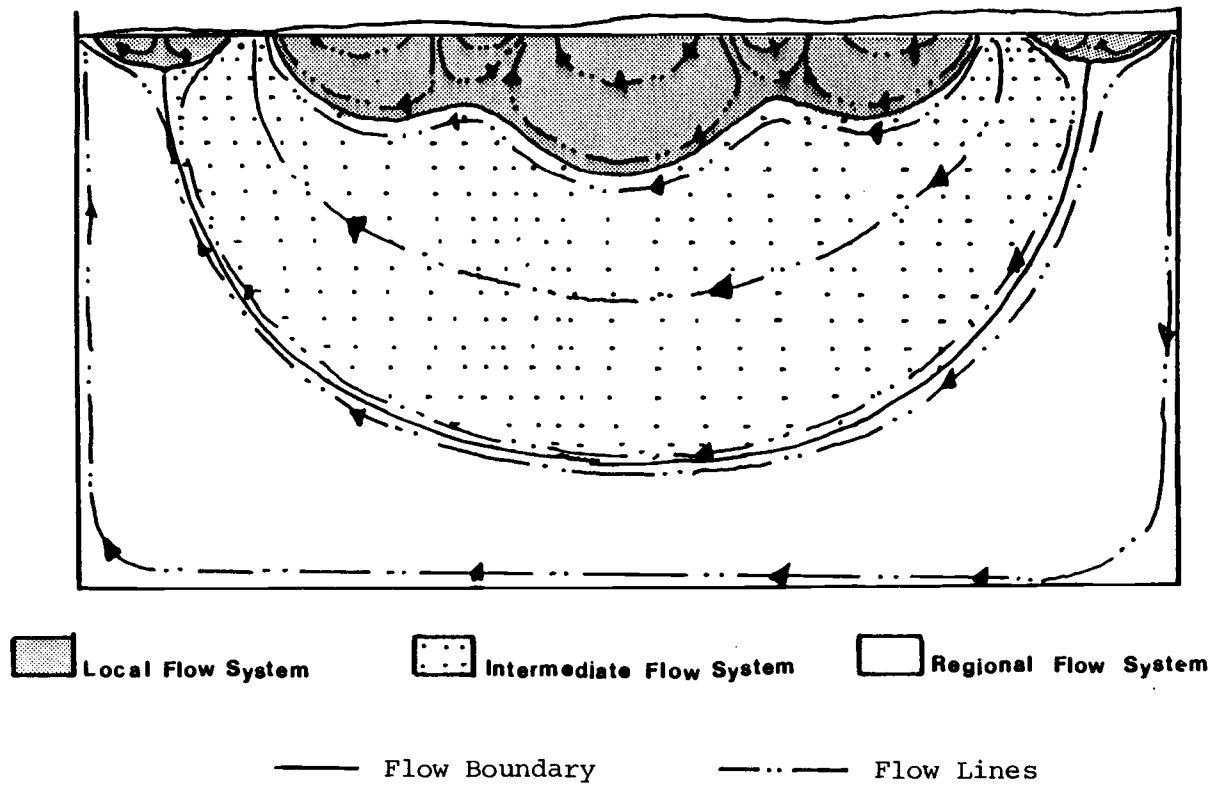


Figure 42. Theoretical flow system of Toth (1963).

flow system recharge occurs at the water divide and discharge occurs at the lowest elevation. The intermediate and regional flow systems are characterized by deeper flow path and lower ground water velocities. These factors tend to bring about an increase of TDS.

Although the system described by Toth is idealized, that is, a homogeneous isotropic aquifer, the conclusions can be applied in general to the three areas from which nonpotable water has been reported. Water with high TDS may be expected to occur at the junction of the three flow systems. This junction would take place at the point of natural discharge, or at lower elevations in the drainage basin.

For the Fruitdale Creek area, a plot of elevation taken from the topographic map vs. TDS shows a trend with most of the higher TDS waters from wells lower in elevation (Fig. 43). An exception is the sample from Well GS-6, a U.S. Geological Survey-Oregon Water Resources Department sample.

This trend suggests that the Fruitdale Creek area can be usefully interpreted in terms of the three flow systems. The low EC waters are thus associated with the local flow system; the high EC waters are part of the intermediate or even the regional flow system. This implies that recharge for the high EC waters may be coming from as far away as Grants Pass Peak.

Water Level Map

Movement of ground water is an important parameter in hydrologic studies. Water level elevations describe local ground water movement as water flows from higher to lower elevations. Contours on a water level map thus show direction of flow. Movement indicates discharge and recharge areas. If ground water pollution is a problem, movement can indicate areas that may be affected.

A water level map was prepared for the Murphy area (Plate III). The survey was conducted by R. B. Almy, other personnel at Oregon Water Resources Department, and the author in September, 1980.

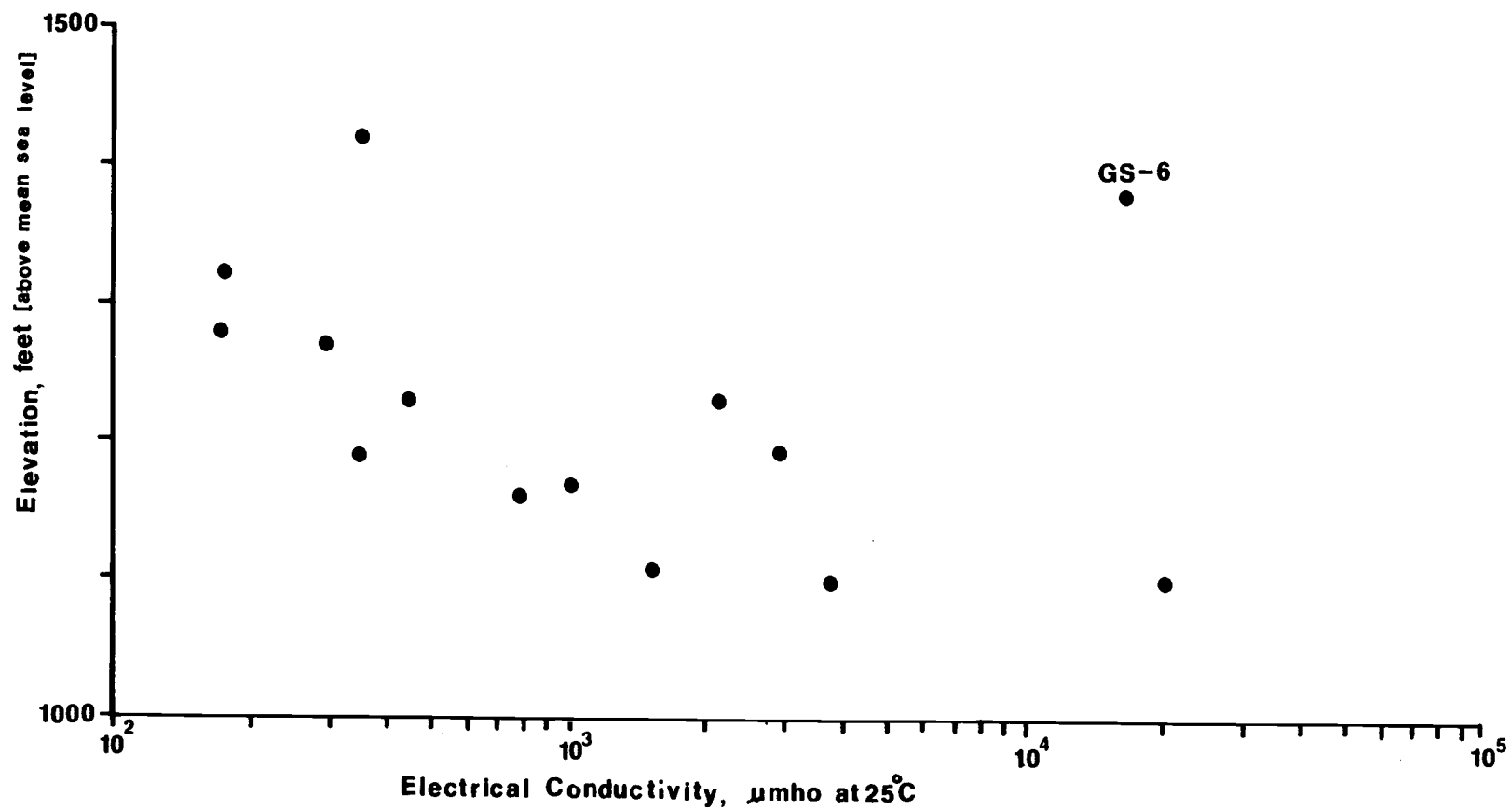


Figure 43. Relation of elevation to EC in Fruitdale Creek area.

Data include 12 samples from this study and two from Almy (in press).

Each data point consists of a depth-to-water measurement and an altitude of the measuring point above sea level. Depth to water was measured with an electric tape. An altimeter survey was conducted using an American Paulin Altimeter. The depth-to-water measurements were taken to the nearest 0.01 ft. Altimeter results were reproducible within ± 2 ft. The difference between the two readings is the water level elevation at the time of measurement. The water level elevations are contoured like a topographic map.

Changes in ground water storage are reflected by corresponding changes in water levels. Factors other than pumping and natural recharge and discharge influence water levels, especially in shallow aquifers; such factors include barometric pressure changes, tidal effects, and the use of ground water by plants. Water level fluctuations may lead to erroneous interpretations concerning water movement. To minimize ephemeral fluctuations, water level measurements were completed within a two-week period.

Unfortunately, few data points could be collected. Contours have been drawn where sufficient data justified an interpretation. Because of the lack of data, the map is restricted to 50-ft contours. The data do show, however, the general flow from highland areas to the lower valleys.

Summary

Quantities of ground water in the study area are suitable for most single family use, but marginal for high capacity needs. The Applegate Group metavolcanic rocks form aquifers of fractured bedrock which are rich in clay. Values of T and S (Sya) have not been measured; these values would be expected to be low. The Grants Pass Batholith forms fairly uniform aquifers. The water-producing zone is the upper grus layer, as determined by the occurrence of cascading water during testing. The range of T values for this unit is $36 \text{ ft}^2/\text{day}$ ($3.3 \text{ m}^2/\text{day}$) to $77 \text{ ft}^2/\text{day}$ ($7.2 \text{ m}^2/\text{day}$); the

most reliable value is $59 \text{ ft}^2/\text{day}$ ($5.5 \text{ m}^2/\text{day}$). Aquifer tests conducted in the alluvial gravels of Murphy Creek indicate a T value of $50 \text{ ft}^2/\text{day}$ ($4.6 \text{ m}^2/\text{day}$) and an average storage coefficient of 3×10^{-5} (Almy, 1980b). The model of Toth (1963) can be applied to the study area. Low EC waters are associated with the local flow system, while the intermediate or regional system is providing high EC waters.

V. CONCLUSIONS

(1) Ground water samples from the study area can be grouped according to electrical conductance values (EC). Low EC values ($< 500 \mu\text{mho @ } 25^\circ\text{C}$) characterize HCO_3^- waters, whereas waters with high EC values are typically Cl^- waters.

(2) Simple mixing of water types was found to occur in only one case, a sample from the Sleepy Hollow Loop-Applegate River area. Low EC waters do not appear to be dilutions of high EC waters. Relative abundances of dissolved species suggest that the high EC waters are not a mixture of sea water and low EC waters.

(3) As determined by computer modeling, most reversible, congruent dissolution reactions are undersaturated. In particular, equilibria with calcite, dolomite, and magnesite are undersaturated in most cases, although calcite may be precipitating locally. The waters were found to be supersaturated with respect to quartz, although dissolved silica is believed to be controlled by dissolution of mafic and feldspar minerals.

(4) In most cases, low TDS waters were found to have a Ca/Mg ratio of one. Data from a variety of other locations indicate a similar ratio. This trend is thought to be caused by low temperature weathering and pedogenic reactions involving common rock forming minerals.

(5) The contact of the Grants Pass Batholith with the country rock is a hydrogeologic boundary, as indicated by abrupt changes in water quality across the contact.

(6) Aquifers in the Applegate Group metavolcanic rocks are made up of a weathered, clay-rich zone overlying fractured bedrock. Waters from the fractured bedrock tend to have high TDS values.

(7) The Grants Pass Batholith forms the most uniform aquifers. The main water-producing zone is a layer of grus, as determined by cascading water within a well bore during an aquifer test. Transmissivity values were determined by an aquifer test to be from 36 ft²/day (3.3 m²/day) to 77 ft²/day (7.2 m²/day), with a most reliable value of 59 ft²/day (5.5 m²/day).

(8) Transmissivity values from the aquifer test in the Grants Pass Batholith and the values reported for alluvial gravels in the Murphy Creek area indicate that these aquifers are suited to single family use but are of doubtful capacity for industrial or municipal needs.

(9) The flow systems of Toth's (1963) model can be applied to the study area. Low EC waters are associated with the local flow system. The intermediate or regional systems are producing high EC waters; these waters would have a longer and deeper flow path. The high EC waters represent a junction of two flow systems and have lower concentrations of HCO_3^- and very high concentrations of Na^+ and Cl^- . The recharge for these waters could be as far away as Grants Pass Peak.

(10) Although water quality is suitable for domestic use in most areas, the unavailability of potable water will affect development in certain critical locations having waters high in TDS. These locations include the Fruitdale Creek area, the Murphy Creek area, and the Sleepy Hollow Loop-Applegate River area. For significant additional development to occur in these areas, suitable alternative water supplies will have to be found. For the Fruitdale Creek area, this could mean an outside source such as the city of Grants Pass water system.

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APPENDIX

VII. APPENDIX

Included in this appendix is a brief description of analytical methods used in this study. Analyses were made by the author in the field and at the Department of Geology, Oregon State University. Instruments utilized included a Perkin-Elmer model 103 atomic absorption spectrophotometer, a Turner model 350 spectrophotometer, an Orion model 407A specific ion meter, and three Orion specific ion electrodes (pH model 91-05-55, chloride model 94-17, and fluoride model 94-09A). Two water samples were collected from each well. One set of samples (A samples) was acidified with concentrated HNO_3 ; B samples were not acidified but were refrigerated.

Sodium and Potassium

Dissolved Na^+ and K^+ concentrations were determined by atomic absorption spectrophotometry (Skougstad and others, 1979). The A samples were aspirated directly into an air-acetylene flame. While there are no significant interfering signals for Na^+ , adjustments had to be made to counteract Na^+ interference in the K^+ test. Samples with Na^+ concentrations above 100 mg/l were therefore spiked with an aliquot of 1,000 mg/l Na^+ solution; the spike, by causing similar responses in standards as well as samples, permitted more accurate determinations.

Calcium and Magnesium

Dissolved Ca^{++} and Mg^{++} concentrations were also determined by atomic absorption (Skougstad and others, 1979). Interference for these elements may occur from Al_2O_3 , SO_4^{--} , NO_3^- , and $\text{SiO}_2(\text{aq})$. To mask these effects, an aliquot of 87 g/l LaCl_3 was added to both samples and standards. The A samples and standards were then aspirated into an air-acetylene flame.

Bicarbonate and Carbonate

Potentiometric titrations of the samples were performed in the field using techniques described by Wood (1976). The B samples were titrated with a standard solution of a strong acid (0.02 N H_2SO_4). On a plot of pH vs. volume of acid added, the CO_3^{--} and HCO_3^- end points correspond to inflection points on the curve. An inflection point is the maximum value of the ratio of the change in pH to the change in volume of acid added. The HCO_3^- inflection point occurs near pH 4.5 and the CO_3^{--} inflection point near 8.3. The end point volume of acid added thus corresponds to the amount required to neutralize the solution. Concentrations of CO_3^{--} and HCO_3^- are calculated from this volume.

Because the hydrogen ion is not selective in these titrations, interferences from other dissolved constituents occur. Interfering species include salts of organic and inorganic acids such as SiO_2 and PO_4^{---} . Interferences may have measurable effect on titration values when the pH is above 9.0 (Davis and DeWiest, 1966). Since the highest value obtained from the samples analyzed was pH 8.6, interferences are believed to be insignificant.

Chloride and Fluoride

Water samples were analyzed for dissolved Cl^- and F^- potentiometrically (Whitfield, 1971; Skougstad and others, 1979). Electrodes measure ion activities rather than concentrations. The Cl^- technique uses a constant ionic strength background. A spike of a high ionic strength solution (2 M NaNO_3) was added to samples and standards. Once the dilutions were made, the potential in millivolts was measured with a specific ion meter, a Cl^- specific ion electrode, and a double junction reference electrode. A calibration curve was then constructed.

Dissolved F^- was determined potentiometrically using a buffered

solution of glacial acetic acid, sodium chloride, and (1,2-cyclohexylenedinitrilo)tetraacetic acid (CDTA). The buffer solution adjusts ionic strength in a manner similar to that used in the Cl^- determination. For F^- , interference from dissolved Fe, Al_2O_3 , and SiO_2 can cause problems. The CDTA in the buffer solution complexes these constituents, thereby reducing interference. An aliquot of buffer solution was added to both standards and samples. The potential of each solution was measured with a specific ion meter, a F^- specific ion electrode, and a double junction reference electrode. A calibration curve was then prepared.

Sulfate

Water samples were analyzed for SO_4^{--} using a turbidimetric method (American Society for Testing and Materials, 1979, p. 523). This method involves the formation of a BaSO_4 suspension and comparison of absorbances of standards and samples using a spectrophotometer. A glycerin solution and a 400 g/l NaCl solution were added to stabilize the suspension and to minimize interferences. Suspended matter will interfere with this type of measurement, but in most of the study samples, suspended matter was negligible. The exceptions were Samples 131s and 134; these were filtered twice to remove suspended matter. In addition to the B samples used for this test, several A sample replicates were run. Although results were within analytical error, the best uncertainty that can be obtained with this technique is 5%.

Iron

Total dissolved Fe was determined colorimetrically (Skougstad and others, 1979, p. 373). A red Fe^{++} complex is formed with 2,2'-dipyridine. Since total Fe abundance is desired, hydroxylamine-hydrochloric acid is added to reduce Fe^{+++} to Fe^{++} . Interference from Cu occurs at pH values above 6.0; therefore sodium acetate is

added to adjust the solutions to about pH 5.5. Absorbances of the standards and samples are compared using a spectrophotometer.

The A samples must be analyzed because acidification prevents the oxidation of Fe^{++} within the sample container. If nonacidified samples are analyzed, abnormally low total Fe values result.

Silica

The colorimetric determination of SiO_2 (aq) was made using an ammonium molybdate solution in an acid medium (Skougstad and others, 1979, p. 495; Govett, 1961). In water, SiO_2 will react with molybdoic acid to form a yellow silicomolybdate complex. This complex has two polymorphs with absorbances at different frequencies. The β -silicomolybdate complex is required for this technique. To insure its formation, pH is reduced to below pH 2.5. To eliminate interferences from Fe and PO_4^{---} , disodium dihydrogen ethylenediamine tetraacetate (Na_2EDTA) and tartaric acid were added. The yellow β -silicomolybdate complex was then reduced with NaSO_3 to form a molybdate blue color. The absorbances of all the solutions were then measured and a calibration curve was prepared.