GEOLOGIC SETTING

Rocks exposed in the area range in age from Triassic to Quaternary (fig. 7). Sedimentary rocks are mainly of continental origin and include interbedded shale, siltstone, mudstone, sandstone, limestone, and conglomerate. Igneous rocks of Quaternary and Tertiary age cap the sedimentary rocks on some of the high plateaus, and unconsolidated deposits of Quaternary age locally overlie both the igneous and sedimentary rocks. The unconsolidated deposits include alluvial deposits (basin fill in Cedar Parowan Valleys and alluvium along streams), windblown deposits, and landslide material. The principal coal-bearing units are the Dakota Sandstone and Tropic Shale in the Kolob coal field, the Dakota Sandstone in the Alton field, and the Straight Cliffs Sandstone in the Kaiparowits Plateau field. The lithology and thickness of geologic units is summarized in table 2, and outcrop areas are shown in figure 7.

Geologic units in the study area have undergone relative little structural deformation; however, rocks in the western one-half of the area are cut by several major north-northeast-trending faults (including those that created Cedar and Parowan Valleys). Rocks in the eastern one-half have been folded into a broad structural basin (the Kaiparowits structural basin) with a number of minor folds and faults (Doelling and Graham, 1972, p. 83–88). In most places the rocks dip only a few degrees, but locally near faults and in some folds they dip more 10°.

GROUND WATER

OCCURRENCE

Most geologic units in the area contain water, although none are saturated everywhere. The water occurs in the intergranular spaces of both unconsolidated and consolidated units. Fractures, solution openings, and vesicular openings in consolidated rocks also may contain water. General water-bearing properties of geologic units are described in table 2.

Depth to the regional water table varies markedly from place to place depending largely on topography. The regional water table is virtually at land surface in the lower parts of Cedar and Parowan Valleys and along most perennial stream reaches. The regional water table is several hundred to more than 1,000 ft below the surface of the highest plateaus, however, perched ground water (overlaying relatively impermeable unsaturated rock) commonly exists at relatively shallow depths. Perched ground water sustains the flow of many of the springs that discharge from canyon walls. In most places, the coal is unsaturated where it crops out in canyon walls. Underground from the canyon walls, however, the coal commonly is beneath the water table, and mining of the coal would require mine dewatering.

RECHARGE AND DISCHARGE

Precipitation and snowmelt are the main sources of ground-water recharge. Cordova (1981, p. 27 and 28) and Price and Arnow (1974, p. C69) estimate that recharge in the area averages about 4 percent of normal annual precipitation. Applying this same percentage to estimate normal annual precipitation (fig. 1, sheet 1), annual ground-water recharge in the study area averages about 150,000 acre-ft. It is likely that a larger percentage of precipitation is recharged in the higher altitudes than in lower altitudes of the area and that recharge is affected by other factors such as rock type and slope, but 4 percent probably is a fairly accurate estimate for the area as a whole.

Some water may enter the study area as subsurface flow from adjacent areas. However, the lack of potentiometric-surface data does not allow directions and rates of subsurface flow to be determined. Since 1963 when Glen Canyon Dam was completed, water from Lake Powell has recharged the Navajo Sandstone (Price and Arnow, 1974, p. C11).

Most ground water is discharged close to original recharge areas by springs and by leakage to streams. More than 750 springs have been mapped or inventoried in the study area. Records of springs are listed by Carpenter and others (1967), Goode (1964, 1966, 1969), Mundorff (1971), Bjorklund and others (1977), Cordova (1981), and Plantz (1983).

Most springs issue from formations that overlie the coal-bearing units, including the Wasatch Formation and igneous rocks. Many springs also issue from the Navajo Sandstone and related sandstone strata that underlie the coal-bearing units. The springs issue where the regional or perched water tables intersect the land surface—mainly along stream valleys and canyon walls. The springs usually issue from open fractures or from bedding planes at contacts between permeable and less permeable rock. There discharges fluctuate with time as shown in figure 8, and many springs cease to flow during dry seasons or prolonged drought.

Virtually all of the springs in the area have some beneficial use. Many springs are used for irrigation, either by direct diversion or diversion of streams sustained by the springs. Most of the communities and individual dwellings depend on springs for their water supplies, as do some recreational and tourist facilities. Even the most remote springs are sources of water for livestock and wildlife.

Streamflow is sustained by ground-water discharge. Most streams in the area are perennial; they receive significant quantities of ground-water discharge and flow continually. However, many streams in the Kaiparowits Plateau and some tributaries to Kanab Creek and the Paria River receive little or no ground-water discharge. Consequently, the streams have no flow along extensive reaches during parts of some years and, in some cases, for several years in succession.

AQUIFER CHARACTERISTICS

Unconsolidated alluvial deposits have the largest permeability and readily transmit water to wells and springs (table 2). Permeability of consolidated rocks depends, in part, on the degree of fracturing. The more brittle igneous rocks, sandstones, and limestones commonly are fractured and readily transmit water. Openings along fractures in limestones commonly are enlarged by solution. Shale, siltstone, and mudstone are common in coal-bearing Cretaceous units, and they transmit water very slowly except where fractured.

Laboratory determinations of porosity and horizontal and vertical hydraulic conductivity of several core samples from the coal-bearing Straight Cliffs Sandstone are listed in table 3. The hydraulic conductivities listed in table 3 are representative of permeabilities of unfractured rock. In the sandstone cores, horizontal hydraulic conductivities were larger than vertical hydraulic conductivities, but the differences were usually less than twofold. Hydraulic conductivities of the siltstones generally were 1 to 2 orders of magnitude less than the sandstones. Similar data also are available for the Navajo Sandstone (Cordova, 1981, table 6).

Transmissivity is the product of hydraulic conductivity and saturated thickness of an aquifer, and is a measure of the ability of the aquifer to transmit water. The larger the hydraulic conductivity and saturated thickness, the greater will be the transmissivity and ability of the aquifer to transmit water. Transmissivity of aquifers in the study area are listed in table 4. It should be noted that the transmissivity of 0.3 ft^2/d shown for the coal-bearing Dakota Sandstone probably is representative of the 20 ft of aquifer open to the test well. Where the Dakota is fully saturated in the Alton coal field, transmissivity probably is at least 2 ft^2/d.

Water is unconfined in the upper few tens of feet of coal-bearing aquifers in Tropic Shale and Dakota and Straight Cliff Sandstones. With greater depth, water probably is confined. Water is released from storage in unconfined aquifers mainly by gravity drainage, and the storage coefficient is virtually equal to specific yield. No tests were conducted that allowed for accurate estimates of storage coefficients. However, other studies (Johnson, 1967) have found that specific yield varies from about 0.01 in shale to about 0.1 in sandstone that are similar to those in the coal-bearing aquifers. Where confined, the water is released from storage mainly by compression of the aquifer and the less permeable confining beds as pressure in the aquifer decreases. The quantity of water that can be released from storage is dependent on the storage coefficient, which averages about 1×10^{-6} per foot of thickness for most confined aquifers (Lohman, 1972, p. 8).

CHEMICAL QUALITY

Ground water in the study area ranges from fresh to very saline (table 2). Regardless of geologic source, ground water in the higher plateaus generally contains less than 500 mg/L of dissolved solids. The predominant cation usually is calcium, and the pH and alkalinity indicated that bicarbonate is the predominant anion (fig. 7).

In the lower altitudes, dissolved-solids concentrations generally exceed 500 mg/L, and sodium and sulfate commonly are the predominant ions. Exceptions are the Navajo Sandstone, basin fill, and some alluvium along streams that contain ground water similar in quality to high-plateau areas. As noted in table 2, the most saline water occurs in the coal-bearing Tropic Shale and in geologic units, such as the Carmel Formation, that underlie coal-bearing units. The Tropic and Carmel contain easily dissolved minerals, such as gypsum, that contribute significantly to the dissolved-solids concentration of water passing through them.

General ranges of dissolved-solids concentrations in ground water were delineated by Price (1977a, 1980) for most of the area. Chemical analyses of ground water are listed by Goode (1964, tables 6 and 7), Cordova (1981, table 23), and Plantz (1983, table 6).

POTENTIAL EFFECTS OF COAL MINING

The coal-bearing Dakota and Straight Cliffs Sandstones and Tropic shale contain water that is discharged naturally by springs and by leakage along streams. Future underground and surface mines would intercept some of this water, which would be removed with mine-dewatering systems. Mine dewatering could decrease the flow of some springs. Also, because much of the mine water would be derived from a decrease in ground-water storage, streamflow could increase in mined basins if the mine water is discharged to streams. The quality of water in streams that receive mine water could deteriorate during some periods because ground water generally is more saline than direct runoff. Also water in coal mines is commonly exposed to oil, grease, and other contaminants used in the mining operations. Contaminated mine waters also could seep though mine floors to underlying water-bearing zones.

Another potential effect on surface-water quality is an increase in fluvial sediment. According to Kilpatrick (1979, p. 34), sediment yields can increase tenfold from areas that are actively being surface mined.

Subsidence and associated rock fracturing occurs above all underground coal mines. The degree of subsidence and fracturing are dependent on the thickness and strength of overburden, the configuation and rate of mining, and the thickness of the coal removed. Underground mining in any of the three coal fields in the area could result in subsidence similar to that near Sunnyside, about 140 mi northeast of Escalante. Near Sunnyside in the Wasatch Plateau coal field, subsidence fractures have developed at the land surface about 900 ft above an underground mine. According to Dunrud (1976, p. 9), these fractures emit air from the mine workings and "...divert all surface-and ground-water flow in this area to lower strata or to the mine workings."

It is not possible to quantify the potential impacts without mining and reclamation plans and site-specific hydrologic data. As mining plans are filed, site-specific data should allow impacts to be mitigated.

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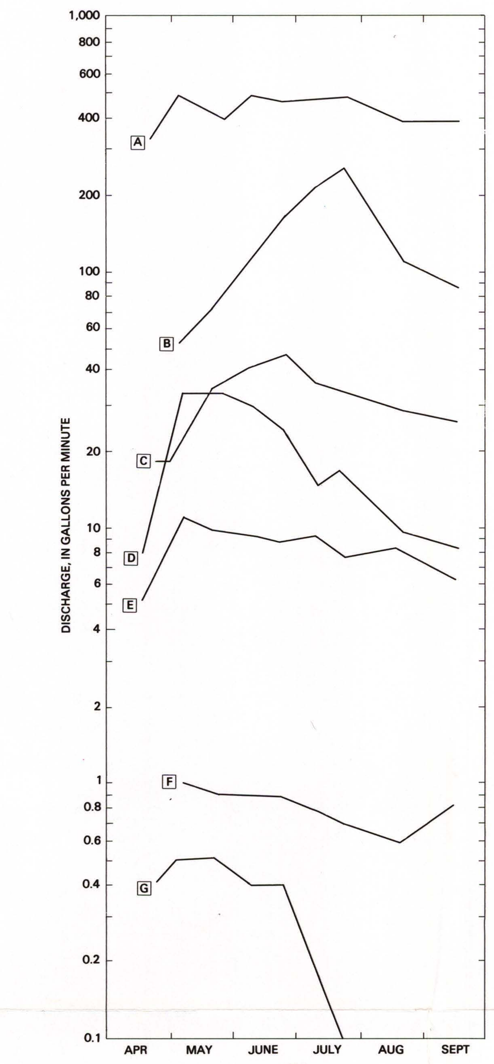


Figure 8.—GRAPH SHOWING DISCHARGE OF SEVEN SPRINGS IN THE STUDY AREA DURING LATE SPRING AND SUMMER 1982 (Letters identify springs, shown in figure 7.)

CONVERSION FACTORS

For readers who prefer to use metric units, conversion factors for inch-pound units used in this report are listed below:

MULTIPLY INCH-POUND UNITS	BY	TO OBTAIN METRIC UNITS
acre-foot (acre-ft)	0.001233	cubic hectometer
acre-foot per square mile (acre-ft/mi^2)	0.004761	cubic hectometer per square kilometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
foot per day (ft/d)	0.3048	meter per day
foot squared per day (ft^2/d)	0.09294	meter squared per day
gallon per minute (gal/min)	0.06308	liter per second
inch (in.)	25.40	millimeter (mm)
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer

NATIONAL GEODETIC VERTICAL DATUM OF 1929 (NGVD OF 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level. NGVD of 1929 is referred to as sea level in this report.

Table 2.—*General description of geologic units, their water-bearing properties, and chemical quality of ground water*

[ft, feet; gal/min, gallons per minute; mg/L, milligrams per liter.]

Chemical quality of water: Fresh, less than 1,000; slightly saline, 1,000 to 3,000; moderately saline, 3,000 to 10,000; and very saline, 10,000 to 35,000 milligrams per liter of dissolved solids.

Geologic age	Geologic units(s) and map symbol(s)	Approximate thickness (feet): West of Sevier fault	Between Sevier and Paunsaugunt faults	East of Paunsaugunt fault	Lithology	General water-bearing properties	Chemical quality of water
Quaternary	Unconsolidated deposits (Qa,Qw,Ql)	0–1,000 in Cedar Valley; 0–100 in most other places	0–500 in upper Sevier River valley; 0–100 in other places	0–100	Mainly alluvial, windblown, and landslide deposits of clay, silt, sand, and gravel; locally cobbles and boulders. Includes basin fill in Cedar Valley and alluvium along the Escalante, Sevier, Virgin, and Paria Rivers and other streams	The basin fill in Cedar Valley and the alluvium along the Sevier River are major sources of water; the deposits locally yield several hundred to more than 1,000 gal/min to individual wells (Bjorklund and others, 1977, table 1; and Carpenter and others, 1967, table 1). In other areas the unconsolidated deposits are too thin or limited in extent to support large sustained well yields.	Generally fresh to slightly saline. Dissolved-solids concentrations in basin fill and alluvium in higher altitudes are commonly less than 500 mg/L. Dissolved-solids concentrations in alluvium in the lower altitudes commonly range from 500 to 1,000 mg/L in the Kolob and Alton coal fields and exceed 1,000 mg/L in the Kaiparowits Plateau field
Quaternary and Tertiary	Igneous rocks (Qb,Tb)	0–500	Unknown	220–660	Mainly basaltic lava flows with associated breccias	Yields water readily but, because of limited thickness in most places, the rocks have a relatively small storage capacity. Yields several gallons per minute to a few wells and many individual springs. Transmits several hundred to more than 1,000 gal/min to several springs (Mundorff, 1971, p. 24)	Generally fresh. Dissolved-solids concentrations are generally less than 500 mg/L; locally less than 250 mg/L
	Sevier River Formation (Ts)	0–450	0–450	0	Unconsolidated to partly consolidated deposits of gravel, sand, silt, and clay	Generally yields water slowly, but coarser-grained unconsolidated strata may yield more than 10 gal/min to wells	Probably fresh
Tertiary	Wasatch Formation (Tw)	0–1,350	1,000–1,300	0–2,000	Mainly red, white, and gray massive limestone with interbeds of mudstone, siltstone and sandstone; base of formation consists mainly of conglomerate	Yields less than 1 to a few gallons per minute to widely scattered springs. The basal conglomerate locally transmits several hundred gallons per minute to springs. Considered to be a major source of base flow of streams (Cordova, 1981, table 2)	Generally fresh. Dissolved-solids concentrations in 14 samples averaged 240 mg/L
	Kaiparowits Formation (Kk)	0–1,200	265–700	2,000–2,500	Mainly light to dark gray, fine- to medium-grained sandstone with interbedded mudstone and some conglomerate	Generally yields less than 10 gal/min to widely scattered springs, but locally yields 10 to more than 100 gal/min. According to Cordova (1981, table 2), it is a major source of base flow of streams	Fresh to slightly saline. Dissolved-solids concentrations in 12 samples ranged from 170 to 1,780 and averaged 580 mg/L
	Wahweap Sandstone (Kw,Kws)	1,000	500–1,300	760–1,350	Mainly buff, fine- to medium-grained sandstone; some interbedded shaly sandstone and mudstone; minor deposits of coal	Generally yields water slowly; flows of individual spring that issue from the formation range from less than 1 to about 5 gal/min. A test well completed in the Wahweap and the underlying Straight Cliffs Sandstone in Bryce Canyon National Park produced 200 gal/min (Marine, 1963, p. 480)	Generally fresh in upper part; fresh to moderately saline in lower part. Dissolved-solids concentrations in 13 samples range from 170 to 3,530 and averaged 640 mg/L
Cretaceous	Straight Cliffs Sandstone (Ks,Kws)	600	80	80–1,500	Mainly gray and tan fine to medium-grained sandstone with interbedded siltstone and shale. The principal coal-bearing unit in the Kaiparowits Plateau field	Similar to the Wahweap Sandstone. The Drip Tank Member, a sandstone stratum as much as 140 ft thick that overlies the coal in the Kaiparowits Plateau area, is the principal water-bearing unit; it has reportedly yielded water to a number of coal-test holes and supports the flow of several springs. A test well reportedly yielded 87 gal/min by pumping with 70 ft of drawdown (Lorang and Sieh, 1975, p. 17 and 18)	Fresh to slightly saline. Dissolved-solids concentrations in 11 samples ranged from 250 to 2,320, and averaged 680 mg/L; generally exceeded 1,000 mg/L in samples from coal-test holes
	Tropic Shale (Kt,Ktd)	1,000–2,000	700–1,000	550–1,000	Gray shale with thin lenses of mudstone and sandstone; considerable salt, gypsum, and carbonaceous material. Contains coal in the Kolob field	Transmits water slowly and not considered as a source of water. Commonly is a confining bed with respect to ground-water flow	Generally very saline
	Dakota Sandstone (Kd,Ktd)	100–150	150–450	0–250	Mainly buff medium- to coarse-grained sandstone with interbedded shale; principal coal-bearing unit in the Kolob and Alton fields	Generally yields less than 1 to about 10 gal/min to springs; probably would yield similar quantities to wells	Generally fresh to slightly saline; dissolved-solids concentrations less than 1,000 mg/L in higher altitudes, but probably more than 1,000 mg/L where in close proximity to the Tropic Shale.
Jurassic and Triassic	Morrison and Winsor Formations, Bluff Sandstone, Summerville Formation, Entrada Sandstone, Carmel Formation, Navajo Sandstone, Kayenta Formation, Moenave Formation, Wingate Sandstone, Chinle Formation, and Moenkopi Formation (JTru)	>4,000	>4,000	>4,000	Mainly sandstone, shale, and conglomerate. Sandstones in the Navajo are as such as 2,000 ft thick. The Carmel Formation is mainly limestone with salt and gypsum deposits	Navajo Sandstone is a major aquifer in the area (Goode, 1964, 1966, 1969; Price, 1977b; and Cordova, 1981). The Navajo yields several hundred to more than 1,000 gal/min to individual wells; it also supports the flow of many springs and is an important source of base flow of streams. The Shinarump Member of Chinle Formation yields more than 200 gal/min to individual wells locally. Other units generally yield water very slowly, but support the flow of a few widely scattered small springs and seeps.	Water from Navajo Sandstone is generally fresh, and dissolved-solids concentrations are commonly less than 500 mg/L. Water from other units is generally slightly to moderately saline, but locally is fresh

Table 3.—*Porosity and hydraulic conductivity of core samples from three test holes in the coal-bearing Straight Cliffs Sandstone on the Kaiparowits Plateau*

[Determinations by Core Laboratories, Inc., Dallas, Texas.]

Lithology: Very fine grained, 0.0625 to 0.125 millimeter; fine grained, 0.125 to 0.250 millimeter; medium grained, 0.250 to 0.50 millimeter.

Site identification	Depth below land surface (feet)	Porosity (percent): Horizontal	Porosity (percent): Vertical	Hydraulic conductivity (feet per day): Horizontal	Hydraulic conductivity (feet per day): Vertical	Lithology
H	590.6	12.3	—	1.3×10^{-7}	—	Siltstone, slightly indurated, very shaly
	655.2	—	31.9	—	8.9×10^{-1}	Sandstone, slightly indurated, fine to very fine grained, moderately well to well sorted
	750.5	12.9	—	1.1×10^{-4}	—	Siltstone, slightly indurated, shaly
	831.2	18.7	18.4	3.6×10^{-3}	2.1×10^{-3}	Sandstone, moderately indurated, very fine to medium grained, moderately well to well sorted, slightly calcareous, slightly silty
	846.5	28.5	28.9	12.6×10^{-1}	8.8×10^{-1}	Sandstone, slightly indurated, very fine to medium grained, moderately well to well sorted
	927.3	25.7	23.8	10.6×10^{-1}	9.1×10^{-1}	Sandstone, moderately indurated, very fine to medium grained, moderately well to well sorted, calcareous
	1,088.3	21.5	21.1	1.8×10^{-2}	9.0×10^{-3}	Sandstone, slightly indurated, very fine to medium grained, moderately well to well sorted, calcareous
I	853.4	25.2	25.7	3.7×10^{-1}	2.0×10^{-1}	Sandstone, moderately indurated, fine grained
	1,023.5	4.9	4.2	$<3.7 \times 10^{-4}$	$<3.7 \times 10^{-4}$	Sandstone, well indurated, very fine to fine grained, calcareous, slightly laminated
	1,165.6	5.6	6.2	$<3.7 \times 10^{-4}$	$<3.7 \times 10^{-4}$	Siltstone, well indurated, slightly laminated
	1,260.5	14.7	13.6	6.3×10^{-4}	3.4×10^{-4}	Sandstone, moderately indurated, medium grained, slightly calcareous
J	631.2	22.9	22.4	8.5×10^{-2}	2.7×10^{-2}	Sandstone, moderately indurated, medium grained, coal lens
	658.0	6.0	5.2	$<3.7 \times 10^{-4}$	$<3.7 \times 10^{-4}$	Siltstone, moderately indurated, slightly dolomitic
	720.9	19.3	19.7	3.9×10^{-3}	3.9×10^{-3}	Sandstone, moderately indurated, medium grained, slightly calcareous
	814.7	9.3	7.6	$<3.7 \times 10^{-4}$	$<3.7 \times 10^{-4}$	Siltstone, well indurated, slightly carbonaceous, calcareous
	878.5	6.3	.77	$<3.7 \times 10^{-4}$	$<3.7 \times 10^{-4}$	Siltstone, well indurated, calcareous, slightly fractured

Table 4.—*Transmissivity of selected aquifers in the study area*

Subarea	Aquifer	Number of values	Range of transmissivity (feet squared per day)	Remarks
Cedar Valley	Basin fill	8	2,540 – 52,000	Aquifer tests (Bjorklund and others, 1978, table 4)
Parowan Valley	do.	15	1,400 – 677,000	Do.
Sevier River valley and Johns Valley	Alluvium	—	10 – 2,000	Aquifer tests (Carpenter and others, 1967, table 6)
Alton coal field	Dakota Sandstone	1	0.3	Aquifer test. Well open to 20 feet of the Dakota Sandstone
Kaiparowits coal field	Straight Cliffs Sandstone			
	Drip Tank Member	1	630	Aquifer test (Lorang and Sieh, 1975, p. 17 and 18)
	John Henry Member	1	66	Aquifer test (Lorang and Sieh, 1975, p. 19 and 20)
Kanab Creek basin	Navajo Sandstone	8	2,500 – 14,000	Aquifer tests (Cordova, 1981, table 8)
Escalante River basin	do.	6	500 – 11,500	Laboratory analyses of core samples
Wahweap Creek basin	do.	2	6,700 – 7,000	Aquifer tests

EXPLANATION

CORRELATION OF MAP UNITS

Sedimentary rocks

Qa Qw Ql — QUATERNARY
Ts, Tw — TERTIARY
Kk, Kw, Ks, Kws, Kt, Kd, Ktd — CRETACEOUS
JTru — JURASSIC AND TRIASSIC

Igneous rocks

Qb — QUATERNARY
Tb — TERTIARY

DESCRIPTION OF MAP UNITS

- Qa — ALLUVIAL DEPOSITS
- Qw — WIND-BLOWN DEPOSITS
- Ql — LANDSLIDE DEPOSITS
- Ts — SEVIER RIVER FORMATION
- Tw — WASATCH FORMATION
- Kk — KAIPAROWITS FORMATION
- Kw — WAHWEAP SANDSTONE
- Ks — STRAIGHT CLIFFS SANDSTONE
- Kws — WAHWEAP AND STRAIGHT CLIFFS SANDSTONE, UNDIVIDED
- Kt — TROPIC SHALE
- Kd — DAKOTA SANDSTONE
- Ktd — TROPIC SHALE AND DAKOTA SANDSTONE UNDIVIDED
- JTru — JURASSIC AND TRIASSIC ROCKS—Includes the Morrison Formation, Summerville Formation, Entrada Sandstone, Carmel Formation, Navajo Sandstone, Kayenta Formation, Moenave Formation, Wingate Sandstone, Chinle Formation, and Moenkopi Formation
- Qb — BASALT
- Tb — BASALT AND BRECCIA

HYDROLOGIC SYMBOLS

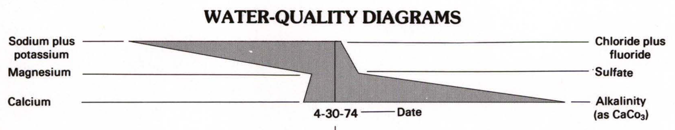
- WELL
- I — COAL-TEST HOLE
- G — SPRING

Letter is site identification used in table 3 and in figures 7 and 8.

GEOLOGIC SYMBOLS

- CONTACT—Approximately located
- FAULT—Dashed where approximately located, dotted where concealed

WATER-QUALITY DIAGRAMS



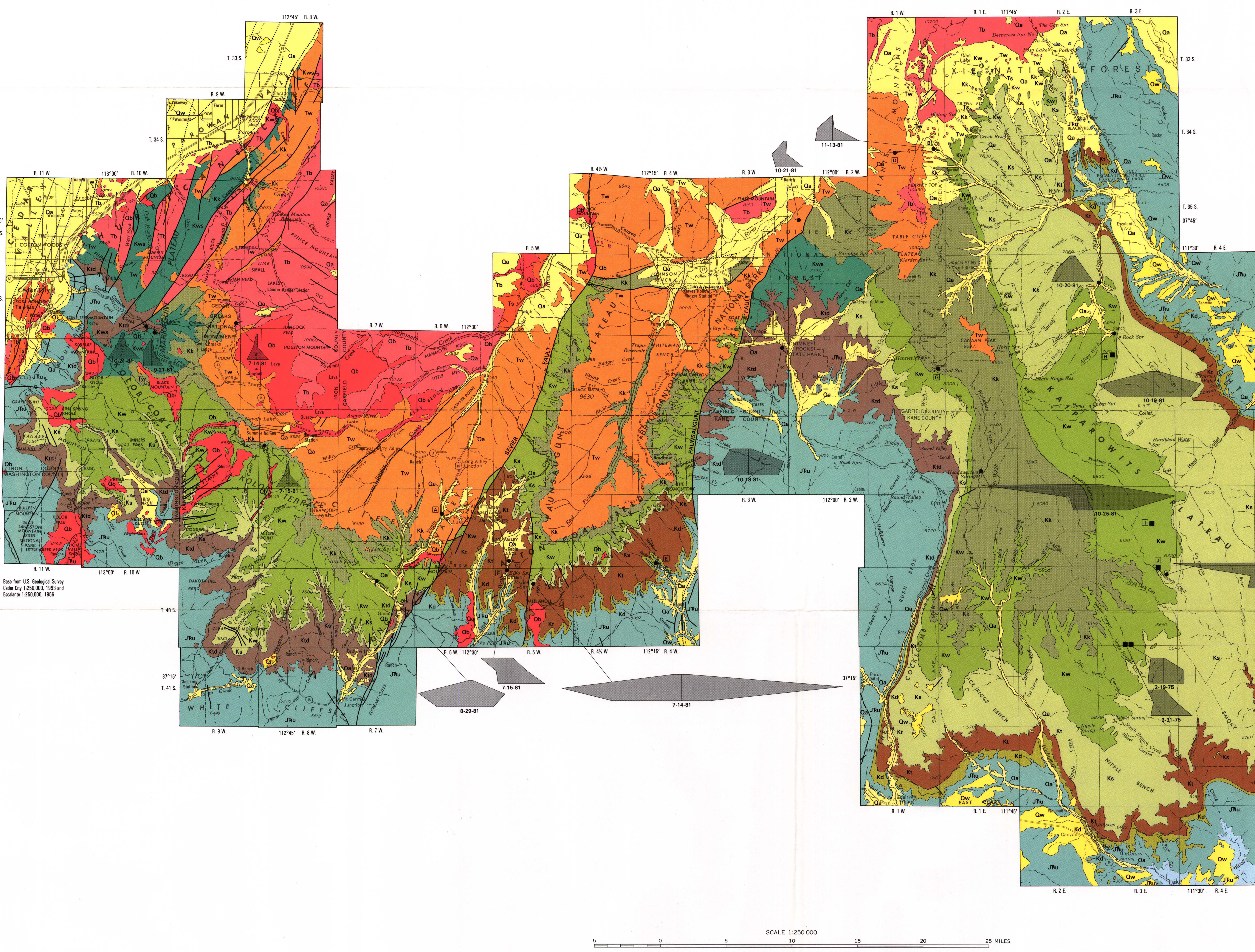


Figure 7.—MAP SHOWING GEOLOGY, LOCATION OF SELECTED WELLS, TEST HOLES, AND SPRINGS, AND QUALITY OF GROUND WATER

HYDROLOGIC RECONNAISSANCE OF THE KOLOB, ALTON, AND KAIPAROWITS PLATEAU COAL FIELDS, SOUTH-CENTRAL UTAH

By
Gerald G. Plantz

1985