Ground Water in Bedrock

in

Big Cottonwood Canyon
and adjacent watersheds
Central Wasatch Mountains, Utah

Ground water: refers to all water present beneath the surface of the earth. It is the water encountered by shallow "dug" wells or deeper "drilled" wells or the water that enters caves, tunnels and other underground mine workings, the artificial openings providing ready avenues of escape for the water contained in the rocks of the earth's crust. Ground water, like surface water, has its ultimate source in precipitation, which in Utah comes mainly from snowfall in the winter months. Gentle, steady rains, though infrequent, are also beneficial, but the "flash floods" produced by the "cloudburst" type thunderstorm of the hot summer months are harmful rather than helpful and are wholly ineffective in adding to the ground-water supply.

Precipitation in Utah is closely controlled by the topography, particularly by the height of the relief features; mountains and high plateaus get the most, desert valleys, the least. The west-facing slopes of the mountain ranges (in this region usually the windward side) get much more abundant precipitation than the opposite or leeward side. The precipitation also increases porportionately with increasing altitude up to an elevation of approximately 10,000 feet, above which the rate of increase drops off markedly. That portion of the total precipitation not lost to the atmosphere by evaporation and transpiration saturates the soil mantle overlying the bedrock formations. And only that water in excess of the capacity of the soil to retain moisture is ultimately transferred downward by gravity into the bedrock.

Porosity and Permeability: The presence of water underground in bedrock is controlled, first by the degree of porosity and permeability of the rock formations underlying the ground surface in the watersheds, and second by the secondary openings that may exist in the rock formations such as: bedding planes and fractures, and solution channels in such soluble rocks as limestones. If the rocks are fine-grained, compact, and possess a homogeneous texture the porosity and permeability are generally quite low; in such rocks the amount of water present and its movement will depend upon the character and abundance of the second class of openings referred to as: bedding planes, fractures, and solution channels.

Rock Formations present: In the central Wasatch Mountains the rock formations consist of a series of steeply inclined metamorphic and sedimentary beds into which molten rock from depths below was injected and intruded and has subsequently solidified. The metamorphic rocks are quartzites and argillites of late Precambrian age; the sedimentary strata are limestones, shales, and

quartzitic sandstones, ranging in age from Cambrian to Jurassic. Both the metamorphic and sedimentary rocks are fine-grained and dense and hence their porosity is low to non existent. The igneous rocks occur as sills, dikes, and larger bodies called "stocks", and they, too, are dense, compact, homogeneous masses of rock and lack "formation porosity".

Thus it will be seen that the presence of underground water in the bedrock in the watershed will depend upon factors other than the porosity and permeability of the rocks which are so low as to be of little importance.

Secondary Openings in Bedrock: As indicated in the foregoing discussion, the absence of "formation porosity" in the bedrock leaves only the secondary openings to guide the infiltrating water further downward in its penetration of the bedrock.

Bedding Planes: Contrary to popular belief, it has been shown in numerous investigations in the Big Cottonwood watershed that bedding planes, which divide the sedimentary rocks into separate layers, exert but little control over the downward movement of ground water; this is especially true where the rocks are tilted at steep angles. When a series of solid rock layers are flexed by "folding" a slippage inevitably occurs between the adjacent beds, as may be readily illustrated by flexing a pack of playing cards. Each layer of rock moves forward along the surface of the underlying layer. The result of this mutual abrasion by the two rock surfaces in contact with each other is to produce a thin seam of rock flour or "gouge" that coats the bedding planes. In impure limestones, slow seepage of ground water along the bedding planes may dissolve a portion of the limestone from the two beds along their mutual contact, leaving a thin, insoluble residue of clay, silica, and often iron oxide, which acts like a putty selvage sandwiched in between the two rock surfaces. When moist this clay-like "gouge" swells in volume and effectively seals the bedding planes against the free movement of ground water. Except where vertical, the bedding planes are tightly pressed together by the static weight of the overlying masses of rock. This downward rock pressure increases proportionately with increasing depth beneath the earth's surface. In deep mines the rock pressure makes costly timbering essential to keep the mine workings open. From the foregoing discussion it should be evident why bedding planes, in general, exert little control over the downward movement of ground water.

The correctness of the foregoing analysis is further attested by an entirely independent line of evidence, namely the record of stream flow in Big Cottonwood Creek between the Argenta gaging station, about half way up the canyon, and the measurements at the mouth of the canyon. Throughout this entire distance the

stream crosses rock formations whose bedding planes dip upstream. In this reach of the stream, if bedding planes actually guided the direction of movement of ground water--as is popularly supposed -- then the stream flow should decrease rather than increase where its channel crosses such a rock structure. The claim is frequently made that rocks dipping upstream tend to divert ground water to adjacent watersheds where the streams flow in the direction of the dip of the beds. After August first, the snow-melt runoff has passed and the only water in the stream channel is ground water contributed by seeps and springs from the adjacent "leaky" bedrock. The actual measurements of stream flow under these conditions show that the volume has practically doubled at the mouth of the canyon over the flow measured at the Argenta gaging station. The stream, therefore, has been increasing rather than decreasing in that reach where the rock formations dip upstream and the records demonstrate that the creek actually receives large contributions of ground water from the rock structure. Thus, by incontrovertible and independent evidence, the bedding planes can be ruled out as important conveyors of ground water in bedrock!

Fractures - Rock Joints: Of the two remaining types of Secondary openings in rocks, fractures and solution channels, extensive studies in the Big Cottonwood watershed over the past forty years have clearly demonstrated that the fractures that abundantly transect all of the rocks in the watershed being considered are by far the most important factor controlling the accumulation and movement of underground water in bedrock. In the order of their relative importance as aquifers, those plane-like fractures called joints rank first, especially those through-going fractures referred to as "master joints." Fissures, another class of rock fractures, rank second.

The joints present in the bedrock in the Big Cottonwood watershed are quite complex, as illustrated in Figure 1, accompanying this report. Those joints that are parallel constitute a "joint set;" a "joint system" comprises two or more joint sets. Jointing represents one type of rock failure under stresses induced by "folding" or "faulting" in essentially solid, brittle rocks.

In the deformation of the rocks in the Big Cottonwood district the earliest formed joints of major importance were probably a double set of steeply-inclined "strike joints," resulting from relatively simple horizontal compression, (see (a), Figure 1). The shearing stresses set up by slippage between the rock layers during folding likely produced a second pair of joint sets, one set crossing the beds at a steep angle, the other being parallel with the bedding (Figure 1 (b)). Thus a third set of "strike" joints and an inconspicuous set of bedding joints were added to the earlier formed joints in the rock mass. Subsequent secondary folding, bending, and torsion or twisting have apparently added a double set of nearly vertical "dip" joints, which cross the beds

at a large angle. It is the combination of these various sets of joints, along with others that are less distinct, that forms the complex joint system now so prominently displayed in the rocks. The three sets of "strike" joints, along with the nearly vertical "dip" joints, constitute the major fractures in the rock body and serve as the principal channelways, or "plumbing system," for the accumulation and movement of ground water.

Fissures: A large, through-going master joint where the two walls are separated by an intervening space is commonly called a "fissure," as contrasted with a simple joint where the walls are fairly tightly pressed together. The space between the walls in a fissure may be occupied by introduced vein matter, or if there has been movement parallel to the two joint surfaces, forming a "fault fissure," the space between the walls may be filled by crushed rock ground up by the mutual rubbing together of the rock walls during fault movements. If the filling is clay-like rock flour, it is called "gouge;" if the gouge contains angular rock fragments, it is "fault breccia." Gouges and breccias that line fault fissures vary in thickness from a few inches to several feet.

Plain fissures are often important channelways for the movement of ground water in bedrock. Fault fissures are of major importance as underground barriers or dams, for their gouge-coated surfaces often intercept percolating water and cause it to be impounded behind them. This has been found to be especially true in the Big Cottonwood district where fault planes cut large bodies of igneous rock. A thick gouge has been formed which effectually prevents water in quantity from crossing the fissured zone. In such cases the water tends to accumulate or back up on the upper or "hanging wall" side of the fault plane, in the area of highly crushed rock, thus forming a water trap or "spring structure." Where faults cut limestones and quartzites but little gouge is formed and water freely enters and passes along the "footwall" from the generally more highly fractured "hanging wall."

These general conditions controlling the movement of ground water in bedrock are well exhibited in the Confidence tunnel of the Union Associated Mines Company, on the south side of Big Cottonwood Canyon just west of the mouth of Butler Fork. Water was observed to enter the tunnel freely where the fault fissure passes through limestone and marble, while the same tunnel was comparatively dry where the same fault crossed a large body of igneous rock (diorite porphyry).

An indication of how rapidly the water issuing from a mine tunnel is influenced by precipitation on the overlying ground surface was observed by the writer and Leonard Tanner, Hydraulic Engineer, at the portal of the Sunnyside Tunnel, also in Big Cottonwood Canyon. The week preceding October 17th, 1932, was

clear and dry and the amount of water flowing from the tunnel over the weir at the tunnel portal was 0.074 cubic feet per second. On Monday, October 17th, 1932, a heavy snow fell. Tuesday, the weather cleared and turned warm. The Sunnyside Tunnel, as the name implies, is driven 700 feet into the north wall of the canyon. By Thursday, the 20th, the snow on the south facing slopes had disappeared and the flow on the 20th had increased to 0.25 cubic feet per second, over three times the amount measured on the 17th of the month. That the water intercepted by the Sunnyside Tunnel is entirely of surface origin is further indicated by the fact that the ground water was observed to enter the tunnel only from the roof ("back") and walls of the mine workings and from the further fact that measurements carried on over many years show a distinct fluctuation in response to the seasonal variation in precipitation.

Solution Channels: In soluble rocks such as limestone, gypsum, or rock salt, fractures, especially master joints, are often enlarged into irregular caverns or tubular channels which readily convey ground water through the rock body. Neither gypsum nor salt occurs in the Big Cottonwood watershed, but limestones of marine origin are common. The following carbonate rock formations, in order from oldest to youngest, are present in the Big Cottonwood and adjacent watersheds: Maxfield limestone (1,000 feet thick), Madison limestone (450 feet thick), Deseret limestone (900 feet), Doughnut formation (300 feet), Morgan formation (300 feet), Park City formation (600 feet), and the Thaynes formation (1,000 feet).

In the previously mentioned Confidence tunnel a heavy flow of water was observed to enter the drift from a tubular solution channel or "water course" about four inches in diameter. Three or four similar water courses were encountered in the several underground workings of the Union Associated Mines Company in the Madison limestone of Lower Mississipian age. Large caverns do not appear to have developed in this region, possibly due to small volumes of water and impeded circulation.

Distribution of Ground Water in Bedrock: Ground water in excess of the volume required to bring the soil water in the soil mantle up to capacity is then transferred downward by the force of gravity into the intricate facture system in the bedrock. This "vadose" water, as it is called, infiltrates deeper and deeper into the rock mass, guided by the previously described "secondary" openings such as joints and fissures. Air as well as water is present in the downward moving "vadose" zone, the amount of water being greatest following the late spring snow melt period and least in fall and winter. Fissures encountered in mine workings in the vadose zone or zone of "aeration" may practically dry up after the seasonal contribution of vadose water has passed downward to lower levels. Eventually, unless artificially intercepted, the vadose water joins the "zone of saturation," where all interconnected openings in the bedrock, of whatever kind, are full of water. This

water is referred to as "ground water" proper and its upper surface is the "water table." In the zone of complete saturation the ground water body occupies the voids in the interconnected joint and fissure system and moves slowly downslope under hydrostatic pressure to escape from the bedrock as seeps and springs. Where stream channels have been cut below the water table the bedrock reservoir leaks into the channels and thus maintains a live surface stream during the late summer, fall, and winter months. If the stream channels fail to penetrate the water table, the streams go dry in late summer and remain so until the next spring snow-melt runoff.

If mine drain tunnels enter the bedrock reservoir at significantly lower elevations than the creek beds, the effect in time is to lower the water table to such an extent that former springs go dry and stream flows are greatly reduced or stopped altogether, the water now discharging at lower elevations, the drain tunnels providing freer avenues of escape for the ground water from the bedrock reservoir. In other words, the barrel, cracked and leaky, has been tapped near the bottom and the water surface is lowered to the extent that it no longer leaks from the cracks in the top of the barrel.

The distribution and movement of ground water in bedrock as presented in the foregoing discussion are illustrated in Figure 2, accompanying this report.

BEDROCK JOINTS

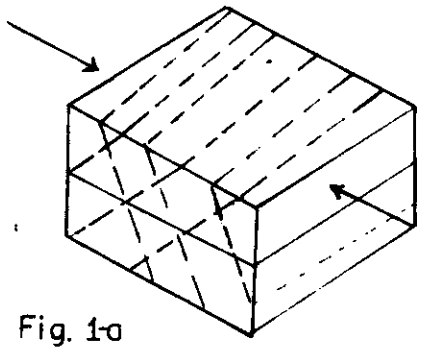


Fig. 1-a

Simple compression

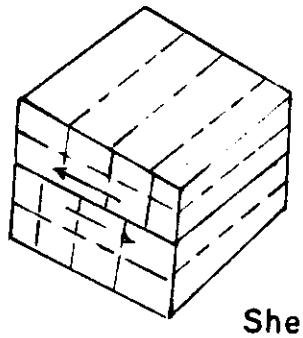
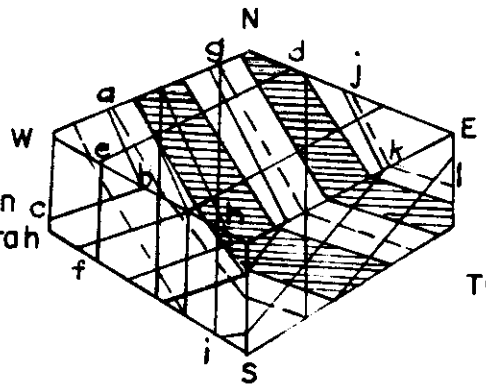


Fig. 1-b
Shear to slippage between beds.

Joint System

Union Asso. Mines
Big Cottonwood Canyon
Salt Lake County, Utah



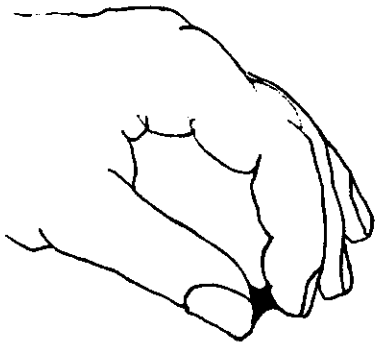
a-b-c = Strike joints (counter inclined)

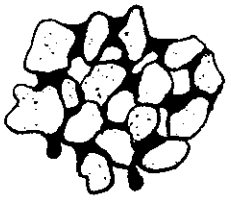
d-e-f = Dip joints (vertical)

g-h-i = Diagonal joints (vertical)

j-k-l = Weakly developed bedding joints

Two of the sedimentary layers are shaded.





Soil Moisture

Molecular forces such as: surface tension, adhesion and cohesion hold water in the soil (granular particles) against the pull of gravity.

Figure-1

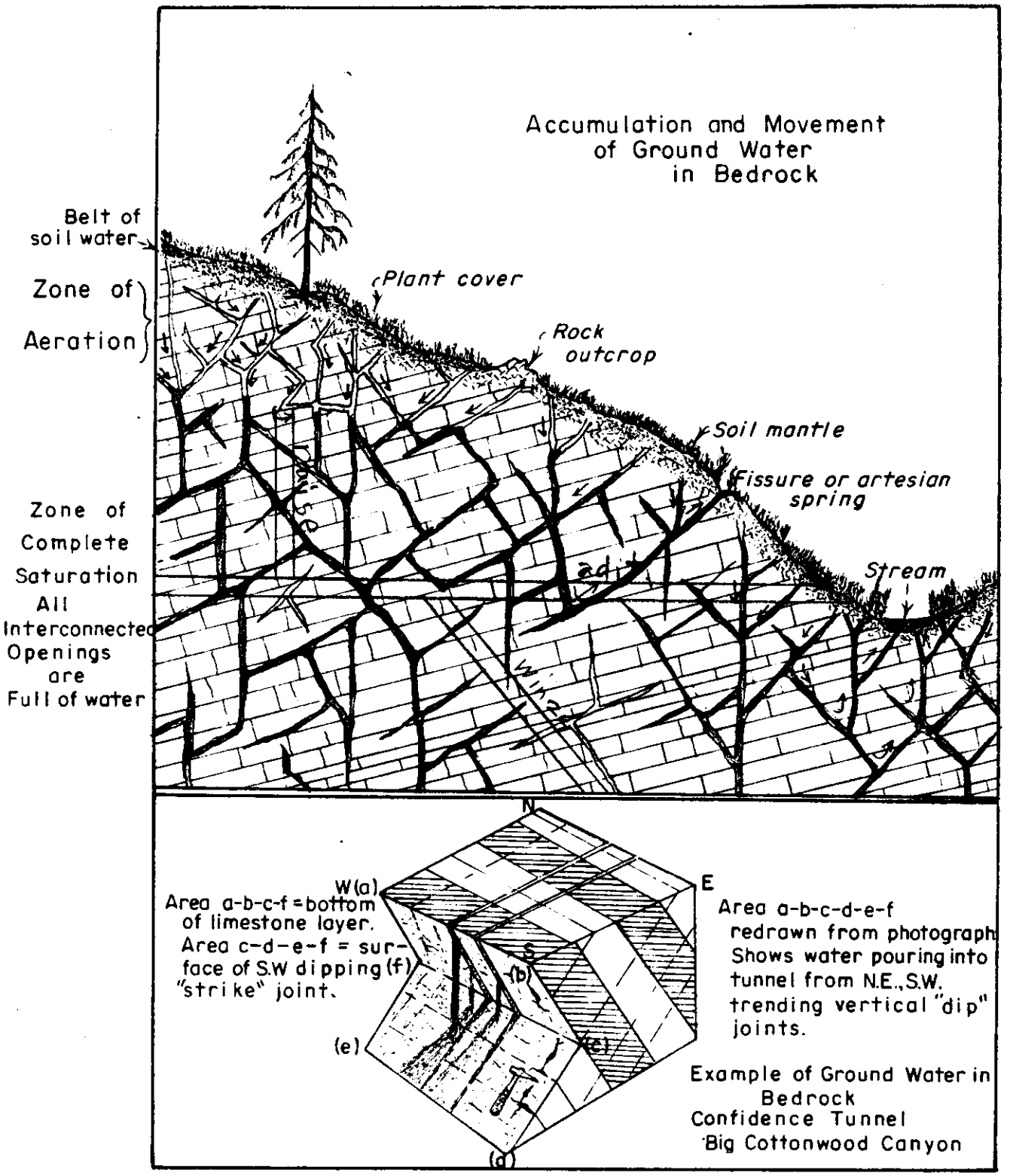

Accumulation and Movement of Ground Water in Bedrock
Belt of soil water
Zone of Aeration
Plant cover
Rock outcrop
Soil mantle
Fissure or artesian spring
Stream
Zone of Complete Saturation All Interconnected Openings are Full of water
N
E
W(a)
Area a-b-c-f = bottom of limestone layer. Area c-d-e-f = surface of S.W dipping "strike" joint.
(f)
(b)
(e)
(c)
(d)
Area a-b-c-d-e-f redrawn from photograph Shows water pouring into tunnel from N.E., S.W. trending vertical "dip" joints.
Example of Ground Water in Bedrock Confidence Tunnel Big Cottonwood Canyon

Figure 2