Geologic-structural control of fracture-dominated ground-water flow at a variety of spatial scales

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Wild rye on Battle Mountain, Nevada

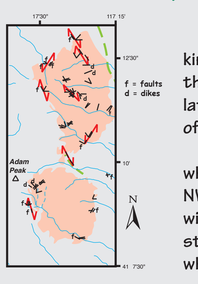
Abstract:

An understanding of geologic structures and fracture networks aids the understanding of fracture-controlled flow at a variety of spatial scales, as demonstrated by case studies from throughout the western United States. These studies were undertaken to understand the role of fractures during mineral formation and their effect on water quality associated with mineralization. Studies in the Patagonia Mountains of southern Arizona demonstrate the control of ground water - surface water interactions along discrete fractures, as detected by changes in surface water chemical and physical properties. Surface water entered the ground as a stream intersected a major fracture zone and re-emerged several hundred meters downstream, where it mixed with water draining an abandoned mine. Chemical parameters and temperature provided a clear indication of the presence of the re-emergent ground water. At Battle Mountain, Nevada, changes in surface-water flow are attributable to ground-water discharge and recharge that occurs in locations where large-scale (10's of km) through-going fractures cross a stream drainage. In the Osgood Mountains in north-central Nevada, interactions between ground water and surface water are controlled by fracture systems at spatial scales from meters to kilometers, as confirmed by hydraulic head measurements and geochemical samples. A final case study on Mt. Emmons in southwest Colorado was performed to discern local flow phenomena within a fault duplex that formed in the Tertiary, but whose fracture sets are still hydraulically conductive. The main strike-slip faults of the duplex extend for several kilometers and are about 1.5 km apart. Local flow regimes are established at the scale of tens of meters within this system, and are observed by chemically dissimilar springs within meters of each other, mixing of dissimilar waters from adjacent stream drainages, etc. The results of these studies are being used to help evaluate the environmental effects of mineral deposits throughout the U.S.

The Osgood Mountains, north-central Nevada

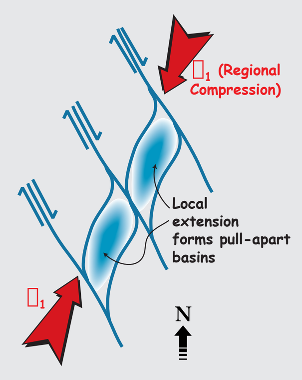
(A on the map of the U.S. shown below)

Two large granodiorite-composition intrusive bodies outcrop in the Osgood Mountains (shown in light tan on the map at right). The surrounding sediments were contact-metamorphosed and metasomatized, leading to the development of tungsten-rich skarn deposits. Within the intrusive bodies, there are zones of pyrite-rich hydrothermal alteration (Hotz and Willden, 1964).

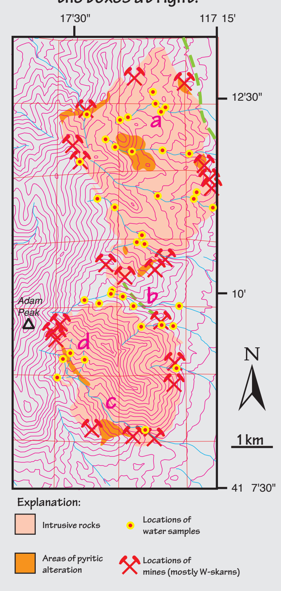


Field geologic observations of the orientations and kinematic indicators for fractures and faults (left) showed three major fracture/fault orientations: a NNW set with right-lateral offset; a NE set with left-oblique offset, and an E-W set of structures including fractures and dikes.

Our geologic observations are consistent with a model wherein regional tectonic compression leads to development of NW stiking, right-stepping, right lateral strike-slip faults, within which smaller pull-apart basins form. These pull-apart structures are zones of local extension and form a conduit into which magma can be emplaced.



The Osgood Mountains study area is in north-central Nevada. Specific sites of interest are shown in magenta letters on the map below, and correspond to the boxes at right.



This spring issues from a ridgetop above Rocky Creek (arrow on photo above). An east-trending dike with sheeted easterly fractures provided the conduit for this unusual flow. The dike is clearly seen in the aerial photograph as a light line forming the ridge.

b

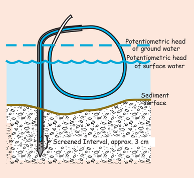
During one sampling trip in 1999, we observed a dramatic increase in the discharge of Osgood Creek as it crossed the Osgood Fault (green dashed line). At the same place, the conductivity decreased from >300 □s to 250 □s, documenting the discharge of ground water along the Osgood Fault.

c

Granite Creek flows to the SE, roughly along the probable trace of a major NW-trending structure. Neuerberg (1966) found an elongated zone of pyrite enrichment in the Osgood intrusive rocks along Granite Creek. From the upstream reaches to the downstream sample point, flow increased by more than 5 times, conductivity increased from 210 to 240 □s, and greater than 2x changes in concentrations were observed for Cl, B, K, Ba, Mg, Na, Sr, and Mn. No surface-water tributaries were observed along this reach of the stream. These changes are consistent with ground water discharge from altered rocks.

d

In the upper reaches of Granite Creek, NE-trending fractures in outcrop intersect the stream at the point shown in this photo. Hydraulic head measurements from 30 cm below the streambed showed this to be a losing reach, with approximately -15 cm of head relative to the stream surface. The geologic model predicts that the NE trending fractures should be hydraulically conductive. Head measurements are made using the device shown at left (Wanty and Winter, 2000).

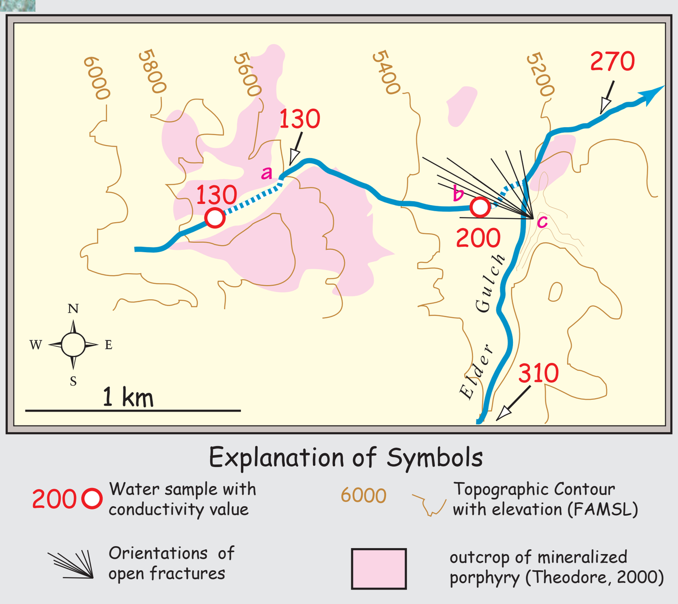


Battle Mountain, north-central Nevada

(B on the location map below left)

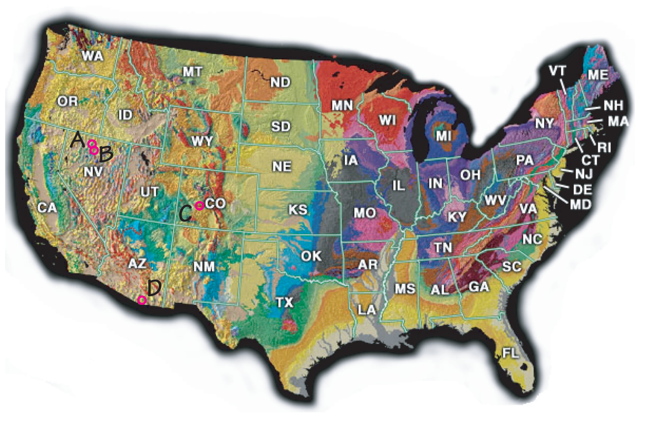
This photograph shows a boulder approximately 1 meter wide. Nitrophilous lichens grow along those fractures that are hydraulically conductive. The lichens depend on the conductive fractures for a supply of water and nutrients. The non-conductive fractures do not support a lichen community.

This photograph demonstrates that not all fractures are hydraulically conductive at the sub-meter scale. The question remains as to whether we can explain, using geologic models, which fracture orientations should be preferentially conductive.



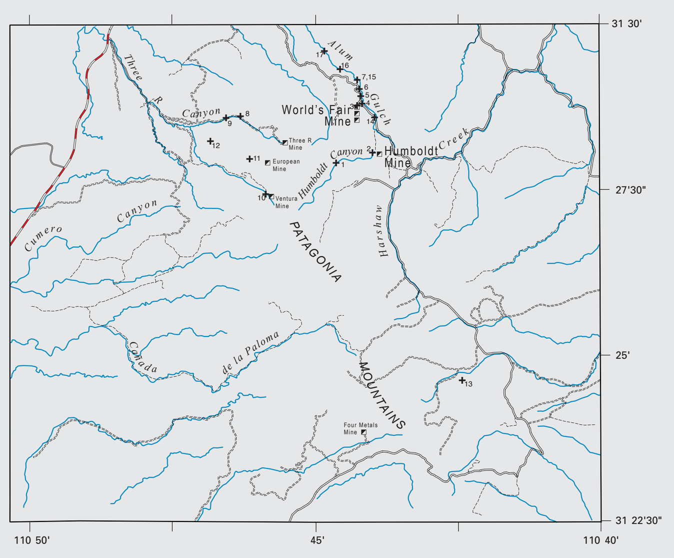
Another example from Battle Mountain shows a stream system flowing to the north and east. In particular, we are interested in the unnamed drainage that flows west to east towards Elder Gulch. Dash-line sections of the stream show reaches over which no surface water was observed. At point a the stream re-emerged with a conductivity of 130 □s. Conductivity consistently increased from point a to point b (as did concentrations of Na, Mg, Si, SO_4, K, Ca, V, As, Zn, Sr, Mo, and W). A known but undeveloped Cu-porphyry deposit is located beneath the stream between points a and b, which could explain the observed increases in concentrations of individual dissolved constituents. The stream disappears again at point b, at a location that coincides with the projected subcrop of a swarm of fractures observed in the outcrop at point c. The vectors originating at point c show the orientations of observed fractures in the outcrop. These fractures are likely to be hydraulically conductive, as suggested by the presence of a species of wild rye, which requires more moisture than is normally available in this arid region. The photograph at the top right of this poster shows the outcrop, with the wild rye visible in the foreground. The decrease in conductivity in Elder Gulch from south (310 □s) to north (270 □s) is evidence of the hydraulic conductivity of the fractures, as the more dilute water from the unnamed drainage enters Elder Gulch.

Four areas in the western US were chosen to represent hydrogeologic systems at a variety of spatial scales. The pink circles on the map at right show the study-area locations.

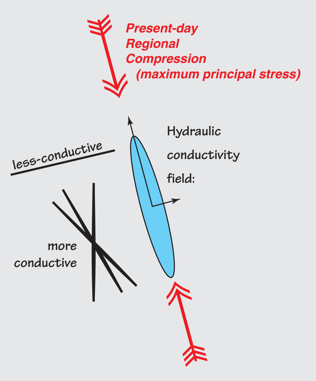


Patagonia Mountains, southern Arizona

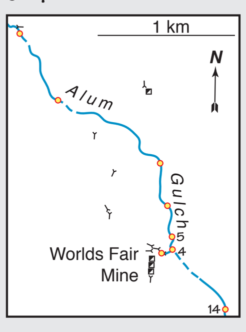
(D on the location map above)

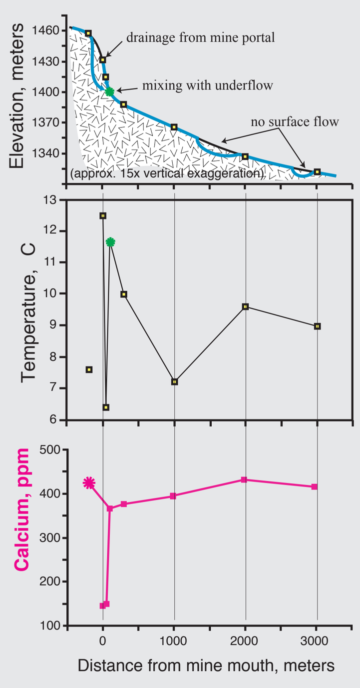


The Patagonia Mountains are in southern Arizona. Our studies there focussed on the now-inactive mines of the Harshaw district on the northeast side of the range. Mining at the World's Fair deposit followed a rather extensive set of north-south veins, which document a great degree of hydraulic conductivity in the geologic past. With the present-day orientation of the regional stress field (shown at right) the north-south and NNW structures in the region are expected to be hydraulically conductive today as well, because the hydraulic conductivity should be greatest parallel to the maximum principal stress direction.



Alum Gulch flows to the north and northwest, at times following the northerly fractures that can be seen in the photograph below.



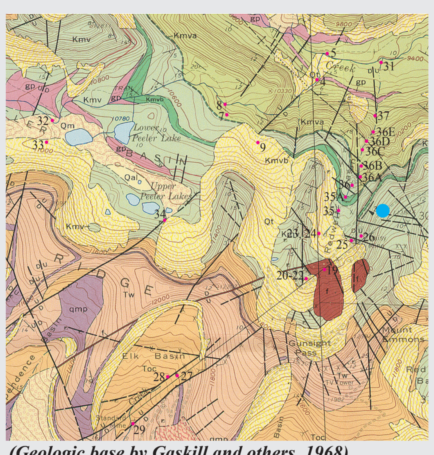


In profile, Alum Gulch follows a higher-gradient section in its headwaters, with a lower gradient downstream. Drainage from the World's Fair mine enters Alum Gulch near the break in slope.

In the steep section of Alum Gulch, no flow was observed at the surface. We propose that all flow of Alum Gulch is below the surface here, following a well-developed NNW fracture set. Where the drainage from World's Fair mine enters, temperature increases, and Ca (among others) concentrations change as well. Most elements are consistent with a conservative mixing model.

Mount Emmons, southwestern Colorado

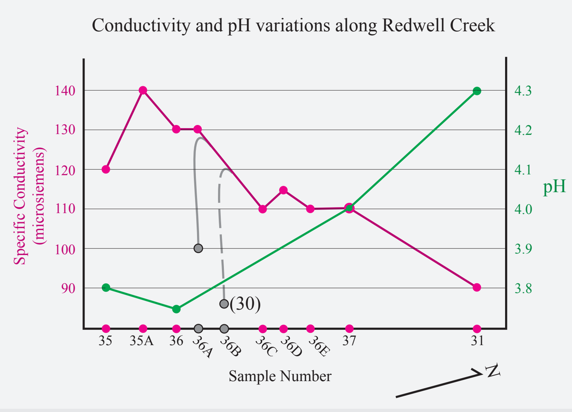
(C on the location map at left)



(Geologic base by Gaskill and others, 1968)

The Mount Emmons study area in southwestern Colorado consists of a structural duplex, similar to that found in the Osgood Mountains (above left), but in a mirror image. The principal bounding faults are NE-trending, left stepping faults with a left lateral sense of offset. Within this area, the Redwell Basin provided an interesting focus for detailed study. At the head of the basin lies an undeveloped Mo-porphyry deposit, which lies directly below the brick-red areas on the geologic map at left. Redwell Creek flows to the NNE, obliquely crossing a series of stepover faults and fractures. Chemical data from Redwell Creek shows progressive dilution of acidic, metal-rich waters as the creek crosses the stepover structures.

This photograph was taken from the point marked with the blue dot on the geologic map, looking southwest towards the headwaters of Redwell Creek. This alpine catchment basin has extremely high relief (average slope is about 0.3). Samples were collected along Redwell Creek at the locations shown in pink dots on the above map.



The pink and green lines on the graph at left show variations in pH and conductivity along Redwell Creek (downstream from left to right). Ground-water discharge near site 35A increases the conductivity and decreases the pH of the creek. Then, progressive dilution by springs such as those found at sites 36 A and B leads to dilution of Redwell Creek. These springs coincide with the location at which Redwell Creek crosses the primary stepover fault in the structural duplex. We propose that this north-trending fault is an open conduit for the flow of short-residence time meteoric water, which has very low conductivity compared to the other waters in the basin.

References:

Gaskill, D.L., Godwin, L.H., and Mutschler, F.E., 1967, Geologic map of the Oh-Be-Joyful quadrangle, Gunnison County, Colorado: U.S. Geological Survey Geologic Quadrangle Map GQ-578.

Hotz, P. E., and Willden, R., 1964, Geology and mineral deposits of the Osgood Mountains quadrangle, Humboldt County, Nevada: U.S. Geological Survey Professional Paper 431.

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