Westwater Canyon

A Geologist's River Guide

With a Focus on Precambrian Rocks

by Wil Bussard

In the fall of 1998, CPRG conducted a volunteer science trip through Horsethief, Ruby and Westwater canyons. It was an eight day trip attended fully, or in parts, by Wil Bussard, Tamsin McCormick, John Dohrenwend, Paisley, Greg Trainor, Earl Perry, Bob Parker, Michael Milligan, Steve Young, Dusty Simmons, John and Susette Weisheit, and Joe Keys. Outfitting assistance was provided by Adventure Bound, Tag-A-Long, Canyon Voyages and Kyler Carpenter. The following is a geology report from that trip and is gratefully provided to the CPRG membership for their use and enjoyment.

The Colorado River in Westwater Canyon cuts down through Mesozoic sedimentary rocks, across The Great Unconformity and into Precambrian metamorphic and igneous rocks of the continental basement. Precambrian rocks in Westwater Canyon vary along the run of the river from coarse-grained igneous at Black Rocks and Miners Cabin to high grade metamorphic at Little Hole and Cougar Bar, and lower grade, layered metamorphic at Big Hole. These rocks are part of a "Migmatitie Complex": a deep crustal intrusion of magma, which cooled in an actively deforming environment. Layered schist and gneiss from Cougar Bar to Big Hole reflect the original sedimentary rocks, which were cut by basalt dikes and regionally metamorphosed prior to the intrusion of granitic magma at Black Rocks and Miners cabin.

The purpose of this writing is to point out that not all the "black rocks" are the same, and to provide some general geologic information.

Mesozoic sedimentary rocks are briefly described from Loma, CO to Cisco, UT and have been written up extensively by Don Baars and other authors. These sedimentary strata are laterally continuous across large portions of the western U.S. They vary in thickness and taper out in response to the changing paleotopographic shape of the continent and intracontinental basins through geologic time. They hold a long variety of fascinating history, much like the pages in a book.

This text is prepared in conjunction with Belknap's *Canyonlands River Guide*, with the intent that the reader will use this guidebook and refer to the mileage, landmarks, geologic time scale and stratigraphic column within for a more direct complete and effective understanding of the matters at hand.

<u>Loma boat ramp</u>

Recent river gravel in the upper parking lot are deposited unconformably on the Cretaceous Lower Mancos shale (85 m.y.) [million years ago]. The Mancos is dark gray to black, high in organic carbon and in many places a source rock for economic hydrocarbon deposits in sandstones above it (like the Roan Cliffs and San Juan Basin). It was deposited in an oceanic environment and in places contains marine fossils (oysters and ammonites, for example). The Mancos Shale is named for Mancos, Colorado. Formations are usually named for the first place, the type locality, where they were identified as a unique set of rocks.

The Cretaceous Dakota sandstone (90-98 m.y.) outcrops on river right about 1/2 mile down river [151.5]. This off-white sandstone was deposited in a coastal plain/ beach environment and stretches from New Mexico to the Dakotas. It is a porous, permeable rock and often a good reservoir for oil and gas. In various places in the Four Corners it has a basal coal layer or a coarse conglomerate named the Burro Canyon (Cedar Mountain) Formation (Fm.). Coals are formed in swamps and the Burro Canyon Fm. is a continental (non marine) river deposit.

The Jurassic Morrison Fm. (138-160 m.y.), in the slopes to river right, is not well exposed at river level. This extensive set of varicolored shales, sandstones and conglomerates tells the story of infilling a large continental basin, which stretched from Nevada to eastern Colorado and Arizona to Canada. Dinosaur fossils are found in the Morrison Fm. near Moab, Utah.

The Jurassic Entrada sandstone (180 m.y.) is off-white and meets the river at about mile 151, followed in quick succession by the rose pink to red Kayenta Fm. (200 m. y.) and the orange Triassic Wingate sandstone (210 m. y.). The Entrada and Wingate sandstones are both remnants of sand seas (Sahara desert type environments). Note the high-angle cross-bedding typical of windblown (eolian) sandstones. The intervening Kayenta Fm. consists of these eolian sand grains reworked into stream and river deposits, and suggests a period of climate change. The Kayenta is not as laterally extensive as the Wingate or Entrada formations and is restricted to a sub-circular area around Four Comers.

These Early Mesozoic sandstones are among the most dramatic rocks in the western U. S. Much of the good rock climbing in Canyonlands (Supercrack, Castleton, Six Shooter Peak) is in the hard, orange Wingate sandstone. The Entrada is present throughout the area as well. At first glance many people do not see much difference between one sandstone and another. Differences become clear when one views the details of these rocks, both in (1.) large scale; outcrop appearance (is it massive, blocky, cliff forming?, how big are the cracks in it?, things like this), and (2.) small scale; grain size and shape, is it clay, sand, clear quartz?, are there fossils?

The Entrada is very fine to fine-grained, very well rounded, has a sugary texture and calcareous cement, it often has a red orange lower member and an off-white to tan upper member. These characteristics are consistent in the Entrada from Wyoming to Mexico and Nevada to Colorado. It commonly erodes as massive slickrock domes, with high angle cross bedding, typical of sand dune deposits, it is very well-sorted (consistent grain size).

The Kayenta is rose pink to red, throughout the deposit, on the Dolores River, in the town Kayenta, in Glen Canyon and here. Color is not always a consistent characteristic, but in some cases it is. The Kayenta is horizontally bedded and ledgy, typical of stream deposits, has blocky splitting and occasional freshwater limestone lenses of sabkha lakes (like the small ones in the White Sand Dunes in southern New Mexico). The grains are well-rounded and well-sorted, some are frosted; they are eolain (windblown) grains reworked in stream deposits.

The Wingate is orange-orange-orange all through the West! It is medium-grained, very well-rounded, well-sorted, non calcareous, and has beautiful cuspate, interlocking grain boundaries surrounded by secondary quartz overgrowths which look like ice crystals with a good magnifier. It is massive and cliff forming, with high-angle cross-bedding, blocky splitting and forms excellent dihedral cracks.

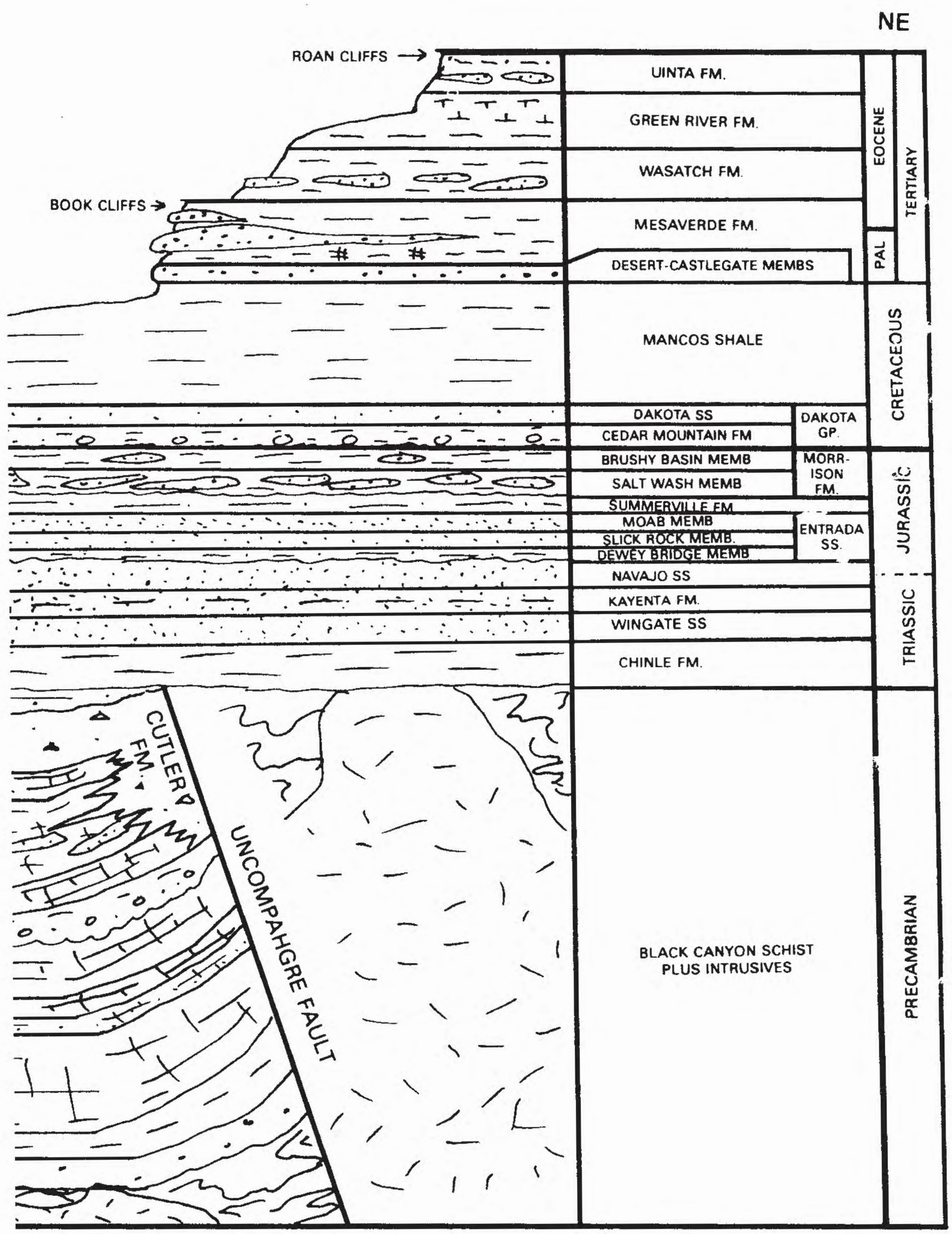
The missing Navajo sandstone is worth noting. It's absence is due to (1.) it was never deposited here, or (2.) it was eroded off between 200 and 180 m.y. It stretches from Wyoming to Mexico and forms Checkerboard Mesa at Zion National Park. It erodes into slickrock domes (Slickrock Bike trail) and with a magnifier has a conspicuously bimodal grain distribution of fine and coarse, round, clear grains. This unique bimodality exists in the Navajo sandstone in Wyoming, Utah, Arizona, and on the Mexican border. The Navajo is an important oil and gas reservoir in places where hydrocarbon source rocks exist beneath it.

Continuing downsection are red beds of shale, siltstone and sandstone in the Triassic Chinle Fm. (210-215 m.y.). The Triassic is the first period of the Mesozoic Era and also records the first appearance of biped dinosaurs. The Chinle was deposited in continental swamps, streams and rivers. It extends from Wyoming to Mexico and Nevada to Colorado. The source of the Chinle continues to be debated; somehow a doming event in the south and in the west, preceding Jurassic subduction, volcanism and mountain building, occurred. Scattered data for this doming exists in the dismembered mountain ranges in Arizona and Nevada. Some workers have discovered paleocurrent data suggesting a source in Oklahoma (the ancient Ouachita Uplift revisited?). The Ancestral Rockies existed in some form right here in the Westwater area and likely provided a source for some of the red beds. We see this at Moore Canyon, where you can actually stand on the surface of the Uncompahgre Uplift and the Ancestral Rockies with the feather edge of the Permian Cutler Fm. coming off the uplifted Precambrian granite and the Chinle Fm. overlying this paleosol.

Sedimentary rocks record geologic history and tell us about paleoenviromnent (beach, swamp, river), paleolatitude, tectonics of the continent and the development and breakup of Pangea. Bentonite clays in the Mancos Shale attest to Cretaceous volcanism. Granitic clasts in the Cutler are derived directly from the Ancestral Rockies, and volcanic detritus in the Chinle and Morrison formations tell us of distant volcanoes.

Precambrian Rocks

Precambrian rocks are generally more complex than younger rocks. They are often highly metamorphosed and have been subjected to a longer and more involved geologic history. Time and history are cumulative, building up layer upon layer, thus every tectonic, magmatic and erosional event that has taken place through time has changed the existing Earth's crust on which it occurred. One of the biggest problems with Precambrian rocks is that the exposure is very limited, in most places they are covered by younger rocks. Outcrops are sporadic and sparse. In the Four Comers region, only a few exist: Westwater, Unaweep, Grand Canyon, and that is about it. Further afield and off the edges of the Colorado Plateau good exposures exist in the Transition Zone of central Arizona, the Rio Grande Rift Valley, the San Juan Mountains and scattered outcrops, north and west of the Plateau in Utah.



Stratagraphic column from Northern Paradox Basin and Uncompahgre Uplift, Grand Junction Geological Society, 1983. Note: In Westwater Canyon, Navajo sandstone is missing.

The Great Unconformity

The Great Uncomformity at the contact of the ancient Precambrian and overlying younger rocks exists throughout the North American continent as a sub-horizontal line of great mystery. It represents an absence of geologic history in our area of 1.1 to 1.8 billion years! In the Grand Canyon there are places where 1.7 billion year old rocks are overlain by 570 million year old Tapeats sandstone. In the San Juan Mountains the unconfonnity is more variable and exists between rocks of 1.8 to 1.4 b.y. and overlying rocks ranging in age from 520 to 23 m.y. Continental tectonics have been more active in the San Juan Mountain area throughout post-Precarnbrian time than in the Grand Canyon region. Observations at the contact guide us to understanding various aspects of regional tectonics (mountain building, basin development, faulting) that have occurred since the Precambrian, but there simply is not information available for geologic history during most of the time from 1.4 b.y. to 570 m.y.

Here in Ruby and Westwater canyons, the Great Unconformity spans from the 1.7 b.y. "black rock sequence" to the overlying 220 m.y. old Triassic Chinle Fm., a gap of 1. 5 billion years! In Moore Canyon at mile 135.5, there is incipient soil formation into the Black Rocks, overlain by the Chinle Fm. This red paleosol may be the very feather edge of the Permian Cutler Fm. (270 m.y.) and is a very interesting field stop for geologists; one can see the breakdown of granitic rocks, weathering of feldspar and mica and the development of paleosol all "frozen in time" by the overlying Chinle Fm. and Wingate sandstone.

Nearby exposures

The longest and most continuous exposure of Precambrian rocks in the southwest USA is across the transition zone of central Arizona. Seven distinct "blocks" of Precambrian rock have been identified as separate entities that were accreted and sutured together during the growth of the earliest continents, specifically proto-Pangea (Anderson, 1989). The geologic history of the Precambrian underpinnings of present-day North America is described as an accretion of volcanic island arcs, undersea volcanoes, beaches, micro-continents, and terrestrial sedimentary deposits. Apparently the convergence was from the southeast towards the northwest as seen in present-day North America. The Wyoming Suture Zone has this same southwest to northeast trend, orthogonal to convergence, present in the central Arizona blocks. A write up of these details is found in *Arizona Geological Society Digest* #17, "Geological Evolution of Arizona."

Precambrian in Westwater

Precambrian rocks in Westwater Canyon consist of coarse, crystalline, granitic rocks (Black Rocks, Mile 136 and Miners Cabin, Mile 124) intruded into a pre-existing crust of high to low grade schist and gneiss, amphibolite, augen gneiss, garnet-bearing schist, granulite and garnet granulite (Mile 124 - 114), and intermittent zones of well developed migmatites (Mile 122-12 1). Similar rocks outcrop in lower Grand Canyon, the Upper Animas Gorge, Black Canyon of the Gunnison and Unaweep Canyon.

In efforts to understand this complex geology we look towards the literature; studies from other areas and the interpretive models. Precambrian rocks exposed in Westwater Canyon appear to fit genetic models for migmatite complexes defined by Haller, 1971: a deep crustal intrusion cooling slowly under pressure in an actively deforming environment. The migmatites are generated as "mixed rocks" in Hallers' "Zone of Detachment" between the infrastructure (intrusion) and the superstructure (wallrock) (see diagrams 19-28, 19-30). Continued upwelling of the hotter, more bouyant magma creates more interaction, in this zone, as the overlying superstructure is partially melted, metamorphosed and deformed. The following text briefly describes the Precambrian rocks along the Colorado river from Loma, CO to Cisco, UT and a concordance of these rocks with Haller's models.

Infrastructure

Coarse crystalline granite with a pronounced alignment of crystals is the intrusive rock in Rattlesnake Canyon (Mile 149), at Black Rocks and Moore Canyon (Mile 136-135), and at Miners Cabin (Mile 124). Orthoclase crystals are euhedral (well-developed crystal faces) and often elongate and quite large. The bigger ones are 1.7 cm. x 6.5 cm., with an elongation factor of four. They exhibit pervasive alignment along azimuth 340 ± 20 degrees. Elongation beyond typical feldspar crystal shape and preferred alignment strongly suggest emplacement of the intrusion into a tectonically stressed environment or cooling of the intrusion in an environment of non-uniform stress. The long axis of crystals grows preferentially in the direction of least pressure. Crystals align with long axes perpendicular to principal stress as the magma cools.

Other possibilities exist, that might explain alignment of crystals in igneous rocks, but these concepts do not fit the outcrop and petrologic relationships as well as cooling within an actively stressed environment. (1.) Alignment of crystals can result from flow within a convecting magma body or in an actively intruding body: This does not fit the outcrop because (a.) the crystals are very large, requiring a long cooling time and as convection and movement occur in an igneous body, the directions of flow change through time, (b.) The alignment is pervasive (consistent throughout). Crystal alignment due to flow is not homogenous across large areas, convection is spherical; hot zones, dikes and sills, flow in accordance with their [irregular] boundaries. There is no good evidence for flow. (2.) Alignment may result from later metamorphism: If this were the case we would see alignment of other minerals in the granite, especially mica (at the lowest temperatures) and this is not here. [Plagioclase feldspar, quartz, muscovite (silver) and biotite (black) mica, and hornblende are also present in this granite]. (3.) Filter pressing of crystals against the wall of an intrusion can produce alignment: If this were the case we would see variations in abundance of crystals across the outcrop(s), and we would see at some place in the outcrop a change in orientation of crystals.

Thus, the most likely scenario is cooling within a tectonic environment with principal stress oriented perpendicular to the long axes of crystals. This also fits outcrop data at adjacent stops and the big picture concepts which may be invoked to explain the entire package of Precambrian rocks and other outcrops regionally (Unaweep, Grand Canyon, San Juan Mountains).

Zone of Detachment

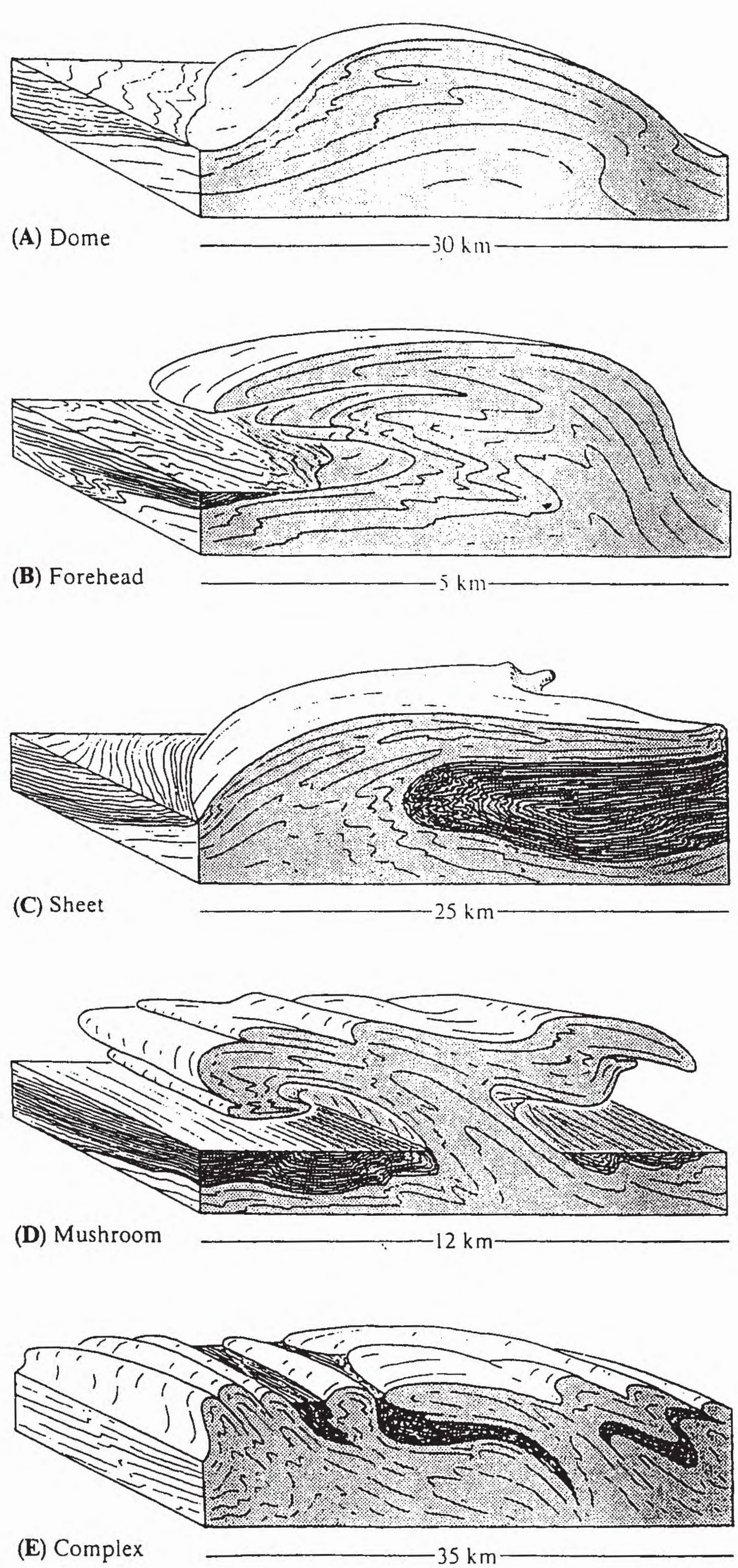
Migmatites are very unusual rocks and contain contrasting mineral assemblages, which appear to have been mixed in a semi-molten state. These are the highly contorted, pink, white and black rocks at Little Hole and up Little Dolores Canyon (see river guide section). Migmatites were not understood for a long time and still present a lot of physical-chemical type problems for those who study them. They are really weird rocks. The only viable explanations put forth involve mixing under multi directional and shear stress at relatively high pressures and temperatures, with perhaps long time intervals. Mechanisms of partial melting are invoked to explain the presence of conflicting mineral assemblages. Textural observations in the rocks support all this, Haller's models (figs. 19-28, 19-30) were based upon field observations in Greenland (and other locales) at outcrops on enormous cliff faces which cut across all three zones in one place. The Colorado River in Westwater Canyon cuts through a similar situation and migmatites also exist in other 1.7 billion year old rocks elsewhere in the western U.S. Perhaps it is not all that uncommon in the deep crust. Geologists in the Grand Canyon describe migmatites and those rock are similar to these at Westwater.

The migmatites are intermittent, oddly-shaped zones of complexly mixed quartz-rich granitic rocks (low temperature) and ultramafic amphibolite rocks (high temperature). The migmatites here are somewhat abundant, and they are really beautiful. These zones pinch and swell, presumably in response to higher and lower pressure areas within the deforming, strained crust. They appear to mix on a fractal scale, from exceedingly fine (centimeters or less) to coarse (meters). Zones are from one half a meter to 5 or 10 meters wide and perhaps as long as ½ mile.

These are the exact zones of detachment and they vary in shape in response to folding and buckling in the infrastructure below and the superstructure above, mixing and deforming, partly granite and partly re-baked metamorphic rocks. Ductile deformation and rock type constrain the depths of occurrence, this is a deep crustal phenomenon.

Superstructure

The pre-existing superstructure was apparently a sequence of sedimentary rocks; shales, sandstones and sandy limestones, intruded with basalt dikes and sills (Mile 122-114). Sedimentary rocks were regionally metamorphosed into garnet-bearing schist, and high and low grade schist and gneiss of the granulite facies. Basaltic intrusions cut the sedimentary rock parallel to layering and across layering and were metamorphosed into amphibolites. Coexistence of these two facies narrows temperatures to between 600 and 700 degrees Celsius and pressures to between 3 and 8 kilobars (10



Types of infrastructure upswellings. From J. Haller, copyright 1971, *Geology of the East Greenland Caledonides* (New York: Wiley Interscience), Fig. 64. Reprinted by permission of John Wiley and Sons, Ltd.] Ehlers and Blatt, 1985.

to 20 kilometer depth) (Ehlers and Blatt 18-1).

This early metamorphism occurred before the intrusion of the granite, as evidenced by the presence of xenoliths (inclusions) of amphibolite gneiss in the granite at Moore Canyon. Layered metamorphic rocks occur at a scale of one to ten meters, and this layering is more pronounced and better exposed and preserved, partly due to a lesser metamorphic grade further down river away from the intrusion and detachment zone, from Big Hole to Big Horn (Mile 116-114).

Near and adjacent to the granite the rocks are high grade banded gneiss, granulite, greenschist and amphibolite and commonly contain large red garnets to 1.5 cm, bladed hornblende to 5 cm, and abundant sheet biotite. In a few places, hydrothermal deposits occur in these rocks. Rocks in Little Dolores Canyon contain a fibrous, soft white mineral sillimanite (?). This unique occurrence of "spot rock" may have been due to ex-solution of water from the intrusion into wallrock. Hydrothermal alteration and epithermal quartz are present in hot springs deposits in the area of a small prospecting and surface operation at mile 123, just down river from Miners Cabin. One of the drill sites appears to have targeted a hot springs deposit within the metamorphic rocks. This box-like network of veinlets is where hydrothermal fluids cooled into microcrystalline quartz. This type of environment is occassionally a site of metal deposition. This operation also appears to have targeted a chloritized fault zone and a rose quartz pegmatite with exploratorv drilling.

Rocks outcropping farther away from the intrusion are somewhat lower grade and less disturbed by the deformation at the interface of the intrusion and zone of detachment. Pelitic schist are interbedded with metagraywacke and biotite and garnet schist on a scale of one to six meters at Big Horn. Foliation parallels larger scale layering, suggesting foliation development parallel to original bedding. Textures in the metagraywacke (impure quartzite) suggest relict bedding and this also parallels layering and foliation. Rotational structure in garnets is rarely found and depicts shear stress during crystal growth. Foliation parallel with bedding is neither required nor uncommon. Bedding planes between different rock units can act as free surfaces and partition or re-orient strain. The more numerous the bedding plane contacts are, the more strain is re-oriented perpendicular with bedding. Often foliation in metamorphic rocks cuts across original sedimentary bedding planes, but here foliation is parallel with layering and perhaps bedding.

Protoliths

Protoliths (rock prior to metamorphism) for the present metamorphic rock are proposed in accordance with chemical, physical and textural constituents in the rocks as follows:

Metagraywacke (impure quartzite); protolith; sandstone, perhaps graywacke. This rock consists mostly of clear, fine to medium, subangular quartz grains, some of which fall off in your hand (and 10% biotite). It has not been metamorphosed to a high grade (lower granulite). Chemically, it did not change much; it was sandstone it is now quartzite. It is found at mile 114, farthest from the intrusion.

Pelitic schist; protolith; shale. These occur throughout "superstructure" rocks, from Mile 123-114. Grade and size of garnets is roughly the same throughout. They contain abundant biotite and chlorite, 0-25% quartz, segregated into lenses and eyes, some layers have 25% actinolite, garnets are present in some layers and not in others. commonly garnet, quartz, biotite and $\pm$ actinolite are intergrown together in layer parallel, irregular masses. Variations in mineralogy from unit to unit in the section, depict variation in original abundance of elements (iron aluminum, calcium) in the shale protolith.

Garnet granulite; protolith; calcareous sandstone/ shaly sandstone/graywacke/arkose. Abundant clear and opaque, coarse angular quartz, big and small garnets, chlorite, biotite, and overall large grain size suggest an impure clastic rock; a dirty sandstone, perhaps like the sandstones in the Cutler Fm., or a marine graywacke.

Amphibolite; protolith; basalt. Chemically, basalt goes directly to amphibole with metamorphism. Outcrop relationships show amphibolites crosscutting and paralleling layers. These were dikes and sills of basalt prior to metamorphism. Crystal size ranges from 1 x 20 millimeters to a whopping 30 x 60 millimeters at Cougar Bar. Some of these are pure hornblende, others have some red garnets and up to 30 % biotite.

Conclusion

The occurrence of Precambrian rocks found here fits into existing genetic models of migmatite complexes, developed at depth. The mineral assemblages and structural observations at the igneous contact and migmatite zones also support this. The infrastructure of coarse granite is seen at Black Rocks and Miners Cabin. The contact of the intrusion is irregular and visible at Cougar Bar, right at Mile 122. It is an intrusive contact with pegmatites sweating out of the granite, xenolithic inclusions of amphibolite gneiss in the granite, structural deformation; boudinage and augen gneiss. Within a mile of the contact, at Little Hole (river right, Mile 121.2), well-developed migmatites of Haller's "detachment zone" occur. Further down river, at Big Hole and Big Horn (Mile 116–114 on river right), higher levels of the superstructure are found, consisting of lower grade garnet-granulites and intervening pelitic schists, all cut by amphibolite dikes and sills.

The intrusion at Black Rocks was emplaced into a "typical" sedimentary section of shale and sandstone that was crosscut by basalt dikes. Deformation with cooling occurred and distinctive zones of migmatites formed at the interface of the intrusion and the pre existing crust.

Acknowledgments

All of the diagrams here are from *Petrology: Igneous, Sedimentary and Metamorphic* by Ehlers, E.G. and H.

Blatt, published by W. H. Freeman and Company, 1982, San Francisco, CA. References appearing on these diagrams refer to the original literature. Belknap's *Canyonlands River Guide* was used for mileage and is suggested as a supplement to this writing.

The knowledge presented herein came from (a.) *Petrology* by Ehlers and Blatt, and (b.) Anderson, 1989, in Penney and Reynolds; *AGS* #17, "Geologic Evolution of Arizona," (c.) verbal communication with river geologists Brad Ilg, Andre Potochnik and Tamsin McCormick.

Field work was made possible through an 8-day river trip sponsored by the Colorado Plateau River Guides in October, 1998. Special thanks to John and Susette Weisheit, Tamsin McCormick, Dusty Simmons and T. Berry, and the other trip participants, for the excellent guiding and great good fun.

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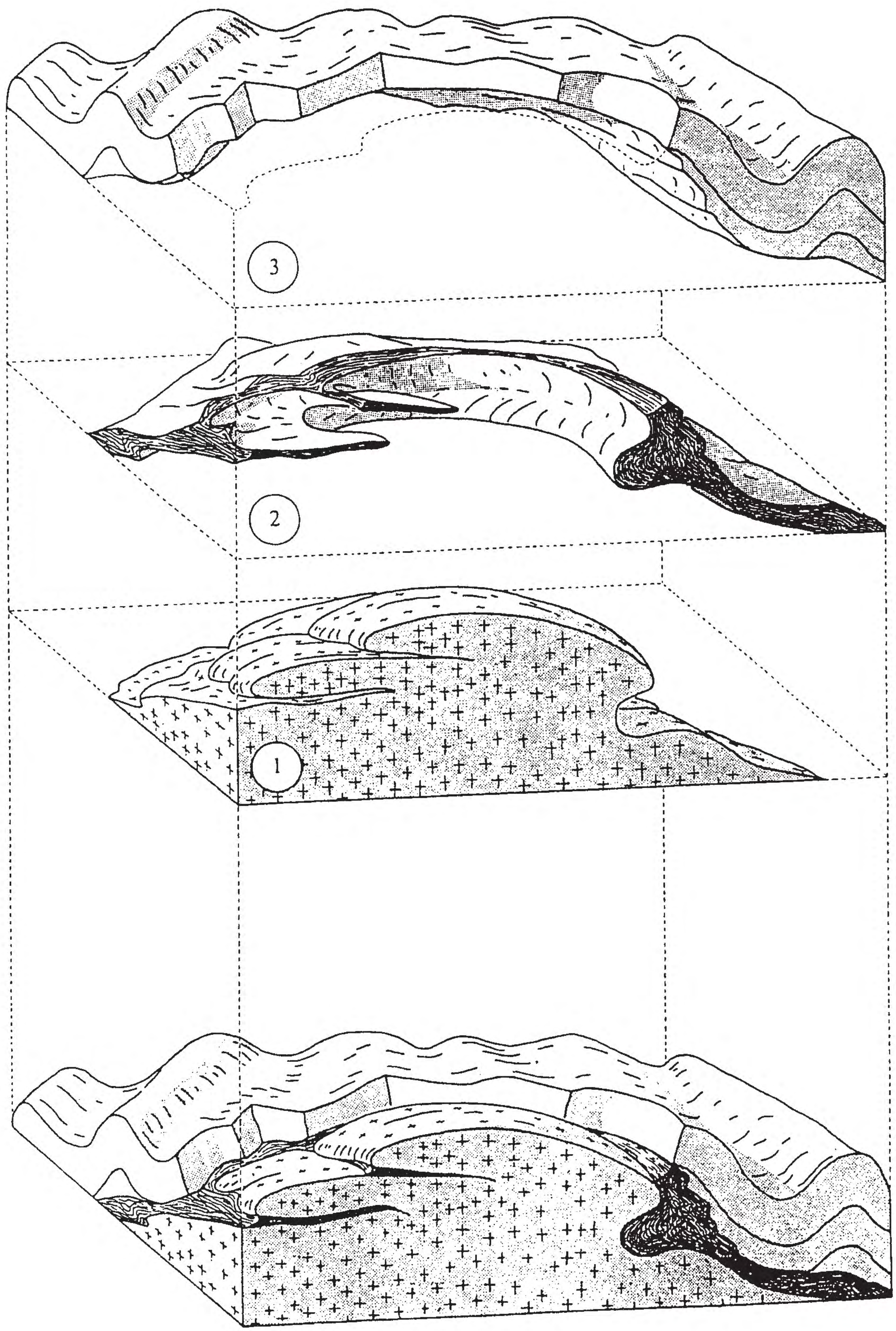


Three-dimensional representation of a migmatite complex in exploded view. Zone 1 is the granitoid basement portion of the infrastructure. Zone 2 is the zone of detachment, a portion of the infrastructure attached to the granitoid basement. Zone 3 is the weakly deformed and detached overlying superstructure. [From J. Haller, copyright 1971, *Geology of the East Greenland Caledonides* (New York: Wiley Interscience), Fig. 51. Reprinted by permission of John Wiley and Sons, Ltd.] Ehlers and Blatt, 1985.

RIVER GUIDE

Precambrian rocks along the Colorado River from Loma, CO to Cisco, UT Westwater, Ruby and Horsethief Canyons Using Belknap's *Canyonlands River Guide*

by Wil Bussard

INTRODUCTION

I left out the sedimentary rock from this section, you can find the descriptions and initial mileage in the first 2 pages of the accompanying text. This guide is really about Precambrian rocks.

Mile 149

Rattlesnake Canyon, small landing on river left. Up the canyon the Bull Canyon Fault brings Precambrian rocks up against Mesozoic sandstone, some small fault structures; poorly developed tectonites, conjugate shears with fault growth calcite steps. Precambrian rock here is granite with big and small crystals, similar to Black Rocks and at Miners Cabin.

Mile136-135

Moore Canyon/Black Rocks, river left, this is a great stop. The Black Rocks exhibit excellent fluting in the river. The rocks are granite with large crystals to 7 cm long and pervasive alignment. Up the canyon, an excellent hike, (a.) xenoliths of amphibolite gneiss in the granite, (b.) zones of larger, strongly aligned and discordant crystals (perhaps incipient pegmatite or the result of flowage after cooling and fracturing of the magma? who knows, they look like a bunch of cars all trying to get on the L.A. freeway at once.). (c.) The big happening here, along with the best outcrop of granite is that you can stand on the surface of the Ancestral Rocky Mountains, and there is a paleosol developed into this surface and on it. This paleosol. is (d.) the feather edge of the Permian Cutler Formation. It is centimeters thick here and hundreds of feet thick at Hittle Bottom, not far down river in Professor Valley. The Ancestral Rockies are one of the really big things that happened here, 300 million years ago, and the basin created when this mountain range was thrust upon the continent to the southwest is called the Paradox Basin and is a major oil and natural gas reservoir, with thousands of feet of fossil-bearing limestones, shales, evaporite minerals and hydrocarbons. Take a deep breath and imagine yourself, while you stand, on this uplifted surface looking down to the southwest over a vast Paleozoic sea filled with trilobites and bony fishes, eurypterids and sharks. Four-footed reptiles roam through the tropical Ginkgo forest, knocking over trees and making babies (there are no upright dinosaurs yet). There are no birds in the sky, just the warm, sultry tropical Paleozoic sun, shimmering off the surface of the Paradox Sea. There are no Wingate sandstones, no Chinle or Morrison formations above you, just you and the phenocryst-rich ancestral Rocky Mountains standing in the sun.

Mile 125-123

Miners Cabin, river left, another good stop. This is where we begin to see the interaction of the intrusive granite (from Black Rocks) and the existing crustal rocks into which it was intruded as magma. Note and investigate the variety of rocks here, they are described in the preceding text. The granite is no longer the only rock here, also present are schist and gneiss. There is a mining claim on the south part of this bench area. It is not legal to trespass on some mining claims and most miners do not like at legal or not [the claim now defunct]. There are some interesting rocks back up in there, but not largely different from other stops in this guide. Apparently they are placer gold from the river gravel on the surface of the bench here. There is a USGS document out describing placer along this section of river. It is doubtful that anyone is getting rich here and it is not advisable to mess around on the claim area.

Mile 122-121

Cougar Bar, river right, excellent outcrops on river particularly as you round the comer to lower Cougar Bar and Little Hole. (a.) The intrusive contact into the crustal metamorphic rocks is visible in the cliffs at river right, note the stoped-out blocks of wallrock and the irregular nature of the contact. (b.) Layered metamorphic rocks 100 yards down river from this contact are worthy of investigation (for rock heads). Here you will find the biggest and best of the amphibolites; one linear body is composed almost entirely of two inch long, greenish black hornblende crystals, also garnet schist and granulite facies rocks are here, and biotite schist. These layered rocks are quite diverse and the layers may reflect original sedimentary rock units. These would be in Haller's "superstructure" (see text).

Mile 121.5

Little Hole, river right, excellent stop, small landing. Migmatites are here in the gully; a layered sequence of all kinds of cool metamorphic rocks; amphibolites, migmatites, schist, gneiss—wowie! The intricately banded pink, white and black rock that looks like taffy in the canyon bottom near the river really is taffy!, in the sense that it has been mixed and pulled around and swirled while hot. THIS IS THE MIGMATITE! This is Haller's Zone of Detachment.

Mile 121

Little Dolores Canyon; river left, good landing, okay geology stop, much of the same as what we have seen. It is hard to beat the rocks at Little Hole. Up the canyon there are some unusual, although not particularly pretty "spot rocks" with a white fibrous mineral that may be sillimanite, why is this here? Calcareous waters?, hmmmm. Migmatites are here as well.

Mile 121-116

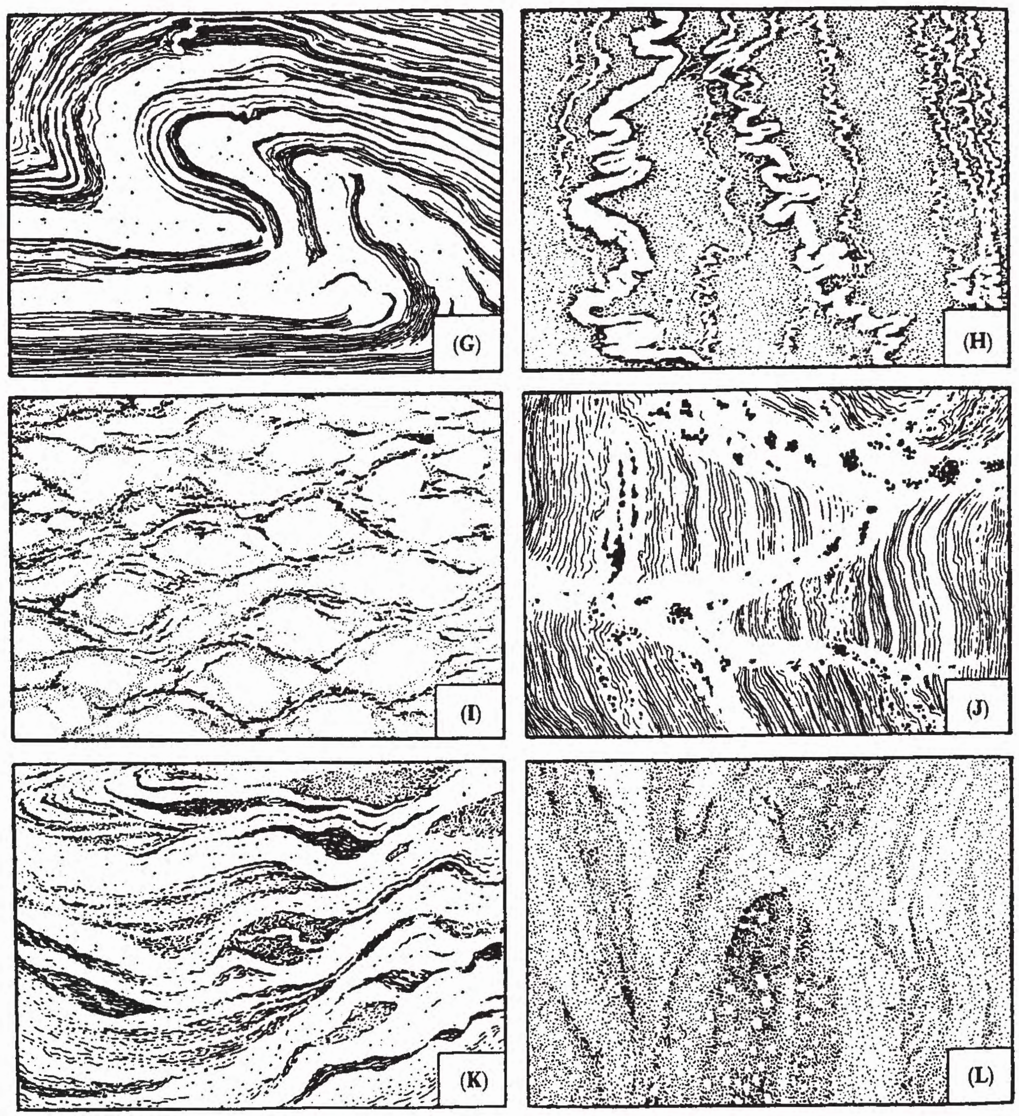
Unknown to this author. Guess I will need to return. It is kind of hard to stop here; narrow gorge, rapids, etc. Some of that at Skull Rapid looks like granite, I think, maybe it is gneiss. I forgot to look at the rocks here.

Mile 116-114

Bighole to Big Horn, river right, excellent stops and you can hike between them. This is the Superstructure of metamorphosed sedimentary rocks and they range from meta-sandstone or low grade quartzite to garnet-granulite and amphibolite. This is a really good place to investigate the layered metamorphic rocks and observe mineralogical changes from layer to layer. These changes probably represent the differences between shales, sandstones and calcareous siltstones in the original sedimentary rocks prior to metamorphism 1.7 billion years ago. That's right, this was an ocean back then, with mountains and volcanoes and back arc basins, all smashing up onto the continent of Proto-Pangea, the original supercontinent.

Hope you like this and I hope to get back out there with you all again sometime! -- Wil Bussard

End



Typical structures in migmatites. The lighter areas are rich in quartz and feldspar; the darker portions are richer in mafic constituents. [From K. R. Mehhnert, 1968, *Migmatites and the Origin of Granitic Rocks* (Amsterdam: Elsevier), Fig. 1a, b.] Ehlers, and Blatt, 1985.