The Saguaro National Park (east) Mylonites, Ultramylonites, and Cataclasites: Evidence in Support of the Genesis Flood

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Abstract

Saguaro National Park (east) is located on the eastern side of Tucson, Arizona. It encompasses both the Tanque Verde Ridge and most of the Rincon Mountains. The park affords a wonderful opportunity to examine a relatively untouched desert environment dominated by Saguaro cactus. We examined the western portion of the Park (defined by the area along Loop Drive) to better understand rocks defined as mylonites, ultramylonites, and cataclasites. In Arizona, these metamorphic rocks are found in the Basin and Range province and are associated with metamorphic core complex mountains. The Saguaro National Park (east) provides an excellent setting to examine these unique shear-altered rocks and understand the processes involved in their formation. Our preliminary assessment indicates that tectonic processes formed these rocks during the Genesis Flood.

Introduction

Saguaro National Park is composed of two distinct areas on opposing sides of Tucson, Arizona. This article limits discussion to that portion of Saguaro National Park on the eastern side of the city, identified as Saguaro National Park (east) (Figure 1). Both the Tanque Verde Ridge and most of the Rincon Mountains are contained within the park. While only a small area is accessible by automobile, foot-trails cover much of the park. The visitor is presented with a beautiful desert environment dominated by the Saguaro cactus and a large variety of wildlife (Figure 2).

Geologists in the early 1970s realized that the rocks underlying this beautiful desert environment are somewhat unique. They are similar to shear-altered strata that occur in specific areas between southern British Columbia, Canada and northern Sonora, Mexico (Coney, 1980; Rehrig, 1986). These metamorphic rocks are identified as mylonites, ultramylonites, and cataclasites (see Appendix). Our preliminary investigation was limited to the area along the Loop Drive on the western side of the park (Figure 1). This area has previously been mapped and described by several geologists (Wright, 1978; Davis, 1980; 1987a; 1987b). Our findings are consistent with the tremendous geologic energy experienced by this region during the global Flood. Having studied granites and tectonic movement elsewhere (Froede, 1995a; 1998a) this region offered an interesting challenge to cast these strata into a young-Earth Flood framework.

Saguaro National Park (east)

Saguaro National Park (east) lies within the Basin and Range province in southern Arizona (Froede et al., 1997). According to Davis (1987a; 1987b) it is one of the finest locations in the world in which to recognize mylonites, ultramylonites, and cataclasites. These metamorphic rocks reflect the full range of shearing (i.e., ductile through brittle) thought necessary to explain the formation of these mylonitic rocks within the metamorphic core complex mountains (Davis, 1987a; 1987b). Examples of each rock type were readily apparent as we followed the Loop Drive around the western portion of the park (Figures 3 and 4). We were greatly aided by the Davis (1987a) field trip guide and supplemented it with additional stops and short hikes. Based on our fieldwork around Loop Drive, we offer an interpretation of the mylonites, ultramylonites, and cataclasites, including their formation and stratigraphic setting, within a Flood model.

Igneous and Metamorphic Rocks Within the Park

A variety of igneous and metamorphic rocks are found within the Saguaro National Park (east), including granite,

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Received 7 June 2002. Revised 25 October 2002

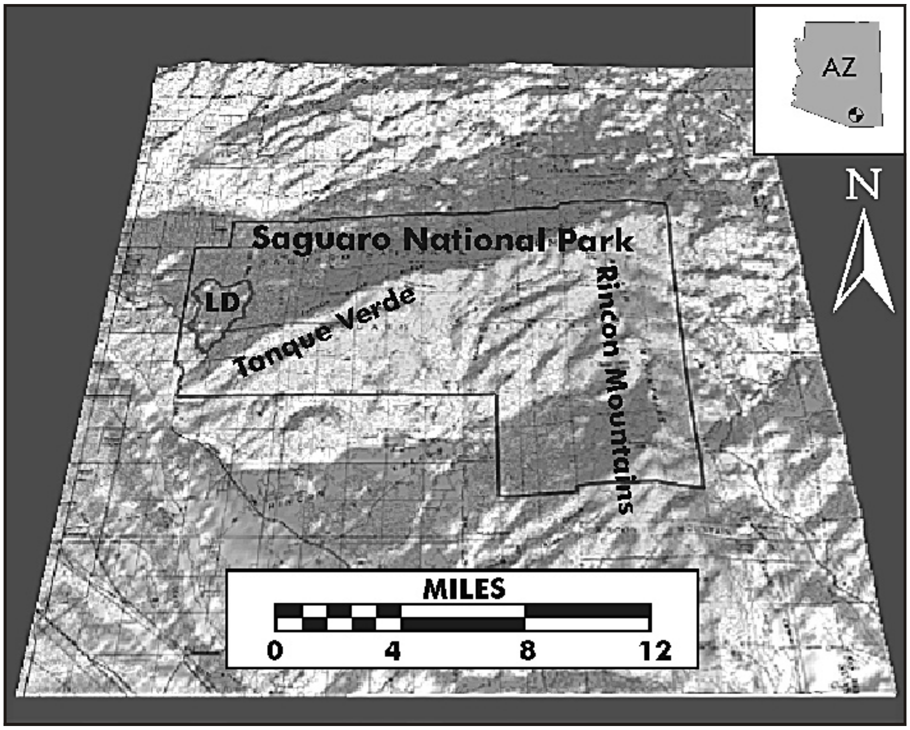

Figure 1. Topographic map showing the extent of Saguaro National Park (east). Note the Park encompasses the Tanque Verde Ridge and most of the Rincon Mountains. Our investigation was limited to areas adjacent to Loop Drive (LD). We found a variety of gneiss, mylonites, ultramylonites, and cataclasites consistent with the Davis (1987) field trip guide. Most of the Park lies within an area of mylonitization. Modified from the United States Geological Survey Tucson, Arizona Topographic Quadrangle using Maptech ©2001 software at 1X elevation.

gneiss, mylonized gneiss, ultramylonites, and cataclasites. Banks (1980, p. 185) describes the four principal rock units within the Park as:

> ...(1) generally light colored gneissic to mylonitic quartz monzonite and granite that intrude rocks as young as late or post-Mesozoic (Windy Point gneiss); (2) generally darker colored gneissic rocks derived mainly from Precambrian granitic rocks (granodiorite and quartz monzonite); and (3) black to tan mylonitic, blastomylonitic, and phyllonitic rocks also derived mainly from Precambrian Y granite rocks; and (4) undeformed granodioritic to granitic (mainly quartz monzonitic) rocks that likewise intrude rock as young as late or post-Mesozoic. The first three of these four main rock units are foliated, lineated, and intruded by abundant pegmatite dikes and sills, and together they comprise the bulk of the complex.

Keith et al. (1980, p.232), described the specific features and types of igneous and metamorphic rocks within the Park as:

> ...composed of muscovite-garnet-bearing granite. The granite commonly envelops a dark biotitic augen gneiss. Some parts of the granite have abundant pegmatite and alaskite. Both the granite and the dark augen gneiss exhibit the distinctive low-angle mylonitic foliation. This mylonitic gneiss complex is overlain to the northeast by metamorphosed and locally highly deformed younger Precambrian and Paleozoic rocks which become lower grade and less deformed up section. The western and southern boundaries of the mylonitic complex are—like those of the southern Santa Catalina forerange—highly jointed, brecciated, chloritized, and overlain by the Catalina fault, a dislocation surface which dips gently off the flanks of the range. The low-angle mylonitic fabric has been deformed into several broad west-southwest-plunging arches and one north-northwest-trending arch and is intruded by several north-northwest-striking undeformed dikes.

Mylonites, Ultramylonites, and Cataclasites

Mylonites, ultramylonites, and cataclasites found within the Park are metamorphic rocks that have been subjected to tremendous shear forces. The mylonitic gneiss exposed in the Park is so strongly layered that it resembles a thick stack of gently dipping sedimentary strata (Figure 4). However, upon closer inspection the variations in lithology are actually the result of penetrative foliation caused by shearing within the rock (Figures 5 and 6). On

Figure 2. Photograph of the Tanque Verde Ridge covered in desert vegetation dominated by the Saguaro cactus.

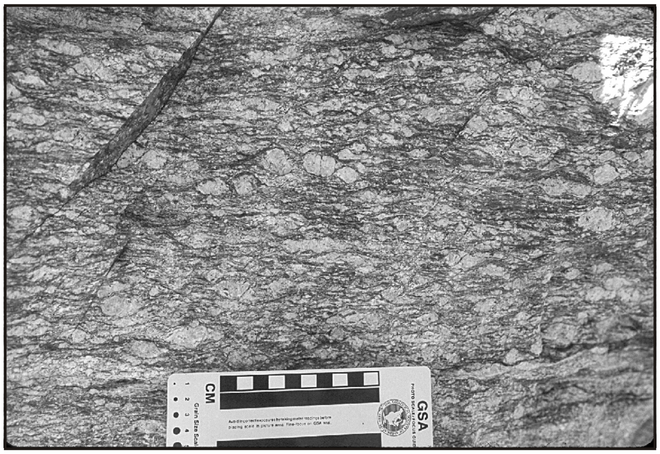

Figure 3. A typical augen gneiss. Note the large lenticular feldspar phenocrysts. Scale in centimeters.

Figure 5. Several layers of mylonized gneiss with pronounced fault boundaries.

average, the foliation gently dips 30° toward the Tucson basin. However, it is believed that the original foliation dip angle was as high as 45° (Davis, 1987a; 1987b). Mineral lineation of the quartz and quartz laminae found within the mylonites has a general orientation of N60°E–S60°W (Davis, 1987a; 1987b).

The origin of the shear force was likely due to the uplift and rotation of the original mountain-sized blocks caused by the injection of a leucogranitic melt into the overlying Precambrian granitic and metamorphic strata (Rehrig and Reynolds, 1980). Gravitational force acted on the uplifted block and created shear zones in its upper portion. The zone of mylonitization (i.e., shear zone) is believed to extend from the surface approximately 0.6 to 1.2 miles downward through the gneiss (Davis, 1987a). According to Rehrig and Reynolds (1980, p. 151):

> The mylonitic fabric formed by flattening perpendicular to foliation and extension parallel to the lineation. Strain ratios recorded in the mylonitic rocks of approximately 9:2:1 indicate that the amount of extension is significant.

Figure 4. Photograph showing layered mylonitic gneiss. Scale in six-inch divisions.

Figure 6. Photograph showing the layering of the mylonized gneiss. Note that a diabase dike is exposed on the right side of the exposure. These mafic features have largely been ignored in constructing models for metamorphic core complex mountains. They indicate a greater (and likely deeper) heat source associated with the granitic magmas. The six-inch unit scale is in front of the diabase dike.

The depth of uplift and cataclasis is believed to have originated from less than 1.8 to 3.7 miles beneath the former ground surface (Banks, 1980). However, Dickinson (1991) proposed a depth of mylonitic deformation in the range of 4.7 to 7.8 mi. Previously, depths were interpreted from 5 to 7.5 miles (Anderson et al., 1988), or perhaps even as deep as 9.3 miles (Anderson, 1988). Davis (1987a; 1987b) suggests that the mylonitization occurred from 6 to 7.2 miles below the surface. While Precambrian rocks are more deformed (ductilely and cataclastically) than the Tertiary-age gneiss, foliation and lineation in both were apparently formed in the same stress field (Banks, 1980).

Banks (1980) proposed that the tectonic event that formed the Rincon Mountains and Tanque Verde Ridge

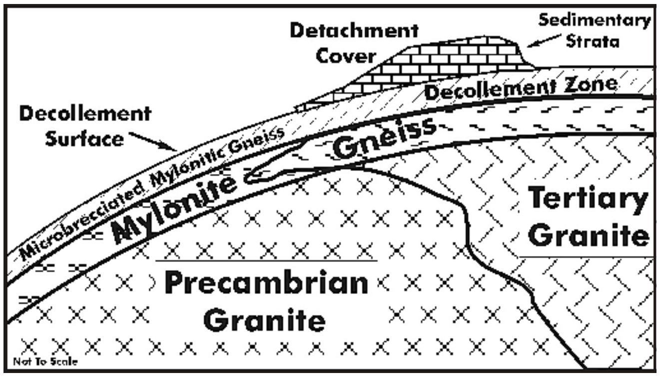

Figure 7. Diagram showing the conceptualized relationship between the various layers composing metamorphic core complex mountains—especially those found within the Saguaro National Park (east). Modified from Davis, 1987, Figure 3.

occurred during the middle Tertiary (20 to 30 m.y. B.P.), and Rehrig and Reynolds (1980) suggest a period from 25 to 15 m.y. B.P. associated with a period of widespread volcanism and plutonism outside the metamorphic core complex.

However, another interpretation has been offered by Keith et al. (1980). Using geochronologic methods, they identified three distinct suites of intrusions and accompanying deformations (Laramide, 75 to 64 m.y. B.P.; Eocene, 44 to 50 m.y. B.P.; and the middle Tertiary, 27 to 25 m.y. B.P.). A variety of age-dating methods were used to determine the ages of the various granitic, gneissic, and mylonitic rocks. This information coupled with trace-element analysis determined the lithologic and structural relationships of the rocks in an attempt to reconstruct the timing and events experienced by each intrusion and corresponding shear event. They proposed that:

> Much of the mylonitic (cataclastic) deformation of the plutonic rocks and recrystallization of the enclosing host rocks may be related to intrusion of the various plutons. At least three episodes of mylonitization (cataclasis) may be delineated by observing relations between mylonitic and nonmylonitic cross-cutting plutons (Keith et al., 1980, p. 218).

Anderson's (1988) work also supports three intrusive epochs involving 12 plutons and coeval mylonitization envisioned by Keith et al. (1980).

The timing and significance of the event(s) that resulted in the formation of the Tanque Verde Ridge and Rincon Mountains remain open to age-dating interpretation. However, geochronologic work conducted on rocks in the nearby Santa Catalina Mountains appears to support the injection of Laramide melts, but only two periods of mid-Tertiary mylonization (Force, 1997). Much remains unresolved in determining the timing and events that magmatic injection created in forming these sheared metamorphic rocks.

Metamorphic Core Complex Mountains

Most metamorphic core complexes are viewed as being derived from the middle crust and were eventually exposed by tectonic unroofing in an extensional setting (Krabbendam and Yardley, 2000). It has been proposed for the Tanque Verde Ridge and Rincon Mountains that approximately 20 to 30 m.y. ago there was *rapid* shedding of cover from the uplifting metamorphic core complex into adjacent basins (Banks, 1980; Drewes, 1977). Although several models have attempted to explain the formation of various metamorphic core complex mountains, none have proven successful on a broad scale.

According to Davis (1980), metamorphic core complex mountains can be defined by four distinct elements: (1) Igneous core, (2) Metamorphic carapace (i.e., decollement zone), (3) Decollement surface (i.e., detachment fault), and (4) Unmetamorphosed sedimentary cover (Figure 7). All four of these characteristics of metamorphic core complex mountains are found within the Saguaro National Park (east).

Core

The core is composed predominately of Precambrian quartz monzonite granite that has been penetrated in places by Tertiary quartz monzonite granite (Davis, 1987). Ductile normal faults are abundant in the core rocks and are always oriented perpendicular to mylonitic lineation (Davis, 1980). No matter the envisioned number of granitic magmatic penetrations, each event has resulted in some level of mylonitization. However, the last (mid-Tertiary) tectonic event resulted in the greatest level of intrusion by granitic melts along with the most significant levels of mylonitization.

Metamorphic Carapace

The strata within the metasedimentary carapace are metamorphosed to upper greenschist and amphibolite grade, are concordantly welded or plated to underlying crystalline rocks, and form a relatively thin sheet (Davis, 1980).

Davis (1987a; 1980) suggests that elevated fluid pressure is largely responsible for the zone of microbrecciation within the carapace:

> The nature of fracturing and the pervasive alteration records the role of fluids and fluid pressure in the fault-induced conversion of mylonites to microbreccias.

However, the extent that water played in the development of the detachment and emplacement of the core complex remains the subject of much controversy (Krabbendan and Yardley, 2000).

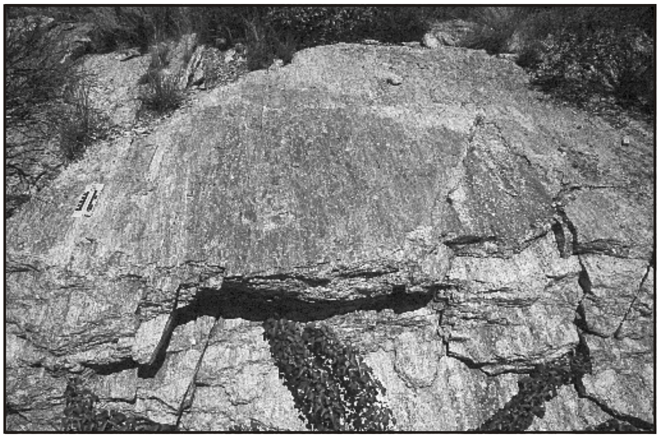

Figure 8. Photograph of the detachment (i.e., decollement) surface. Striations occur along the surface. The surface of the mylonized gneiss is also iron-stained, indicating the presence of water at the time of formation. Scale on left is in inches and centimeters.

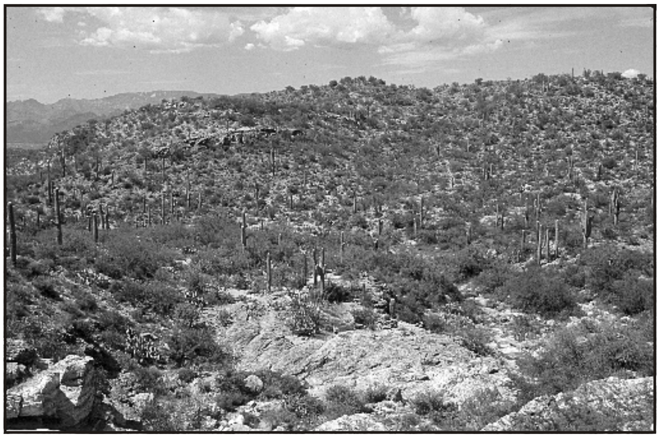

Figure 9. Large hill composed of sedimentary strata that has slumped westward toward the Tucson basin. The strata are contorted as a result of their lateral displacement.

A variety of shear related rocks can be found within the metamorphic carapace (i.e., decollement zone), including microbrecciated mylonitic gneiss, ultramylonites and cataclasites. The thickness of this carapace is likely a function of intense shear zone penetration as a result of the extensive lateral movement of the overlying rock.

Decollement

The boundary separating the mylonized rocks from unmetamorphosed strata is commonly a low-angle dislocation surface that develops within the gneiss (Rehrig and Reynolds, 1980). Movement within the fault plane then creates the metamorphic carapace. Striations along the top of the decollement surface confirm gravity-driven movement of the overlying sedimentary strata across this plane (Figure 8). According to Krabbendam and Yardley (2000, p. 670):

> The detachment fault and the underlying shear zone are the result of a progressive evolution. The deep and hot part of the shear zone (at a depth of 20 km [12.4 mi] or more) initially deforms in a very ductile manner, resulting in a wide zone of mylonitic gneiss. During further extension, the lower plate is pulled towards higher regions and brought against the cooler upper plate, Ductile deformation is localized in narrow shear zones, cross-cutting the mylonitic gneiss. Continuing extension cools the shear zone further and drags the rocks through the brittle-ductile transition; the ductile structures are locally overprinted by cataclasis and brecciation.

Sedimentary Cover

The sedimentary cover rocks have largely detached from the underlying basement rocks and moved under gravity toward the Tucson Basin (Figure 9). The fault contact between the bulk of the overlying sedimentary strata and the underlying mylonites is identified as the Santa Catalina fault. The trace of this fault extends from the southern end of the Rincon Mountains north and west across the Santa Catalina Mountains, a distance of 42 miles (Davis, 1987a). Most of the gravity-induced folding of the overlying sedimentary strata is associated with the final period of uplift associated with the Rincon Mountains (Davis, 1975).

According to Davis (1980, p.68), the sedimentary cover rocks have been affected by their lateral movement towards the Tucson Basin:

> Overturned asymmetric folds, detached isoclinal folds, and unbroken cascades of recumbent folds characterize the sheets of the Paleozoic and Mesozoic cover rocks. Most of the folds are transitional between ideal parallel and ideal similar folds and, thus, are characterized by some hinge-zone thickening. The scarcity of axial-plane cleavage, the abundance of bedding-plane cleavage, and the obvious influence of layering on the morphology of folds indicate that the folds evolved through slippage between layers and flow within layers.

Coney (1980) has suggested that water played a large role in the deformation and lateral transport of the overlying sedimentary strata.

The completeness of the sedimentary cover has also come into question. According to Davis (1980, p.68):

> Sedimentary rocks on the west side of the Rincon Mountains within the Saguaro National Monument (East) consist of limestone, dolomite, and shale of Permian age, as well as remnants of Mississippian(?), Pennsylvanian, and Cretaceous formations. Along the southeast flank of the Tanque Verde antiform, Cretaceous shale and limestone, with interbedded

siltstone, dolomite, and limestone conglomerate, lie directly on the decollement. The thickness of the sheet is less than 90 m (295 ft). Sedimentary rocks near Colossal Cave on the south side of the Rincon Mountains form a sheet approximately 150 m (492 ft) thick that rests on the decollement zone. The rocks consist of limestone interbedded shale and include formations of Cambrian through Permian age. At the southeasternmost corner of the Rincon Mountains, a 75 m (246 ft) sheet of Paleozoic rocks rests on the decollement zone. Although formations from Cambrian to Permian time are represented, the thickness of the sequence is less than 10% of the full Paleozoic section exposed in the Whetstone Mountains only 20 km (12.4 mi) south.

The individual sheets of Phanerozoic strata range from about 40 to 120 m (131 to 394 ft) in thickness. Strata within each sheet are generally unmetamorphosed, except near the base where limestones are commonly marbleized over thicknesses of 10 m (33 ft) or so.

A Possible Young-Earth Flood Interpretation

Our fieldwork is not the first investigation seeking to understand metamorphic core complexes within the framework of the global Flood of Genesis. An excellent detailed study of the detachment faulting in the northern Trigo Mountains (southwestern Arizona) was conducted by young-Earth creationist Scott Rugg (1986). He believed that the metamorphic core complex mountains that he investigated formed and developed during the global Flood. Our findings along Loop Drive are completely consistent with Rugg's (1986) interpretation. We believe that the Rincon Mountains and Tanque Verde Ridge were formed, uplifted/unroofed, and eroded during the Flood event when tremendous tectonic forces were still in effect (i.e., Middle Flood Event Timeframe; Froede, 1995b; 1998b).

Uniformitarian geoscientists suggest that abundant levels of water played an important part in the development of the mylonized gneiss. The sedimentary cover above the gneiss also indicates by its deformation that it was semi-lithified when it experienced tectonic uplift and lateral transport. Additionally, the fact that the regional Paleozoic and Mesozoic stratigraphic sections are thinner above the uplifted mylonite gneiss complex than "complete" sections found 12.4 miles to the south suggests that uplift of the metamorphic core complex mountains prevented the deposition of the uniformitarian-envisioned full stratigraphic sections.

We offer the following young-Earth interpretation that we believe is consistent with scripture, although other interpretations are possible. We view the Precambrian granites as likely formed during the Creation week. These granites were thousands of feet below the existing pre-Flood ground surface. We believe that the Flood eroded away any former (i.e., pre-Flood) sedimentary overburden above the igneous and metamorphic basement rocks. Turbulent Floodwater later deposited sediments and organic matter derived from a variety of source areas within this same area. Uplift of the Tanque Verde Ridge and Rincon Mountains occurred by granitic intrusion during the middle of the Flood. This created both erosional conditions and gravitational instability. The mountain-sized blocks rotated, causing the newly-deposited sedimentary layers to slide off the top of the basement surface toward the newly formed basin. Within the semi-molten area of the uplift, gravitational force created planes of weakness that we recognize today as normal faults within the granite. As the upper section of the uplifted basement rock gave way to gravitational sliding, it altered the vertical profile of the composition of the granite (from granite to gneiss, then to mylonitic gneiss, including ultramylonites and cataclasites). We see a transition from soft (at depth) to brittle (closer to the surface) deformation of the quartz monzonite granites along with the development of intense shear zones as we move up in section to the decollement surface. The tectonism coupled with the mylonitic strata is consistent with catastrophic processes that we would expect during the global Flood of Genesis.

Conclusion

The Loop Drive within Saguaro National Park (east) provides an excellent setting in which to observe mylonites, ultramylonites, and cataclasites in a beautiful desert setting. These rocks reflect the tremendous tectonic forces they experienced in Earth's past. Geologists continue to study these rocks in an effort to understand both how and why they formed. Found in the Basin and Range province, metamorphic core complex mountains reflect unique conditions and unusual tectonic forces.

We believe that the evidence for the abundance of water as a factor in both the mylonitization of the gneiss and the deformation of the overlying sedimentary cover strata points to the Flood. Additionally, the tremendous tectonism necessary to form the Tanque Verde Ridge and Rincon Mountains can best be understood as occurring during this same period of Earth history. All the evidence appears to support a rather brief period of time in which all of these events occurred.

Appendix

The following definitions may prove helpful in understanding the variety of mylonites found at Saguaro National Park (east). All definitions are from Jackson (1997) unless otherwise noted.

Cataclastic: Pertaining to the structure produced in a rock by the action of severe mechanical stress during dynamic metamorphism; characteristic features include the bending, breaking, and granulation of the minerals.

Cataclasite: A fine-grained, cohesive cataclastic rock, normally lacking a penetrative foliation or microfabric, formed during fault movement. The fracture of rock and mineral components is a significant factor in the generation of a cataclasite, and it may play a significant role in the continued deformation of the rock.

Cataclastic Flow: Flow involving intergranular fracturing and movement, i.e., mechanical displacement of particles relative to each other; a brittle flow mechanism.

Microbreccia: A well indurated, massive rock that has been crushed to a very fine grain size through cataclastic flow, commonly found within detachment faults.

Mylonite: ... a microbreccia with flow texture. It occurs in a variety of different forms, including protomylonite, ultramylonite, and blastomylonite. According to Yardley (2000), mylonites occur in zones of high strain or shear zones which vary in thickness from a few millimeters to several kilometers. The mylonitic textures result mainly from syntectonic recrystallization, in which large original grains become strained, leading to the nucleation of small unstrained grains that grow at the expense of the parent grain.

Mylonite Gneiss: A metamorphic rock that is intermediate in character between mylonite and schist. Felsic minerals show cataclastic phenomena with little or no recrystallization, and commonly occur as augen surrounded by and alternating with schistose streaks and lenticles of recrystallized mafic minerals.

Mylonitization: Deformation of a rock by extreme microbrecciation, due to mechanical forces applied in a definite direction, without noteworthy chemical reconstitution of granulated minerals. Characteristically, the mylonites thus produced have a flinty, banded, or streaked appearance, and undestroyed augen and lenses of the parent rock in a granulated matrix. Also spelled: mylonization.

Ultramylonite: An ultra-crushed variety of mylonite, in which primary structures and porphyroclasts have been obliterated so that the rock becomes homogeneous and dense, with little if any parallel structure.

Acknowledgments

The authors thank the many donors to the Creation Research Society Research Fund, interest from which financed a portion of these studies. We are grateful for the continued support we receive from our families. Dr. Steve Austin kindly provided a copy of the Scott Rugg thesis completed at the Institute for Creation Research. Dr. Emmett L. Williams and Mr. Jerry Akridge provided review and commented on a draft of this article. However, any mistakes that may remain are our own. We give our Creator God and His Son all the glory. Proverbs 3:5–6.

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Lest We Forget

Precambrian Pollen in the Roraima Formation, British Guiana

Stainforth (1966) reported on researches conducted in 1963 by Dunsterville who collected samples of "shale-like" beds in the Roraima Formation of British Guiana. Later, palynologist Fournier, "... processed the samples and recovered well-preserved pollen spores... Subsequently, L. Nijssen and J. A. Sulek... processed other pieces [of shale-like material from the Roraima] and recovered identical plant microfossils" [brackets are mine], Stainforth (1966, p. 292).

"This discovery of pollen and spores in a formation of supposed Pre-Cambrian age was so remarkable that a reconnaissance expedition of qualified geologists was organized to verify the facts of the case" (p. 292). Note that it was only the discovery of pollen in the Roraima material that led to further research; had no pollen been found, it"s Precambrian "status" would probably have gone forever unchanged. This second research venture occurred in 1964 and included seven workers who repeated the collection and analysis.

> They confirmed the salient facts as recorded by Dunsterville, "New samples of unweathered rock were collected ... On their return to Caracas, the three palynologists made independent investigations of the new samples. Utmost care was taken to avoid any possibility of superficial contamination... [M]icrofossils of the same type as before were recovered" (p. 292).

Fournier concluded that the fossils Precambrian pollen was "... not the same... "as pollen from plants currently