

Saguaro National Monument, Arizona: Outstanding display of the structural characteristics of metamorphic core complexes

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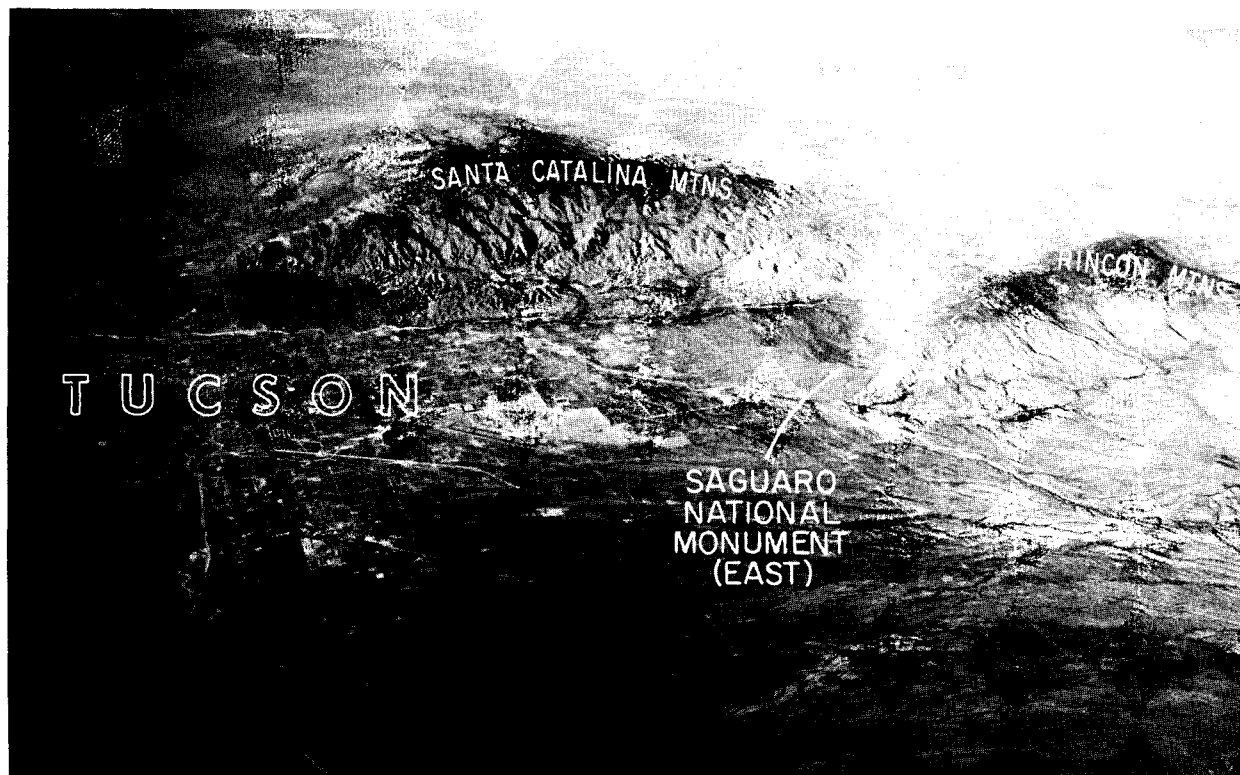


Figure 1. U-2 photograph showing the location of the field site with respect to the city of Tucson and the Santa Catalina, Tanque Verde, and Rincon mountains.

LOCATION AND ACCESSIBILITY

The Saguaro National Monument Centennial Field Site lies on the eastern outskirts of Tucson, Arizona (Fig. 1), along the flank of the Tanque Verde Mountains. Access to the site is via the Loop Drive, a paved road which serves visitors to Saguaro National Monument (east) (Fig. 2). The stops, which provide a clear view of the structural characteristics of metamorphic core complexes, are located near the half-way point of Loop Drive. Stops 1 through 4 need take only 1 hour. Allow yourself a second hour to see the geology at Stops 5 and 6, and a third hour to examine the structures at Stop 7. The walking is easy within the area of Stops 1 through 4. There are some slopes to descend and ascend in reaching Stops 5 and 6. Those who visit Stop 7 should be prepared for hillslopes and some sharp, steep-sided vertical ribs of limestone bedrock. In general, however, hiking within the site is straightforward and scenic.

Saguaro National Monument has beautiful desert vegetation, including saguaro, ocotillo, palo verde, prickly pear, and barrel cacti. Deer and javalina commonly may be seen in the vicinity of Stops 5 through 7, especially late in the afternoon. A

canteen of cold water will be a comfort on warm days and a necessity on hot days. Be on the lookout for the hazards of cactus spines, thorny shrubs, scorpions, and rattlesnakes. Snakes are seldom seen during the months of November through mid-March. The rattlesnakes generally do not venture out during the heat of summer days.

Be advised that you are not permitted to collect anything within Saguaro National Monument.

SIGNIFICANCE

More than any other locality, the geology of this site served as the basis for distinguishing and classifying the fundamental structural characteristics of metamorphic core complexes as presented in Davis (1977, 1980) and Davis and Coney (1979). This site was the showpiece used in presenting the diagnostic features of metamorphic core complexes to participants in the Geological Society of America Penrose Conference on Cordilleran Metamorphic Core Complexes, held in Tucson in May, 1977 (Crit-

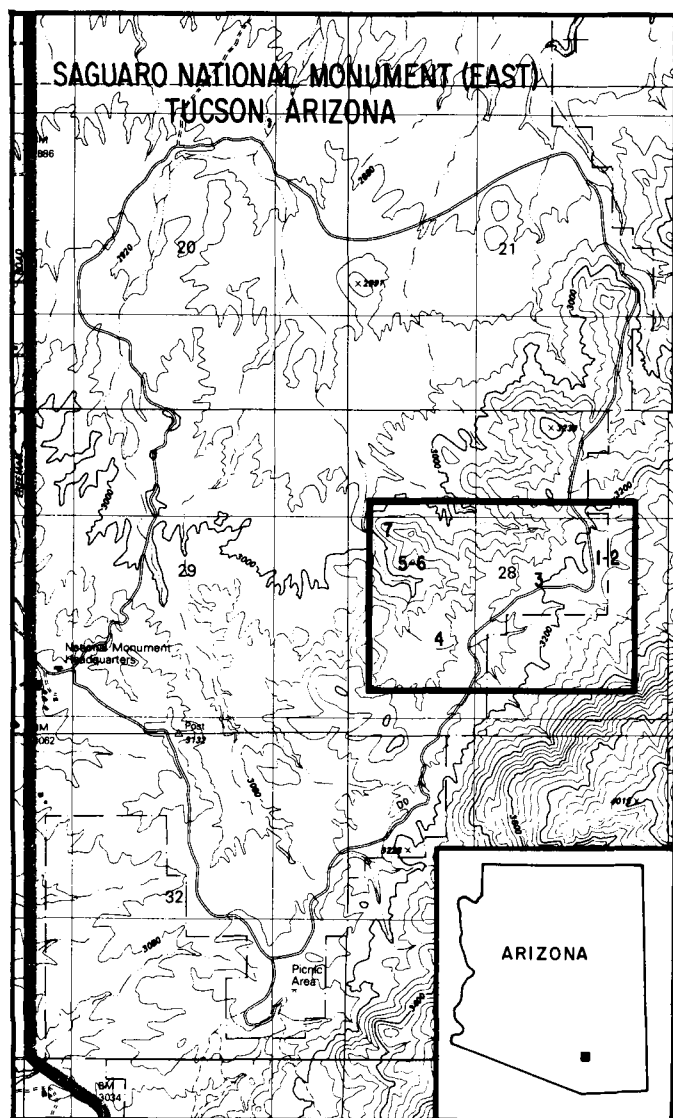


Figure 2. Location map showing Stops 1-7 in relation to Loop Drive of Saguaro National Monument (east).

tenden and others, 1980). It is now recognized that the mylonites, ultramylonites, and cataclasites exposed at the Saguaro National Monument site are among the very finest. The fault rocks and structures, taken together, provide an illuminating, stop-action glimpse of the progressive, ductile through brittle shearing which is responsible for fashioning the characteristics of metamorphic core complexes.

SITE INFORMATION

Beginning at Stop 1, and proceeding through Stop 7, an opportunity is presented to traverse the fundamental components of a metamorphic core complex (Fig. 3): mylonite and ultramylonite derived from Precambrian and Tertiary quartz monzonites;

chloritically altered microbreccias derived from the mylonite and ultramylonite; fine-grained microbreccias (cataclasite and ultracataclasite) derived from the chloritically altered breccias; the detachment fault (or décollement) separating cataclastic and mylonitic rocks below from nonmylonitic, noncataclastic cover rocks above; and some folded Paleozoic cover rocks.

The distribution and character of each of these components of the Rincon Mountains metamorphic core complex are presented in Figure 4, a structural geologic map of the site. Note that the locations of the seven stops highlighted in this guide are posted on the structure map. The relationship of the geology of this small area to that of the entire Tanque Verde and Rincon mountains can be appreciated by studying the geologic map of the Rincon Valley Quadrangle, prepared by Harald Drewes (1978). This useful map generally has been available for purchase at the Visitors Center at Saguaro National Monument. Drewes' mapping shows quite clearly that the site of interest lies on the northwestern flank of Tanque Verde arch, a gently southwest-plunging antiform of lineated quartzo-feldspathic gneiss.

Stop 1 reveals the character of one of the two major phases of mylonite gneiss exposed in the Tanque Verde and Rincon mountains. It is identical texturally and compositionally to a mylonitic gneissic phase interpreted to be mylonitized 1400 Ma quartz monzonite. Shakel and others (1977) extracted zircons from this phase of gneiss in the nearby Santa Catalina Mountains, and using Ur-Pb isotopic analysis, found them to be Proterozoic. The results of progressive mylonitization of unfoliated Precambrian porphyritic quartz monzonite to coarse-grained mylonitic gneiss can be observed in metamorphic core complexes at a number of locations in southern Arizona.

The mylonite gneiss is beautifully expressed in the physiography of the Santa Catalina and Rincon Mountains. The rock is so strongly layered that it resembles a thick stack of gently dipping, massively bedded sedimentary and/or volcanic rocks. However, in outcrop view the bedrock is seen to be mylonitic quartzo-feldspathic gneiss, and the layering proves to be just one of many expressions of the penetrative foliation within the gneiss.

The mylonitic gneiss at Stop 1 is coarse-grained augen gneiss with abundant large feldspar porphyroclasts (0.5 cm to 6 cm). (Stops 1A and 1B are additional sites where the mylonitic gneisses are especially interesting.) The mylonitic nature of the fabric is especially evident in microscopic view. Ribbon-quartz

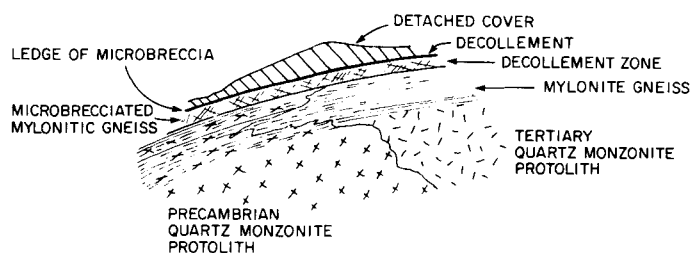


Figure 3. Schematic diagram showing the fundamental structural components of metamorphic core complexes.

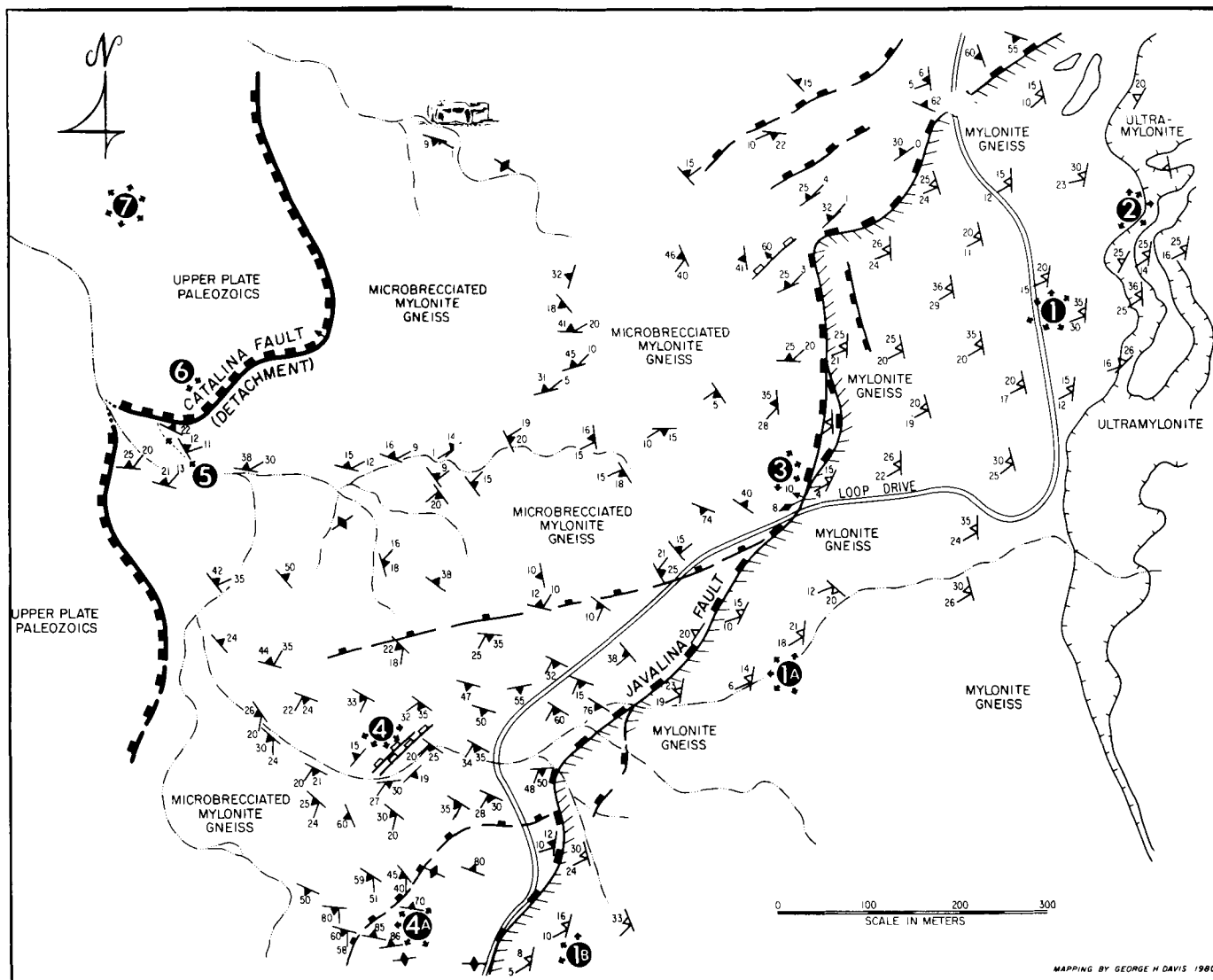


Figure 4. Structural geologic map of the field site, showing locations of stops.

layers and laminae wrap around the feldspars in a gently undulating habit. Alignment of nonequidimensional feldspar porphyroclasts also contributes to foliation expression. The strike of foliation at this stop is north-south. The foliation dips gently, typically less than 30° , to the west.

Mineral lineation is exquisitely developed. It lies within the plane of foliation and thus is everywhere gently plunging. The lineation shows an extraordinary degree of preferred orientation; $N60^\circ E-S60^\circ W$. Lineation is defined mainly by the structural response of quartz and quartz laminae to crystal-plastic deformation.

The strain significance of the mylonite gneiss has become understood through detailed structural analysis. The dominant foliation (S) is the XY plane of flattening, and the lineation direction is the X direction of greatest elongation. Locally, C

surfaces cut the mylonite as planes of slip, spaced at 1 cm or less. These dip more steeply than S and reveal a normal-slip sense of simple shear along a $S60^\circ W$ line. This same movement plan is revealed by asymmetric folds and sheath folds whose low-dipping axial surfaces are axial planar to the S surfaces.

Although the mylonites observed at this stop were derived from Precambrian rocks, the mylonitization event was actually Tertiary in age (Davis and Coney, 1979). This is clear because the same fabrics are seen in a phase of mylonitic gneiss that is derived from Tertiary quartz monzonite. This second dominant phase of mylonitic gneiss is abundantly exposed in the Santa Catalina and Rincon Mountains. Its protolith is interpreted to be approximately 50 Ma in age, based on radiometric dating (Shakel and others, 1977; Keith and others, 1980). This rock expresses itself as a light-colored, fine- to medium-grained garnet- and

turned, although this is difficult to prove. From place to place, faults are well exposed at the outcrop scale. In fact, one of the diagnostic structural characteristics of large areas of brecciated mylonite gneiss is the presence of long, continuous, very gently dipping planar fracture partings. These are expressions of faults which may have accommodated meters or tens of meters of fault translation.

The zone of microbrecciation appears to have been produced by prolonged superposed faulting and fracturing under conditions of elevated fluid pressure (Davis and Coney, 1979). Breccia fragments at all scales are themselves seen to be composed of breccia, and this suggests that microbrecciation was carried out by a progressive deformation through time. 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. Although the microbrecciation and rotation of fabrics obviously postdated the formation of the original mylonites, the structural movements which produced microbrecciation and rotational faulting seem to have been coordinated with the geometry of shearing which fashioned the mylonites. This is shown in part by the tendency of the strike of rotated relict foliation in the microbreccias to be aligned roughly at right angles to the trend of lineation in the footwall mylonites.

Stop 5 is the ledge of cataclasite and ultracataclasite which marks the very top of the zone of microbrecciated mylonite gneiss (see Fig. 4). The top surface of the ledge of cataclasite is the Santa Catalina fault, the structure to be examined at Stop 6. The cataclasite has no directional fabric whatsoever, and the entire gently dipping, 13-ft- (4-m-) thick, tabular ledge of cataclasite is discordant to the moderately steeply dipping relict foliation in underlying microbrecciated mylonitic gneiss. The cataclasite formed at the expense of microbreccia, presumably in the waning stages of the episode(s) of cataclastic deformation. The ledge of cataclasite and ultracataclasite may be an expression of the crushing and grinding of microbreccia within a zone of coalescing fault surfaces. Cataclasis was carried out at a time and at a structural level such that no upper-plate cover rocks became interleaved structurally with either the cataclasites or the microbreccias.

Stop 6 is the Santa Catalina fault, the detachment or décollement which separates nonmylonitic, noncataclastic cover rocks above from cataclasites, microbreccias, and mylonites below (see Fig. 4). It marks the very top of the ledge of cataclasite.

The Santa Catalina fault has a sinuous trace that can be followed for 42 mi (70 km) along the front of the Santa Catalina, Tanque Verde, and Rincon mountains (Banks, 1976; Drewes, 1978; Pashley, 1966). Its form is that of a cylindrically folded surface plunging 15° to 30° to the southwest, parallel to the dominant direction of mineral lineation in the mylonite gneiss. It wraps around the nose of Tanque Verde arch. Although foldlike at the scale of the entire Santa Catalina-Rincon mountain front, the fault in outcrop view is typically planar and gently dipping, as at Stop 6. Striations can be seen and measured from place to place along the surface, and locally (although not at this site) the

fault surface is polished and deeply grooved. The dominant direction of movement on the fault is S60°W, the same as the orientation of mineral lineation in the mylonites.

The Santa Catalina fault appears to be a low-angle normal-slip fault which helped accommodate crustal extension in mid-Tertiary time. Its hanging wall contains faulted strata as young as 20 Ma. The sense of movement along the fault is the same as that of the simple shear which created the microbreccias and the mylonites. This coordination suggests that the fundamental components of the Rincon Mountains metamorphic core complex may have been fashioned through a progressive ductile through brittle normal-slip shearing and faulting (Davis, 1981a, 1983, 1986). As a result of sustained normal-slip shearing, mylonites forming within the approximately 1-mi- (2-km-) thick shear zone (at a depth of approximately 6 to 7 mi; 10 to 12 km) were steadily raised to higher levels characterized by lower temperatures and pressures. The continued shearing and faulting became more brittle. Mylonite was converted to microbreccia, and microbreccia was progressively transformed to cataclasite. Final movements were achieved not within a zone of deformation, but along a discrete fault surface, the Santa Catalina fault.

Shearing and faulting resulted in more than 6 mi (10 km) of normal-slip translation of the cover rocks. Cover rocks exposed at the site were translated from locations to the east-northeast. The extensive normal-slip shearing and faulting quite naturally brought rocks of strikingly different original depth levels into juxtaposition: unmetamorphosed, nonmylonitic hanging-wall cover rocks rest on chlorite-stable microbreccias, which in turn rest on biotite-stable quartzo-feldspathic mylonites.

When the ductile-brittle shear zone formed, it probably dipped at an angle of 45° or more, not at its presently observed inclination of 30° or less. The zone may have steadily rotated to progressively shallower inclinations as the crust which it occupied was progressively stretched (Davis, 1983, 1986).

Many workers have emphasized that the Santa Catalina fault formed originally as a Laramide thrust fault, which accommodated tens of kilometers of northeasterly transport (for example, Moore and others, 1941; Drewes, 1976, 1978, 1981). As of the time of writing of this guide, the question of the ancestry of the Santa Catalina fault continues to be hotly pursued through investigations of gross structural relations, microstructures, and geochronology. Bykerk-Kauffman (1983, 1986), for example, has recognized penetrative fabrics within the Santa Catalina Mountains that may in part reflect east-directed thrust movements during the Laramide. Davis (1986) has portrayed the uncanny structural relationships that might result from normal-slip simple shearing of a geologic column that had already been subjected to the kind of superposed faulting that distinguishes southeastern Arizona as a whole (Davis, 1981b).

Stop 7 brings us to cover rocks which lie above the Santa Catalina fault. Rocks ranging from Precambrian to Miocene in age can be expected to be found in the hanging wall of the Santa Catalina fault. All tend to be brittily deformed and commonly the cover rocks are back-rotated along bounding faults which are

intercepted by the Santa Catalina fault at depth. In some places, including this stop, the cover rocks display fold structures. Some of the fold structures may be Laramide compressional features which, in the mid-Tertiary, were passively transported to their present locations by movements associated with the Santa Catalina fault. However, the geometry of most of the folds appears to be compatible with their formation during southwest-directed normal-slip simple shearing under moderately ductile to moderately brittle conditions.

The deformed cover rocks above the Santa Catalina fault at Stop 7 are Pennsylvanian-Permian limestones and interbedded fine-grained clastics of the Earp Formation. Fold structures and faults within what appear to be five discrete plates or sheets were mapped in fine detail by Davis and Frost (1976). The folded and faulted limestones are heavily veined by thin, locally penetrative, calcite veins. Abrupt truncations and offsets of veins suggest the

effects of pressure solution. The structures of Stop 7, taken together, constitute a small museum of well-exposed, provocative structures.

POSTSCRIPT

As you leave the site, continue clockwise along Loop Drive; you will come to a location known as "Javalina Rocks" within less than 1,300 ft (400 m). Javalina Rocks is a distinctive outcrop of moderately microbrecciated mylonite gneiss, which forms a beautifully exposed west-dipping homocline. The rocks invite a short stop to climb about and closely examine the fault rocks. Continuing further around Loop Drive, you will spot the turn-off to the Monument's picnic area. The picnic area contains ramadas, water, and restrooms, and is positioned within close walking distance of excellent ledge exposures of mylonite gneisses that crop out in steep drainages on the flank of Tanque Verde Mountain.

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