

Sierra Madera Astrobleme

Pecos County, Texas

By Donald McGooley

Abstract

Just 17 miles south of Fort Stockton, US Highway 385 crosses this astrobleme. One of Texas' best secrets is that Sierra Madera, immediately to the northeast of the highway, is the central peak of an eight-mile diameter astrobleme. An astrobleme is the scar left on the earth's surface by the impact of a very large meteor. This astrobleme was thoroughly studied by the United States Geological Survey (Professional Paper 599H, 1972), because it is like astroblemes on the moon and Mars. They are characterized by: an outer rim, a large circular depression and a sharp peak in the middle. The USGS found that rocks in this peak originally were more than 4000 feet below the surface and were rebound from the impact pressure of the large meteorite. The information gained here, that collecting rocks from central peaks provided samples of rocks from far below the surface, led NASA to program some landings on the moon and the robot Curiosity on Mars to land in the depression near central peaks. The rocks that make up this peak are highly folded and faulted, and have high pressure features, crystals and minerals found nowhere else in the southwest.

Sierra Madera Astrobleme

If you look at the moon through a telescope or good binoculars and find a region that has a low sun angle (lots of shadows), you will see that the surface is completely pockmarked with circular depressions of all sizes. Each depression was the result of a meteorite or comet hitting the surface of the moon with enough force to blast rocks outward and leave a crater, a so-called astrobleme. Many of these craters have a central conical peak that looks like a volcano. Seventeen miles south of Fort Stockton, U. S. Highway 385 crosses the western half of a circular astrobleme that is the best-exposed example of this type of crater in the United States. It has a 600-foot high prominent central peak called Sierra Madera

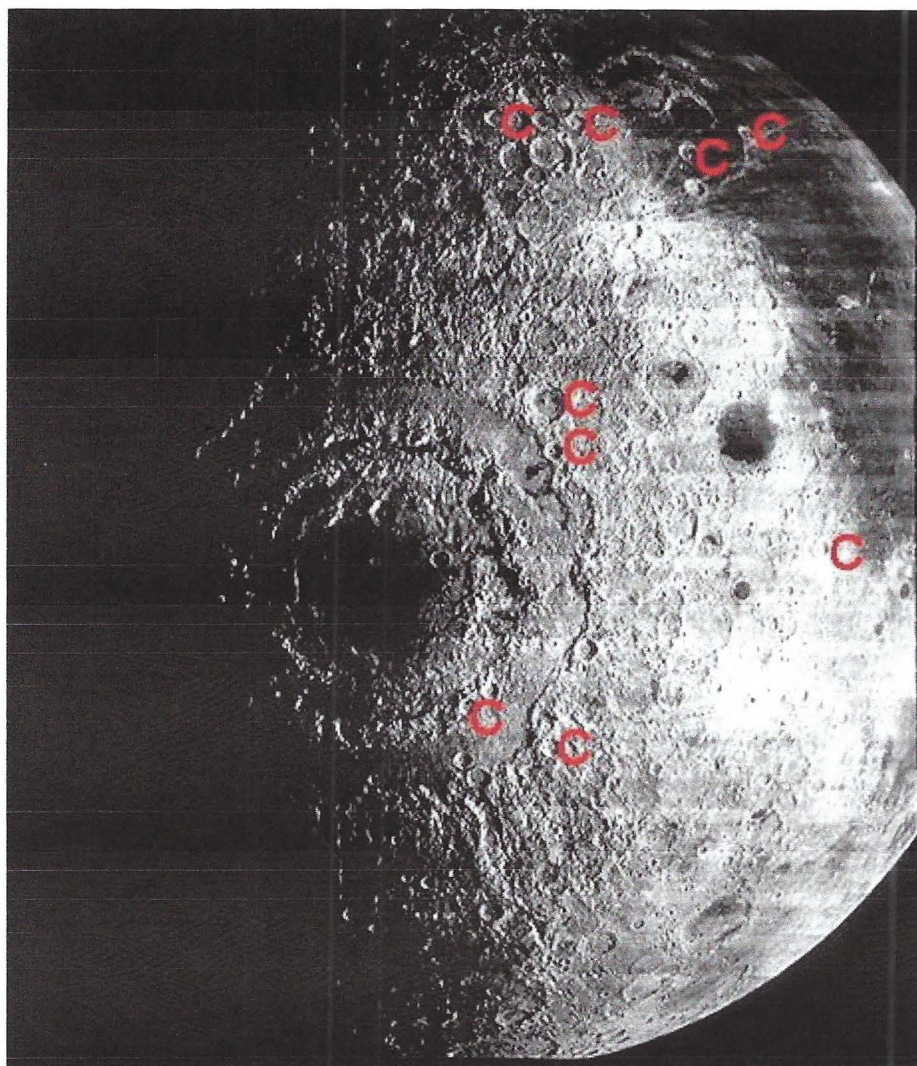
(wooded hill) that is composed of intensely folded and faulted Permian limestone rocks that were originally more than 4000 feet below ground. This central uplift is four miles in diameter. The depression around this central uplift is eight miles in diameter and the concentrically constructed outside rim is about one-half mile wide. The rocks of this rim are Lower Cretaceous carbonates that are locally folded and cut by concentric normal faults downthrown toward the center.

Detailed study of this astrobleme began in 1960 by E. M. Shoemaker when travel to the moon was first contemplated. The main impetus was to obtain information on terrestrial examples of lunar structures. Sierra Madera Astrobleme is so well preserved and exposed that it should be either a state park or a national monument.

The rocks of the central peak exhibit many features that record the severity of the impact.

Brecciation (rock that is completely broken into angular pieces), shatter cones (high pressure impact structures in rocks), and certain types of internal structures of minerals at Sierra Madera are ascribed to shock deformation. The most common type of breccia consists of thoroughly shattered rocks in which the fragments are generally so little displaced that thin beds maintain their continuity. A second type of breccia contains fragments of different lithologies.

Shatter cones, a very common mode of rock failure in cryptoexplosion (impact) structures, are well developed in the Permian rocks of Sierra Madera. Within the area in which breccias and shatter cones occur, quartz grains commonly have cleavages and other planar elements characteristically formed by shock (Sierra Madera Figure 7). Wilshire et al. (1972) concluded that shocked quartz in the mixed breccias indicates pressures of over 200 kilobars (kb), grading to 100 kb and 50 kb at the flanks of the uplift.



Sierra Madera (SM) Figure 1. Low angle view of part of the moon's surface. Red "C's" are alongside craters that have central peaks (Source: NASA).

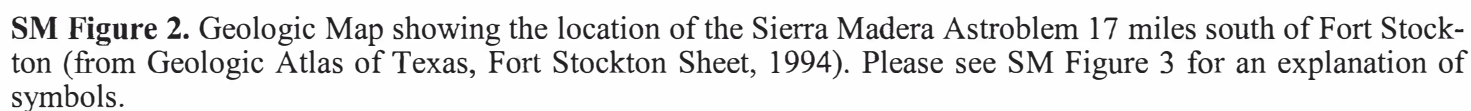
Holes drilled for oil and gas in formations below the astrobleme, along with seismic data (that record reflections from formations deep in the earth), show that the intense deformation observed at the surface dies out rapidly below the surface and disappears between 6,000 and 8,000 feet. The gross structure is represented by a bowl-shaped body approximately 8.5 miles in diameter and 6,000 to 8,000 feet deep, the central part of which has a high structural relief near the present ground surface, with intensely shattered beds that are tightly folded and cut by numerous faults. The intensity of deformation and brecciation decreases outward and downward from the central peak.

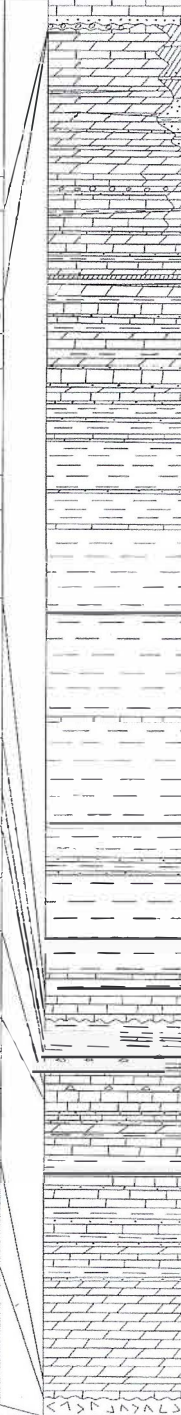
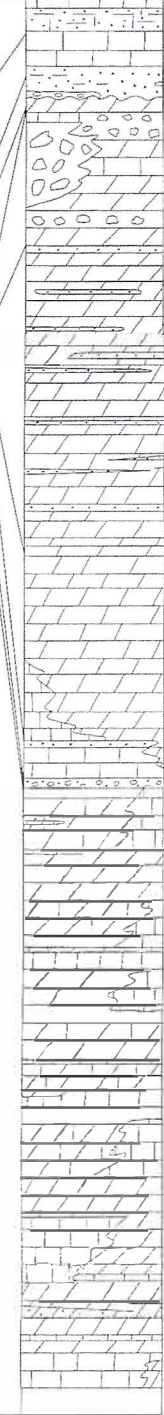
The ring depression separating the outer rim and the central uplift is largely buried under alluvium. Drill holes and outcrops on the southeast side show that the depression is floored by Cretaceous rocks that have dips up to vertical and are cut by faults. The

depression is separated from the outer rim by concentric normal faults but is not separated from the central uplift by any significant change in style of deformation.

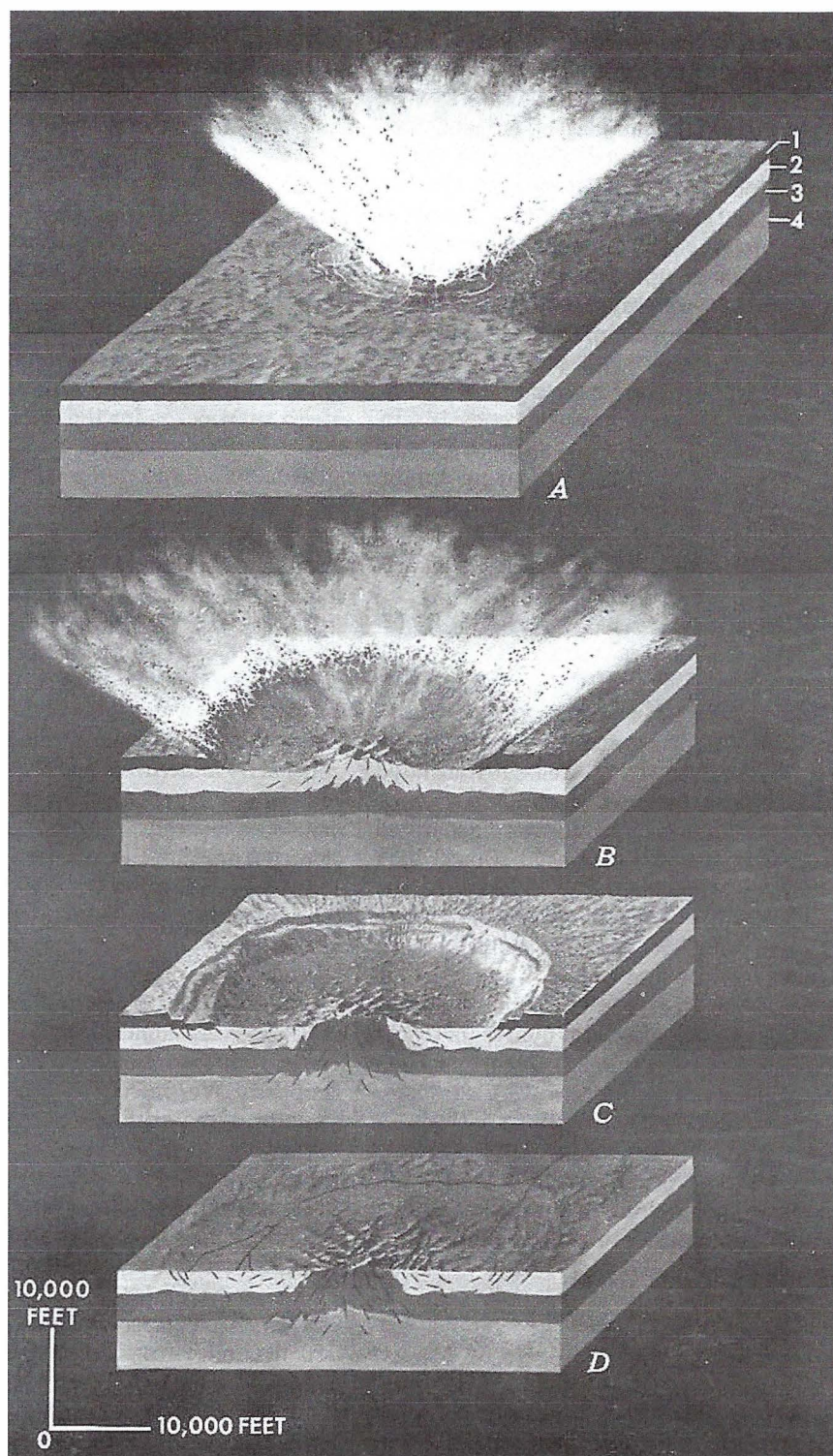
Compared with the setting and structure of surrounding Cretaceous strata and the nearby Pennsylvanian and Permian rocks of the Glass Mountains, the Sierra Madera is unique in its form, style, and severity of deformation. The Astrobleme was formed sometime after the Lower Cretaceous strata were deposited. The next younger event recorded in the area is some mild Miocene or Pliocene faulting, but the nearest fault is too far removed from this area to provide any help in determining the age of impact. The best guess is that the feature formed during the Late Cretaceous or Early Tertiary.

Astroblemes have been found in many parts of the world. They range in age from Precambrian for the



SYSTEM	GROUP	FORMATION	REGIONAL		SIERRA MADERA	
			THICKNESS (FEET)	LITHOLOGY	THICKNESS (FEET)	LITHOLOGY
CRETACEOUS	Lower part of Washita <i>Kw</i>	Georgetown Limestone	200-740		30-475	
		Duck Creek Limestone			130-250	
		Kiamichi Formation			50-100+	
	Fredericksburg <i>Kwf</i>	Edwards Limestone				
	Trinity	Basal Cretaceous sandstone <i>Kb</i>	50-360			
TRIASSIC		Bissett Conglomerate <i>Kb</i>	0-500		0?	
PERMIAN		Tessey Limestone <i>Pt</i>	400-1460		0-400	
		Gilliam Limestone <i>Pg</i>	590-980		700-980	
		Word Formation <i>Pw</i>	Vidrio Limestone Member <i>Pww</i>		200-750	
			Sandstone member		0-35	
			Limestone member		0-250	
		Cathedral Mountain Formation <i>Pcm</i>	0-1800		0-80	
		Hess Formation (King, 1930) <i>Ph Phv</i>	1870-2850		1200-1400	
		Wolfcamp Formation (King, 1930) <i>Pwc</i>	6995-12,220			
PENNSYLVANIAN	Strawn		0-850			
MISSISSIPPIAN		Barnett Shale equivalent <i>Pmt PMmk</i>	70-450			
		Novaculite of Kinderhook(?) age <i>MNISD</i>	40-180			
DEVONIAN		Woodford Shale equivalent <i>MDO</i>	70-255			
		Chert of Devonian(?) age <i>MDO</i>	30-185			
SILURIAN		Fusselman Dolomite	15-190			
ORDOVICIAN		Montoya Dolomite	160-590			
	Simpson		2130-2480			
	Ellenburger		1420?			
CAMBRIAN			100?			
PRE-CAMBRIAN						

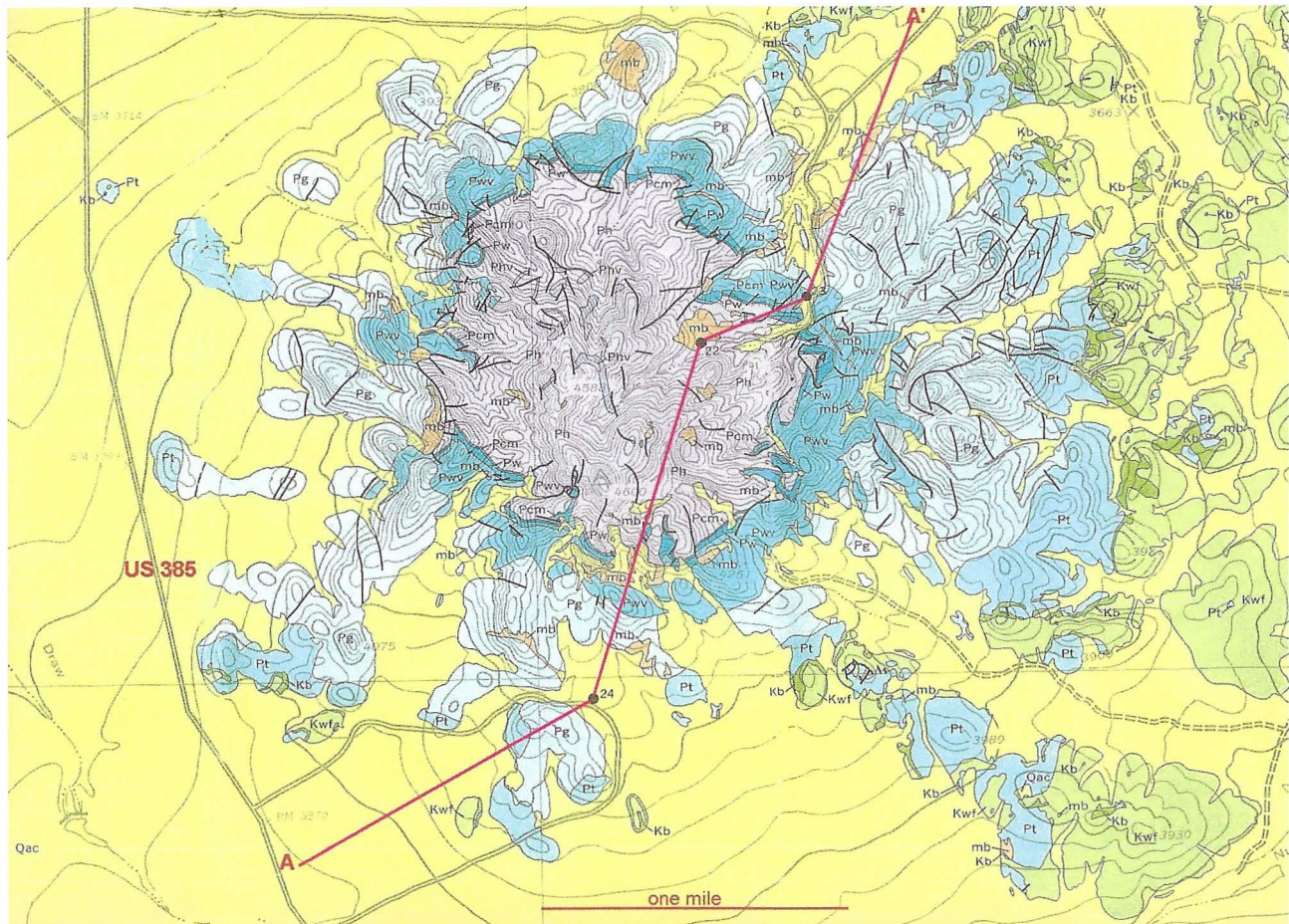
SM Figure 3. Generalized stratigraphic column of Paleozoic to Lower Cretaceous rocks at Sierra Madera (left column) and detailed stratigraphic column of rocks at Sierra Madera (right column, from Wilshire, et al, 1972).



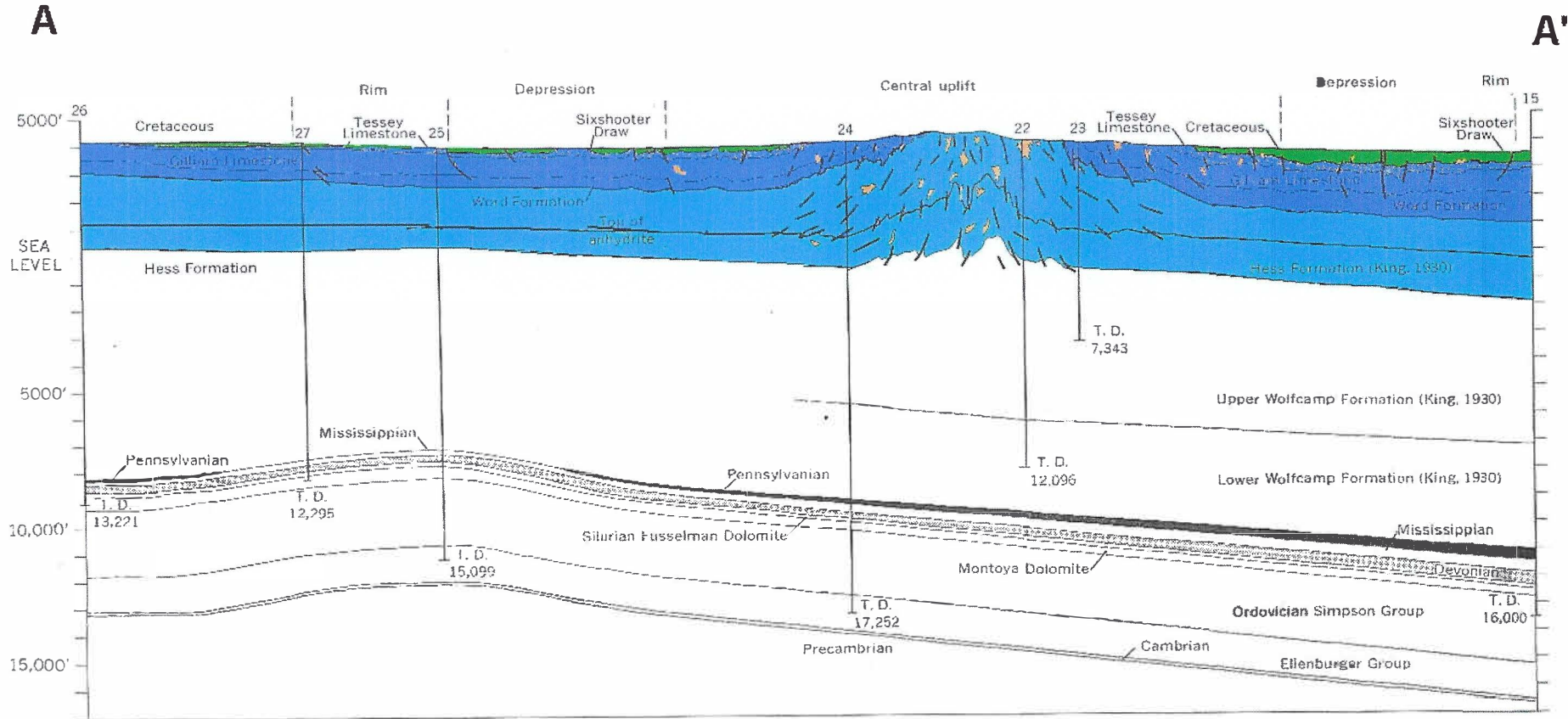
SM Figure 4. From Wilshire, et al, 1972. Hypothetical reconstruction of events forming Sierra Madera. Layers of rock: 1. Post-Cretaceous (hypothetical); 2. Lower Cretaceous, and Permian Ochoan and Guadalupian strata; 3. Permian Leonard strata; and 4. Permian Wolfcamp strata. **A.** Shortly after impact showing growth of crater by low angle jetting. **B.** Seconds after **A**, showing crater growth by ejection and formation of overturned flap; **C.** Freshly formed crater days after impact, showing uplift protruding into crater, crater-rim modification by slumping, and fall-back, **D.** Present form of Sierra Madera, modified by erosion.



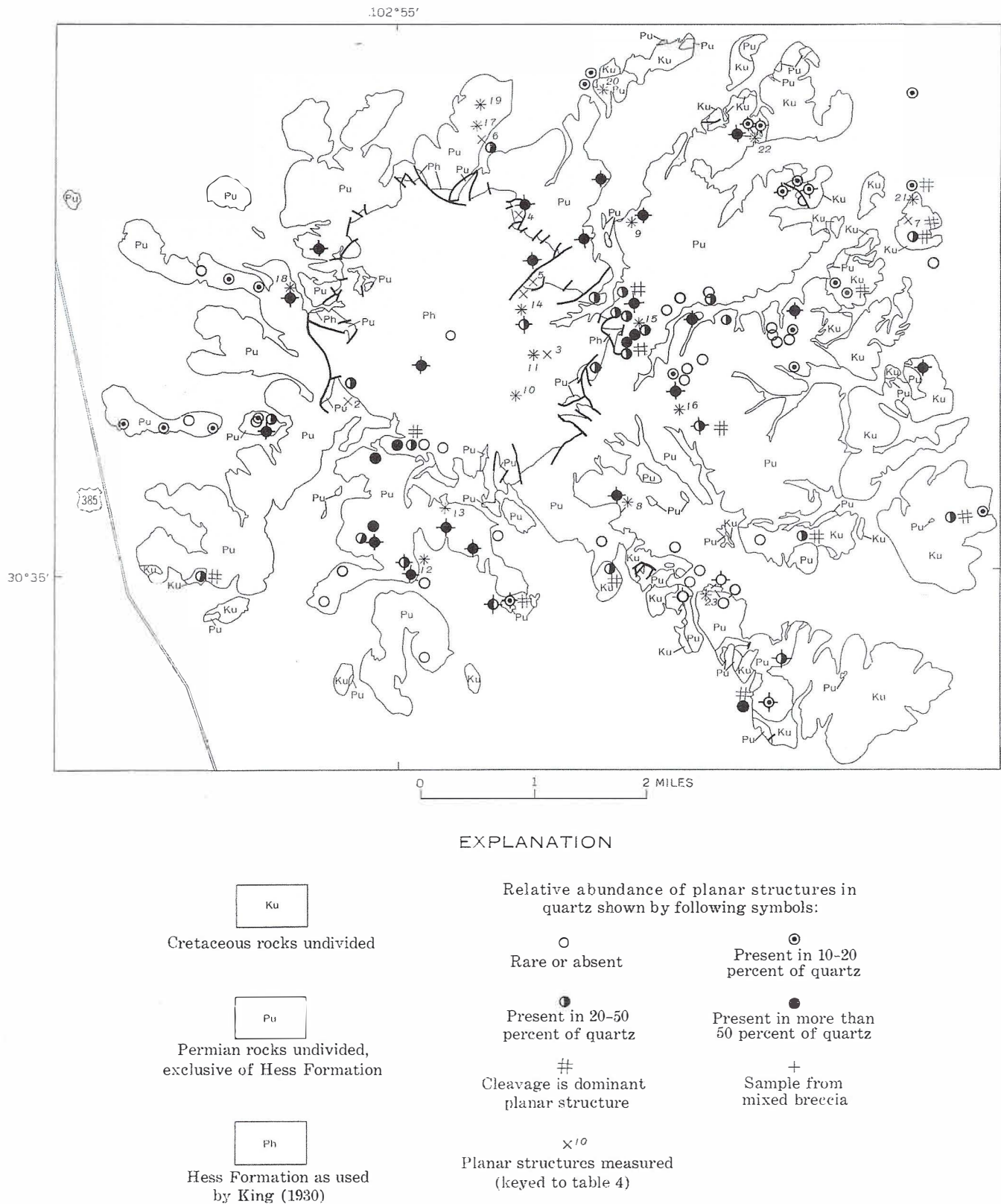
SM Figure 5. Aerial view of Central Peak from the northeast. Red arrows indicate the dip of some of the blocks in the uplifted and fractured Permian rocks of the peak. K identifies a syncline in Lower Cretaceous limestones. Airplane was provided by Betty Hargus and Bob Elliott was the pilot.



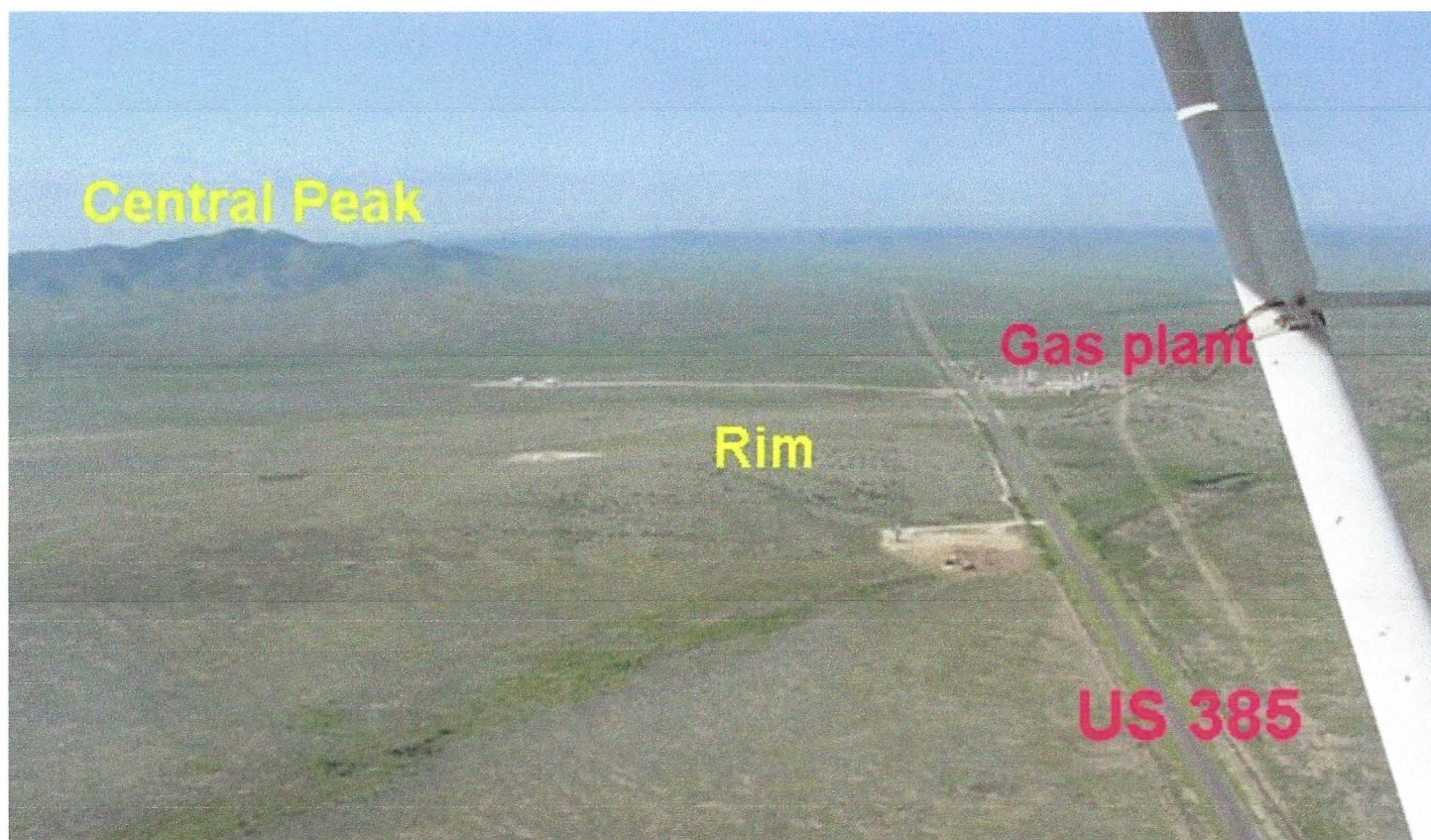
SM Figure 6. Geologic map of Central Peak. Please see Sierra Madera Figure 3 for an explanation of formation symbols. From Plate 2 of Wilshire, et al, 1972.



SM Figure 7. Cross section A-A' from southwest to northeast across the Central Peak. Line of section is posted on Figure 6. Please see Sierra Madera Figure 3 for an explanation of formation symbols. From Plate 2 of Wilshire, et al, 1972.



SM Figure 8. From Wilshire et al, 1972, figure 31. Distribution of shock-deformed quartz. Shock quartz provides one of the principle clues to the impact origin of the astrobleme.

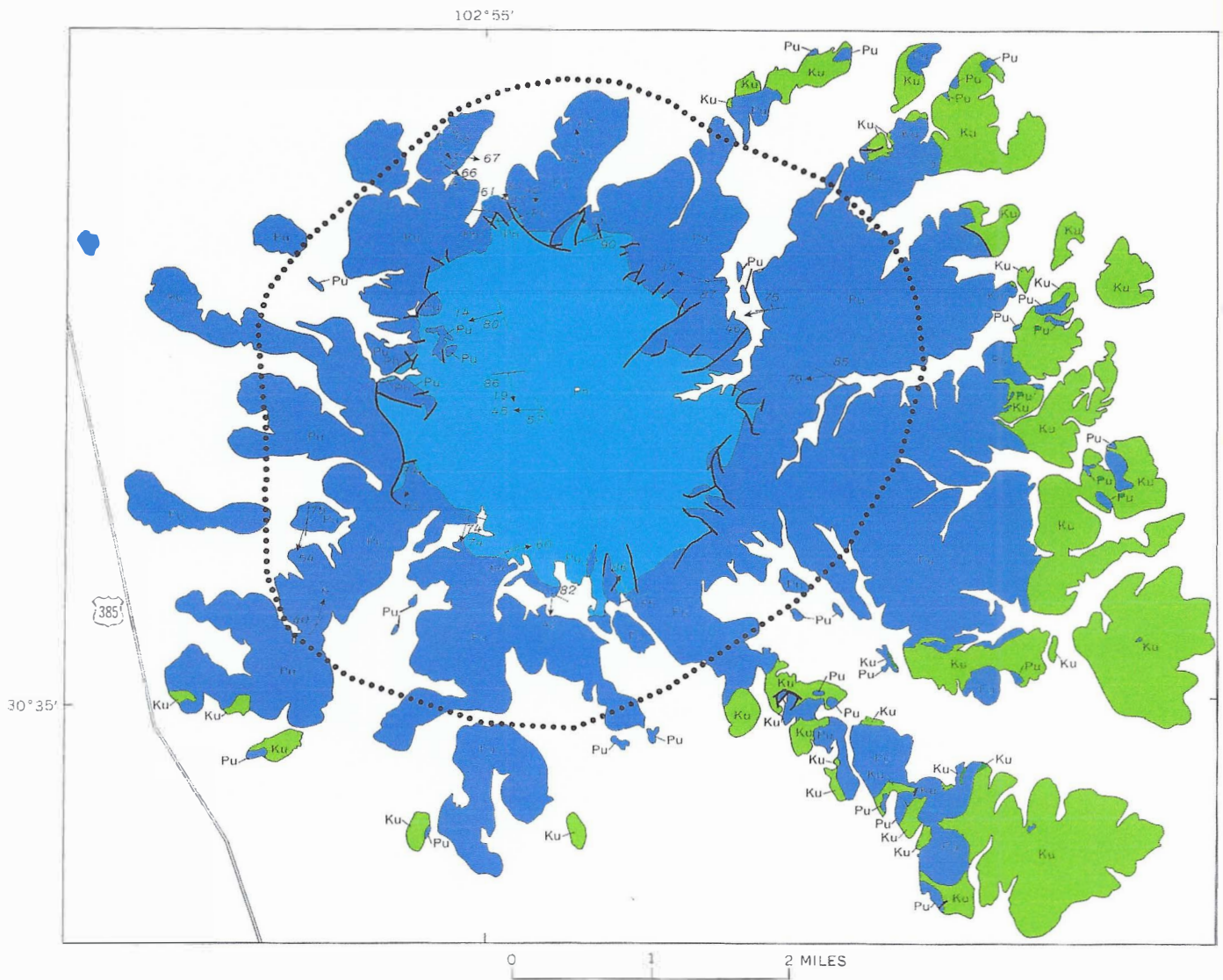


SM Figure 9. Aerial view of Central Peak looking southeast across west rim near gas plant. Fractured Cretaceous limestones of west rim in foreground; the alluvial covered ring depression in middle ground. Airplane was provided by Betty Hargus and Bob Elliott was the pilot.

Sudbury Complex of Ontario (Naldrett, 2003) and the Vredefort ring of South Africa, to the Miocene age Steinheim Basin of Germany. Present exposures show a wide range of erosional level. Astroblems have common characteristics that tie them together and allow the more deeply eroded structures, such as Sierra Madera, to be reconstructed by comparison with the astroblems that are less eroded. The structures at Flynn Creek, Tennessee and the Steinheim Basin represent the highest levels of exposure in well-studied astroblems. Both structures have a small central uplift surrounded and partly buried by a lens of breccia that occupies a shallow crater. A somewhat lower erosional level is preserved at Gosses Bluff, Australia, where some highly shocked and melted fallback breccia is preserved, but the original crater walls have been destroyed by erosion. Sierra Madera represents a still lower erosional level from which most vestiges of a crater-form depression, fallback, and ejecta have been stripped (Wilshire, 1972, p.37). Scaling to the dimensions of Flynn Creek crater and various experimental craters suggests that about 2000 feet of cover may have been originally present over the Lower Cretaceous beds that has since been removed by erosion (Sierra

Madera Figure 4).

Sierra Madera was extensively studied in preparation for lunar exploration. These results indicated that one could sample the thickness of lunar crust in the walls of craters and that rocks from the central uplifts would provide data on subcrater material from depths approximately one-tenth of the crater diameter. The typical lunar crater considered was over 15 miles in diameter. Thus, sampling rocks from the central uplift would allow study of rocks from over 1.5 miles below the surface.



EXPLANATION

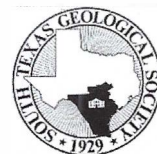
- Ku
Cretaceous rocks undivided
- Pu
Permian rocks undivided,
exclusive of Hess Formation
- Pu
Hess Formation as used
by King (1930)

-
Outer limit of abundant shatter cones
- 
Strike and dip of beds containing shatter
cones
Arrow shows direction of point of cones, number
shows angle of cone axis measured up from
horizontal

SM Figure 10. Distribution of shatter cones. These cones form in solid rock because of the extreme impact pressure. From Wilshire, et al, 1972.

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On The Cover

Photo from Donald McGookey's paper on the Sierra Madera Astrobleme

STGS Lunch Meeting Notice

Date: Wednesday, April 10, 2019
Time: 11:30 am
Location: Petroleum Club
8620 N New Braunfels Ave # 700
San Antonio, TX 78217
Speaker: Dale Short
Topic: Tectonics of the Texas Portion of the
Sabine Island

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