ARIZONA ROCKBOUND SOCIAL EXCURSION

in association with the Open University Geological Society

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This trip was organised by the Open University Geology Society to look at the geology in Northern Arizona, covering all three major types of rocks; sedimentary, igneous and metamorphic. We learnt about the social history of the Indians as their culture and way of living was very much dictated by geology. We also saw plants and birds that had adapted to the climate. Here is a snippet of some of the localities visited.

Campe Verde area.
34°33'44.77" N 111°51'12.46" W.
Elevation 3131 ft

After a few days of acclimatisation and a visit to the Montazuma Castle and Well, we drove down the Mogollon Rim onto a rough side road off Highway 260. Not knowing what to expect we started walking along a path when we had our first sighting of some strange features. We were looking down into a side valley of a massive caldera. In the valley were conical-shaped mounds of varying sizes which appeared to be light in colour *(Photos 1 and 2).* It was difficult to establish exact sizes at that distance. We scrambled down through rocks to find ourselves amongst these mounds some of which reached up to 30 feet. An obvious feature in the mounds was holes of varying sizes, some of which spiralled up the mounds. Occasionally, some had joined up to form a hole right through the cone. Some mounds still had cap stones in situ which were darker in colour. There was no evidence of definite layering and no fining upwards.

Photo 1 *J. Browning*

Photo 2: Ash Cones *J. Browning*

Our guide Colin was able to tell us the 'official' explanation for these cones. Arizona has been under salt water at least 7 times in the last 100 million years or so. The cones were formed in molten pyroclastic flows while Arizona was undergoing one of these culture shocks. To the south west is the 6 mile long Hackberry Caldera on an east-west direction, which was erupting under water during this period. The ash fall welded together whilst it was hot, becoming ignimbrite. An explosive deposit from above

(ash) would account for the absence of fining upwards. There is no dating evidence although they are older than the lake sediments as these sit on top of the ash. Basalt is both underlying and overlying the lake deposits. It is basalt that forms the cap stones. The ash cones are in a valley which increases turbulence in the wind, with wind speeds of 50-60 mph. Coupled with copious amounts of rain the mounds will gradually erode away. It is thought erosion could be explained by the Venturi effect, a consequence of Bernoulli's principle, which relates the pressure of a fluid to its velocity, i.e. as velocity increases pressure decreases.

We then visited an old abandoned salt mine – well, not the mine itself as the adits were unsafe and had been destroyed by explosives, but the surface deposits. The salt formed from the lake which built up behind a natural dam, created when volcanic material (basalt) blocked the valley. Once we got our eye in we saw plenty of calcite pseudomorphs after glauberite. Glauberite does not keep well in collections for it is efflorescent developing white powder on its surface which dulls its lustre. This site is the most famous for these pseudomorphs in the US, although we were not lucky enough to find one.

Sunset Crater.
35°21'53.89" N 111°30'21.96" W.
Elevation 6969 ft

Sunset Crater is the most recent volcano, last erupting in 1066-67. It is a basaltic cinder cone which erupted in Strombolian style. It is so-called as under certain light conditions it looks like a sunset due to the final burst of activity being red and yellow oxidised cinders. Cinders and bombs came to rest at an angle of 33°. It is 1 mile in diameter at its base, 2250 feet in diameter at the top and the elevation at the summit is 8,039 feet. It is estimated approximately 1 billion tonnes of material has been extracted during the eruptive phase and the extent of the ash fall was ~ 800 sq. miles. Sinagua Indians previously lived here, but their homes were buried under the cinders. They moved away but returned to take advantage of the blanket of ash which gave them a new moisture retaining layer which is good for growing crops.

One theory for the formation of Sunset Crater is the hotspot theory. By calculating the distance against time for Mt. Williams, the oldest, through Mt. Washington to Sunset Crater, the youngest volcano, the speed is the same as the movement of the tectonic plate. However, this theory does not explain why there are young volcanoes south of the Colorado plateau and then east into Oklahoma. Another theory is that the North American Plate is extending. It has created the Basin and Range Province to the south and west which is still occurring and extending into the Colorado Plateau. This process could activate ancient faults that serve as pathways for magma to move to the surface.

Photo 3: Climbing Lenox Crater J. Browning

Sunset Crater is out of bounds to tourists, but we were able to climb over the lava field and down a lava tube. We then climbed Lenox

Crater, a smaller cinder cone. At this altitude we took it slowly and congratulated ourselves that we all made it to the top. Ponderosa pines and shrubs have colonised the summit and from here we had a good view of other cinder cones and, to the west, the San Francisco Peaks. We found green crystals of epidote and incipient amber around the base of the Ponderosa pines.

We then followed a trail round the Bonito Lava Flow. The lava here is approximately 1,000 years old and over 100 feet thick. It is uneven and brittle, mostly a'a type, although pahoehoe was seen, as were ravines caused by collapsed lava tubes. There were several splatter cones, or hornitos (Spanish for oven), visible where molten lava had oozed out through cracks in the solid lava shell. This molten lava was very plastic. We could see that it had been molded into wedge-shaped masses as it forced its way through gaps or cracks in the solid lava shell. This molten lava was very plastic. We could see that it had been moulded into wedge-shaped masses as it forced its way through gaps or cracks in the country rock.

Meteor Crater.
35°02'58.90" N 111°01'15.02" W.
Elevation 5641 ft

Meteor Crater is located in the Northern Arizona desert, near Winslow, just east of Flagstaff. The impact took place ~500,000 years ago during the Palaeocene Epoch. It is the first confirmed impact crater on Earth and the smallest out of the 150 proven craters worldwide of which 28 are in the US. Preservation in this area is excellent due to the altitude and arid conditions limiting erosion. Our guide for this part of the trip was Harold, who gave us an excellent historical overview of the crater and the surrounding area starting with the Holsinger Meteorite on display in the Crater Museum. Composed of

Photo 4: San Francisco Peaks J .Browning

Photo5: Meteor (Barringer) Crater M. Freeman

92% Iron, 7% nickel and 1% trace elements including cobalt and platinum, it weighs in at 1406 lbs and was discovered 2 ½ miles west of Canyon Diablo.

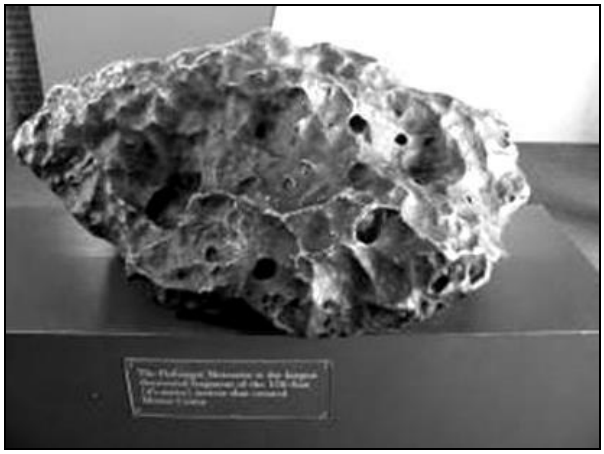

Photo 6: The Holsinger Meteorite M. Freeman

Photo 7: A warning sign on the crater rim. We don't know what it is! *M. Freeman*

Around the time of the impact this area was grassland, roamed by woolly mammoth, great sloths, camels, bison and bear (although a new species has recently been discovered – see photo 7). Man didn't come to this region until 12,000 years ago. The 150ft meteorite struck the earth at an angle of ~ 80° and a speed of ~26,000 mph. Originally thought to have come from the NE, the actual direction is not really known. The force of impact would have been greater than 20 million tons of TNT, lifting and folding the earth beneath it. Reversed strata have been found. A white powder (rock flour), which is pulverized Coconino sandstone, lies on the bottom. This has very high silica content and would have originally been ~ 600 - 700 ft thick. Above this are the Toroweep and Kaibab formations with the Moenkopi on the top. Ejecta covers an area of 5 – 7 miles with meteorite oxides and spheroids found near to the site, and more recently shocked sandstone and silica. After the initial impact a large shallow lake was formed**.** There is now a dry lake bed containing fresh water fossils at the centre of the crater including bivalves, *Giganteus Productus*, trace fossils and a foot print in the Moenkopi. The floor is very loose and absorbs any liquid straightaway. Two pre-existing faults that have been linked to the Laramide Orogeny are also visible inside the crater.

Photos 8 and 9: Some of the fossils found on the crater floor *M. Freeman*

Although there is evidence of the crater being known by local Native Americans, the first written report was made by Franklin in 1871, whilst scouting for General Custer. The first documented name of the crater was Franklin's Hole but it has also been known as Coon Butte as it was thought to be an extinct volcano, part of the Hopi Buttes volcanic field located nearby. In 1891 the crater was visited by USGS Chief Geologist G. K. Gilbert. Although he had earlier concluded that the majority of craters found on the moon were formed by impacts, he decided this one was of volcanic origin.

The crater site has been owned by the Barringer family for over 100 yrs and was originally used for mining, with 5 shafts and 28 holes drilled. In 1903, Daniel Barringer, who suspected a meteorite impact, formed the Standard Iron Company and spent the next 26 years or so searching for ore. In 1922 the mine was closed following problems with water – they had only found a few meteorite fragments by this time. In 1928 they tried

again to drill avoiding the water table and eventually, whilst drilling at site 27, they hit something hard. It took them 3 hours to drill 2ft, when they broke both the drill bit (which had become lodged) and the drill cable. These problems along with a lack of funds caused the mine to finally close.

It was in the 1960's that Shoemaker and colleagues, whilst studying nuclear test sites in Nevada, saw similarities and interest in the crater increased again. They found shatter cones, coesite & shistovite created during the impact confirming earlier suspicions on the crater's origin.

Meteor Crater has since become a NASA training site. Astronauts are taught about the structure of impacts and also the site has been used to fine tune moon rovers and space suits. There has also been a light aircraft accident, and Star Man, with Geoff Bridges, was filmed here in 1984. The site now exists as a national landmark and tourist attraction. An excellent trip!

Petrified Forest.
34°48'24.15" N 109°51'38.62" W.
Elevation 5474 ft

En-route to the Petrified Forest, first stop of the day was Jim Gray's Petrified Wood Shop. What a treat for all - and plenty of money changed hands.

The Petrified Forest is split into several sections; Blue Mesa, Jasper Forest, Crystal Forest and Rainbow Forest. In the background are the grey peaks that make up the Chinle formation. These are erosional features from the Triassic, (208 – 240 Ma), and represent over 10 million years of deposition. The area has been bevelled flat and has the Shinerup formation lying unconformably below. During the Triassic the region was hot and humid, with a fertile landscape created by swamps and large river systems similar to the Mississippi or Amazon river systems of today. Plant fossils such as the lycopods, cycads and ferns have been found here along with early dinosaurs (eg *Coelophysis* and *Chindesaurus*). We saw some of these on display in the Rainbow Forest Museum. Over the years, this area has been subject to looting by souvenir hunters and prospectors. It gained National Park status in 1962 following petitions from locals who wanted to preserve what was left.

We followed the Long Logs Loop, then the Agate House Trail before heading back to the museum for a picnic lunch.

Photo 10: Inspecting a fossil log
M. Freeman

The fossil logs, (typically *Auracaria Oxylon Arizoniaicum*), are thought to have been

washed down the fast flowing rivers during storms and deposited on the flood plains. There are no roots or bark, which suggests they travelled great distances before settling and being covered in sediment, (layers of silt, mud, sand and volcanic ash), which protected the logs from decay. Mineral laden ground water percolated down through the layers of sediment saturating the dead wood

Over time, silica crystals grew within the porous cell walls and replaced the remaining organic material keeping the structure of the wood intact.

The beautiful colours are due to trace minerals that also soaked into the wood. The reds, browns and yellows have come from the iron contained in volcanic ash. The black, blue and purple have come from either manganese or carbon, with copper adding blues and green. The white and grey is from the silica itself.

Some of the logs are still complete, but others have been broken into sections and have been scattered over a large area, visible as far as the eye can see. During the Laramide Orogeny (~ 80Ma), the region was uplifted. The logs had already been lithified so were brittle and easy to break under stress.

Towards the south end of our trail was the stunning agate house which is the partial reconstruction of a pueblo originally built by Native Americans in the 13th Century. Fossil logs have been laid in a clay mortar creating one of the eight rooms originally thought to be here.

Painted Desert.
35°04'27.22" N 109°47'23.19" W.
Elevation 5807 ft

This is an area of badlands that stretches from the Grand Canyon into the Petrified Forest National Park, running roughly along the Little Colorado River. It comprises 93,500 acres and stretches over 160 miles. The name is derived from the array of different colours that are displayed depending on the time of day and amount of light available. We saw the colour change from greys to browns and reds right before our eyes.

Photo 11: Agate House reconstruction *M. Freeman*

Photos 11 & 12: The ever changing Painted Desert *M. Freeman*

We were in the Blue Badlands (or Blue Mesa). Composed of stratified layers of easily erodible siltstones, mudstones, shales and clays, it forms part of the Chinle Formation. iron and manganese compounds that provide the pigments for the various colours. The clay layers are bentonite containing mostly montmorillonite which is a clay mineral composed of volcanic ash from the smectite family. This is very soft clay that is eroding rapidly. Recent calculations show approximately 7.5cm in 10 years which compared to granite is very fast (7.5cm in every 10,000 years). The rocks are poorly consolidated here and the torrential rain that rarely falls in this area easily washes sediment away. Gullies, rills and caves are constantly being created as the clay minerals expand and shrink. The shrinking and cracking also creates dimples, giving the surface the 'elephant skin' appearance.

As the surface is washed away fossils are constantly being found that shed light on the past environment. Teeth and bones from long-extinct reptiles, clams, insects and some tropical plants are just some of those that have been identified.

The scale of this landscape takes your breath away; it is desolate and beautiful. The way the light plays upon the rocks and changes the appearance is quite spectacular. A visit is recommended!

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