Black Hills of Dakota

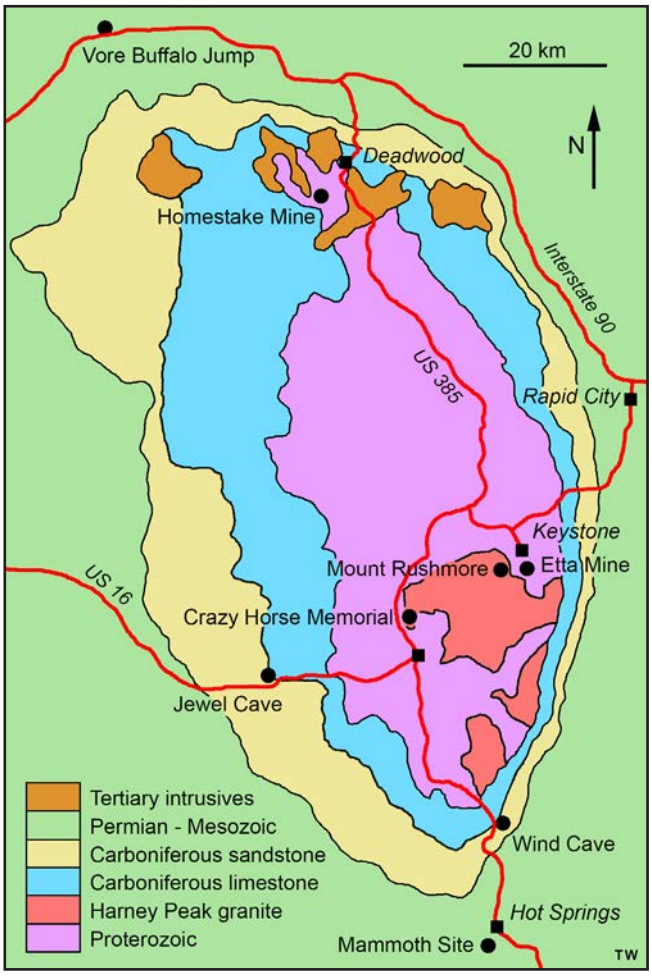
Immortalised in song by the recently departed Doris Day, the Black Hills of South Dakota are a feature of American geology all too often overlooked by those heading for the Cascades, Yellowstone or Colorado Plateau. Yet they have a lot to offer.

The Hills' rocks are far from black. They take their name from the cover of dark conifer trees that stands out from afar when viewed from the pale grasslands of the surrounding Prairies. And they rise only about 1000 metres above the plains. Geologically the Black Hills are formed by a classic breached anticline. This is periclinal and therefore leaves Proterozoic basement exposed inside an ellipse of Carboniferous sandstone and limestone. All are surrounded by huge expanses of Permian and Mesozoic outcrops.

Harney Peak granite

Intruded into the southern end of the Proterozoic outcrop, the Harney Peak granite dates from around 1750 Ma. It forms a highland with some dramatic areas of tors shaped into tall spires and pinnacles. Most of it is better described as migmatite or granitic gneiss where it is distinguished by foliation that varies from weak to conspicuous. However there are also areas of homogeneous, coarse-grained granite, along with dykes of pegmatite and aplite. This unit is perhaps best known for the enormous carvings created on its outcrops, which are notable for their minimal jointing.

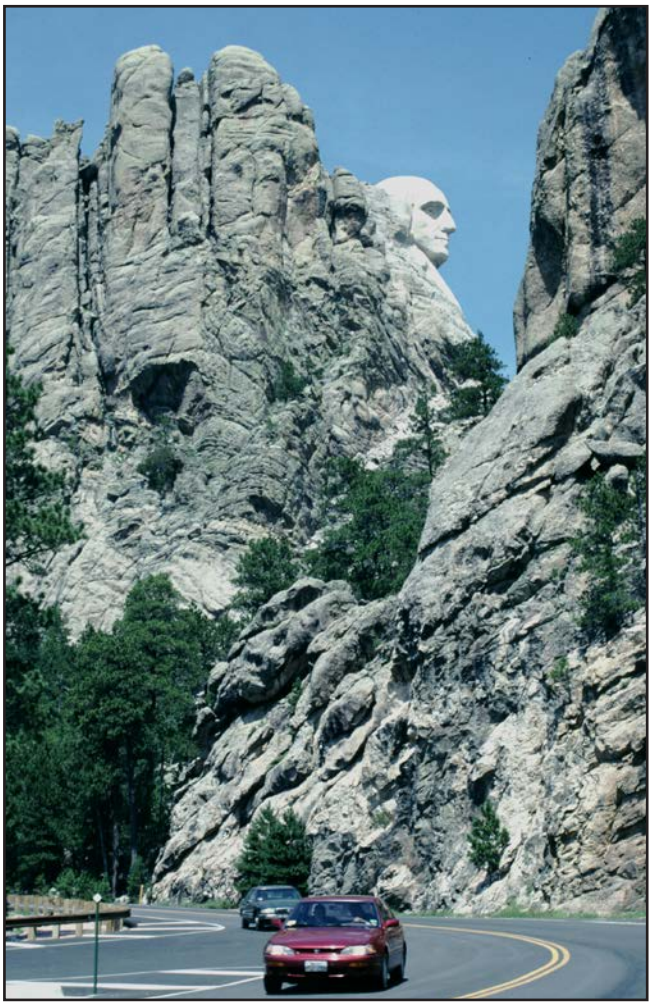
Mount Rushmore has the well-known heads of four presidents carved into its eastern face. The original idea for these enormous statues was to carve each figure into one of the tall granite tors known as the Needles (beside a highway southwest of Keystone). In the 1920s, a sculptor named Gutzon Borglum had carved a massive bas-relief memorial into the face of Stone Mountain, near Atlanta, and he was asked by state officials of South Dakota to manage their project. He soon rejected the fragile Needles, and moved the site to the stable face of Mount Rushmore, where four heads were completed during the 1930s, with Borglum's son supervising the work by then. Each head is about 18 metres tall. The rock faces beneath



Outline geology of the Black Hills of South Dakota.

[Above] The completed face of Crazy Horse in 2017, with excavators giving some scale to the carving.

[Left A plaster model at the Crazy Horse Memorial visitor centre standing more than 1200 metres in front of the real thing, as it was in 1997, and gives some idea of the enormous scale of the project as it will be when completed many years hence. Work then was still in progress on the warrior's face, and a rough outline of the horse's head had been painted onto the granite wall.



In profile high on Mount Rushmore, a granitic George Washington is actually in granitic gneiss and migmatite)

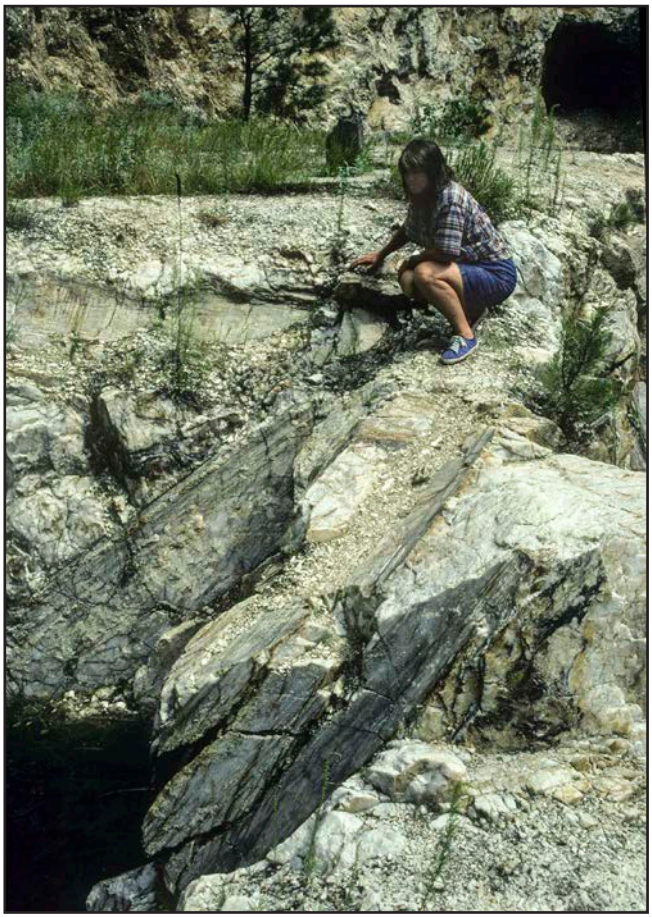
the heads have only been roughly hewn to a smoothed profile; these best show the foliation in the rock, along with various cross-cutting veins and a large segment of dark schist beneath George Washington's head (which is in the most prominent position as the far left of the four sculptures).

The Crazy Horse Memorial is currently being carved into Thunderhead Mountain, some 12 km southwest of Mount Rushmore. It is also within the Harney Peak unit, but its coarse, homogeneous rock forms a small pluton that is rather different from the granitic gneiss of Rushmore. Work was started in 1948, when Lakota Chief Henry Standing Bear invited Korczak Ziolkowski to carve a memorial to the native peoples of the region. It is on a gigantic scale. Crazy Horse's head is nearly 28 metres tall, but the rock carving will have him mounted on a horse, so that the final statue will be 171 metres high. To date, the spur of the mountain has been roughly shaped, but only Crazy Horse's face has been completed. This was to create a visitor attraction at an early stage, as the project is financed entirely by private donations and fees at the site's visitor centre. It will probably be another 50 years before it is completed, with the work being managed by successive generations of the Ziolkowski family.

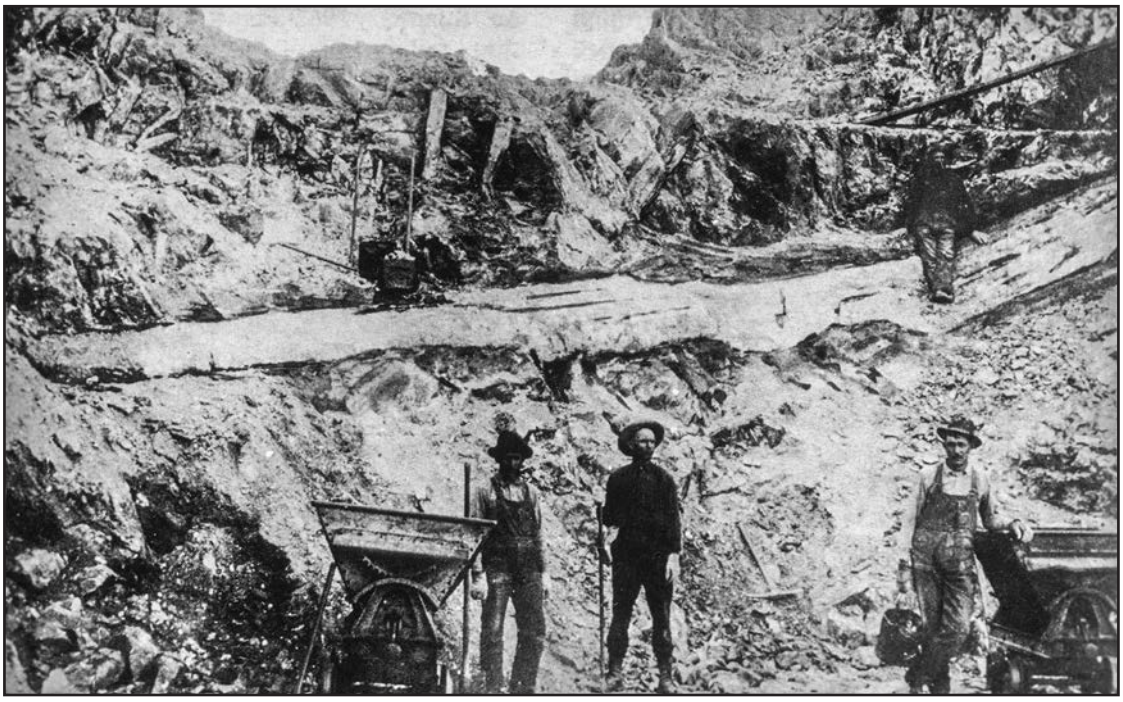
The pegmatites at Etta

Associated with the Harney Peak granite, a number of pegmatite bodies are famous for the enormous crystals that they have yielded from the hills just south of the small town of Keystone. These pegmatites contain potash feldspar crystals up to five metres long, some plagioclase, and muscovite crystals that yield cleavage flakes the size of dinner plates, all set in a groundmass of coarse-grained quartz. In addition, they contain giant crystals of spodumene, the lithium aluminium silicate that looks very like the feldspars. Known as 'spod logs', these crystals have been found up to 13 metres long and more than a metre in diameter.

The original Etta Quarry worked its pegmatite from an almost vertical lens that was 50 metres long and nearly 20 metres wide, within a country rock of schist that overlies the source granite at depth. An open quarry worked downwards from the hilltop outcrop, and had adits driven from the adjacent hillside into its lower levels. The quarry was originally opened, in 1883, to extract mica, but the operators were distracted by 'black ore' of cassiterite that they found within the same pegmatite. However, the tin yields were never viable, and by 1898 attention had switched to the lithium resources. Working ceased in 1960. The lower part of the quarry is now flooded, but the upper parts are accessible through the short horizontal adits (though changes in land ownership may vary this situation). The visible mineralogy is still spectacular.



Giant spodumene crystals exposed in the old Etta Quarry.



The well-known but un-credited USGS photograph of one of the longest 'spod logs' exposed in Etta Quarry, probably in the early 1900s.

Other small quarries have also worked, and are still working, some of these pegmatites around Keystone. Feldspar goes into ceramics, with production peaking in the 1940s, but quartz was never commercially usable. Beryl has been found in some pegmatites, with fine crystals, but little of gem quality. However, the mineral was worked in various small mines around Keystone during the 1940s and 1950s when beryllium was required within the nuclear industry. Besides the mines, active and deceased, there are exposures of pegmatite with very large crystals in natural outcrops, and even in some road cuttings in the same area.

Enormous crystals of feldspar exposed in a road cutting along the Iron Mountain Road that extends southwards from the town of Keystone; the person is standing on a mass of (rather pale) rose quartz.

Wind and Jewel Caves

Within the Black Hills' rim of limestone, which constitutes the Carboniferous Madison Formation, Wind Cave and Jewel Cave are both in the top ten of the world's longest caves, when they are measured in terms of their known passage lengths. Both are maze caves with joint-guided, rectilinear networks packed into quite small areas, and they bear no relation to modern drainage patterns. They have previously been thought to be hypogenic caves, which had been formed by rising artesian water that was geothermally warmed and acidic. However, this does not fit their distribution, whereby the mazes are restricted to shallow zones, without deep passage extensions. It appears that they were formed largely by waters that infiltrated through the thinner parts of the overlying sandstone. These invaded areas of the limestone that had high fracture densities and also contained relics of Carboniferous caves and collapse breccias formed by dissolution of lenses of evaporite gypsum. This complex origin is disputed by some, but other theories to date cannot be supported by field evidence.

The caves are also notable for their distinctive calcite mineralogy. Jewel Cave takes its name from the extensive crusts of nail-head calcite crystals that coat the rounded walls of dissolutionally sculpted cave passages. These crusts date from 25 to 15 Ma, and appear to have formed when the limestone, with its pre-existing Carboniferous caves, was deeply buried by Tertiary sediments. In contrast, Wind Cave is noted for the extensive boxworks of thin calcite veins that project from the cave walls. The veins were originally of gypsum, which survived attack by sulphuric acid that dissolved the intervening limestone; only later did fresh water invade the caves and replace the gypsum with the calcite that survives today. This complex evolutionary process probably matured when the sites were deeply buried during Mesozoic times.

Both caves are now within the National Park system, and have short sections of passages developed as show caves. Their mineralogy makes them very different from show caves elsewhere.

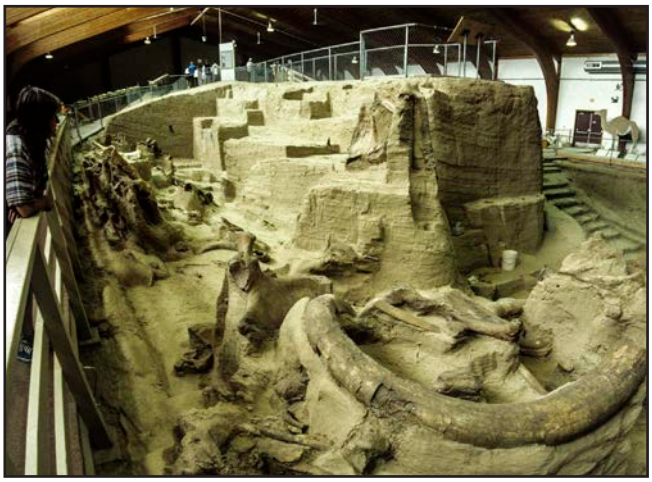
Outlying sites

Just inside the northern end of the Black Hills, the Homestake Mine was the largest and deepest gold mine in America, reaching depths of 2000 metres. The site was worked for 125 years until it closed down in 2001, after yielding more than 1100 tonnes of gold. Its ore occurred as multiple greenschist horizons within a steeply dipping sequence of Proterozoic volcanics, carbonates and ironstones. It appears to have been a volcanic exhalative deposit of the type commonly found as base-metal sulphides, derived from deposition around black smokers on ocean floors. The nearby small Tertiary intrusions are not associated with the gold mineralisation.

Placer gold deposits were worked in the Black Hills Gold Rush in the 1870s, when the town of Deadwood grew from the mining camp. Homestake was the Mother Lode of the placer ores, and was found by prospectors working their way upstream. Elsewhere in the Black Hills, gold placers were found but none beyond Deadwood Creek yielded significant riches.

Homestake Mine's surviving open pit is now a tourist site on the edge of the town of Lead, an eastern part of Deadwood. Most of the mine's underground stopes have been backfilled with waste or tailings, though one section at a depth of 1600 metres is now an underground laboratory for the study of neutrinos.

The thick crust of columnar calcite exposed in Wind Cave where it has broken away from the dissolutionally rounded limestone wall of a pre-mineralisation cave.



Mammoth tusks displayed in situ within the partially excavated silts that fill the Mammoth Site sinkhole.

Just outside the southern end of the Black Hills, the Mammoth Site lies on the edge of Hot Springs, a small town named after its geothermal waters. A Quaternary caprock sinkhole developed by collapse of a cave within underlying Permian limestone. This became a classic sinkhole trap, with the result that the bones of numerous mammoths and many other mammals were preserved within its silt fill. Since discovery during ground clearance for a housing project in 1974, the site has gained a huge building to protect the sediments that are now exposed, and a visitor centre that is open year-round. The spectacular fossils date from 26 ka, within the Ipswichian Interglacial.

Another spectacular sinkhole was formed by collapse in gypsum, and is now known as the Vore Buffalo Jump, because Cheyenne hunters stampeded buffalo over its edge around 500 years ago. It is now a major bone site adjacent to Interstate 90 near the northern end of the Black Hills.

These sites are just some of the main geo-attractions of the Black Hills. With the Badlands just to the east, Devils Tower not far to the northwest, and the Powder River coal basin nearby to the west, the region has plenty of appeal for a geology holiday.

Tony Waltham

The surviving open pit of the hugely productive Homestake gold mine (photo: Tim Colman).