

The sandstone fantasy of Petra

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The rose-red city half as old as time is an incredible series of monuments carved out of Cambrian sandstone, which offers more than a little geological interest. Both the site of Petra and its approach canyons are tightly controlled by the geology, and the sandstone itself is mineralized and coloured on a surprising scale.

Petra just wasn't appreciated at the right time to be included as one of the seven wonders of the world, but it is certainly one of the most fabulous tourist destinations available today. Preserved with a minimum of weathering and erosion in the desert of southern Jordan, the huge carvings in the bedrock of the sandstone cliffs are silent testimony to the achievements of the ancient world.

The credits belong to the Nabataeans, a little-known group of people who rose to affluence owing to their key position on the trading routes across the Middle East. They occupied Petra over the period 600 BC to 400 AD. The Romans arrived around 110 AD, and the final demise of the site was hastened by two destructive earthquakes. In the twelfth century, passing Crusaders added a small fort to the site. Then Petra was forgotten, except by the bedouin herders who lived there and were not really into either tourism or archaeology. The site was rediscovered in 1812 when the Swiss traveller, Johann Burckhardt, disguised as a Moslem scholar, was taken by local guides to see the hidden ruins.

Burckhardt's reports amazed the western world, and Petra has attracted a steady stream of visiting archaeologists and the more dedicated travellers ever since. The sheer spectacle of the site never fails to impress, and it can never be diminished; but there is also considerable interest for the geologist in the structures and setting of Petra.

The geological setting

Western Jordan is scored by the massive rift valley which extends from the Gulf of Aqaba, northwards along the Wadi Araba to the Dead Sea and the Jordan Valley. East of the rift, the Arabian shield tilts gently to the east. Its basement rocks are only exposed around Aqaba and further south along the Saudi coast, and the sedimentary cover thickens progressively to the east as it dips into the great basin of the Persian Gulf. The highest ground in Jordan is along the mountain ridge formed by the uplifted western edge of this block. This ridge separates the Wadi Araba from the main desert basin (Fig. 1). Petra lies hidden in its eroded slopes which drop towards the Wadi Araba.

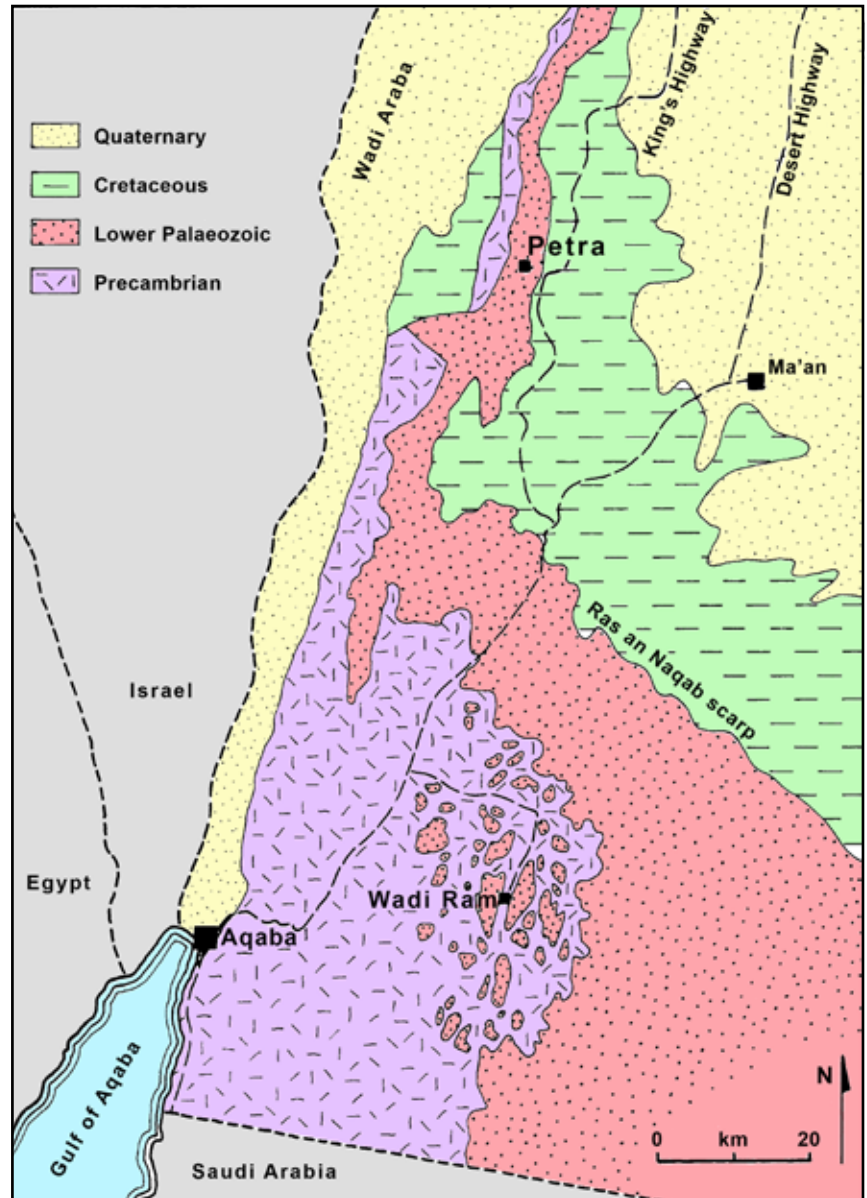


Fig. 1. Simplified geological map of south-west Jordan.

The geology is best appreciated by an approach to Petra from the south. Aqaba is the port and resort at the head of the gulf of the same name. To the north, the Wadi Araba is a natural corridor, but is politically sensitive as it marks the border with Israel. So the highway to Amman climbs directly into the granite mountains. It crosses a spectacular terrain of bare rock, huge slopes and wild wadis. The Proterozoic biotite aplite granite is beautifully exposed and is laced with swarms of dolerite dykes (Fig. 2). These are also Precambrian,



Fig. 2. Roadcut exposure of Precambrian dolerite dykes in the Aqaba granite.

the main highway. Here the desert valleys have just cut through to the granite, isolating residual blocks of the nearly horizontal sandstone. Often compared to Arizona's Monument Valley, the mesas of Wadi Ram are a good deal higher, rather older and a little more rounded; they lack the lower shale units which allow slope steepening by undercutting. However, this is superb desert scenery, visited by both T. E. Lawrence and Peter O'Toole. One mesa south-east of Ram village has the spectacular Brdah rock bridge across a very deep gully (Fig. 3); it is actually a natural arch left by weathering and not carved in a meander core. It is well worth the jeep ride, local guide and energetic scramble to reach it.

These sandstones are host to the rock carvings of Petra, which lies in the northerly continuation of the outcrop between the mountains and Wadi Araba. The red Cambrian sandstones are about 300 m thick. A white sandstone beneath them is exposed in the canyons below Petra, but is absent at Wadi Ram. Above the red sandstones lies yet more white sandstone, of Ordovician age; this forms paler caps on some of the hills at both Petra and Wadi Ram.

Between the Palaeozoic sandstones and the overlying Cretaceous sequence, there is a major unconformity with little angular break. Lower Cretaceous sandstones over 200 m thick are followed by a thinner limestone and then a mixed series of limestones, chalks, marls and cherts. These form the Ras an Naqab escarpment which the Aqaba highway climbs northwards, to leave the desert basin containing Wadi Ram. The limestones cap the mountain ridge, and dip gently eastwards to underlie the deserts east of Ma'an (Fig. 1).

From the top of the Ras an Naqab scarp, the old King's Highway heads north along the limestone ridge. It leaves the heavy traffic to the modern Desert Highway through Ma'an, and winds across rolling country which hides a scatter of bedouin camps. Wadi Musa is a small town sited on the edge of the limestone, which takes its name from a limestone spring supposedly used by Moses in biblical times. The town now thrives on tourism, because Petra lies just below. It is almost hidden within the dissected slopes which fall away more than 1500 m to the floor of the Wadi Araba.

The graben

Rivers draining from the limestone highlands have had to cross the outcrop of the Palaeozoic sandstones in their steep descents to the Wadi Araba. They have utilized the major joints in the sandstone to cut deep, narrow canyons which are rectilinear in plan; in Arabic they are known as siqs. This canyon country can only

and are an expression of early phases of a very long history of tensional opening on the line of the rift valley.

Red Cambrian sandstones overlie the granite, and the first outliers are encountered around Wadi Ram, south-east of Quwayra on



Fig. 3. The rock bridge in the sandstone at Wadi Ram.

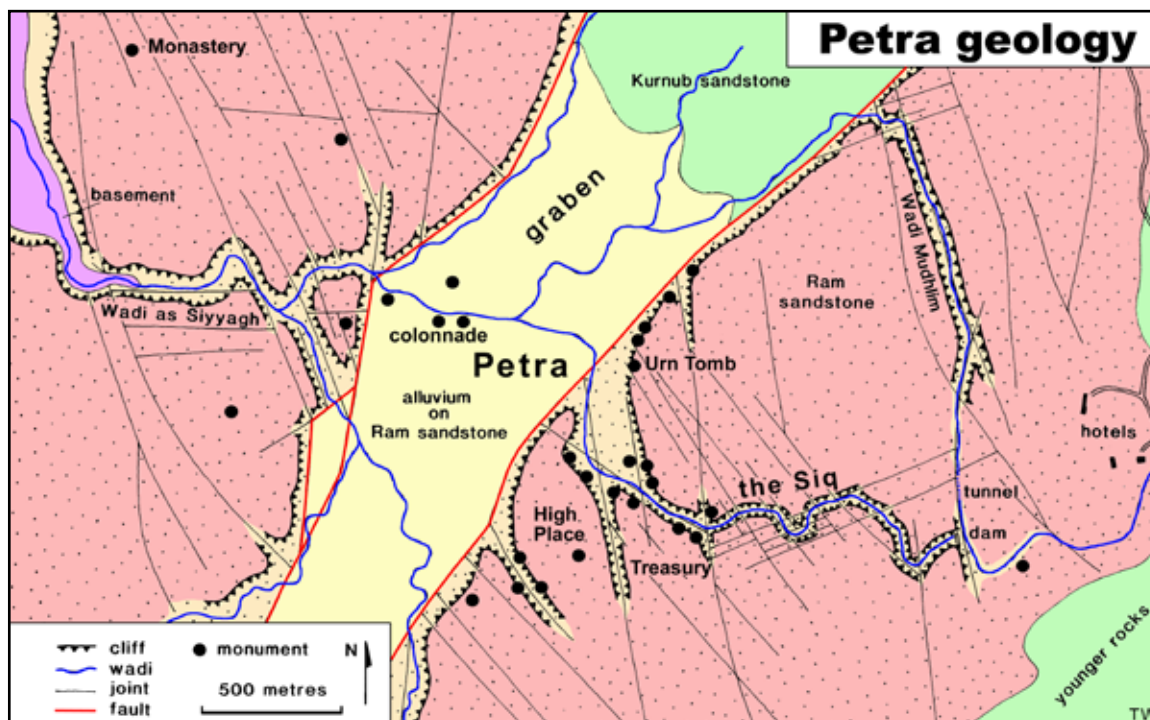


Fig. 4. Geological map of Petra. The sandstone joints marked are only the major ones with significant topographical expression. There are over 800 monuments carved in the rock; only a few of the largest are marked.

be crossed by keeping to the canyon floors, which therefore became the routeways, and then the homes of the Nabataean traders. Siq el Barid is one such canyon, 20 km north of Petra; there are about 50 carved structures in its sandstone walls, cool in the shade of the deep, straight fissure, but there is a severe shortage of space.

The Nabataean capital required a more spacious site, which is why Petra lies in a dramatic graben (Fig. 4). A down-faulted block about 700 m wide is floored with Cretaceous sandstones and limestones between high walls of the red Cambrian sandstone (Fig. 5). The throw on both faults is around 250 m (Fig. 6).

Five wadis converge on the graben, bringing intermittent flows of water, and there are also perennial springs in the floor. With 200 hectares of gently graded land, the graben floor

Fig. 5. The Petra graben seen from the northern end. One boundary fault cuts the shadows on the left, and the other is at the foot of the distant high cliffs.



provided scope for farming when cleared of the original oak and juniper forest. It also housed the core of the Nabataean city. Petra is thought to have reached a population of 25 000. Most people lived in adobe-built houses; these are notoriously unstable in earthquakes, and it is thought that nearly all were destroyed in the two recorded quakes of 363 and 551 AD. Some stone buildings, mainly from the Roman period, do survive, and little of the ground has been seriously excavated in search of more relics. Almost all that remains to be seen at Petra are the structures carved in the rock, and most of them appear to be tombs.

Contrary to popular opinion, there is not just the one entrance to Petra. The easiest ways in are down the gentle slopes at each end of the graben, and both these were important old trade routes. From the west, the routes were more difficult because of the steep terrain up from the Wadi Araba; the best of them followed at least part of the Wadi as Siyyagh, which takes all the drainage out of the graben. But the famous entrance to Petra is from the east, down the spectacular canyon known simply as the Siq.

The Siq

The valley down through Wadi Musa meets the top of the Palaeozoic sandstone not far from the bottom end of town. It widens onto the sandstone bench, then narrows as it cuts down into the sandstone at the head of the Siq. The main section of the Siq is 1200 m long. Parts of it follow the major fractures (Fig. 4), but other parts follow shorter joints; at nearly

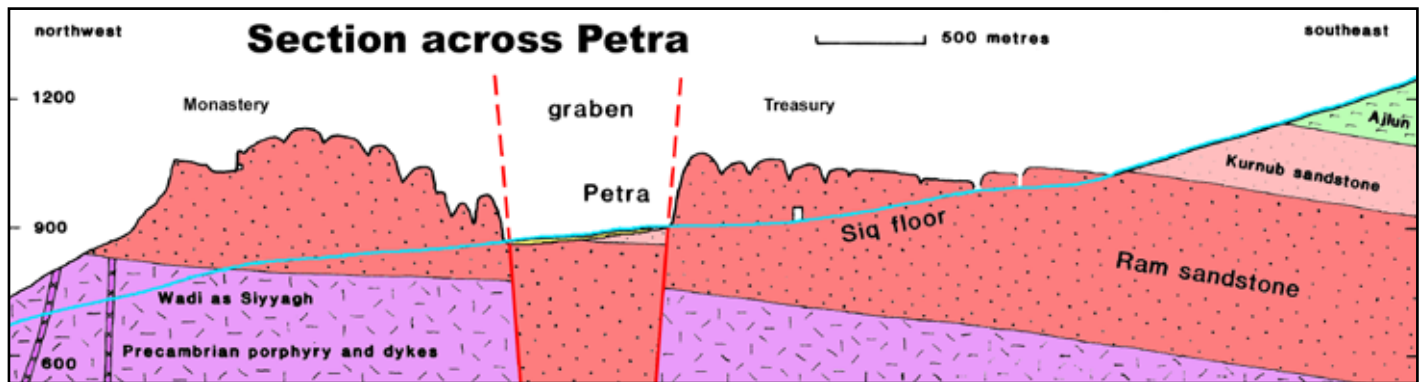


Fig. 6. Cross-section through the Petra graben.

every bend the joints can be seen continuing into the sandstone walls (Fig. 7). At its start, the Siq is only 10 m deep, but its floor descends while the rim rises with the dip, so that it reaches a depth of 100 m. With rock walls that are vertical for nearly their full height, and a floor which is mostly around 5 m wide, it is extremely impressive to walk through.

Clearly, the Siq is a fluvial feature, although it now carries only water as flash floods after local rainstorms. The Nabataeans paved much of its floor with blocks of sandstone. Some stretches survive, but most has been undermined and scoured by subsequent floods. In the lower reaches, 2000 years of sediment aggradation is indicated, where cobble banks partly bury doorways into some of the tombs cut in the sandstone walls.

Flash floods were a hazard which the Nabataeans eliminated with some imaginative

engineering. In the first century AD, they cut a tunnel 88 m long from the head of the Siq through to Wadi Mudhlim, just to the north (Fig. 4). With a low dam in the Siq, floods were safely diverted away from both the entrance road down the Siq and also the heart of Petra within the graben; yet the precious water still returned to the graben where it was always needed on the farmlands. The dam and tunnel fell into disrepair with the demise of the Nabataean occupation, but they were restored in 1963 after a group of tourists were drowned by a flash flood which caught them in the Siq. Today, a storm directly over Petra would exploit the Siq as an active drain, perhaps more exciting than dangerous, while storms on the hills above Wadi Musa are rendered harmless by the diversion works.

Every visitor should enter Petra via the Siq. The 20-minute walk is awesome, and is also a geological treat. But the real benefit is the first sighting of Petra's carved monuments at the lower end of the Siq. The Khazna is one of Petra's finest, carved into the vertical wall of a joint rift across the line of the Siq. Just a slice of it is first glimpsed between the shadowy walls of the canyon (Fig. 8). No monument could have a better frame; the sight is unforgettable.

The sandstone carvings

The Khazna symbolizes Petra's carved monuments. Its facade is 30 m wide and 43 m high, and every single feature of its columned and ornamented structure has been carved from in situ bedrock – the red Cambrian sandstone. However, it is little more than a facade; it dwarfs the pair of small square rooms behind its towering doorway. Al Khazna is Arabic for the Treasury, but these are misnomers based on myths; like almost every other rock structure in Petra, the Khazna was a tomb. The Nabataeans may have lived in simple style, but respect for the dead was an important part of their life.

Below the Khazna, the Siq widens out a little and its walls are crowded with carved struc-



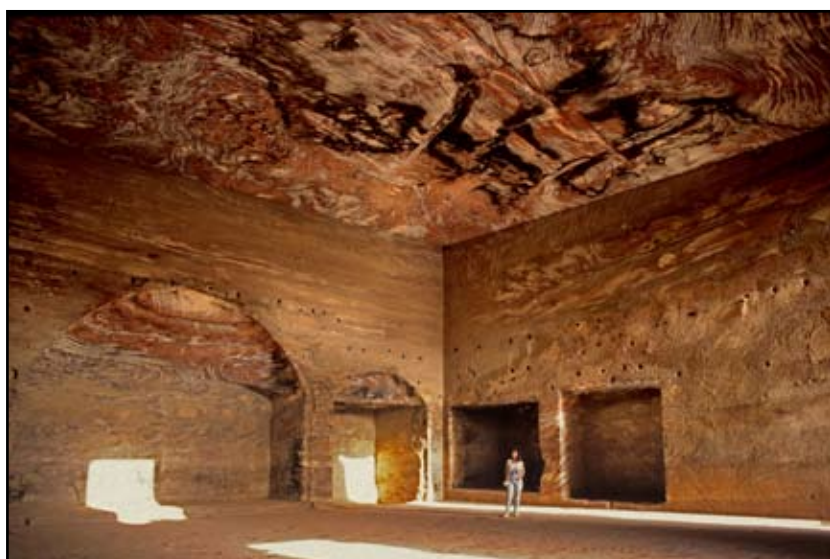
Fig. 7. Vertical joints in the sandstone exposed on a bend in the Siq.



Fig. 8. The first view of the Khazna monument seen through the narrow exit of the Siq.

tures large and small. An amazing feature of Petra is the sheer number of carved monuments; more than 800 are listed. Many are simple small rooms with square openings, the largest group forming the Necropolis, a short way down from the Khazna. Others have the most elaborate facades; these were the tombs of the kings, and most of the finest are in the walls of the outer Siq and the adjacent graben cliffs (Fig. 4). There is also an amphitheatre cut from the rock, carved by the Nabataeans but very much in Roman style; it can seat 7000 people. Rock carving was to this ancient race both an artform and a practical craft. Paths

Fig. 9. The interior of the Urn Tomb. The walls and ceiling reveal some of the colour banding in the rock, but parts of the roof are still blackened by soot from the fires of bygone bedouin residents.



were made up the cliffs to holy sites on the hilltops; wide flights of steps with bedrock barriers along the exposed side were carved from solid sandstone obliquely up near-vertical faces. Perhaps the most vital carvings were the rainwater catches and channels; these grooves were cut in the sandstone down and across sloping slabs and precipitous faces alike, to collect precious rainwater into cisterns, also cut in the rock.

The red sandstone is a medium-strong rock, which at most localities is virtually a freestone devoid of major bedding plane weaknesses. Significantly, the joints are widely spaced so that nearly all the carvings are in single blocks of rock. The combination of medium strength, uniform texture and massive structure is ideal for carving on the monumental scale of Petra. Some of the carved features are truly bold in their design, and there are almost no signs of rock distress, though one facade is reported to have collapsed in 1929.

The highest stresses are imposed on the sandstone around the artificial caves excavated behind the ornamental fronts. The largest room is in the Urn Tomb (Fig. 9); it is square, 20 m across and 6 m high. Alcoves break its interior walls, and three doorways with overhead windows let in daylight through the outer wall. Its ceiling is flat with square corners. There was no attempt to create a stable arched roof, and the square profile causes maximum stress concentration at the corners; but there is no sign of collapse or failure on any scale. The Urn Tomb is the finest testimony to the quality of the sandstone.

The rock colours

Petra was once elegantly described as 'the rose-red city half as old as time'. But the mellow rose red of the sandstones is actually only a weathering veneer. The real bonus for the visiting geologist is the colouring of the unweathered sandstone. It is a quite phenomenal melee of colours, with all hues of brown, red, orange, yellow and white. The colours are various forms of limonite and other iron oxides, and the bands represent oxidation zoning behind weathering fronts where groundwater soaked through the sandstone. The structures are superb examples of Liesegang rings, locally superimposed on subtly defined cross-bedding.

Some of the tomb facades were cut deeply enough into the cliff faces to reach the unweathered rock. These still reveal the fresh colours, untarnished by 2000 years in the desert (Fig. 10). The colour banding is broadly horizontal, reflecting the bedding control on the original groundwater circulation. Some of



Fig. 10. Splendid colour banding of the unweathered sandstone on one of the lesser tomb facades.

the best colours are seen on the ceilings of the underground rooms. There the cut surfaces are nearly parallel to the colour banding, which therefore appears as great overlapping swirls, each up to 1 m across (Fig. 11). These form the hidden face of Petra, no less amazing than the famous great rock facades.

A visit to Petra should always include time for the walk up to ad Dayr – the Monastery. This isolated monument stands high on the sandstone plateau west of the graben; a good path climbs to it, providing along the way some spectacular views down into the sandstone fissures and canyons. Ad Dayr is the largest single carving at Petra, 45 m high and 50 m wide. Its facade is cut in the proportions of the gods, which only become apparent when a mere human gives scale to the enormous doorway (Fig. 12). Inside, there is just a single square room, which was a feasting hall for Nabataean banquets in honour of the dead. It was cut in the first century AD, and 400 years later Christian visitors carved crosses in its interior walls. From these came its misleading name; it never was a monastery.

Fig. 12. Ad Dayr, Petra's largest monastery, with a full-size human in its oversize doorway.



Fig. 11. The complexities of the iron-oxide banding within the sandstone, exposed in the roof (a) and wall (b) of minor tombs cut in the north wall of the lower Siq.





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Fig. 13. The Cambrian sandstones sit unconformably on the basement complex in the cliffs below ad Dayr.

The geologist has another reason for visiting ad Dayr. The plateau extends just a short way in front of the monument to the rim of a massive cliff. It is the very edge of the sandstone outcrop. Down the cliff, the whiter basal Cambrian sandstones can be seen, just above the strong unconformity (Fig. 13). Below this, the Precambrian is a complex of quartz porphyries cut by numerous dykes. Deep wadis provide perfect exposures, and further away the faults of the rift-valley margin step down slices of younger rocks. Far to the west, the floor of the Wadi Araba can be seen over 1000 m below. It is a splendid panorama, which neatly completes the geological perspective of Petra.

Suggestions for further reading

Bender, F. 1975. *Geology of the Arabian Peninsula: Jordan*. United States Geological Survey Professional Paper 560-I, 36pp.
Taylor, J. 1993. *Petra*. Aurum Press, London, 80pp.

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