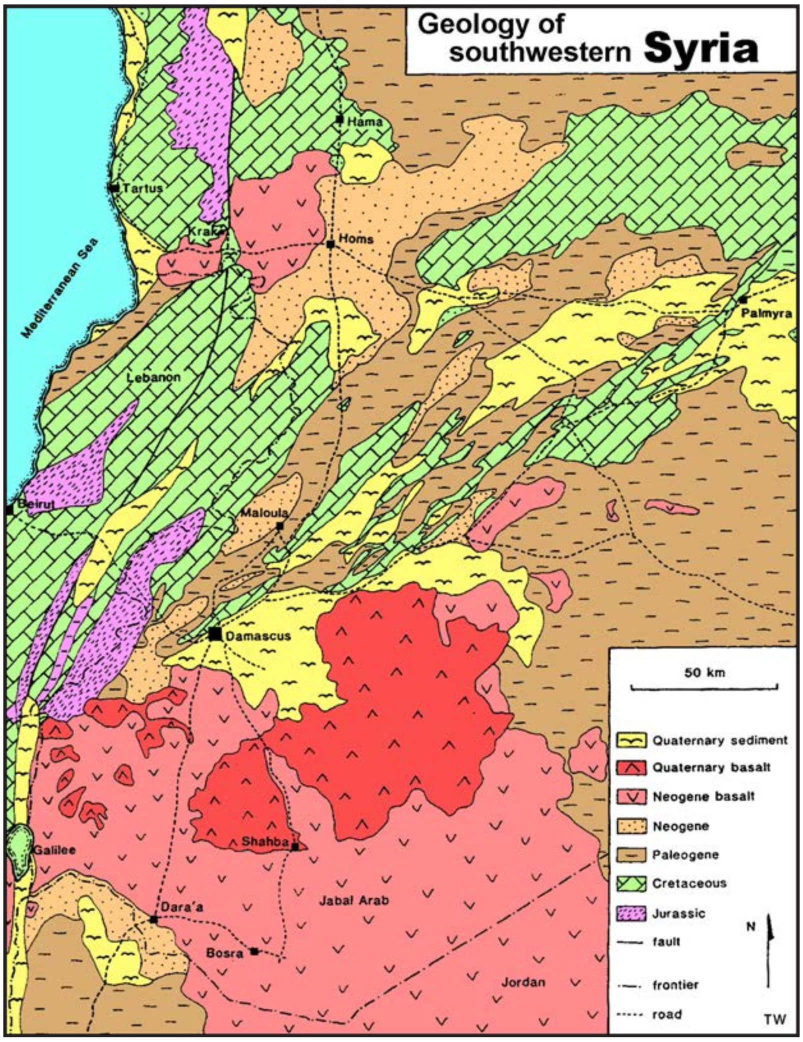
Syria: a geological excursion

Tony Waltham

These notes have been extracted from the guidebook that was prepared for tours to Jordan and Syria, run for the Geologists' Association in 1996 and 1997. The key feature of the tours was time spent in the red sandstone country of Wadi Rum and Petra, both in southern Jordan. The itinerary then covered various other geological features that were accessible and worthwhile, but also included the major historical sites in both countries.

The geology of southern Jordan was described in a feature entitled *The sandstone fantasy of Petra*, which was published in *Geology Today*, on pages 105–111 in Volume 10, published in 1994, and a pdf is available as a free download from www.geophotos.co.uk.



Geology of Jordan and Syria

The main feature of the geology in this region is the extensive outcrop of the Mesozoic and early Tertiary sedimentary rocks which were deposited in the southern shallows of the Tethys. This oceanic sedimentary trough lay between the continents of Eurasia and Africa (including Arabia). Today, Syria and much of Jordan are dominated by the Tethyan rocks, which overlie the subsided northern sector of the Arabian plate. A Paleozoic sandstone sequence and the basement complex of the Arabian-Nubian craton (now split by the Arabian-African plate boundary) are only exposed in the deserts of southern Jordan. Closure of the Tethys Ocean created the fold mountains of the Taurus, Elburz and Zagros mountains, but the effects to the south were less strong. The regional geology also includes the volcanics on the Syria-Jordan frontier, the rifts of the Dead Sea, and various fold belts.

Precambrian and Palaeozoic events

The granites around Aqaba are the most northerly exposures of the Arabian-Nubian Shield, which extends as far south as Ethiopia. The complex of plutons, and also some volcanics and pyroclastics, are largely Precambrian, but their latest radiometric dates are around 550 Ma, placing them in the Cambrian. They are laced with dolerite and porphyry dykes, all of which are truncated by the Cambrian unconformity. Some porphyries may have housed primary copper sulphides which became the source of the secondary copper deposits worked from the Paleozoic sandstones by King Solomon's mines, within the Dead Sea rift.

Cambrian uplift of the shield provided sediment which was carried to the north. This was deposited to form the massive wedge of coarse, red, fluvial sandstones of the Ram Group, up to 600 m thick, now forming the desert landscapes of Rum and Petra. Thickening of the basal units in the sequence, towards Wadi Araba, suggest that an ancestral depression already existed in the area of the Dead Sea. Later Paleozoic sediments are missing in the Rum-Petra area, but further east and south they include fluvioglacial valley fills of outwash from Late Ordovician glaciers on the Arabian shield when it was part of Gondwonaland.

The Ram Sandstones partly filled a broad basin which remained as land, and largely as an erosional environment, right through to Cretaceous times. Across most of the region, there are few rocks of intervening age known even in deep boreholes. Jurassic rocks are known in anticlinal cores in the Anti Lebanon and the Palmyrides, and in a small inlier near Jerash.

Sharply folded Cretaceous limestones exposed along the margin of the Dead Sea graben.

Cretaceous and Paleogene sediments

The basin across Syria and northern Jordan was inundated by the worldwide rise in Cretaceous sea level. Further uplift of the Arabian Shield produced more fluvial sediment from the south, forming the Lower Cretaceous Kurnub Sandstone in Jordan, up to 300 m thick. The contemporary rocks in Syria are limestones and marls deposited in the Tethys further from land. By Middle Cretaceous times, calcareous sediments had extended across the whole region. In Jordan, these became the Ajlun Group - shelf carbonates and marls, with fringing reef facies thickening into the Mediterranean basin west of the Dead Sea fault.

These were followed by the Upper Cretaceous and Paleogene sediments of the Belqa Group, whose chalk-chert-phosphate facies formed on a shelf adjacent to oceanic depths in the Tethys to the north. Much of the Jordanian desert is floored by Paleocene chalky limestones. The carbonate sequences with various units of marl, chert and phosphate continue into Syria, where the Upper Eocene Maloula Limestone is one of the thicker units.

The total thickness of the Tethyan rocks broadly increases to the north. The Ajlun and Belqa Groups are 300 m thick in southern Jordan, and 700 m thick in northern Jordan. Their stratigraphic equivalents reach over 2000 m thick in the Anti Lebanon, where subsiding basins within the Tethys lay in the zone of tectonic disturbance later marked by greater folding; the sequence is only 500 m thick in the more stable shelf area around Palmyra.

Neogene sediments and tectonics

Most of Jordan and southern Syria was dry land though the Miocene, but notable terrestiaf sediments accumulated in subsiding basins in Syria. Middle Miocene continental sediments are over 500 m thick in the Damascus basin. The Euphrates valley has Miocene marine sediments, reaching over 700 m thick, but even this basin was dry by Pliocene times.

Miocene tectonics produced much of the folding and block faulting now seen in the limestone mountains of the Anti Lebanon. The Dead Sea rift also became a more active feature. This depression is formed on a complex fault system, which is a northern extension of the East African rift system. The crustal fractures extend from the Gulf of Aqaba, north along the descending Wadi Araba, through the Dead Sea, up the Jordan Valley, through the freshwater Sea of Galilee (Lake Tiberius), and northwards through the Bekaa Valley of Lebanon and the Ghab Depression (on the lower Orontes valley) of Syria, before ending on the Anatolian Fault in Turkey. It is the transform boundary between the African and Arabian plates, and its accumulated lateral displacement of about 100 km largely corresponds with the opening of the Red Sea rifts. This offset can be seen in the matching copper deposits at Wadi Dana on the Jordanian side, and at Timna, 100 km further south on the Israeli side. Limited modern movements create occasional earthquakes.

The rift system appears to have been active in Precambrian times, and the early crustal extension is associated with some of the many dykes in the Aqaba granites. The major depression of the graben block accelerated in Oligocene times; since then, over 4000 m of Tertiary sediments have accumulated within the rift, while less than 100 m of contemporary material is found on the plateau to the east. As the graben subsided, its eastern margin was gently uplifted, so that the main Jordanian plateau now tilts eastward into the desert basin.

The Palmyride fold belt was also created in Miocene times. This may overlie a very old crustal suture whose weakness was also expressed in localised subsidence basins and thick sediment sequences within the Cretaceous stratigraphy. These folds and others in southern Israel may also be due to shear stress adjacent to the Dead Sea transform plate boundary. Further crustal stress beside the uneven plate boundary created the fractures that allowed basaltic magma to rise into the volcanic province of Jabal al-Arab, reaching west to the Golan Heights and south as flood basalts into Jordan, and also the volcanic zones west of Horns and south of Kerak. Activity started in Pliocene times, and continued through into the Holocene on the flanks of Jabal al-Arab.

Landscape evolution and the Quaternary

Ever since the Tertiary uplift, most of Jordan and Syria have been in an erosional environment, where the landscape has evolved very slowly in the largely semi-arid conditions. The Paleogene and Mesozoic rocks have been partially stripped from the anticlines of the Anti Lebanon and Palmyride mountains, and have been eroded from the retreating escarpment overlooking the Dead Sea Rift. Similarly, the Ras an Naqab escarpment has retreated northwards, and south of it the Paleozoic cover has been stripped from the Arabian shield, leaving only the outliers around Wadi Rum.

Fluvial valleys, now largely dry and known as wadis, have been excavated largely during wetter climate regimes of the past. The deepest wadis were incised into the western margin of the rising Jordanian plateau in response to falling base levels in the subsiding Dead Sea rift. These were cut largely during the Pliocene, and Pleistocene lake deposits now fill some of their lower reaches. During the Pleistocene, periods of increased erosion occurred during pluvial stages, which corresponded with the glacial cycles of the higher latitudes. A pluvial phase at 70-60 ka is well documented, prior to more moderate conditions. Another pluvial phase at 16-12 ka correlates with the Devensian glacial maximum, and was marked by major annual snow accumulations on the mountains of the Anti Lebanon. Since then, conditions have become progressively more arid, though there have been short periods of wetter conditions during the Holocene as part of the world's continuing, small scale climatic fluctuations. The impact of one of these cycles in the lowlands of Mesopotamia, just to the east, was probably the source of the stories of Noah's biblical flood.

Wadi and gully erosion, mainly by infrequent flash floods, continue to be significant processes in the semi-arid desert regions. Aeolian transport of dust and sand is a subordinate and localised process in the modern environments of minimal change. The closed desert basins continue to collect fluvial sediment, and calcrete duricrusts have been deposited in many carbonate areas by evaporating groundwater. The basalt volcanoes of Jabal al-Arab were active throughout the Pleistocene, and some of the youngest Holocene cones and lavas have suffered little erosion in the semi-desert.

Excursion locations

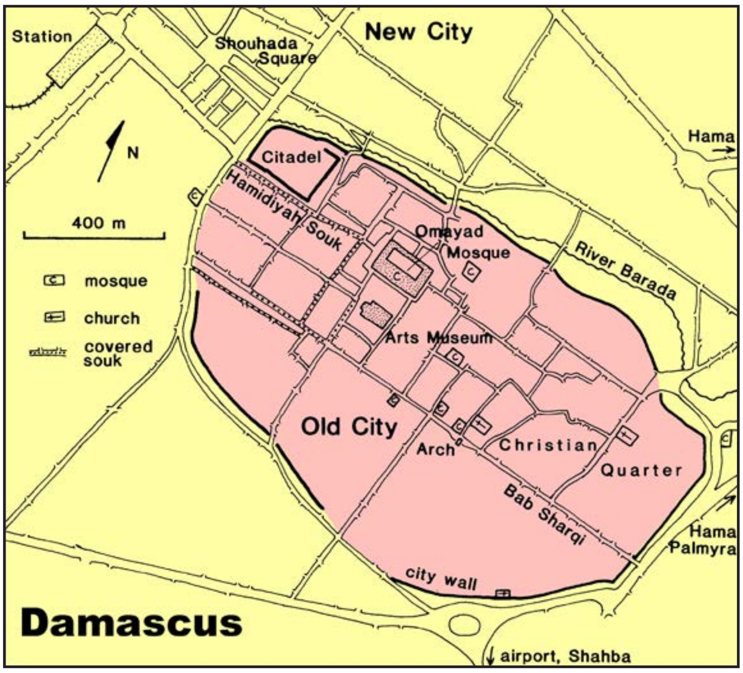
The following brief notes describe the main sites that were visited on the GA tours. Assuming that they will become accessible again after Syria's civil war comes to an end, there will be noticeable changes to many built structures as a result of collateral damage or intentional destruction during the years of war; restoration of key features at Palmyra is planned but may be many years into the future.

Damascus

Claimed as the oldest continually inhabited city in the world, Damascus is lively and interesting, even if the traffic is half way to chaos. It is built largely on an alluvial plain; mountains of steeply folded Cretaceous limestone rise immediately to the northwest. A walk through the old city reveals little geology but is very worthwhile. Either way round the Omayad Mosque leads to the southern covered souk that continues east into the uncovered Bab Sharqi Street. This is the "street which is called Straight" where Ananias searched for St Paul (Acts 9:11). It leads through the heart of the Christian Quarter that contains various chapels and churches in the maze of backstreets.

Damascus suburbs to the edge of a bare limestone mountain.

The road north from Damascus climbs through gorges cut into steep escarpments of strong Cretaceous and Eocene limestones, folded and overthrust in an anticline at the end of the Palmyrides fold belt. The gorges are fluvial features, probably cut largely during the wetter climates of the late Tertiary and Pleistocene. They rise into a high-level valley following an Eocene marl covered by Pliocene fill between limestone ridges. Passing Seydnaya, the Convent and Church of Sophia are seen high to the north on the Eocene limestone hills. Beyond here, the left (northwest) horizon is increasingly dominated by the long scarp face of an Upper Eocene limestone, breached by a series of widely spaced wadis draining from the west.



Maloula

This spectacular village is sited on the limestone scarp face between two deep, converging wadis, 1650 m above sea level. The cascade of colour-washed houses and the Greek Orthodox Catholic churches are unusually attractive, but communication with the locals may be tricky as they still speak Aramaic (the first language of Jesus). The road up the steep western wadi leads through the escarpment and out onto the steep dip slope. The limestone walls and slopes are breached by numerous artificial caves, cut as shelters and house sites in some softer beds; some may be enlargements of small natural caves.

Limestone escarpment above Maloula.

A good path lies down the northern wadi, which descends as a deepening ravine through the limestone scarp, against the dip. The local story is that it was cleft by God to allow a Christian girl, Thecla, to escape a band of murderous Roman pursuers. The concept of subaerial fluvial erosion by seasonal flows of snow meltwater during the Pleistocene may be more realistic. It provides a pleasant walk via meander undercuts, relict moulins and a breached pothole. The ravine opens out beside the Convent of St Thecla (Deir Mar Taqla), built around a holy, natural cave in the cliff. A maze of paths, partly covered, straggles between and under the houses of the old village; they provide a fascinating walk.

Wadi footpath down to Maloula.

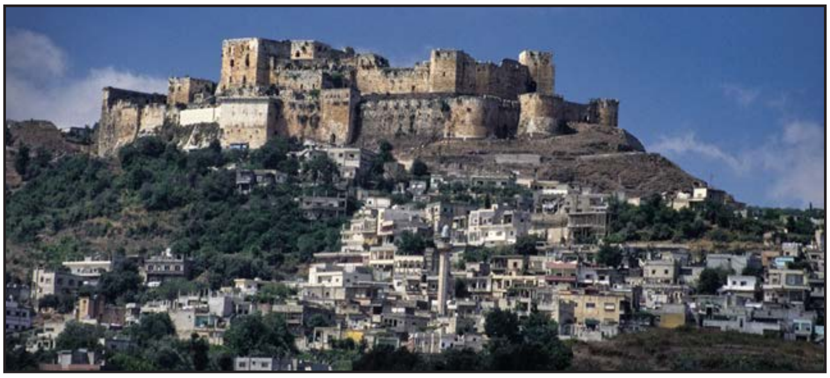
Hama

A delightful city on the banks of the Orontes River. It is famous for its beautiful waterwheels (norias) - there were once 185 of them in the valley; these were built centuries ago to lift water for irrigation and the town supply, into aqueducts level with the valley terraces. The aqueducts are now disused, but the norias still turn (unless the river flow is cut off by the control sluices on the Rastan dam); there are seven groups of norias close to the centre of town.

Krak des Chevaliers

Also known as Hissn al-Akrad, this is the finest surviving Crusader castle. Building started in 1170 and it could house a garrison of 4000. It stands on a crag of limestone overlooking limestone hills and valleys to the west and basalt slopes to the east; it commands strategically important views over the passes, through the fold-belt mountains, from the coast to the desert interior. The castle is truly massive; how it was captured by the Mamluk army of Sultan Baibars, in 1271, defies the imagination. The structure is made of blocks of white limestone, with some dark basalt.

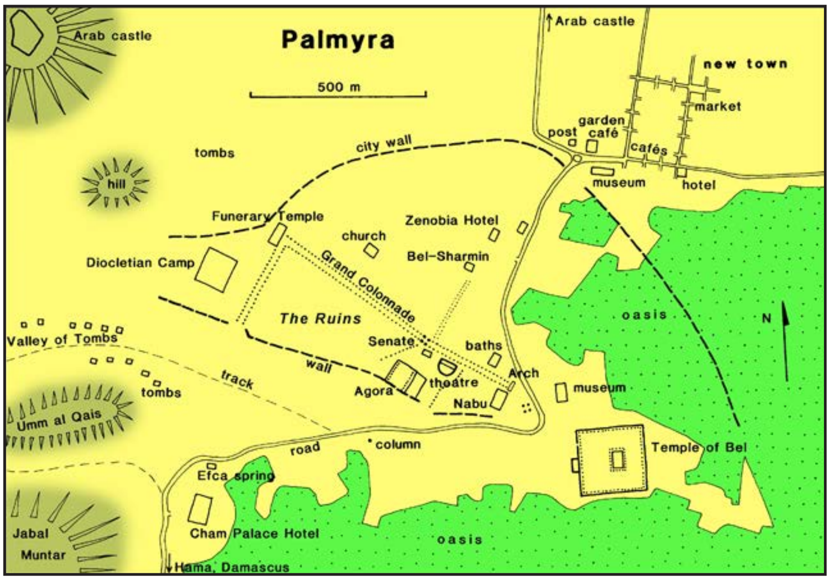
Noria waterwheels at Hama, which raised water onto the stone aqueduct.



Krak des Chevaliers standing high on its limestone crag.

Palmyra

The ancient caravan routes between the Euphrates Valley and the Mediterranean made the Palmyra oasis an important stopover, where perennial springs poured from the limestone ridge of Jabal Muntar. A Pleistocene and early Holocene lake has now dried to a sabkha and salt flat beyond (southeast of) the palm groves. The original Efca spring, close to the Cham Palace, has now run dry for three years; this is largely due to over-abstraction by wells sunk into the local alluvial aquifers that are linked to that of the limestone. The oasis now relies on well water; resources are considerable, but will not support endless irrigation and town growth.



Palmyra (town of palms) was known originally and in modern Arabic as Tadmor (town of dates). The history of the site is long and it was thriving in the time of Alexander the Great from about 300 BC. Most of what stands now derives from the Roman occupation. The Temple of Bel was built in 32 AD, and most of the colonnaded street dates from the 2nd century. In the twilight of Roman power, Palmyra became an independent state under King Odainat in 258 AD, and he was followed by the charismatic and beautiful Queen Zenobia. But Rome reacted, and the city was sacked by Aurelian in 273. It was finally destroyed by a major earthquake in 1089. The site was rediscovered in 1678; excavations started in 1924, with increased renovation since 1950, and the resident Arab villagers have resettled in the new town of Tadmor.

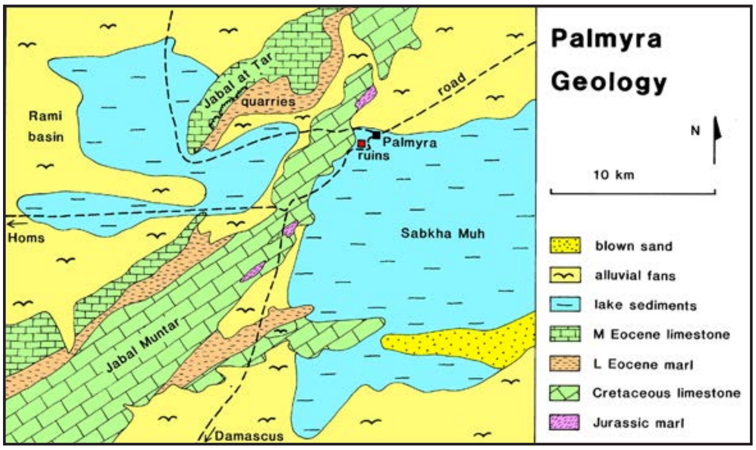
Most of the standing columns and other stonework are cut blocks of local limestone. A strong Cretaceous stone for some structural blocks and for polishing (therefore referred to as marble) is from quarries 10 km north of the city. Softer Eocene freestone is from quarries 7 km to the west; it was more easily worked, case hardened on exposure, and was used in foundations where loads were spread. Four tall, restored columns on the north side of the street are largely a coarse pink granite with black xenoliths (probably from Aswan in Egypt). Nearby there are fallen columns of coarse white granite from Anatolia in Turkey. The Tetrapylon's 16 restored columns are largely concrete. Many limestone columns are badly eroded by sand blasting in a band 1–3 m above their bases; the lowest metre was buried and protected until exposed by the modern excavations; wind-blown and saltated (bounced) sand is only abrasive up to a couple of metres above the contemporary desert surface. Other columns were corroded where buried in wet soils.

Deserts

The ridge to the west of Palmyra is an escarpment of Cretaceous limestone within the Palmyride fold belt. Further northwest, a desert basin of gently graded gravel fans and an old lake flat extends to the gently dipping escarpment of Middle Eocene limestone forming Jabal at-Tar, which looks like a mesa seen from below. Its upper face is a single massive bed scored by the clean vertical walls of the quarries that yielded much of Palmyra's building stone. From the main road, gravel tracks extend northwards across the lower gentle slopes of the bajada. This has a veneer 1–4 m thick of alluvial debris over a sloping bedrock pediment exposed in a small meandering wadi. The higher slopes are formed on cemented scree. The limestone in the quarries is notably massive; bedding planes and joints are solutionally widened only in the metre or so below the modern surface; tool marks have been removed by post-Roman rainwater dissolution.

Palmyra, looking southeast from the viewpoint at the Arab castle.

The limestone quarries that yielded building stone for Palmyra.



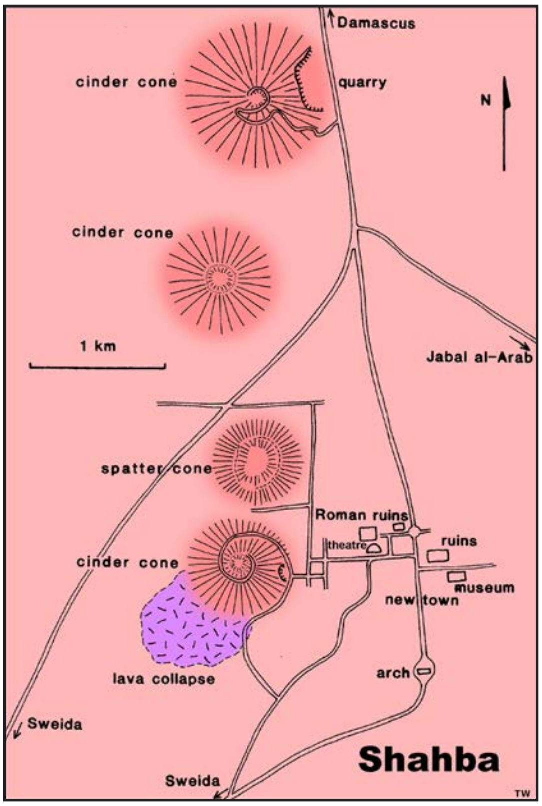
Limestone hogsbacks across the Palmyra desert.

The road to Damascus crosses a vast area of rather empty desert and only has significant farming and irrigation within 50 km of the capital city. Most of the desert surface is covered by thin or thick layers of Quaternary gravel, sand, silt and dust. A few shallow, road cuttings through low ridges reveal mainly Tertiary and Cretaceous, gently folded, thinly bedded limestones and marls, many with conspicuous thin bands of black chert; good fossils are not common. The hills close to the right (northwest) are inlers of Cretaceous limestone within the Palmyride fold belt. Parts of the hills are anticlinal stratimorphs, but their flanks have been breached; outcrops of the breached beds appear to reveal large overfolds, but this illusion is created by the surface/structure relationships where hillsides cut the fold axes obliquely.

View south from the limestone quarries of Palmyra.

Desert road east of Damascus.

After the Sawaneh road junction, a low cutting exposes part of the Upper Cretaceous phosphate beds. These were deposited in shallow shelf seas from currents of nutrient-rich water rising from adjacent depths in the Tethys Ocean. The phosphate is mainly fluor-apatite from animal excreta and skeletal remains, occurring as pellets within a carbonate matrix; a single thin bed of coarser pelletal material and some nodular horizons are richest in phosphate. The rock which can be mined economically, for its value as a fertiliser, forms units only 1-3 m thick, within sequences of thinly bedded limestones, marls and cherts. Extensive, shallow opencast workings of the phosphate beds are passed soon after at Khnefees. South from Damascus, the road is across farmland with poor outcrop, until the first Quaternary lava flows are recognisable around Buraq.



Jabal al-Arab

Also known as Jebel Druze, this is an enormous, gently graded, basaltic, shield volcano rising 1000 m above the limestone plateau. It lies within a volcanic zone that extends southeast to the flood basalts of the Jordanian deserts around Azraq. Volcanism was active from early Tertiary times until about 3000 years ago; historical records of eruptions in the region do exist, but are not precise. Many of the Recent lavas are undersaturated alkali basalts containing felspathoids.

All post-Pliocene eruptions have been flank events, with extrusion of lava from fissures mostly aligned close to NNW-SSE. As is typical of such shield flank eruptions, large outpourings of fluid basalt were followed by rapid construction of small cones of hot spatter or cooled tephra cinders. Many of the Holocene cones survive, in varying states of degradation and vegetation; most occur in groups, aligned on their source fissure.

Three of the volcanic cones of Shahba, seen from the most northerly.

Shahba is a small town on the northern slope of Jabal al-Arab, with four late Holocene volcanic cones on its west side. Three of these are cinder cones, and one is made of spatter; they are aligned on a buried fissure and are surrounded by poorly exposed lavas. A pleasant walk to the west takes about an hour; it rises through the town and then loops up the road onto the southern volcanic cone. This is a cone of cinders that are only well exposed in a small quarry at the foot. The view from the summit is across the lava fields and the other three cones; central craters are very much degraded on all the cones, Just to the south, an area of broken ground appears to be the collapsed crust of a drained lava pond, though there may have been subsidiary vents which complicate the structure. The next cone north is made entirely of welded spatter. Small caves in its flanks penetrate only a few metres, and the spatter structure is poorly exposed. The two cones further north are built entirely of tephra.

Along the road to Bosra, a volcanic cone south of Risas has a roadside quarry. Stratified tephra is multi-coloured, composed of normal and oxidised basalt, with later internal hydrothermal discolouring, and also some layers of geyserite and surface hydrothermal alteration. The quarry exposes at least one vein with clay and sulphate mineralisation; this was the site of hot water rising through the cinder cone to a fumarole. The route continues to Bosra over poorly exposed lava fields with deeply weathered soils.

Bosra

Once the northern capital of the Nabataean state, Bosra was annexed by the Romans in 106 AD, who built the 15,000 seat theatre and greatly expanded the city's structures; it continued to flourish through Byzantine and Christian periods. The Mosque of Omar was built in 720 AD (the only older mosques are in Medina and Cairo). The massive Citadel was built around the much earlier Roman theatre in time to be a fortress during the Crusades, though it was invaded by the Mongols in 1261 and was strengthened through the Middle Ages, when Bosra was again an important trading centre. After about 1700, the site went into serious decline. The new town was built in, on, and partly of, the Roman remains; relocation and re-excavation are ongoing.

Ruins of the Roman city are only partly restored and have unrestricted access. Construction totally in the dark basalt gives them a slightly sombre air. Not to be missed is the massive and well preserved theatre, which is inside the fortified Citadel.

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Remains if the spatter cone at Shahba, with the two northern cinder cones in the distance, all are minor vents within the basaltic volcanic priovince of Jabal al-Arab.