Field Trip 9:

INTRODUCTION TO THE RAMON NATIONAL GEOLOGICAL PARK*

Emanuel Mazor

F.W. Considine Professorial Chair of Hydrological Research, Department of Environmental Sciences and Energy Research, The Weizmann Institute of Science, 76100 Rehovot, Israel, and The Ramon Science Center, Mizpe Ramon, Israel

Introduction

A makhtesh is an elliptical valley surrounded by steep walls composed of hard rocks at the top and friable rocks at the bottom, and drained by one major stream. The word "makhtesh" (plural, makhteshim) stems from the Hebrew word for mortar, and is used internationally for similar land forms, providing a term that is more specific than "erosion cirque" or "breached anticline." In the Negev there are five makhteshim: Qatan, Gadol, Ramon, and the twin makhteshim of Har Arif. The makhteshim of the Negev have the following common features:

a) the soil and plant cover are sparse, with magnificent exposures of rocky desert features;
b) the surrounding walls are formed by an upper cliff built of hard limestone and dolomite (Hazera Fm., Albian–Cenomanian), and a lower slope built of friable sandstone (Hatira Fm., Lower Cretaceous); and
c) drainage is eastward into the Rift Valley.

Makhtesh Ramon (40 km long, ~9 km wide, 400 m deep) exposes numerous geological features: a large variety of rock types with superb assemblages of macro and micro fossils from the Triassic (~220 million years ago) up to the upper Cretaceous (~70 million years ago) (see fig. 2 of Benjamini et al., 1993); dikes (hundreds!), sills, stocks, and a laccolith (3 km diameter); as well as a multitude of well-preserved Lower Cretaceous volcanoes and basanite flows. Structural geologists can find bedding plane slips and different styles of faulting and folding. The morphological features of the makhtesh and its surroundings include peneplains, pediments, terraces, gaps in the SE wall made

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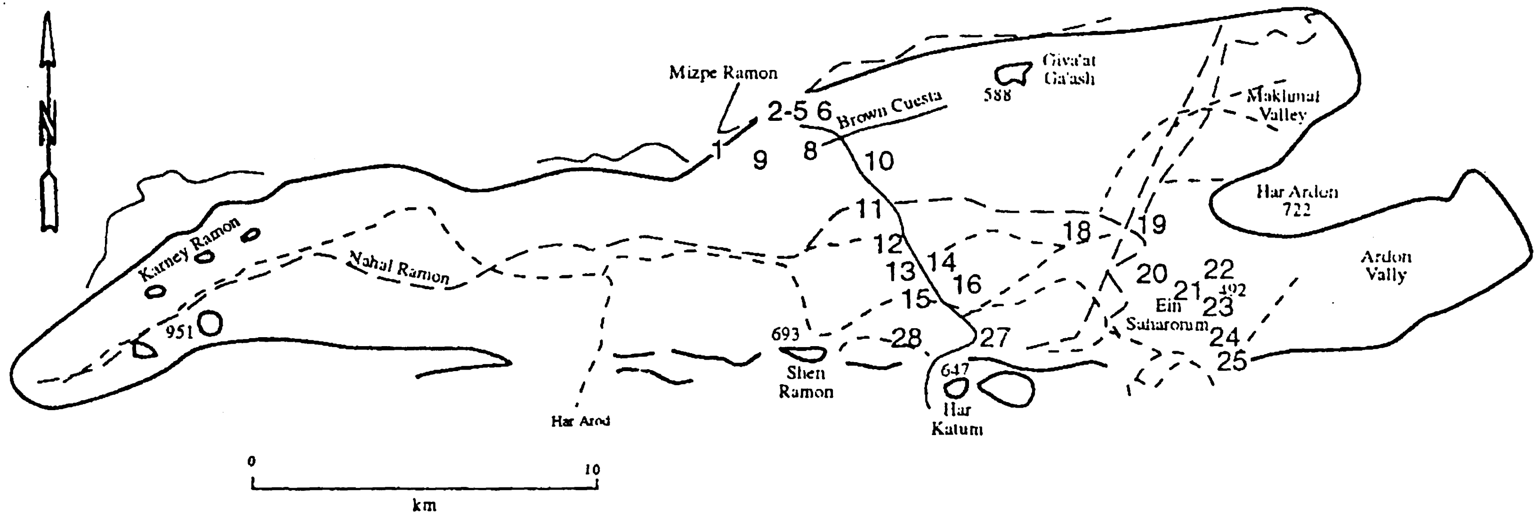


Fig. 1 Major geographical features and the stations of the excursion.

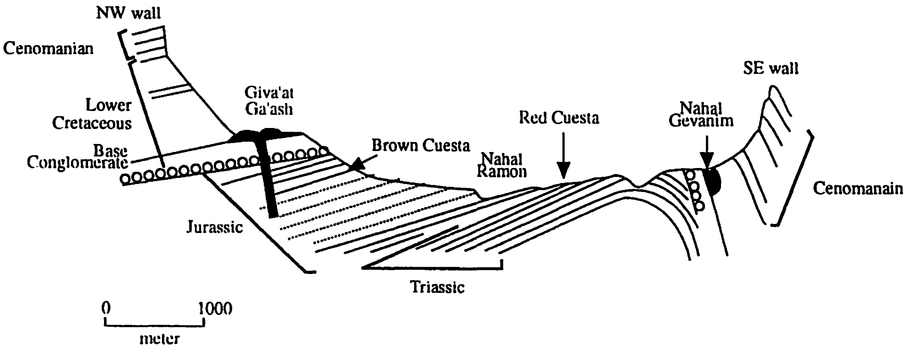
by water and wind, dry river falls, paleo-karst and rock shelters, lacustrine sediments, conglomerates, sinter, red soil, desert pavements, and loess deposits.

The Ramon area is a geologists' paradise, and scientific research flourishes. Hundreds of geological papers have been published by researchers from Israeli and international institutes (Bartov and Arad, 1988). The Ramon region is one of the best-studied terrains on earth, but the full research potential is still ahead. The variegated lithological and morphological landscapes of the Ramon host a variety of arid and semi-arid habitats, studied by numerous ecologists. Delicate remains of millennia of nomadic cultures are the basis for extensive archeological studies. Quarrying in the makhtesh is limited so far, and most of the Ramon is a well-preserved wilderness, that vanishing commodity so much sought by scientists and nature lovers all over the world. To ensure the continuity of long-range and multidisciplinary research, the concept of the Ramon Laboratory of Nature was raised (Mazor, 1990). The makhtesh was declared as the Ramon National Geological Park, part of the Ramon Nature Reserve that encompasses nearly 1000 km^2 (Mazor, 1978). Scientific research has been an integral part of the park since its foundation, besides educational aspects and the main goal — nature preservation. The concept of a biosphere reserve was followed, with the makhtesh constituting the maximally-protected core of wilderness; a strip around the rim of the makhtesh developed as a buffer zone, including the Park's Visitors Center, the Bio-Ramon, and the Ramon Science Center; with the growing settlement of Mizpe Ramon on its edge. The Ramon Science Center is devoted to basic and applied research, guiding the management of the Reserve, and promoting research by scientists from all over Israel and abroad. A basic function of the Ramon Laboratory of Nature is the development of the Park as a field base for geological and ecological training, to be incorporated into the curricula of educational institutes. This guide to geological excursions in Makhtesh Ramon is an important step in this direction.

During the excursions in the Ramon area let us remember the rules of the Nature Reserve: nothing should be moved from its place, or collected; all trash should be carried out; driving and walking are restricted to marked roads and trails. And — especially for geologists — no use of a hammer and no specimen collection without written authorization from the park authorities.

Station 1: View from the northern rim at Mizpe Ramon

Main features seen from this viewpoint (Fig. 1): the wall of the makhtesh, Giv'at Ga'ash (a Lower Cretaceous volcano), the "Brown Cuesta", Mahmal and Ardon valleys with Mt. Ardon between them, Shen Ramon (an igneous stock), Mt. Arod (the highest peak of the Lower Cretaceous volcanic structures of the Karnei Ramon complex), and the meandering dry bed of the Ramon River (Nahal Ramon).



*F*ig. 2. A schematic cross section through Makhtesh Ramon, revealing the structure of an asymmetric anticline into which the makhtesh has been eroded.

Conspicuous geological units (Fig. 2): the northern cliff is built of limestone, dolomite, and interbeds of clay (Hazera Fm., Albian–Cenomanian), while the lower slope is built of variegated sandstone (Hatira Fm., Lower Cretaceous) and is much covered by debris. A number of black hills of basanite flows, are seen at the foot of the makhtesh wall, ending eastward at the volcanic black hill of Giv'at Ga'ash (Mazor, 1961). The basanite outcrops are accompanied by red shales of the Lower Cretaceous, called locally the "Red Member", and it seems that the volcanoes erupted into a landscape of marshes and lakes, some 110 million years ago. Traditionally, the term basalt was applied to the black volcanic rock of the Lower Cretaceous in the Makhtesh Ramon. However, recent work has established that this rock is basanite (Samuelov, Eyal, and Becker, in preparation).

Two rows of talus aprons, or the ends of pediments, are seen along the wall of the makhtesh, one partly touching the wall, the second disconnected (Fig. 3). Other pediments and terraces occur in the makhtesh at different altitudes, descending toward the dry bed of the present Nahal Ramon (Ben-David and Mazor, 1988).

Southward, the "Brown Cuesta" dips to the north (towards the observer). It is built of sandy dolomite, and beneath are siltstone and shales belonging to the Mahmal Fm., the marine unit forming the top of the Jurassic rocks of the Ramon area. Further south is the flat floor of the makhtesh, built on sandstone (Inmar Fm., Jurassic). Behind is the Nahal Ramon bed, and south of it is seen the "Red Cuesta" dipping to the north (dolomite, limestone, and shale, Ardon Fm., Jurassic). Between the Red Questa and the SE wall are seen rocks of the three Triassic formations, the Mohila, Saharonim, and Gevanim. The SE rim of the makhtesh is built of the same three units as the NW rim: black basanite at the foot, sandstone at the lower slope, and limestone and dolomite at the uppermost cliff.

The Ramon anticline: The rocks of the northern cliff, the Brown Cuesta, and the Red Cuesta are seen to dip to the north, but the rock beds of the SE wall dip to the south, as do part of the Triassic rocks. These tilted rock beds mark the asymmetric Ramon anticline. The makhtesh was eroded into the anticline. The stages of the evolution of the makhtesh are discussed by Avni (this issue).

Station 2: The montmorillonite ("bentonite") quarry

Midway along the descent into the makhtesh (coord. 1324/0037) are a number of green-yellow and green-gray beds of montmorillonitic clay. At the roadside, two entrances into abandoned mines are seen, part of a past large-scale exploitation of the montmorillonite, under the commercial name "bentonite". The material served as an ingredient in chicken feed. It is of marine origin, as indicated by fossils, including small oysters and crabs (Fig. 4). The latter indicate that the respective Cenomanian sea was very shallow. The underground galleries total 8 km in length! Entrance has to be coordinated with the Harsit Vechol Sach Company. The montmorillonite is highly plastic and has a high absorption capacity. It is crossed by gypsum veins, and contains tiny pyrite nodules.

Station 3: The glauconitic bed

About 50 m down the road, an outcrop of greenish glauconitic sand marks the base of the marine rock sequence of the Hazera Fm. Glauconite is a greenish mineral with a lattice structure close to that of biotite, and a composition of $(K, Na) (Al, Fe, Mg)_2 (Al, Si)_4 (OH)_2$. It is regarded as an indicator for sedimentation in a very shallow sea.

Station 4: The variegated sandstone

About 50 m down from the previous station, variegated sandstone of the Lower Cretaceous Hatira Fm. occurs. In it are seen delicate tubes of fossil plant roots, indicating continental sedimentation. Let us remember — the fossil roots may be photographed but in no case removed or collected.

Station 5: The Orange Cuesta

About 500 m further along the same road (coord. 1328/0038), an outcrop of hard orange-yellow mudstone and shale is seen on the left. Locally called the Orange Cuesta, it occurs within the Hatira Fm. continental sandstone and indicates a marine intercalation. To the north, three such intercalations occur at Makhtesh Gadol, while at Makhtesh Qatan two occur. These marine intercalations demonstrate that the Negev was in the range of transgressions and regressions of the Tethys. Beneath this layer is, again, the

Fig. 3. The NE wall of the makhtesh. The upper part is a cliff built of limestone, dolomite, and clay beds of the Hazera Fm. (Albian–Cenomanian). The lower part has a more gentle dslope and is built of sandstone of the Hatira Fm. (Lower Cretaceous), largely covered by debris from the cliff. Talus and pediment surfaces stretch from the makhtesh wall down to the present Nahal Ramon bed, marking stages in the evolution of the Makhtesh.

Fig. 4. Fossil crabs found in the montmorillonite from a mine located at the cliff, indicating that the Cenomanian sea was extremely shallow.

Fig. 5. Countless quartzite pillars, in situ and strewn about, at the Carpentry Hill. A number of such sites of prismatic pillars of quartzite are found in the Inmar Fm. sandstone. They were probably formed by the action of steam and hot fluids that accompanied the intrusion of dikes and sills.

Fig. 6. Prismatic pillars of Lower Cretaceous basanite, 2 km west of the Carpentry, at the foot of Mizpe Ramon. Formed by cooling cracks that were enlarged by weathering. A large number of basanite outcrops in the Ramon have prismatic pillars. The long axis of the cooling joints of lava are perpendicular to the cooling surface, and therefore the direction of pillars is used to reconstruct the original geometry of the various intrusive and extrusive basanite bodies.

Fig. 7. A fault bringing cross-bedded sandstone of the Inmar Fm. against the Ardon Fm., including a kaolinized sill; Nahal Ramon at the point where it is crossed by the main road. The fault plane is impregnated with iron oxide.

Fig. 8. Quartzite walls and a trench formed by the weathering of a kaolinized dike, Ardon Valley. Quartzite walls and white kaolinite are found in the dikes crossing the Inmar Fm. sandstone.

variegated continental sandstone of the Hatira Fm., containing fossil plant roots and siliceous and iron oxide-containing fossil wood.

Station 6: A walk to basanite hill 548 m

Continue along the road for about 1 1/2 km to a trail on the left side, just before the Brown Cuesta (coord. 1345/0038). Walk 3/4 km northward to the basanite hill marked on the topographic map with an altitude of 548 m (coord. 1345/0046). The trail begins in *sandstone of the Mahmal Fm.* containing fossil wood (to be left in place!). Then there is a greenish-brown weathered *andesite sill*, with an onion-like weathering structure. Above and below are sandstone beds metamorphosed to quartzite, formed by the sill when it intruded the sandstone. After a short distance is an outcrop to the *Arod Conglomerate*, composed mainly of quartzite pebbles, cemented by secondary quartz. This conglomerate overlies various rocks as old as the Triassic, marking the relief at the commencement of the Lower Cretaceous. Hill 548 is a basanite flow with prismatic jointing. At the foot of the hill is an outcrop of red sandy shales of the Lower Cretaceous *Red Member*. The Red Member, which occasionally also includes white kaolin, occurs in the Ramon area associated with the basanite, and it is well developed in the eastern makhtesh in the same stratigraphic position that the basanite is missing. Near Har Arod fossil frogs were found in the red shales, reflecting the existence of lakes or marshes at the time of the volcanic eruptions. From Hill 548, return to the main road.

Station 7: The Brown Cuesta (Giv'ot Reved)

The northward-tilted brown rock bed seen from the rim is composed of hard dolomite with quartz grains. It makes up the upper part of the Mahmal Fm. (the top of the Jurassic in the Ramon region). Walk along the road cut through the colored siltstone, shale, sandstone, and dolomite of the Mahmal Formation. The formation is intruded by an altered sill that is marked in the terrain by prospecting pits of white alunite $\{KAl_3, (SO_4)_2\ (OH)_6\}$, the latter occurring at the contact.

Station 8: The "Carpentry" — Hill 545

The rock sequence of the Brown Cuesta is underlain by the sandstone of the Inmar Formation (Jurassic), with a total thickness of about 280 m. A major part of the flat bottom of the makhtesh is built of the rocks of this formation (Station 10). After a few hundred meters the road reaches the junction of the track leading westward to the "Carpentry" (Hill 545, coord. 1344/0028, about 600 m from the main road). Stop at the parking area and walk along the signposted trail. Part of the hill is covered with prismatic pillars of hard quartzite, having 3 to 8 facets; these are 3–12 cm wide and 20–80 cm long. The pillars occur in beds with a total thickness of about 6 m, outcropping along 60 m. Countless fallen pillars cover the hill slope, reminiscent of a carpenter's yard (Fig. 5).

Additional "Carpentries" are known in the Ramon: the Eastern Carpentry (at the Ardon Valley), Giv'at Harut (Nahal Ardon), The White Carpentry (near Giv'at Ga'ash), and the Western Carpentry (near the Ramon Pass). Features in common are:

a) occurrence at the upper part of the Inmar Formation;
b) occurrence of the prismatic pillars in irregular patches;
c) similarity of the jointing system to that of the surrounding Inmar sandstone; and
d) nearby occurrence of magmatic bodies but with no direct contact with the pillars.

The formation of the quartzite pillars is still an enigma. Quartzitic rocks occur in the Ramon in a variety of geological environments. Most conspicuously, the walls of quartzite on both sides of kaolinized dikes intruded into the Inmar Fm. sandstone (Station 21; Fig. 8). This quartzitization seems to have been connected to hot fluids that accompanied the magmatic intrusion (Bentor et al., 1966). In a few sections of these quartzite walls prismatic pillars are seen, with the long axis perpendicular to the dike, presumably formed by cooling-induced jointing (Station 21). On the other hand, single quartzite walls not connected to dikes cross the Inmar Fm. sandstone as well, most probably formed by low-temperature water–rock interactions. No prismatic pillars are found in the latter. The pebbles of the Arod Conglomerate (Station 6) are cemented by hard quartzite as well, demonstrating low-temperature formation of quartzite. Dikes and sills are seen in the vicinity of the Ramon Carpentries, but the pillars occur in an irregular geometry, revealing no direct relation to the magmatic bodies. Hence, it has been suggested that the quartzitic pillars were formed by hot fluids that accompanied the igneous intrusions and infiltrated into the sandstone (Mazor and Cohen, 1987).

Station 9: The basanite prisms at the foot of Mizpe Ramon

Nearly 2 km westward of Carpentry Hill (coord. 1324/0018), between two basanite hills (604 m and 606 m), there is an impressive wall made of prismatic pillars (Fig. 6). They were formed by cooling-induced jointing, enhanced by weathering. Prismatic jointing in the basanite can be seen at various points in the Ramon. Return to the main road.

Station 10: View of the kaolinite quarries and the Inmar Formation rocks

The next stop is at the roadside, about 1 km after the junction to the Carpentry (coord. 1358/0028). To the east are seen large open-pit quarries of kaolinite (Harsit Vechol Sach Co.). The kaolinite, a white clay composed of aluminum hydrosilicate

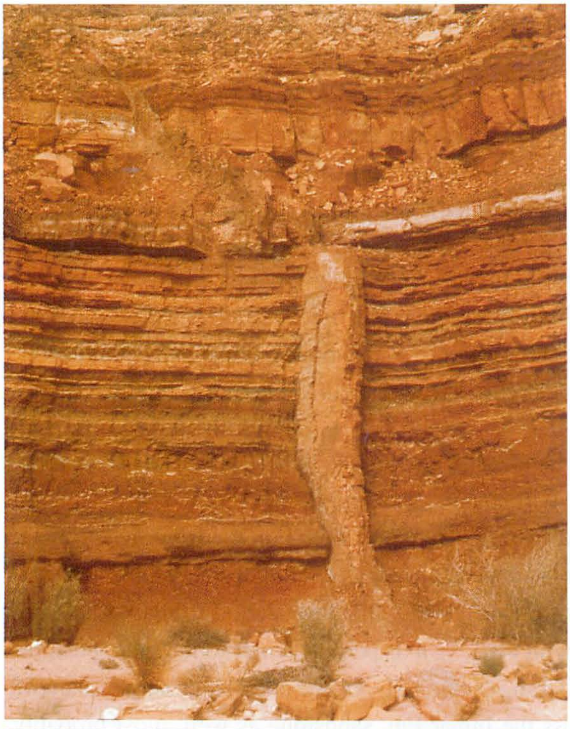


Fig. 9. The Tall Dike at Nahal Ardon, intruded into rock beds of the Ardon and Mishhor formations. The upper quarter is offset to the left (north) where it is crossed by a sill.

Fig. 10. An overturned block of Turonian rocks, adjacent to horizontal beds of Senonian flint and chalk; the SE wall of the makhtesh, near the main road to Elat. The Ramon Fault zone exhibits thrusts and bedded gliding.

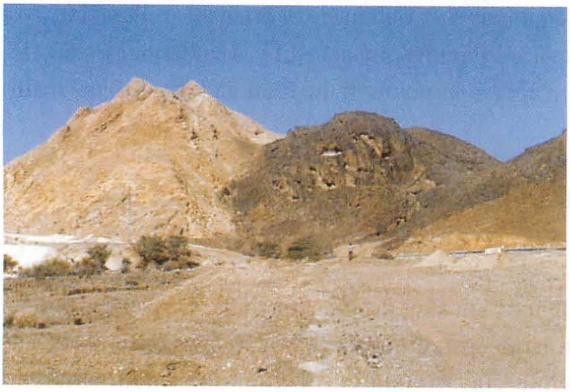


Fig.11. A small stock of quartz-syenite intruded into the Triassic rocks, here faulted against Cenomanian Rocks; the SE wall of the makhtesh, at the exit of the main road from the makhtesh.

($2H_2O.Al_2O_3.2SiO_2$), contains delicate imprints of fossil plants, indicating sedimentation in lakes and marshes. The white material (low in iron traces) is a major raw material for the production of white porcelain and sanitary ceramic products. All around are seen the rocks of the Inmar Fm. (the continental middle part of the Jurassic section of the Ramon): light-colored sandstone with lenses of the white kaolinite and dark layers of iron oxide-cemented sandstone. The sandstone contains fossil branches and trunks of continental plants.

Station 11: Nahal Ramon dry river bed

After 1.5 km the road reaches the dry bed of Nahal Ramon. Park near the road and walk westward in the river bed for 1 km. The river bed is incised into the surrounding rocks. On both sides of the river bed are terraces, their levels rising away from Nahal Ramon, indicating that the present river bed is the last stage of a process of gradual incision (Mazor, 1988). The terraces are the lower extension of the pediments of the type seen at Station 1 at the foot of the northern wall of the makhtesh. The terraces document erosive incision stages that were triggered by the gradual subsidence of the eastward drainage base in the Arava segment of the Dead Sea Rift Valley. Archeological remains — stone circles of a camp of the Bronze Age — are seen on the lower terraces. The pebbles in the river bed reflect the variety of rocks exposed in the drainage basin of the makhtesh and are only partly rounded, reflecting the low erosion energy of the present Nahal Ramon. At the beginning of the walk, we pass cross-bedded sandstone of the Inmar Fm. After a few tens of meters we cross a small fault (Fig. 7) in bedded rocks of the Ardon Fm. (a partly marine unit of the Jurassic). The fault plain is marked by iron oxide mineralization with delicate striation, reflecting vertical movement. A gray sill, intruded into the marine rock beds of the Ardon Fm., is identifiable as of igneous origin by white kaolinized ghosts of feldspar crystals. The ~3-mm-long crystals are oriented parallel to the adjacent rock beds, marking the direction of magma flow. The sill and its companion rock beds disappear after a short distance at a second fault. Continue to walk and admire the "paintings of nature" formed by iron oxide solutions that moved through siltstone and mudstone of the Ardon Fm. After a short distance you will pass a fallen rock block with shallow-water ripple marks, and behind this is a vertical channel in the rocky river bank which hosts a dike. Return to the main road to continue the excursion.

Station 12: Conglomerate and red soil of the Ra'af pediment

Blocks of a well-developed conglomerate are seen on the western side of the road cut, about 2 km south of Nahal Ramon, at the junction of the track to Nahal Ra'af and Shen

Ramon (coord. 1374/0014). Large blocks of conglomerate were moved during the road construction, exposing a section otherwise concealed beneath the desert pavement. The section at the road cut reveals a well-consolidated conglomerate at the base, cross-bedded sandstone above it, and red soil with pebbles at the top. This is a cross section through terrain formed by the Ra'af pediment that has a well-developed desert pavement on its surface. This widespread pediment marks an earlier stage of erosive incision, when the makhtesh had a flatter bottom. The paleoclimatic meaning of the red soil (wet and warm climate?) and dating of the cement of the conglomerate are under study.

Station 13: The "Chocolate" Shale

Quarries of dark brown shale are seen on both sides of the road, 200 m after the last station (coord. 1375/0014). This rock bed, locally called the "Chocolate" Shale, is part of the Red Cuesta sequence of the Ardon Fm., the lower part of the Jurassic of the makhtesh. The shale acts as an aquiclude in the Ramon, and above it are local perched groundwaters. The shale is mined for the manufacturing of red roof-tiles.

Station 14: The flint clay pockets

A few tens of meters after the last station one reaches the junction of the track leading eastward to the clay treatment plant of the Harsit Vechol Sach Co. A 100-m-walk on the track leads to an abandoned open pit quarry, exposing a cross section through a karst-like cavern developed in the top of the Triassic limestone (coord. 1363/0028). The cavern is filled with red iron oxides (resembling laterite) with pockets of whitish flint clay (kaolinite enriched with aluminum oxide, resembling bauxite), both occasionally with a pisolithic structure. The flint clay and iron oxide belong to the Fm. of the base of the Jurassic in the Ramon area. Eastward the flint clay lenses constitute an almost continuous rock bed (Goldbery, 1979). The mode of formation is not clear — the deposit resembles lateritic soils, but no candidate source rock is in sight. The flint clay is used to manufacture fire-proof bricks to isolate high-temperature industrial furnaces. Return to the main road to continue the excursion.

Station 15: The bituminous limestone of the top of the Triassic

After 50 m, the road crosses beds of gray bituminous limestone with stromatolites and ripple marks that indicate sedimentation in a shallow sea. This limestone marks the top of the Triassic sequence in the Ramon area and belongs to the upper member of the Mohila Fm. The rocks of the Mishhor Fm. overlie the limestone and fill caverns dissolved in it. Beneath the bituminous limestone occurs the gypsum sequence of the middle member of the Mohila Fm.

Station 16: The laccolith

After 200 m, a large black laccolith occurs on the left side of the road (Fig.12; its center is at coord. 1393/0015). As seen from the road, a dark bed of andesite, belonging to a sill imbedded in whitish beds of gypsum, underlies the olivine gabbro of the laccolith complex. Climb up the hill to see the laccolith valley. The laccolith has been tilted along with the Ramon anticline and the erosion truncated it obliquely, providing ideal exposures through this intrusive body that has a 3-km diameter and is 60 m thick at its center. The laccolith has been intruded in several stages and it is crossed by several dikes. For a more detailed excursion, see Rophe et al. (1993). At its edges the laccolith merges into a number of sills that can be seen in the gypsum section for about 2 km eastward, in the Mohila fold, and about 5 km westward, up to the Shen Ramon area. A transect through the laccolith has been marked by geological bench marks, as part of the Ramon Laboratory of Nature concept. Please do not enter the laccolith valley by car; park beside the main road. Return to the main road to continue the excursion.

Station 17: The gypsum quarry

Gypsum quarries are seen on both sides of the road near the laccolith. The main quarry is on the right, hidden from the road. Enter with caution, as some quarrying may be going on. The huge quarry provides superb exposures through the Mohila Fm. — gypsum beds, alternating with black shale beds, crossed by dikes and sills. Gypsum ($CaSO_4$. $2H_2O$) is precipitated from seawater when it is evaporated to less than 1/3 of its original volume. Hence, gypsum is usually formed in near-shore lagoons. The succession of gypsum beds and shale beds reveals repeated cycles of regressive lagoon regimes and transgressions by the deeper sea. Commercial exploitation is for the cement industry. Portland cement contains up to 6% gypsum, needed to retard the solidification of concrete that otherwise occurs quickly.

Station 18: Be'erot Mishhor (Mishhor wells)

After 1 km the road reaches a junction with a track going eastward (coord. 1392/00060). Turn left and drive 4 km along Nahal Afor through the gypsum landscape, passing the laccolith on the left, until the Mishhor wells are reached (coord. 1419/0034). The site is marked by tamarisk trees that indicate the presence of near-surface groundwater. A small ancient well, 1 m deep, is seen at the foot of the Mishhor Hill. On the hill are seen ruins of houses dated to the 7th century. The Mishhor Hill provides a good view of the "bends" of the gypsum beds and intruded sills that constitute the edge of the Mohila anticline (left half of Fig. 12).

The Nature Reserves Authority dug two more wells, protected with small stone structures. The water is slightly salty but potable. The composition (mg/1) is:

K	*Na*	*Mg*	*Ca*	SO_4	*Cl*	HCO_3	*total*
6	190	79	116	547	135	357	1430

In dry years the wells dry up. The aquifer is in rocks of the Ardon Fm., whereas rocks of the Mishhor Fm. act as an aquiclude.

Station 19: The Meanders of Nahal Ramon

The track passes the Mishhor camp site, and after a few hundred meters turns east, crossing the dry river bed of Nahal Ramon (coord. 1429/0036). Nahal Ramon has its head at the western tip of the makhtesh, and it flows for 35 km in a NE direction. At the present point it bends sharply to the south, meandering to the Saharonim Gap where it leaves the makhtesh. At its long NE section Nahal Ramon follows the contact of the Inmar Fm. sandstone with the underlying hard rocks of the Red Cuesta of the Ardon Fm. In its southward bend the river bed continues to follow the Red Cuesta, which turns south with the flank of the Mohila anticline. Here, Nahal Ramon is up to 200 m wide, with well-grown tamarisk trees. Fresh groundwater was encountered at a depth of 18 m in a borehole drilled in the river bed.

In its long NE section Nahal Ramon has 8 terraces, the highest one 38 m above the river bed. In contrast, at the southward-meandering section only 2 low terraces are seen, indicating that this is a relatively recent river section. A recent study raised the possibility that originally Nahal Ramon flowed eastward and left the makhtesh through the Nahal Holit Gap. Accordingly, the present bend of the river to the Saharonim Gap is recent and resulted from capture by the evolving Nahal Neqarot (Ben-David and Mazor, 1988; Mazor, 1988).

Station 20: Ancient tumuli at Ramat Saharonim

The track crosses the river bed and reaches a junction with one road south to Ein Saharonim and the second leading eastward to Nahal Ardon. The excursion continues along the eastward road, which climbs on beds of gray limestone and dolomite of the Ardon Fm. This is the small plateau of Ramat Saharonim. On both sides of the track (at coord. 1437/0033) stone piles are seen, called tumuli (singular, tumulus) by the archeologists. These structures are known throughout the region and in most cases served as burial sites of nomad cultures, mainly during the Bronze Age. Leave the car at the marked roadside if you wish to visit the ruins.

The road continues for 1 km on the plateau up to its eastern edge, which provides a view of Nahal Ardon. The road ends here; leave the car at marked parking area.

Station 21: The positive dike and a view into the eastern makhtesh

The trail from the edge of the plateau starts near a positive dike, i.e., a dike "wall" that withstood erosion. It is built of weathered trachyte. Try to trace it in the area. The dry river bed ahead is Nahal Ardon, and the prominent dark hill is Giv'at Harut.

Station 22: Giv'at Harut

The hill of Giv'at Harut (Cone Hill) is a major reconnaissance point for the eastern makhtesh. The climb and descent require 1.5 h. Cross the river bed of Nahal Ardon and take the trail that ascends Giv'at Harut from the NW. Giv'at Harut is built of sandstone of the Inmar Fm., and resisted weathering thanks to quartzite walls formed by dikes that intruded the sandstone. The trail passes a number of channels, formed by the weathering of soft kaolinized trachyte dikes (Fig. 8). The quartzite walls were formed at the intrusive contact with the sandstone (Bentor et al., 1966). The kaolinite is reached by digging in the sand that fills the space between the walls. The top of Giv'at Harut is ornamented by quartzite pillars, another Carpentry, smaller than the one at Station 8. Here too, it seems that the pillars were formed by the activity of steam or hot solutions that accompanied the intrusion of the adjacent dikes.

The top of the hill provides an excellent view of the makhtesh. Of special interest are the many ridges in the terrain of the Inmar Fm. sandstone, formed by the weathering-resistant quartzite walls of the kaolinized dikes. The Red Valley (coord. 1462/0037) is marked by its walls, and the Red Member shales found in it and around it. The dike ridges do not cross the Red Valley, indicating it is a relatively young feature. For a more detailed excursion see Baer (this issue).

Station 23: Ein Ardon

At the foot of Giv'at Harut, on the bank of Nahal Ardon, is a small spring, Ein Ardon (coord. 1451/0028), recognizable by lush vegetation. The spring flows most years but following a dry winter it occasionally dries up, and from time to time its outlet has to be cleaned of accumulated soil and plant material. The water emerges from the Inmar Fm. sandstone above the impermeable shale of the Ardon Fm. The spring location is possibly controlled by a dike seen to descend from Giv'at Harut. The water is potable (when clean of mud and algae), and the composition is (in mg/1):

K	*Na*	*Mg*	*Ca*	SO_4	*Cl*	HCO_3	*total*
7	180	99	126	577	184	333	1506

This composition resembles that of Be'erot Mishhor. Two wells were dug by the Nature Reserves Authority on the other side of the Nahal Ardon dry river bed. They are covered by stone structures and occasionally contain water. The water is relatively mineralized, reflecting the proximity of gypsum of the underlying Mishhor and Mohila formations.

Station 24: The Nahal Ardon dikes

The eastern wall of the little gorge of Nahal Ardon hosts a number of dikes, exposed downstream from Ein Ardon. Their original composition was basanite but they are weathered and kaolinized. The following dikes warrant some description:

The *Father and Son* dikes are the first to be met, so named because one is short and the other is tall. The "son" dike stopped in the Mishhor Fm. and the crack above it demonstrates the opening of joints by intruding magma. The "father" dike crosses into the overlying Inmar Fm. sandstone.

The *Black Heart Dike* occurs further on, so called for its black (fresher basanite) interior. This dike has different inclinations in its different parts. At this point notice the "chocolate shale" in the upper quarter of the river wall. At its base is a hard brown-gray rock bed, similar in appearance to the rock of the dikes. This is a sill, named the *Chocolate Sill*. Interestingly, the Black Heart Dike is cut by the sill, and at this point the upper quarter of the dike is shifted to the right (south).

The *Tall Dike* comes next (Fig. 9). Its upper quarter is shifted to the left (north) at the point where it is crossed by the Chocolate Sill (Fig. 9). Thus, the shift is in an opposite direction to the shift of the upper part of the Black Heart Dike.

The *Broad Dike* follows, its upper quarter shifted to the left. Further dikes are intruded into the rocks exposed along the walk down the dry river bed.

The intrusion of the Ardon dikes is explained by two competing hypotheses: the traditional one, of vertical ascent of magma from a deep chamber, and a hypothesis of lateral intrusion from a rather shallow magma chamber (explained in detail by Baer, this issue). The following observations were interpreted in support of the lateral intrusion model:

a) on the dike wall are small ripples with a dominating horizontal direction,
b) the shift of the upper part of the dikes is in different directions, resulting from different directions of intrusion above and beneath the hard Chocolate Sill that accordingly intruded earlier; and

c) many of the dikes seem to have a radiating direction with a focus at a point outside the Ramon, presumably the location of the magma chamber.

However, the following observations support the vertical intrusion model:

a) Striae and ripples represent the very last movement of the nonconsolidated magma relative to the intruded rocks, and may be due to resettling of blocks in an entirely different direction from that of the magma intrusion;
b) the shift of the upper parts of the Ardon dikes suits a horizontal resettling movement of the rocks above the intruded Chocolate Sill, including the upper segments of the nonvertical dikes, that accordingly intruded before the sill; and
c) dikes cross the set of radiating dikes in many directions, and hence, a large number of lateral magma chambers is needed for the lateral intrusion model.

In contrast, in the vertical intrusion model all dikes could originate from a single magma chamber, ascending within different systems of jointing.

Station 25: Nahal Ardon–Nahal Harerim junction

Nahal Ardon joins Nahal Harerim at coord. 1458/0019. The junction overlooks a number of important features: the SE wall of the makhtesh, the Ardon Valley, and the Gypsum Amphitheater (Mohila Fm., west of the junction, entrance at coord. 1454/0017). The joint Ardon–Harerim River joins the Neqarot River, tangential to the SE wall just outside the makhtesh.

From the junction there is a possibility to return through Nahal Ardon to the car and drive to the next station, Ein Saharonim, or to proceed to the Ma'aleh Dekalim ascent to Ein Saharonim, following the Ramon Fault for about 2 km.

Station 26: The Ein Saharonim Area

Ein Saharonim is recognizable by the dense water-loving vegetation. The spring flows in exceptionally rainy seasons, but most of the time it is necessary to dig for 1/2 to 1 m to reach the water. The water is salty, but potable by animals. It has a high sulfate concentration, indicating saturation with respect to gypsum.

K	*Na*	*Mg*	*Ca*	SO_4	*Cl*	HCO_3	*total*
10	254	120	676	2180	268	286	3794

Surprisingly, it was found that the water is devoid of anthropogenic tritium, and hence it is older than 30 years. This rules out an origin from flood water stored in the gravel of the river banks, and indicates remote recharge.

The ancient Saharonim road station. The hill east of Ein Saharonim hosts a large square stone structure with a double wall divided into rooms, and a gate on the northern side — a common plan for a road station that provided services to trading caravans. Excavations revealed pottery and coins that indicate the place was active in Nabatean–Roman times for about two centuries around the beginning of the common era. The location is on the Spice Route that connected Jordan and Arabia with Europe. Stations along the road were at one to two days travel distances, the local section of the road including the following stations from south to north: Mo'a, Neqarot, Saharonim, and the city of Avdat. The nature of the traded merchandise is not known but they must have been commodities that (a) were expensive, i.e., had a high value/weight ratio, and (b) originated in the East and were appreciated in the West. Coffee and drugs were as yet unknown, so scents and spices are a plausible possibility.

The outlet of Nahal Ramon. Follow the dry bed of Nahal Ramon to the nearby Saharonim Gap, through which the river leaves the makhtesh, and after 1.5 km joins Nahal Neqarot. The outlet through the Saharonim Gap is an impressive canyon, cut into the Saharonim dome, built of the rocks of the Triassic Saharonim Fm. The river passes the Ramon Fault and continues through Cenomanian and Turonian rocks.

Return to the parking area to continue the excursion. The next station can be reached by driving 5 km westward through Nahal Gevanim until the main road crossing the makhtesh is reached, or by returning through Nahal Afor.

Station 27 (coord. 1396/9997): The crossing point of Nahal Gevanim and the main road

Crossing the makhtesh, it is seen along the road that the rock beds are gently tilted to the north and only at the last kilometer, near the SE wall of the makhtesh, are the beds tilted to the south. Thus, the Ramon structure is an asymmetrical anticline or a monocline.

In Nahal Gevanim, east of the main road, an outcrop of the *Arod Conglomerate* occurs, marked by small quartzite pebbles cemented by quartzite. The Arod Conglomerate marks the base of the Lower Cretaceous Hatira Fm. in the makhtesh, and it overlies dark limestone of the Triassic Saharonim Fm. Thus, at this point the unconformity is maximal. Nahal Gevanim flows in the Hatira Fm. sandstone and small outcrops of basanite and the shale of the Red Member are seen as well. Hence, at this point there is no indication of a vertical offset due to the Ramon Fault.

Here the southern wall of the makhtesh includes an overturned block (Fig. 10). Nearby, outside the Ramon, are seen two table mountains, Har Marpek and Har Katum, built of hard dark flint at their top (Mishash Fm., Senonian), and white soft chalk on their slopes (Menuha Fm., Senonian). This is a small assortment of the complex features seen along the Ramon Fault line (Garfunkel, 1993).

Station 28: The Gavnunim intrusions and Har Gevanim

Near the southern exit of the main road from the makhtesh is a junction with a track that turns right (coord. 1395/9997). Follow the track, and after 200 m you will enter the narrow valley called Gey Zochalim. The facing slope of Har Gevanim exposes fossiliferous limestone, shale, and sandstone, mostly of the Saharonim Fm. Along the climb to the top of Har Gevanim you may encounter ammonites and other fossils — please do not touch them! The stratigraphy of the Triassic rocks at this place is discussed by Benjamini et al. (1993). The top of the hill provides a superb view of the interior of the makhtesh.

Small intrusive stocks of quartz-syenite (Fig. 11) are exposed in the valley between Har Gevanim and the SE wall of the makhtesh. These intrusive bodies are similar to the Shen Ramon stock, located 3 km to the west, and seem to belong to the same igneous complex. The dark-colored stocks, named Gavnunim in Hebrew, are intruded into sandstone, siltstone, shale, and limestone of the Gevanim Fm. Stratigraphically this is the core of the Ramon. The contact of the stocks with the intruded sediments contains mineralization phenomena described in detail by Itamar and Baer (1993).

The Triassic type section has been marked by small signs with the names of the stratigraphic units by workers of the Ramon Science Center.

Here ends the introduction to the Ramon National Geological Park. Enjoy your visits!

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