RAO JODHA DESERT ROCK PARK
SMALL FIELD GUIDE SERIES

rocks

About the different kinds of rock inside Rao Jodha Desert Rock Park

JONATHAN J WILSON

RAO JODHA DESERT ROCK PARK FIELD GUIDES

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Image on front cover
Welded tuff rock inside Rao Jodha Desert Rock Park

A RAO JODHA DESERT ROCK PARK SMALL FIELD GUIDE

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About the different kinds of rock inside the Park

JONATHAN J WILSON

www.raojodhapark.com

Series Editor's Note

When I visited Mehrangarh in 2005, there was an old, rusting signboard on the roadside which said: WELDED TUFF. NATIONAL GEOLOGICAL MONUMENT. I had no idea what 'welded tuff' was and I have learned that most people in Jodhpur are completely unaware of the volcanic origins of this iconic hill on which the Fort stands. It seems fitting that the first booklet in our new series explains in layman's terms what welded tuff is and how it came into being.

I first met Jonathan Wilson in 2012 when he sent me an e-mail saying that he was going to visit the Park and was there some way in which he could 'do something' for us. When he told me he was studying geology in Auckland (New Zealand), I asked him about the possibility of writing a booklet that explained what all these rocks were about. So he made the visit, walked around the Park and responded very quickly by saying, 'yes!'

This field guide is the first of several in the pipeline: on birds, butterflies, moths, dragonflies, grasses and reptiles and a bigger guide to all the plants found inside Rao Jodha Desert Rock Park. Most of these guides are being written and photographed by first-time writers who have taken on the difficult job of creating booklets for readers with no previous knowledge of the subject.

It gives me the greatest pleasure. I can see no better purpose of creating a nature park than to see it becoming a theatre of enjoyment, exploration and learning especially for young people. Thank you, Jonathan Wilson, for being the first in our new series and for leading the way!

Pradip Krishen

Contents

ROCKY OUTCROPS
In the vicinity of Mehrangarh Fort, you will see many outcrops of a fine-grained, dark pink rock, sometimes tinged with rusty orange. Most people do not give these rocks a second glance but (we hope) this booklet will change your perception forever!

The rocks inside the Park

The rocks you see around Mehrangarh Fort and inside Rao Jodha Desert Rock Park tell us about events that happened millions of years ago to make this landscape the way it is today

This is the story of the rocks you can see as you walk around Jodhpur and especially inside the Park. Most people only know sandstone because it is so common and is extensively mined as a building stone. But the trained eye of a geologist or an earth-scientist would immediately pick out outcrops of volcanic rocks dotting the landscape in Jodhpur. Once you've been shown these distinctive volcanic formations, especially as you travel up the hill to Mehrangarh Fort, it will not be easy to forget the tall, flat-faced columns all along this route.

These are characteristically shaped columns of a volcanic rock called 'rhyolite.' It is very unusual that these two rock types – sandstone and rhyolite – are seen together. This is because sandstone is made underwater, usually in the shallow bed of an ocean, while rhyolite is hardly ever found on the ocean floor.

I invite you now to journey back in time with me to sense the scale of events that shaped and moulded the ground you walk on today. You will need to stretch your mind to try and think of gigantic events which occurred on a time-scale that is very hard to imagine. But this is how earth-scientists have pieced together a picture of what happened when the immense 'tectonic plates' bearing the continents moved around and rearranged themselves to look like they do in modern maps of the world.

We are taught in school that the Indian subcontinent crunched into Eurasia to start building the world's highest mountains, the Himalaya, roughly 55 million years ago. You must now go back to an even earlier time.

THE SUPERCONTINENT OF RODINIA
Earth-scientists believe that this is how the Earth's surface looked about 650 million years ago. The continents as we know them today have moved immense distances and have changed their shapes and sizes too.

Drifting continents

About 700 million years ago, the Indian subcontinent was part of a huge Supercontinent that earth-scientists call 'Rodinia'. The world as we know it is a result of Rodinia splitting up into smaller land-masses, including Gondwanaland, of which the Indian subcontinent formed a part

The volcanic rocks that you see at Rao Jodha Park today were made even before this time – somewhere between 745 and 680 millon years ago – in one of the earliest and largest episodes of volcanic activity in the history of the Earth.

It is important to understand that these volcanoes (in what is now western Rajasthan) were active long before India 'arrived' at the place where it now is, attached to the base of the Eurasian continent. Hard to imagine? Of course it is, but earth-scientists have uncovered plenty of evidence to know it is true. The theory of shifting land-masses – known as 'continental drift' – is less than a century old and provides us with a rich understanding of how the continents have moved and are still moving, very, very slowly.

Igneous rocks

How igneous rocks come into being from molten lava deep inside the Earth is key to understanding the kinds of volcanic rocks that we find in the Park today

The word 'igneous' (from Latin *ignis* = fire) is used for rocks that have solidified from a molten state. They are formed when hot, molten lava (magma) moves from deep within the earth up to the surface and cools slowly and hardens to become a rock.

There are many different kinds of igneous rocks with varying colours and densities. As magma moves to the surface, minerals in the magma are 'sorted' by temperature and pressure. This sorting results in rocks with a mixture of minerals quite different from the magma they originated from.

MINERALS TELL A STORY

Imagine a vast lake of magma deep underground. The temperature of that lake grades from scorching heat down to less extreme temperatures. As the magma moves upwards, some minerals solidify and get left behind because it is too 'cool' for them to remain molten at that point. Other minerals – silica is one of them – have the ability to stay molten at lower temperatures. So magma that travels the longest route to the surface accumulates the most silica. The proportion of silica in a rock is thus an indicator that earth-scientists use not only to distinguish between different kinds of igneous rocks but also to piece together how far a rock might have travelled and the environments it has endured to be in its present state.

KINDS OF IGNEOUS ROCK

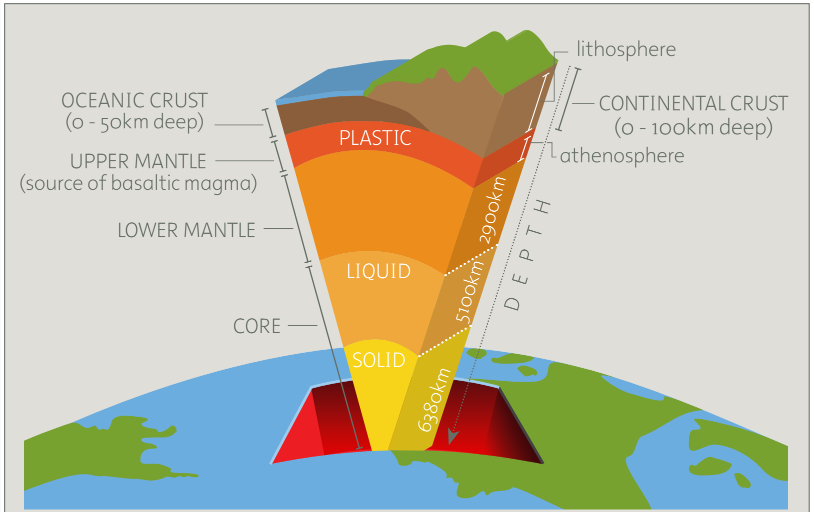
We will have to stretch our minds some more to try and understand how different kinds of magma reach the surface. The diagrams on the next few pages should help. Beginning deep under the Earth's crust – about 300 km below – in a region known as the 'upper mantle', let us follow the journey of a blob of molten lava as it travels by stages up to the surface of the Earth.

BREAKING THROUGH

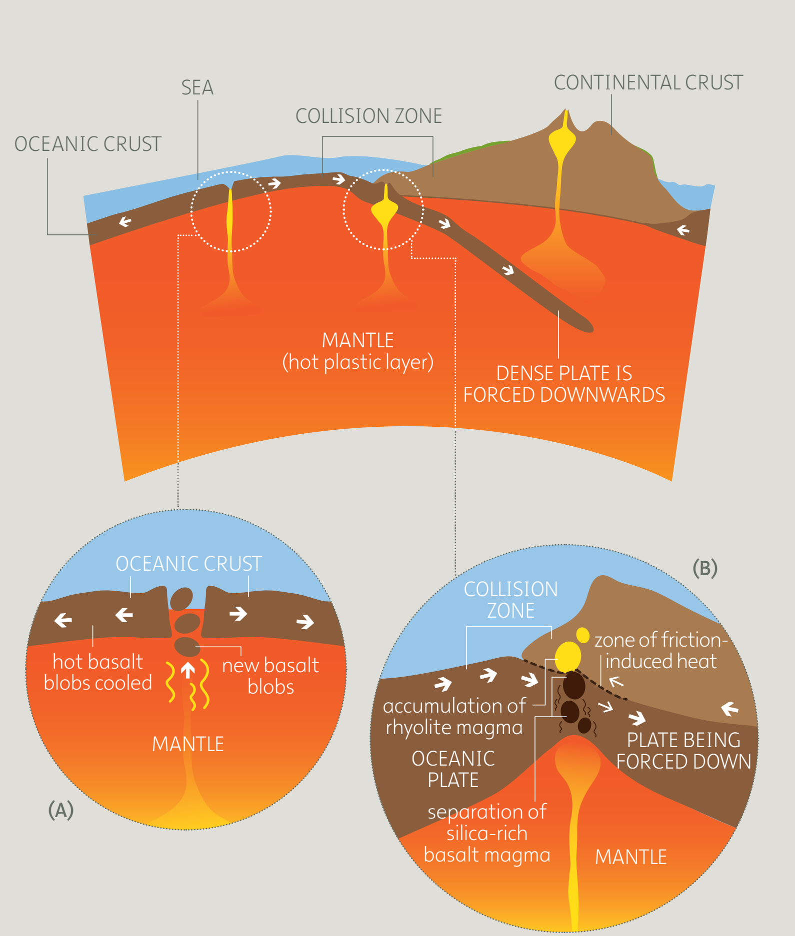
The upper mantle is rich in dark-coloured (deep grey, black and dark green) minerals which owe their colour mostly to the presence of iron and magnesium. Only small amounts of pale silica-bearing minerals are present in this layer. As our blob cools very slowly while it is still inside the mantle, it forms a dark igneous rock known as 'basalt'. Heat and pressure now begin to squeeze the blob upwards to the surface.

As you might expect, the blob is most likely to break through to the surface where the Earth's crust is thinnest or weakest and offers least resistance. This is not likely to happen under a thick continental land-mass. Compared to continental crust, the Earth's crust underlying oceans is much thinner, so the 'plate boundaries' or places along the ocean floor where two continental plates are moving apart, are precisely where the blob might find vents or fissures to squeeze through.

Once our blob of basalt has broken through to the surface and cooled, it joins together with and becomes part of the rigid oceanic crust. Over time, other similar blobs of basalt keep pushing their way to the surface along this plate boundary, gradually pushing the two plates further and further apart. In time, our blob will be pushed even further away from the place where it first squeezed through to emerge at the surface.



HOW IGNEOUS ROCKS ARE FORMED
The red layer in the image above is the source of molten lava that erupts onto the Earth's surface. This layer is called the 'asthenosphere' (it forms the topmost layer of the 'upper mantle') and exists in a plastic/toothpaste like state, unlike the solid mantle underneath.



HOW CONTINENTAL CRUST IS FORMED
(A) A blob of basalt in liquid rock behaves somewhat like a bubble of water in toothpaste. The blob is much hotter than the surrounding plastic layer so it rises.
(B) The yellow blobs represent the ponds of silica-rich magma which melt easily and separate from their iron- and magnesium-rich parent rock, basalt. Notice how the silica-rich magma has migrated from the oceanic plate underneath to the one above. So now the oceanic plate above has its silica content increased, making it thicker and more buoyant. This plate will eventually turn into continental crust.

MAKING MOUNTAINS

We need to understand a few basics about how the Earth's tectonic plates 'behave' before we can complete our story of how our blob of basalt finishes its journey.

For a simple model of what happens in plate tectonics, think of the Earth's crust being somewhat like biscuits floating on top of a sluggish custard. The custard is the hot, molten rock which lies under the Earth's crust. We know that these 'biscuits' are in constant (if immensely slow) motion. As two biscuits move apart, they bump into other biscuits at their opposite ends. Where two biscuits collide, they form what are called 'converging boundaries'.

What always happens at converging boundaries is that the thinner, more dense biscuit dips under the thicker, more buoyant biscuit and plunges back downwards into the custard – or the layer of hot, soft rock below.

Oceanic crust is relatively thin and dense and when it collides with thicker, less dense continental crust, it is always the denser oceanic crust which is forced to dip down under the less dense continental plate.

All along a converging boundary, the plates also undergo 'folding', which leads to mountain chains forming all along the length of the boundary. This happens in much the same way as a tablecloth bunches up when it is pushed against an immovable obstacle on a table.

Now we can return to our story of what happens when our blob of basalt reaches a converging boundary. We last saw our blob as a new constituent of less buoyant oceanic crust. Now, in the process of one plate getting pushed under another, an enormous amount of friction builds up as a result of the plates moving and rubbing against one another.

DID YOU KNOW?

Both the Atlantic and Pacific Oceans have distinct ridge-lines along their basins (easily seen on maps of the sea-floor) where new lava is constantly being pushed to the surface and added to oceanic crust. Scientists refer to this process as SEAFLOOR SPREADING. There are only rare instances when a blob of magma can erupt through continental crust and to do so it needs to be 'propelled' by much greater heat. The Deccan Traps in west-central India – the greatest 'floods' of volcanic lava in the Earth's history – are an outstanding example of such an occurrence and they have left their signature over large areas of Maharashtra, Gujarat, MP and a large tract in southern Rajasthan.

You will have to try and think of friction on a giant scale, producing heat on an equally massive scale, to picture what happens. Geology and earth-history often deal with huge numbers and gigantic processes.

The immense heat melts parts of both the plates, as well as our blob. But the blob of basalt does not melt entirely. Typically, there will be a thin layer of less dense minerals (like silica) in the upper part of the blob. And it is this lighter portion of the blob which melts to form ponds of molten, silica-rich lava. The remainder of the blob (now rich in iron and magnesium after it has shed its silica) is denser and harder to melt, so it sinks back into the Earth along with the plate that it is part of.

Our new blob of silica-rich minerals – having shed all or most of its dark basalt – is now hotter and lighter and so rises up through cracks and fissures in the crust above it. When this bubble of lava cools, it forms a rock called RHYOLITE.

Some of the best preserved specimens of welded tuff can be seen in Rao Jodha Desert Rock Park and along the road leading up to Mehrangarh Fort from the city below.

It is time now to introduce you to this beautiful and special rock form.

Singhoria Hill overlooks Rao Jodha Desert Rock Park from the north.

WHAT TO LOOK OUT FOR IN THE PARK

This is a close-up of the surface of rhyolite porphyry at the base of Singhoria Hill in Rao Jodha Desert Rock Park.

Notice the tiny flecks of pale feldspar minerals against a ground of fine-grained rock. Most of Singhoria hill (except for a thin capping of sandstone at the very top) is made up of rhyolite. It is worth climbing to the top to see it for yourself. The view is splendid too!

Notice the tiny pore-like 'vesicles' all along the surface of this piece of rhyolite. They would have been formed by escaping (tiny) pockets of gas as the lava was cooling.

Rhyolite is hardly ever a uniform rock and you will come across minor differences in its colour and appearance. This picture shows a 'porphyry' where large-grained felspar crystals show up against a fine-grained groundmass.

RAO JODHA DESERT ROCK PARK

The hill of welded tuff

Up to a few years ago there was a weatherbeaten sign on the road leading up to Mehrangarh which said: WELDED TUFF. NATIONAL GEOLOGICAL MONUMENT

The sign has disappeared now, but there must be something very special about this rock formation for it to be considered a national geological monument. It seems a pity that so few people know anything about it.

'Tuff' is a term used by earth-scientists to describe ultra-fine particles of rock as small as tiny flecks of ash or dust. Tuff is produced in the tremendous, shattering explosion that takes place when a volcano blows its top. Here's how:

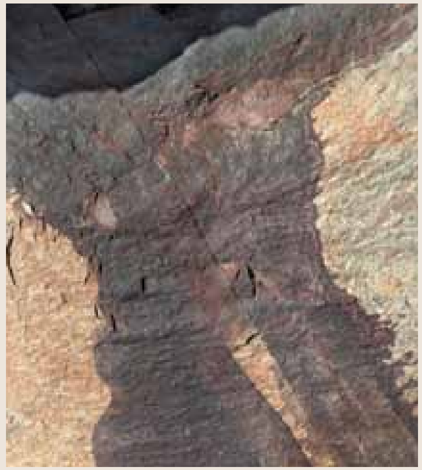
Before it sets, rhyolite is a thick, sluggish (viscous) material – think of it as having the consistency of toothpaste. When most of the molten magma in a volcano is made up of rhyolite it causes immense pressure to build up inside the vent. The molten material that has been thrust up to the surface cools and clogs the vent of the volcano but at the same time more magma tries to push to the surface. When pressure builds to a maximum, the top of the volcano explodes, releasing an unimaginable amount of energy. The magma interacts violently with gases and steam, shattering the rock into tiny fragments of tuff.

Tuff blown into the air forms hot clouds that can travel many kilometres, depending on the strength of the wind and which direction it is blowing in. A proportion of the shattered material may also flow down the sides of the volcano like an avalanche of hot bread crumbs intermixed with hot gases, eventually to settle at the base of the volcano. Ultimately the tuff also spreads onto the ground forming thick layers that are still very hot. The immense heat binds the particles of this ash-like layer together and that is why it is called 'welded' tuff.

Gradually, as the tuff cools, it shrinks and hardens into characteristic vertical columns. It is because the columns of welded tuff in Jodhpur are so perfectly formed and are still largely intact that the Geological Survey of India considers them worthy of being notified as a geological monument. It is time now to restore the old sign because readers of this booklet will be able to appreciate just how special it is.

NATURAL FLAT-FACED PILLARS
These pillars are formed by welded tuff. Notice that their colour is relatively consistent and if you look closely at a rock sample you will see that it is made up of very minute compacted grains less that half-a-millimetre in diameter.

WEATHERED TUFF
If you look at a weathered surface you can often see dark bands which run the length of cracks in welded tuff. The cracks tend to be filled by minerals — usually calcite, iron or quartz — deposited by groundwater which stain the surface prominently.



Here is a good example of the dark stain left behind by chemical alterations in and around the crack. In the picture (ABOVE) you can see how the vertical surface is also stained.

COLUMNS OF WELDED TUFF

As volcanic lava cools, it starts to contract and the whole structure begins to split into a number of vertical columns. Typically, these columns tend to be hexagonal (5-sided) much like the cells in a honeycomb, simply because this is the arrangement in nature which allows the largest number of units to occupy a given space.

When you walk across the top of a welded tuff formation, you are looking from a bird's eye perspective at the rock formation and you may not notice the columns because at the top they are marked only by cracks in the surface. It is when you are on one side of a formation that the columns stand out because this is where the weathering process has had room to 'pry' out the columns from the main mass of rock and lay bare their structural form.

These vertical fractures act as passages for rainwater seeping downwards or for groundwater pushed upwards by pressure. The walls of these fractures get 'chemically weathered' as water dissolves some minerals, creating micro-pores in the fracture-wall and oxidising other minerals, causing them to change colour. Iron is common in volcanic minerals, and iron oxidises easily to become rust, which is the most likely explanation of the orange-brown rings or streaks.

Other kinds of volcanic rock

As you become more familiar with rhyolite you will start to notice that it is by no means uniform and it is possible to make out varying textures

Follow me now as we drop down into the Gully (or Yellow) Trail behind the Visitors Centre of the Park, because this is where you can see some of the different forms of rhyolite.

The Gully is actually an old aqueduct or canal that was created many decades ago in order to bring rainwater from a wide catchment in the north to Padamsar lake, near the base of the Fort. The Gully is now used as a walking trail into the Park from the Visitors Centre.

The workers who created the aqueduct had to dig deeper and deeper as the canal lengthened so that water could flow down the gully by gravity. As the canal grew longer, miners had to cut their way through a huge volume of volcanic rock, exposing a vertical section. This is where we can see different kinds of rhyolite today. One form is called 'breccia' (pronounced 'bretch-ee-ya' from its Italian origin).

Like welded tuff, volcanic breccia is made up of broken or shattered rocks that have been compressed. But a breccia always appears very different from tuff because the fragments of rock or 'clasts' of which it is formed are large and angular.

HOW A BRECCIA IS FORMED

When a volcano erupts with massive force and shatters the rocks near its vent, it usually results in a wide range of rock particle sizes being created. As we have seen, the ultra-fine, small-grained material is thrown up in clouds to form welded tuff but the larger size of particles – ranging from centimetres to a few metres thick – flows down the sides of the volcano like a chunky landslide. When these pieces of broken rock settle near the base of the volcano, smaller particles fill in the gaps between the larger, angular clasts. As this material becomes compressed over time, the finer material acts like a cement holding the larger clasts together to form a breccia.

Both welded tuff and volcanic breccia are classed as 'pyroclastic' rocks (pyro = fire) because they derive from molten lava. There are other, non-pyroclastic forms of breccia too which originate in weathering processes such as 'frost-shattering' but this is not likely to be a factor in Jodhpur's warm, dry climate!

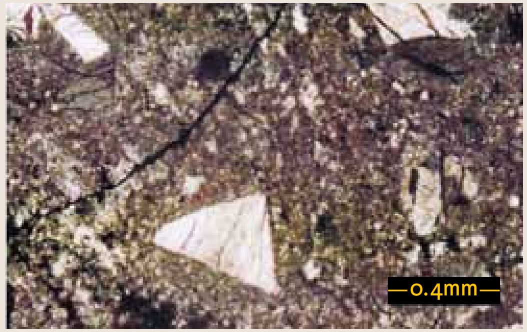
As you walk through the Gully, if you look around carefully you are likely to come across other forms and textures of rhyolite. Crystal-sizes will vary from large to intermediate and you will soon learn to distinguish the extremely fine texture of tuff from large-grained (porphyritic) rhyolite.

IDENTIFYING BRECCIA
This is a breccia in the Gully Trail in Rao Jodha Desert Rock Park. See if you can make out where the larger clasts of rhyolite are held together by finer material. Contrast this with welded tuff in the lower picture.

IDENTIFYING DIFFERENT ROCKS

The picture below shows 'ash biscuits', which are a striking feature seen at the surface of some of the welded tuff columns. Ash biscuits are the pale areas surrounded by darker pink minerals. It is surmised that ash biscuits are the remains of older beds of ash which have become embedded in minerals called 'ignimbrite', which (like tuff) are formed from hot ash and gases.

Photographs (*left and top right*) by Dr. S.C.Mathur



This is a 'thin section' of rhyolite made in a laboratory, in which a thin sliver of the rock is cut and ground flat. When viewed between two polarizing filters, the minerals show up clearly, in this case: large white crystals against a background of quartz and feldspar. Most of the dark material is iron oxide.

Here is a breccia made up of clasts of welded tuff. Notice how the texture changes from the bottom-right of the picture to the top-left. The larger clasts have the texture of welded tuff and the darker material in between is gritty and acting as a cement holding the clasts of welded tuff together.

Stone from sand

Pale pink sandstone is mined locally and used nearly everywhere in Jodhpur as a cheap building stone

Sandstone is a 'sedimentary' rock, which means that it forms very slowly as layers of sediment build up in the bed of a shallow lake, river or sea.

Sedimentary rocks vary enormously in colour and texture because any kind of rock – including rhyolite – can contribute its granules to sediments which harden into a sandstone.

Sandstones are by far the most common sedimentary rocks on earth. As their name suggests, they are made up primarily of sand which gets 'sorted' as it is transported (by rivers or the sea) and tends to become more and more fine as it travels further and further away from its source or origin.

HOW SAND IS DEPOSITED

Sand gets 'dumped' because of a gradual loss of energy in the process of being transported. A fast-flowing stream will hold on to its silt while it is rushing down at speed. But as the stream bottoms out and begins to slow down, it loses energy and begins to drop its load of silt. This happens in a continuing process so you can imagine how much sand gets buried as fresh deposits pile up. The weight of overlying sand deposits acts to compress the sand particles together. Helped further by chemical reactions between sand particles (which fuse the particles together), a harder rock is gradually formed.

Water is by far the dominant agent for transporting sand but don't forget the other big player – wind! In hot, sandy deserts of the world like the Sahara in north Africa or the Thar in India, the wind piles up huge quantities of sand to form dunes which eventually get buried, and in the process also become compressed into a sandstone.

Jodhpur's sandstones are a mix of marine (formed in the ocean), deltaic (formed in a delta) and fluvial (or riverine). How do we know this? Simply because it is possible for earth-scientists to 'read' the ripple marks whose forms and patterns always tell a story about how and where the sediments had built up.

HUGE SANDSTONE BEDS

Extremely wide beds of sandstone are only found on the floors of oceans and seas. They begin as 'delta-deposits' at the mouths of rivers and then spread further out onto the sea or ocean floor. These beds are so large because seafloors provide huge, unimpeded space for sand to be deposited.

Sandstones formed along riverbeds, on the other hand, will always tend to be limited in extent because the space for deposition in a river-valley will always be relatively narrow.

RIPPLE MARKS

When geologists wish to know more about the original landscape in which a sandstone was created, they look at 'ripples' preserved in the stone.

Ripples are a series of wavy lines that were originally formed by the action of wind or water flowing across a surface. You will have seen such ripples on a sandy beach. They are formed because the ripples and waves you see at the surface of flowing water are mimicked by molecules underneath the surface. Wind creates the same effect in deserts in the form of dunes but dunes are ripples on a gigantic scale – often several metres tall – while ripples produced by flowing water or waves are only a few centimetres high.

Take a look at the rippled slabs in the walkway of the Visitors Centre. They were all collected from Jodhpur's mines and speak of the different origins of the sandstone here.

RIPPLES IN SAND

Ripples in sand — the kind you might see on a dune in a sandy desert — are not unlike those formed by sand in shallow water. In this case, more or less regular wave-like ripples are formed at right angles to the direction of the wind.

RIPPLES IN STONE

There are many different kinds of ripple marks. They can be symmetrical, with or without 'tuning-fork' branching, asymmetrical, and so on. Each of these patterns tells a story about the action of currents in shallow water.

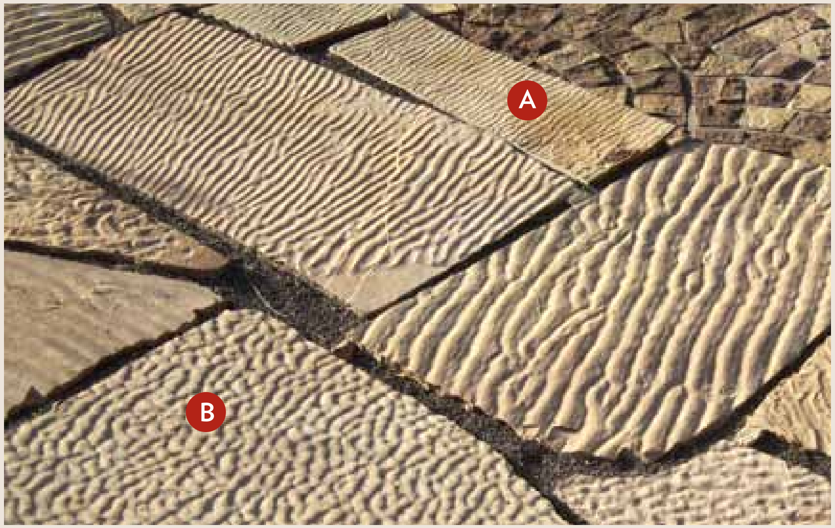
WHAT RIPPLES TELL US

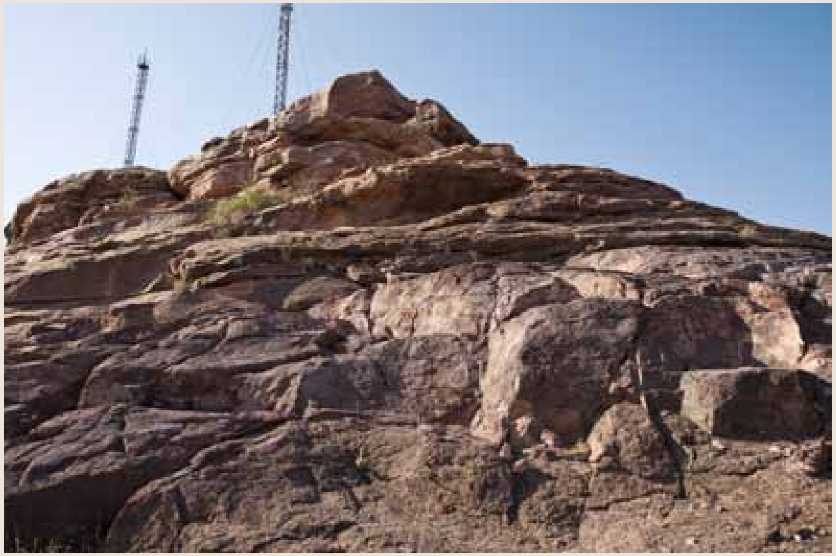
Because they preserve the direction in which sediments were deposited, sandstone ripples are like 'signatures'. They are a fossilized record of processes at work in past environments. By studying the patterns of ripples – such as whether they are symmetrical or not – geologists can infer several things about the environment in which the sand was deposited. Wave ripples look very different from current ripples and it is even possible to tell which direction the current was flowing in and whether or not the ripples were formed on what was once a shallow beach.

If we are to summarize (and simplify, somewhat) the findings of earth-scientists about Jodhpur's sandstones, it can be said that most of these sandstone beds once formed part of a huge beach tilting into the sea!

WHERE TO SEE RIPPLED STONE IN THE PARK

The Park's Visitor Centre is paved with large slabs of sandstone with ripple marks preserved on their surfaces. No two slabs bear the same ripple pattern. The slab marked A, for example, is an example of a wave ripple with symmetrical straight crests. By contrast, B is called an 'interference ripple'. There are several others.





SANDSTONE AT SINGHORIA HILL
Singhoria Hill is a dome of rhyolite capped by sandstone formed in a riverbed. Millions of years of weathering has eroded most of the sandstone away, specially along the sides of the hill. Only at the top can you see remnants of the sandstone cap.

A PIECE OF MISSING TIME

Just before you step into the elevator that takes you up into Mehrangarh Fort, there is a spot where you can see a massive slab of pale sandstone lying in contact with dark pink welded tuff.

The two kinds of rock are easily distinguished. Welded tuff has a very fine texture. The sandstone is clearly seen to have layers. The welded tuff lies below and must be older than the sandstone.

Geologists call this an 'unconformity'. We know that 50 million years could have elapsed between the time that the welded tuff was created and the sandstone began to form. One way of thinking about an unconformity is that it indicates a piece of missing time, or events that were not recorded as geological processes.

There is another unconformity at the top of Singhoria Hill. Here it comes as even more of a surprise because it takes a feat of the imagination to picture sandstone being laid down in a riverbed at the top of a hill! This is the magic and the mystery of geology. There is no end to the ways in which it can surprise you.

What was Rajasthan like long ago?

We know – mostly by studying the rocks – that a significant part of what we know today as Rajasthan was once a continental sea-bed about 600 million years ago

How do we know this?

With the help of modern, accurate methods of dating rock, we know with a reasonable amount of certainty that the Himalaya are about 55 million years old. We also know that the Himalaya were formed as a result of the Indian continental plate pushing up against the Eurasian plate. As a result of the collision, a sea – earth-scientists call it the 'Tethys' – which lay in the space between the two plates, was gradually squeezed out of existence.

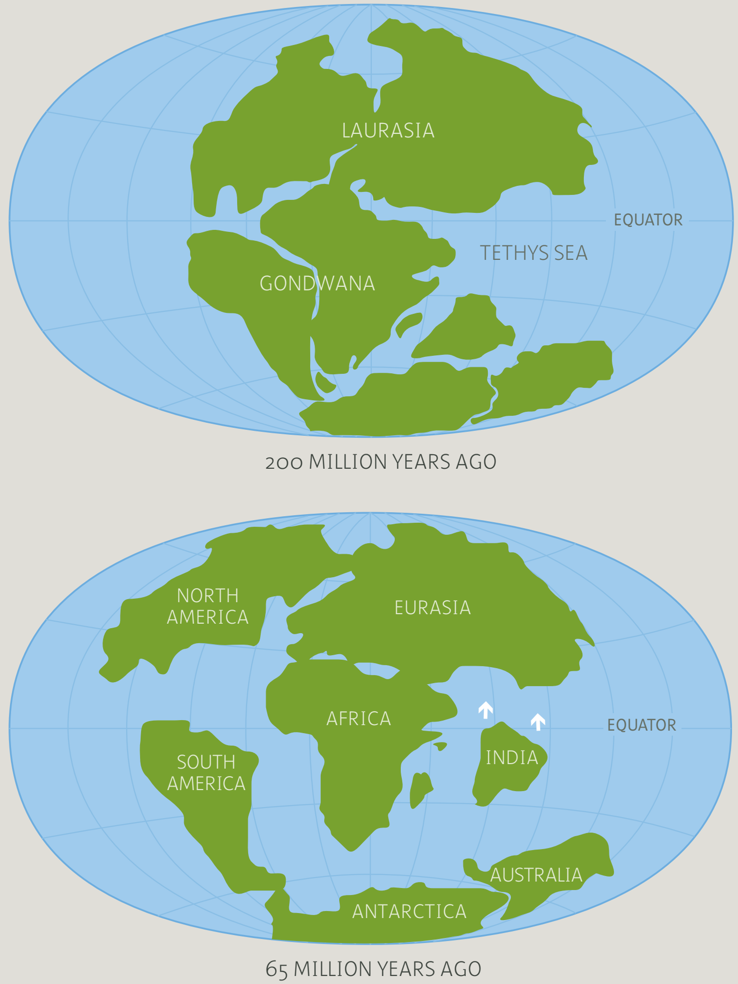
We also know now that the more or less level parts of Rajasthan which lie west of the Aravallis once formed part of the sea-floor of the southern Tethys. As the Tethys waters were being squeezed out by the colliding plates, its waters would have drained out south-westwards towards the Arabian Sea.

This sounds as if it happened in a short span of time but the process of collision, squeezing, water flowing out and uplifting of the sea-bed would have taken a few million years!

During this period, large parts of modern-day Rajasthan would have been submerged under a shallow sea. Were it not for this extended episode, Jodhpur's marine sandstones would not have come into existence.

RAJASTHAN WAS ONCE UNDERWATER

In Jodhpur it is sometimes possible to trace an unbroken surface of rippled sandstone for hundreds of metres horizontally. This fact alone tells a story. A river is not capable of creating ripples over such a wide horizontal expanse. That is why we can say with reasonable certainty that most of the sandstones that you see in and around Jodhpur city must originally have been deposited in the wide bed of a sea. Geologists have dated Jodhpur's oldest sandstone beds to be roughly 630 to 542 million years old. This was a time when the Indian subcontinent was an island located well south of the equator with many of its adjoining areas submerged under water. The region we know today as 'Rajasthan' would have been one of them.



TIME-TRAVELLING
The two maps above are like snapshots of the Earth's continents in different time-frames. See how the vast Tethys Sea became narrow and restricted 65 million years ago as the Indian subcontinent moved northwards.

Courtesy Mehrangarh Museum Trust

ARTISTS OF AN EARLIER TIME DEPICTED RHYOLITE

The watercolour (TOP) by Englishman G.F. Lamb was painted in 1890 and you can see howthe artist was struck by the jagged rhyolite columns in the foreground. Was he perhaps suggesting that the builders of the Fort may have taken inspiration form the vertical forms of the parent rock? The lower image is a Rajput painting from circa 1775 which celebrates the (dark pink) rhyolite columns which dominate the landscape.

Living in rocky landscapes

Welded tuff and other forms of rhyolite are important elements of the highly individual rockscape of Rao Jodha Desert Rock Park. They give the Park a unique character and differentiate it from the sandy desert which lies all around Jodhpur and specially further out west

The desert is a hard place for a plant to survive and prosper in. And rocky conditions impose an even more difficult regime on plants, much more so than sand does. In order to survive in inhospitable rocky conditions, desert plants have had to find ways of overcoming the limitations of poor (or no) soil, quite apart from searing heat and the lack of moisture.

They do this in various ways: some store moisture in their stems and leaves. Others have learned to eke out a precarious living in the small rocky hillocks (called *tekri* in Marwari) where soil is scarce or absent. The only opportunities for a plant lie in thin fissures and cracks where tiny bits of soil may have accumulated. This is what gives the Park its special character and abiding interest.

Jodhpur's volcanic rocks are such a distinctive feature of the hill on which Mehrangarh Fort is perched that it is surprising that Jodhpur's residents do not know and appreciate it.

Paintings from Jodhpur's Royal Court from a few centuries ago clearly show the pink columns of welded tuff. Now housed in Mehrangarh Fort, the paintings show that there was a time when people knew and celebrated their distinctive forms.

Have we become so closed to nature that we have stopped noticing natural beauty in our cities? I hope not. I hope too that you will not be able to drive or walk up Mehrangarh's hill again without thinking of the amazing history of these beautiful and unusual rock formations.

Plants from rocky habitats

Plants that are well adapted to living in rocky habitats are called LITHOPHYTES. All of them have found ways of coping with dry conditions and a lack of soil

You can see nearly every one of the lithophytes of the Thar Desert inside Rao Jodha Desert Rock Park. There are succulents, storing water in their tissues like a cactus does. There are 'crack-dwellers', specialized at growing in thin rock crevices. Most, however, are small plants that live and set seed only in the monsoons when there is moisture in the ground.

1 *Tephrosia uniflora* subsp. petrosa is one of many species of biyani that specializes in living in dry, rocky ground

2 Kumatiyo (*Acacia senegal*) is the foremost lithophytic tree of the Thar

3 Thhor (*Euphorbia caducifolia*) is hugely successful as a gigantic succulent

4 Some grasses show an uncanny ability to exploit the thinnest crevices in rock

5 Safed vajradanti (*Barleria acanthoides*) grows happily in rock, specially if there is plenty of limestone in the ground

6 After the first rains, grasses compete furiously to occupy every available niche and crevice in rocky ground

7 *Corbichonia decumbens* is known as 'pathhar-chatti' in local parlance

8 Peelvaan (*Cocculus pendulus*) is a pendant creeper with an outstanding ability to grow in rocky outcrops

9 Aakari bel (*Blyttia spiralis*) scaling a massive rockface inside the Park

10 *Vernonia cinerescens* is a tall herb that successfully colonizes rocky ground

Glossary of terms

basalt *noun*
A hard, dark volcanic rock of fine-grained texture. One of the most common volcanic rocks on Earth, made up of the primary minerals plagioclase feldspar, pyroxene and olivine.

breccia *noun*
A rock made by the compression of 'angular clasts' of any rock suspended within a matrix of smaller clasts and/or particles which act like a cement.

clasts *noun*
Fragments of rock large enough to be visible to the naked eye, derived from the breakup of larger 'parent' rock.

continental crust *noun*
Younger, less dense, thicker crust that makes up the dry land masses of Earth. It can be and often is submerged under an ocean.

continental drift *noun*
The horizontal movement of the Earth's crust (and the continents) over millions of years.

converging boundaries *noun*
The boundaries between two or more 'plates' of the Earth's crust that are pushing against each other (i.e. converging).

delta-deposits *noun*
Accumulations of fine material that are deposited at the mouths of rivers where they meet the sea. The loss of energy of a river results in dust-sized particles falling out of suspension and piling up.

deltaic *adjective*
Of or pertaining to the landforms that occur at a river delta, where a river flows into an ocean, sea or even a lake.

feldspar *noun*
A very commonly occurring rock-forming mineral (~60% of the Earth's crust) made of aluminium and silica molecules with the elements sodium, potassium, calcium and rarely, barium, within its lattice.

fissure *noun*
A (usually) fine crack, cranny or cleft in a rock surface.

fluvial *adjective*
A term used in the earth sciences to describe the processes, landforms or deposits associated with rivers.

folding *verb*
Bending in a u-shape. This term is applied in the earth-sciences to the deformation which happens to earth strata under conditions of compression or stress.

igneous rock *noun*
Rock formed when molten magma/lava is cooled.
NOTE: *Magma forms underground and is called 'lava' when it reaches the surface.*

iron *noun*
A metal element known and used for its strength, hardness and ductility.

magma *noun*
Molten rock while it is still under the Earth's surface. (SEE *igneous rock*)

magnesium *noun*
An alkaline metal that is the fourth most common element in the Earth.

marine *adjective*
That which relates to or is found in the sea. In our context, it expresses one of the possible places (in the sea) where sandstone is formed

oceanic crust *noun*
Relatively thinner, but more dense and older than continental crust. Oceanic crust forms the large basins of the Earth's surface that hold the oceans and seas.

porphyry *noun*
An igneous rock with conspicuously large-grained crystals of feldspar, nestled in a compact, fine-grained (usually dark) groundmass.

pyroclastic *adjective*
Shattered material of varying particle-sizes from a volcanic eruption.

rhyolite *noun*
A pale, extrusive, igneous rock with very fine-grained texture. Rhyolite has relatively high silica content >60%. Rhyolite contains minerals like quartz, feldspars, mica and some amphiboles.

Rodinia *proper noun*
A name used by earth-scientists for the super-continent that existed between 1.1 billion and 700 million years ago. The shape and form of Rodinia has been hypothesized by geologists who have reconstructed what the Earth's crust would have looked like in the past.

sandstone *noun*
One of the most extensively found rocks on the Earth's surface made up of sand particles compressed together.

sedimentary rock *noun*
A rock formed by the compression of particles or fragments of other rocks that have been broken down by erosion and then been transported and piled up.

silica *noun*
A hard, common, colourless compound that occurs naturally as mineral quartz.

sorting *verb*
Sieving or arranging (for example, by size) in response to some external stimulus such as flowing water or heat.

tectonic plates *noun*
The name given to the rigid, jointed 'plates' which make up the entire surface of the Earth. Tectonic plates 'float' on molten rock which lies underneath them.

Tethys *proper noun*
The name given to the mass of oceanic water that would have separated the continent of Eurasia and India to its south.

upper mantle *noun*
The outermost part of the Earth that includes the crust at the surface and the molten layer underneath.

vesicle *noun*
A tiny cavity formed in volcanic rock formed by a trapped bubble of gas in the process of solidification

weathering *verb*
The process of breaking down rocks, soil and minerals through contact with the Earth's atmosphere, waters or living things.

welded tuff *noun*
A very fine, ash-like material blasted out of a volcano that gets deposited while still hot, resulting in its particles 'welding' together to form a fine-grained crystalline rock.

Have you heard of 'welded tuff'? Or wondered about the striking flat-faced columns of pink rock that you see as you drive up the hill to Mehrangarh Fort? Did you know that Jodhpur was the site of violent volcanic eruptions 750 million years ago and that it once lay underwater? These and other questions about the rocks and landforms in RAO JODHA DESERT ROCK PARK are answered in this engaging booklet by Jonathan Wilson. Written lucidly for students and laymen, this is a field guide that could change the way you look at rocks anywhere you go.

Jonathan J. Wilson grew up in the Nilgiris district on the border between Tamil Nadu and Kerala and says that this beautiful rural setting fostered a keen interest in natural lansdcapes and the earth-sciences. He graduated in geology from the University of Auckland in New Zealand and now works in a geo-technical and environment engineering firm in Auckland.

Rao Jodha Desert Rock Park (in Jodhpur, Rajasthan) was created by the Mehrangarh Museum Trust in 2006 as a project to restore the natural ecology of a large rocky tract that abuts Mehrangarh Fort. The Park officially opened in February 2011. Visitors are welcomed and oriented at the Visitors Centre from where they can choose from several walking trails that wind through different aspects of the landscape.

RAO JODHA DESERT ROCK PARK

www.raojodhapark.com

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