

# Science and the Miracles of Exodus

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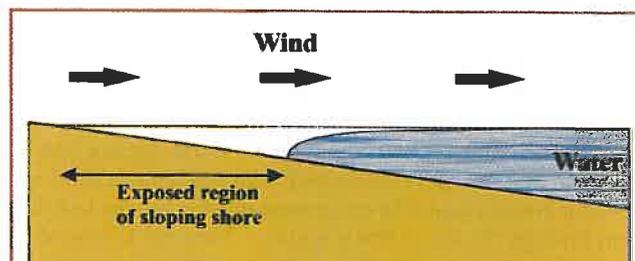
**D**id Moses and the Israelites really cross the Red Sea? If so, can physics explain how? Is it physically possible to obtain water from a rock? Is there a scientific mechanism underlying the crossing of the River Jordan? How can a mountain like Mount Sinai emit a sound like a trumpet? At first sight, these miracles in the biblical story of the Exodus of the Israelites from Egypt over 3000 years ago seem incredible. Because they appear to violate the normal running of the natural world, many scientists are sceptical that they could have happened. However, is it true that the well-known miracles mentioned above violate the normal running of the natural world? In this article I will take a closer look at some of the Exodus miracles through the eyes of a scientist.

## Water from a rock

The miracle of obtaining water from a rock is described in just two verses in the Old Testament book of Exodus: "The Lord said to Moses 'Take in your hand the staff with which you struck the Nile, and go. I will stand there before you by the rock at Horeb. Strike the rock, and water will come out of it for the people to drink.' So Moses did this in the sign of the elders of Israel" (Exodus 17:5-6).

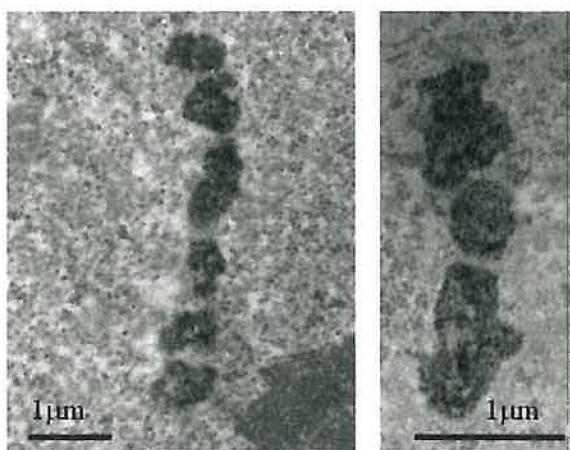
What a curious incident! Obtaining water from a rock would seem to be like obtaining blood from a stone: impossible. But let us look more closely. The Hebrew word used for "strike" in "strike the rock" implies a heavy blow: so Moses gave the rock a good thump. For a rock to give out water it has to be able to store water, so it has to be porous. Do porous rocks exist? The answer is yes, and porous rocks like sandstone and limestone can absorb huge quantities of water from rain. In fact, when they are underground we use them as aquifers, natural reservoirs of water, and we sink wells and boreholes into them to extract the water.

If porous rocks, such as sandstone and limestone, are above ground, rainwater isn't normally stored in them: it flows out through the pores. However, in a desert region, rocks weather in an unusual way because of sandstorms, which at high speed sweep sand and organic matter from decaying plants and animals on to the rocks. Over time, porous rocks in a desert can develop a hard impervious crust, rather like cement, due to this weathering.

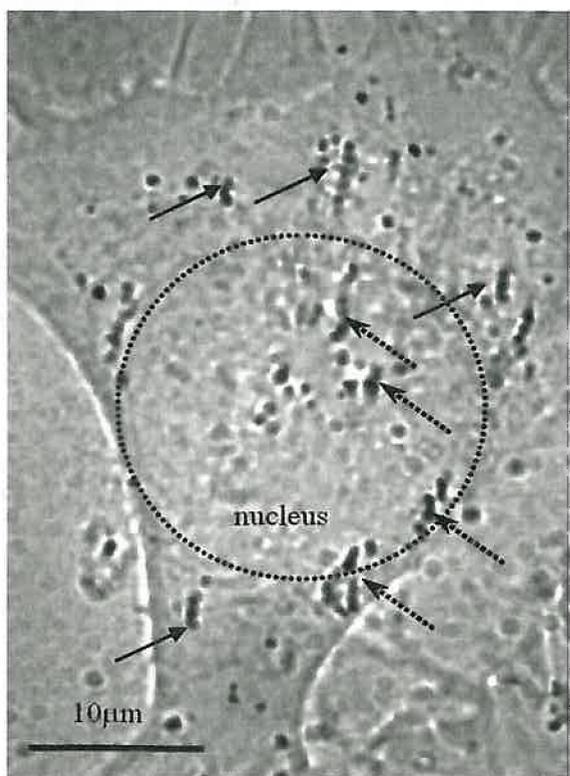


▲ **Fig. 1:** Diagram of wind setdown. The water is blown back, exposing a region of sloping shore (normal waterline drawn dotted).

**A**



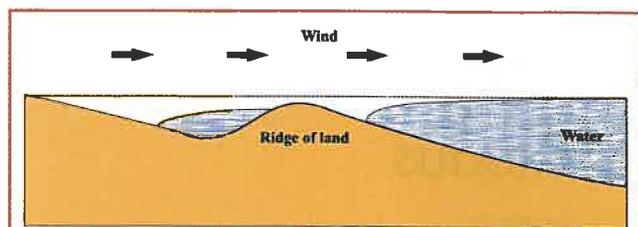
**B**



- .....→ Chains near the nucleus
- Chains far from the nucleus

▲ **Fig. 4:** Subcellular magnetic micromanipulations. (A): Electron micrographs of chains of magnetic endosomes formed in a magnetic field of 150 mT. (B): Light micrograph of magnetic endosome chains inside a living cell. Local viscoelasticity can be deduced from the rotational behavior of the chains piloted by an external magnetic field. Chains of endosomes located close to the nucleus are "stuck" in a dense viscoelastic matrix, while viscoelasticity is markedly lower at a distance from the nucleus.

features



▲ **Fig. 2:** Water on both sides of a ridge of higher land. Normally the ridge is submerged below the waterline (dotted)

Modern Bedouin call this hard crust “desert varnish”, and it provides a smooth surface for their rock art. If the crust of a porous rock is broken by a sharp blow, water can indeed flow out, and this is an effect that is well known to geophysicists working in desert regions.

There is an interesting account of obtaining water from a rock in *Yesterday and Today in Sinai* written in 1936 by a former British governor of the Sinai Peninsula, Major Jarvis. He writes: “The striking of a rock by Moses and the gushing forth of water sounds like a veritable miracle, but the writer [Major Jarvis] has actually seen it happen. Some of the Sinai Camel Corps had halted in a wadi [a dried up river stream] and were digging in the loose gravel accumulated at one of the rocky sides to obtain water that was slowly trickling through the limestone rock. The men were working slowly and the Colour Sergeant said “Give it to me” and, seizing a shovel from one of the men, he began to dig with great vigour. One of his lusty blows hit the rock, when the polished hard face that forms on weathered limestone cracked and fell away, exposing the soft porous rock beneath, and out of the porous rock came a great gush of clear water. It is regrettable that the Sudanese Camel Corps hailed their Non-Commissioned Officer with shouts of: “What ho, the prophet Moses!”

Physicists at NASA utilised their knowledge of a hard crust forming on rocks in a desert in their search for water on Mars. For example, an Associated Press report dated 25 February 2004 states: “NASA Rover Drills Martian Rock for Water. The six-wheeled Rover used the rock-abrasion tool on its instrument-tipped arm to grind a fraction of an inch into the surface of a rock called “El Capitan.” The rock’s weathered surface was ground away, so that the Rover could examine the material underneath.”

We have seen that Moses obtaining water from a rock violates no physical laws. The biblical story fits what we know from science. So was the event a miracle? I will discuss this later, after we have looked at some other Exodus miracles through the eyes of a scientist.

## Crossing the Red Sea

Moses and the Israelites crossing the Red Sea is one of the best-known miracles in the Bible. The miracle is essentially in two parts. First, the sea is driven back and the Israelites cross on dry land. Then, the sea comes rushing in and the Egyptians pursuing the Israelites are drowned. This is how the Bible describes these events: “Then Moses stretched out his hand over the sea, and all that night the Lord drove the sea back with a strong east wind and turned it into dry land. The waters were divided and the Israelites went through the sea on dry ground ... Then the Lord said to Moses, ‘Stretch out your hand over the sea so that the waters may flow back over the Egyptians and their chariots and horsemen’ ... The water flowed back and covered the chariots and horsemen – the entire army of Pharaoh that had followed the Israelites into the sea (Exodus 14: 21-22, 26-28).

The water of the Red Sea retreating and then rushing back may bring to mind the tsunami that devastated parts of Asia at the end of 2004. A number of people have in fact proposed that the crossing of the Red Sea was made possible by a tsunami, which resulted from the eruption of the volcano Santorini, a Greek volcanic island in the Mediterranean. However, we can dismiss this idea because the eruption of Santorini occurred well before the events of the Exodus. In addition, although a tsunami frequently causes the sea to retreat before it rushes in, the retreat only lasts for a few minutes, as was the case in the recent Asian tsunami. A few minutes would not have given thousands of Israelites sufficient time to cross the Red Sea.

A further suggestion is that the crossing was made possible by a very low tide followed by a very high tide. However, although in some locations in the world the tide can come in rapidly because of how the land lies, and people can be trapped and drowned, this is not the case in the Red Sea and its two branches, the Gulf of Suez and the Gulf of Aqaba, where the tide comes in slowly.

So if there is a natural explanation of the crossing of the Red Sea, it has to be different from those given above. In fact the biblical description is explicit that there was indeed a natural mechanism: a strong east wind that blew all night. A wind blowing along the surface of a body of water exerts a stress on the water which forces it back. If the water is on a sloping shoreline then the wind can force the water back and expose hundreds of metres of shore. Oceanographers call this “wind setdown.” If the direction of the wind is reversed, the water is forced higher up the shore and this is called “wind setup.” An alternative name sometimes used for wind setdown or setup is wind tide.

The physics of wind setdown and setup involves second order differential equations. The solution of these equations shows that the effect is only appreciable if the wind blows along a long stretch of water, which increases the total force on the water, and if the wind blows for a long time, because the water is slowly blown back. In a typical situation, a steady state is reached, when the water is blown back a maximum distance, only after the wind has been blowing for a number of hours. It is interesting to note that the Bible says that a strong east wind blew *all night*: just what is required for appreciable wind setdown. Wind setdown effects can be surprisingly large. For example, a strong wind blowing along Lake Erie, one of the Great Lakes, has produced water elevation differences of as much as five metres between Toledo, Ohio, on the west and Buffalo, New York, on the east.

Various sites for the Red Sea crossing have been proposed, including inland lakes and the Gulfs of Suez and Aqaba. If the physical mechanism which enabled the crossing was wind setdown then we can rule out the inland lakes in the Sinai Peninsula, because they are not long enough for appreciable wind setdown to occur. This leaves the Gulfs of Suez and Aqaba as the only possibilities, both of which are long enough for large wind setdown effects. (There has been much debate on the meaning of the Hebrew words translated “Red Sea”, whether the term refers to inland lakes, or to the Red Sea and its two gulfs, or to all of these. For a detailed discussion see my book *The Miracles of Exodus*).

Since the book of Exodus refers to a strong east wind that blew back the waters of the Red Sea, I believe we can rule out the Gulf of Suez (since an east wind would blow *across* this gulf and not *along* it), leaving the Gulf of Aqaba as the only possibility. I have shown (see *The Miracles of Exodus* for details) that a very strong wind could push back the sea at the head of the Gulf of Aqaba for about 800 metres. Interestingly, the mathematics show that the water that is pushed back rises up vertically from the seabed at the receding point, just like a wall (see figure 1). The book of Exodus

states: "By the blast of your [God's] nostrils the waters piled up. The surging waters stood firm like a wall" (Exodus 15:8). The Bible also refers to "a wall of water on their [the Israelites] right and on their left" (Exodus 14:22). This is more difficult to explain, but one possibility is due to a ridge of land as shown in figure 2.

At figure sight, the drowning of Pharaoh's army is more difficult to understand than the Israelites crossing of the Red Sea on dry land. Why didn't the Egyptian army see the water of the Gulf of Aqaba flowing back towards them and escape? The clear implication of the Exodus account is that there wasn't time.

What happens if a strong wind blows for a number of hours, producing appreciable wind setdown and then suddenly stops, which is the implication of the Exodus account? The mathematics shows that the water returns as a fast-moving vertical wave called a "bore". I have performed some calculations for the Gulf of Aqaba, and the speed of the returning bore wave is about five metres per second: sufficient to knock over a horse and its rider and hurl them into the sea. So the natural mechanism of wind set-down followed by a wall of water rushing back in fits well the description of events in the book of Exodus.

### The sound of a trumpet from Mount Sinai

Perhaps the most controversial aspect of my book *The Miracles of Exodus* is that I believe Mount Sinai was a volcano. I am not the first to suggest this, but I have come up with some new insights from physics which further supports the volcano theory.

The most obvious signs that Mount Sinai was a volcano are the clouds and fire on the top: "You came near and stood at the foot of the mountain [Mount Sinai] while it blazed with fire to the very heavens, with black clouds and deep darkness (Deuteronomy 4:11). What a vivid description of an erupting volcano!

The book of Exodus also refers to lightning: "On the morning of the third day there was thunder and lightning, with a thick cloud over the mountain [Sinai]" (Exodus 19:16). Lightning occurs in some volcanic eruptions for a good physical reason: the ash particles emitted are charged and huge potential differences build up in an eruption cloud, which then discharges as bolts of lightning.

Intriguingly Exodus refers to the sound of a trumpet coming from Mount Sinai: "On the morning of the third day there was thunder and lightning, with a thick cloud over the mountain with a very loud trumpet blast ... the sound of the trumpet grew louder and louder" (Exodus 19: 16-19). How can a mountain produce a sound like a trumpet blast? Molten volcanic rock, called magma, contains dissolved volcanic gases, such as water vapour and carbon dioxide. If these gases are forced out through cracks in the rocks surrounding the erupting hot zone of a volcano, then the sound of a loud trumpet blast can indeed sometimes be heard. (A normal trumpet blast is similarly produced by blowing air at high speed into a trumpet). The Roman historian Dio Cassius reported that the sound of trumpets was heard coming from Vesuvius in its famous eruption in AD79.

It is clear from the physics involved that if the "sound of a trumpet" is heard coming from a mountain, then that mountain is a volcano. In fact in its description of Mount Sinai the Old Testament gives no fewer than six characteristic features of a volcano: (1) it blazed with fire to the very heavens (Deuteronomy 4:1), see fig 3; (2) smoke and clouds billowed up from it (Deuteronomy 4:11 and Exodus 19:18), see fig 4; (3) the noise of explosions – an explosive eruption (Exodus 19:16); (4) a very loud trumpet blast – the sound made by hot gases escaping through cracks in the rocks (Exodus 19:16); (5) lightning – electrical discharges in the

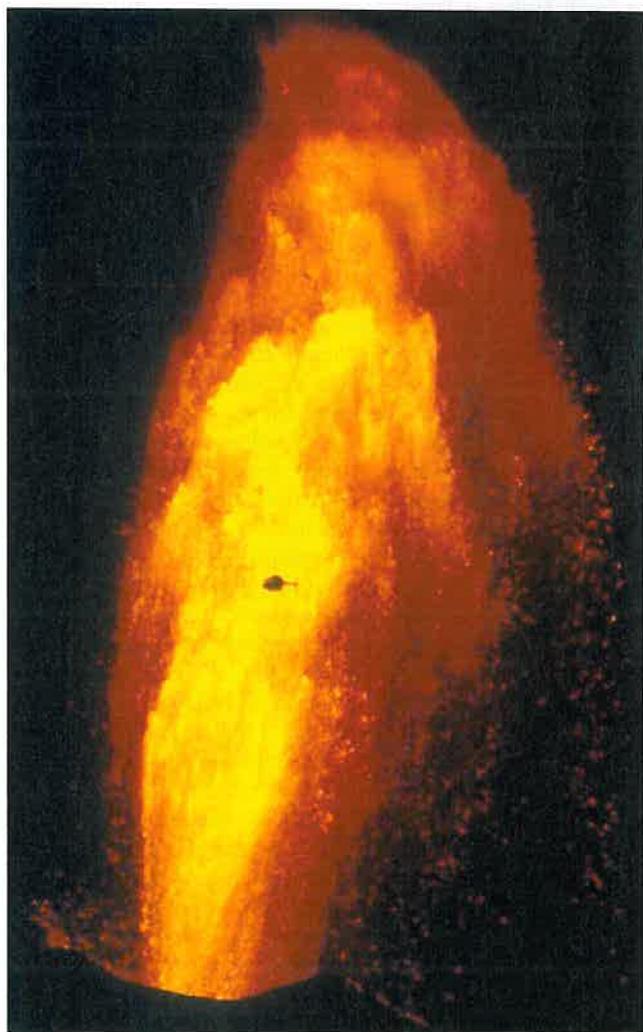
eruption cloud (Exodus 19:16); (6) volcanic earthquakes – the whole mountain trembled violently (Exodus 19:18). Here we have a remarkable description of an erupting volcano based on careful observations.

There are no volcanoes that have been active in the last 10,000 years in the Sinai Peninsula or Egypt. For this reason, and others, I believe Mount Sinai is in Saudi Arabia, which does have historically active volcanoes, in particular that it is the volcanic Mount Bedr, which fits the biblical description of Mount Sinai impressively well.

### The Pillar of Fire and Pillar of Cloud

The mysterious pillar of fire and pillar of cloud that guided the Israelites to Mount Sinai have long puzzled scholars. Here is what the book of Exodus says: "By day the Lord went ahead of them in a pillar of cloud to guide them on their way and by night in a pillar of fire to give them light, so that they could travel by day or night. Neither the pillar of cloud by day nor the pillar of fire by night left its place in front of the people" (Exodus 13: 20-22).

The traditional interpretation of the pillars of cloud and fire is that these pillars were just in front of the Israelites and that they moved with them as they marched, rather like tour group leaders holding up a rolled umbrella and walking at the head of the group. But the book of Exodus does not imply that the pillars of



▲ Fig. 3: A pillar of fire by night, from a volcano in Hawaii

cloud and fire were just in front of the Israelites, and neither does it state that they were moving pillars; they could have been a considerable distance ahead and fixed, like a beacon on a hill giving light.

There is, in fact, a natural event that fits perfectly the description “pillar of cloud by day and pillar of fire by night”: a volcanic eruption. Why does a volcano often appear to emit cloud by day and fire by night? Physics provides the answer. In a volcanic eruption huge towering flames leap out of a volcano surrounded by thick clouds of vapour. By day, often only the surrounding cloud is visible, reflecting the light of the sun. But by night the cloud is invisible and the volcanic fire becomes visible. Similarly in a smoky bonfire seen from a distance, by day you see mainly the smoke and by night mainly the flames. Figures 3 and 4 show a typical pillar of fire by night and pillar of cloud by day emitted by a volcano.

Madame Louise Vigée-Lebrun, who had painted Queen Marie Antoinette’s portrait, emigrated to Italy at the start of the French Revolution. In a letter she wrote: “Now I must tell you of my various expeditions up Vesuvius ... Then night came on, and the smoke was transformed into flames, the most beautiful sight imaginable.” So once again we have smoke by day and fire by night.

Since I have identified Mount Sinai as the volcanic Mount Bedr in Saudi Arabia, it clearly makes sense for the erupting volcano that produced the pillars of cloud and of fire to be none other than Mount Sinai itself, since the purpose of the pillars was to guide the Israelites to Mount Sinai. Mount Sinai was therefore the guiding light drawing the Israelites to itself, like a mountain with a fiery beacon on its summit.

### Were the Exodus miracles really miracles?

In this article I have suggested how science can explain some of the miracles in the Exodus story. In my book *The Miracles of Exodus* I give scientific explanations of some other Exodus miracles (for example, crossing the River Jordan, the burning bush, the ten plagues of Egypt and turning bitter water sweet). Do these scientific explanations mean that the miracles of the Exodus story were not really miracles and rule out the supernatural? Europhysics News is not the place for a detailed discussion of this, but let me give a few brief comments. First, the fact that we can explain an event in terms of physical mechanisms does not mean that we have explained it away. Physics can explain how all the notes in Beethoven’s Pastoral Symphony are produced, but that does not mean that physics has explained why it is great music, nor that physics has eliminated the need for an expert composer.

Many years ago Aristotle wrote about miracles and he said that the “efficient cause” of a miracle could be a natural agent, with the “final cause” being the will of God. The miracle is revealed by the extraordinary timing of the event. I believe that the “efficient cause” in many of the Exodus miracles was a natural agent (a porous rock, a strong wind, a volcano, etc.) and that science can discover this natural agent and give the mechanism of the miracle. Indeed, as we have seen, the Bible is explicit that the crossing of the Red Sea was enabled by a natural agent, a strong east wind.

Although the water from the rock event was not particularly time critical, the biblical description of the Red Sea crossing was: the Egyptian army had trapped the fleeing Israelites and was about to take them back into captivity. Of course, the Red Sea being driven back by a strong wind at just the right time to save the Israelites could have been lucky chance. However, in the Exodus story we have event after event occurring at just the right time. If we accept the Old Testament description, then the timing of

these events does seem to be extraordinary and that is why I suggest the events of the Exodus described here and in my book were miracles, even though science can explain them: they were miracles of timing. ■

### About the author

**Colin Humphreys** is the Goldsmiths’ Professor of Materials Science at Cambridge University and is the Director of both the Centre for Gallium Nitride and the Rolls-Royce University Technology Centre for Advanced Materials at Cambridge. He is also the Professor of Experimental Physics at the Royal Institution in London. He has been awarded various international and national medals and has published over 500 papers on electron microscopy, semiconductors, metals and superconductors. He is a past-President of the Physics section of the British Association for the Advancement of Science and has been the Institute of Physics Fellow in the Public Understanding of Physics.

### Further reading

Further details of the miracles described in this article, other Exodus miracles, the date of the Exodus, the number of people involved, etc., are given in *The Miracles of Exodus – a Scientist’s Discovery of the Extraordinary Natural Causes of the Biblical Stories* by Colin Humphreys - Harper San Francisco (USA) and Continuum (UK) 2003 (hardback) and 2004 (paperback).



▲ Fig. 4: A pillar of cloud by day, from an erupting volcano