Ancient Oceans and Ice Sheets On Mars

Adapted from a 1998 presentation by Robert G. Strom

Robert G. Strom specializes in planetary geology and has been teaching and doing research at the University of Arizona since 1963. Beginning with the Apollo missions to the Moon, Prof. Strom has been a member of many NASA science teams including the Mariner missions to Venus and Mercury, and the Voyager missions to Jupiter, Saturn, Uranus and Neptune.

His present research interests span the solar system and utilize data from many planetary spacecraft: ancient oceans and ice sheets on Mars; the impact cratering record on solid bodies in the solar system, and the surfacing history of Venus. Along with his current teaching and research duties at the University of Arizona Lunar and Planetary Laboratory, he is also a member of the science team for the proposed Messenger mission to Mercury.

A comparison between Earth and Mars is a good place to start in making the case for ancient oceans and ice sheets on Mars. Mars is about half the size of Earth, and receives about 44 percent as much sunlight. Mars is, of course, further away from the Sun than Earth, and the surface temperatures are very cold, about minus 180° or so on average. Mars' rotation time is similar to Earth, about 24-1/2 hours, and its axis of rotation is tilted at about 25° which is also similar to Earth. So Mars does have seasons, but they are about twice as long as Earth's because its orbit around the Sun is about twice as long.

Surface water, which has implications for life, existed on Mars between half to a billion years ago; in the recent past, geologically speaking. Another provocative item is that Mars is the only planet in the Solar System with features similar to those on Earth. It is very Earth-like in its geology and the distribution of certain land features, some of which we will discuss today.

Another similarity to Earth is that Mars has ice caps, but they are mostly frozen carbon dioxide. Mars' atmospheric pressure is only 7 millibars, a very tenuous atmosphere, made up of over 90 percent carbon dioxide which freezes in the polar regions during the winter. There is also water ice: when the CO_2 ice melts there is a residual ice cap of H_2O. Presently these ice caps are much, much smaller than Earth's, occupying perhaps 2 percent of the surface of the planet.

A mosaic picture of Mars from Viking shows the polar caps, and the one at the south is water ice, not carbon dioxide (figure 2). Color photos reveal an orange-red color which is why we call Mars the "red planet." Why is Mars red? The answer is that it's oxidized, rusted. The reason, just as it is on Earth, is water, and in fact Mars is a water-rich planet. Most of that water is located in its subsurface at the present time, and I'll show you evidence of that. Mars is a planet of extremes; it has the largest channel system in the Solar System, the largest volcanoes and the largest canyons. In this discussion, I'm going to focus on those channels.

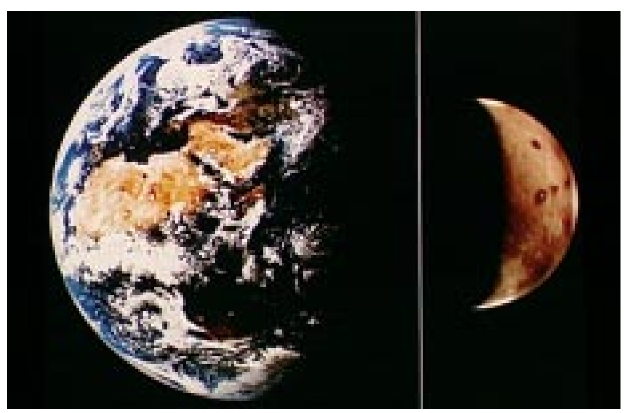

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Figure 1. Mars is about half the size of Earth

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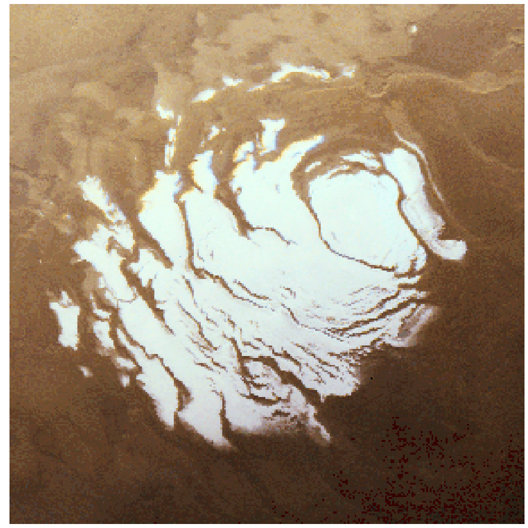

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Figure 2. North (left) and south polar caps. Mostly carbon dioxide, the ice caps are smaller than Earth's, occupying about 2 percent of Mars' surface.

Ancient Mars a Watery Planet

A picture of what Mars may have looked like in the past (figure 3), shows a lot of water in the Northern Plains. The Northern Plains are a lower area on Mars, and they average about 2 km below the heavily cratered highland region. A large canyon system, Valles Marineris, may have been filled with water, and there are layered deposits, sedimentary in origin, that may have been laid down by water. One thing that's missing from the picture is probably a large ice cap. The oceans are the likely source of the water in the ice cap, just as they are on the Earth.

At the present time Mars does not have an ocean, but it may have looked something like figure 3 in the past—this is an artist's rendition, and should be taken with a grain of salt. Mars' atmosphere is now too thin for there to be an ocean, so the presence of oceans—and if there were oceans there were probably ice sheets—in ancient times implies an atmosphere that was quite different. There was a lot more carbon dioxide-which you all know is a greenhouse gas—possibly from 1 bar to 4 bars, enough to allow water to be stable on the surface. Certain features that occur only at high latitudes on Mars resemble glacier features on Earth that only occur at high latitudes. Areas on Mars may have looked something like Earth's Alpine-type glaciers, but its ice sheets probably covered a much larger part of its surface.

Lower areas in the Northern Plains may have been the sites of oceans. One low circular area is Hellas, a large impact crater about 2000 km across, and I'm going to focus on Hellas and Argyre, another impact crater where we think glacial land forms are present (figure 4). In addition to an ocean, the Northern Plains has a very large plateau called the Tharsis Uplift. It is the site of three major volcanoes, and Mons Olympus, the largest mountain in the Solar System, is associated with the plateau. The canyon system, Valles Marineris is yet another feature associated with Tharsis, and to the east is a region of large outflow channels. These outflow channels occur elsewhere on Mars, but there is a concentration of them in this specific region. All of them, almost without exception, discharge into the Northern Plains.

Geologic and topographic maps show that the Northern Plains are about 2 km lower than the average surface; in addition to the Tharsis Uplift, volcanoes and a large canyon system, there are areas called chaotic terrain. This region is the source of the outflow channels, but the source of the water itself is in the subsurface; these are not runoff channels as we know them on Earth. There are different types of channels on Mars. The big ones are outflow channels and are concentrated in one area. Then there are other types of channels

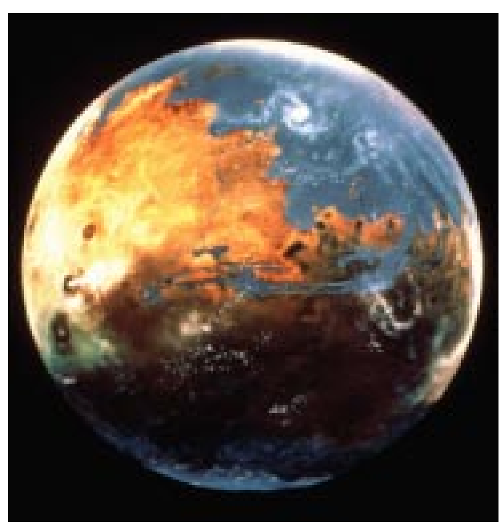

Figure 3. The discovery of possible ancient shorelines suggests to some scientists that the release of water associated with the formation of outflow channels may have led to the temporary formation of oceans as seen in this painting by Michael Carroll.

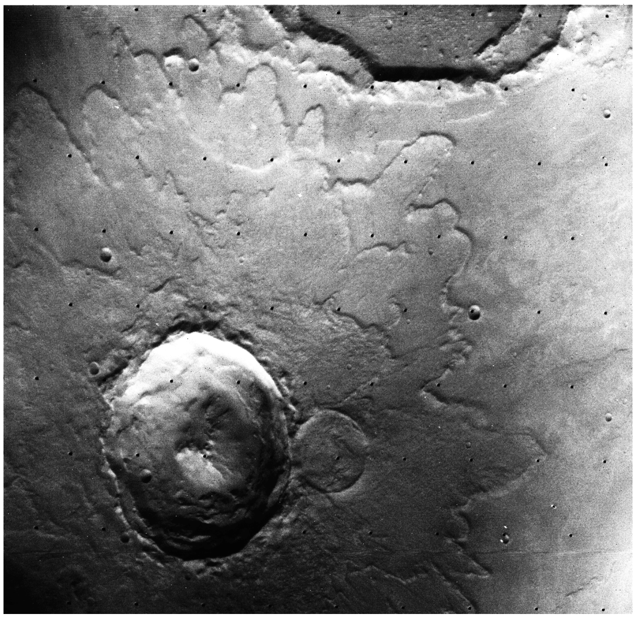

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Figure 5. Yuty crater in Chryse Planitia shows the many overlapping lobes that form when an impacting object rapidly melts ice in the subsurface and the ejected material flows along the surface. The crater is 18 km across.

called valley networks, and also different types of valley networks. Valley networks are located primarily in the highland regions and are due to a process called groundwater sapping.

The Evidence for Subsurface Water

Four main lines of evidence point to subsurface water on Mars. One is flow ejecta deposits around fresh craters. Without exception, every fresh crater that displays an ejecta blanket shows morphology that indicates a flow of this ejecta (figure 5). This is unique in the Solar System, for there's no other planet that shows this type of morphology. It is almost certainly the result of impacts into a subsurface water/ice layer. These flow ejecta deposits are found almost everywhere on Mars' surface, an exception being the summit of Mons Olympus. Here we find ballistic ejecta blankets, very similar to those seen elsewhere in the Solar System.

Mars' unique ejecta blankets are due to impacts penetrating into a subsurface water/ice layer, the mixing of that water with the ejecta, and then flowing out. An impact event would generate heat as well as mechanical energy in excavating a crater; the heat would melt the subsurface ice, and water mixed with ejecta would flow across the planet's surface. Laboratory experiments on Earth demonstrate the same type of ejecta flow in a water-saturated target, but I want to remind you that we see this phenomenon only on Mars.

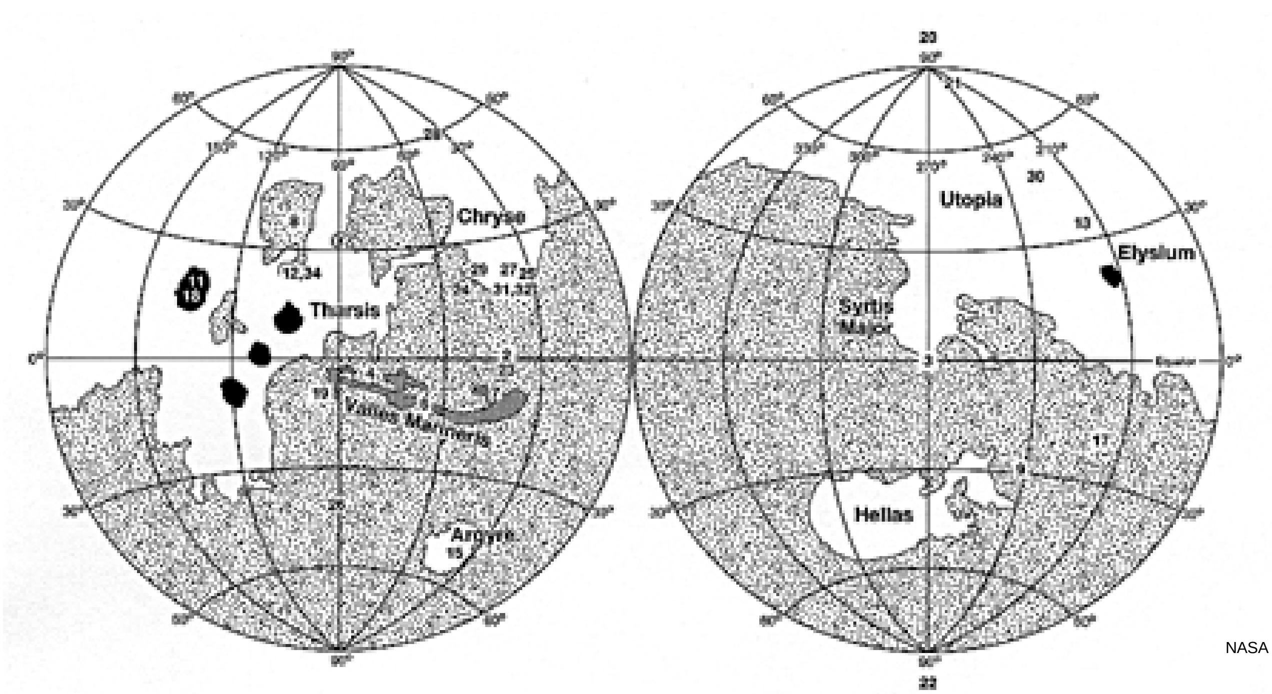

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Figure 4. Map showing approximate location of major topographical features.

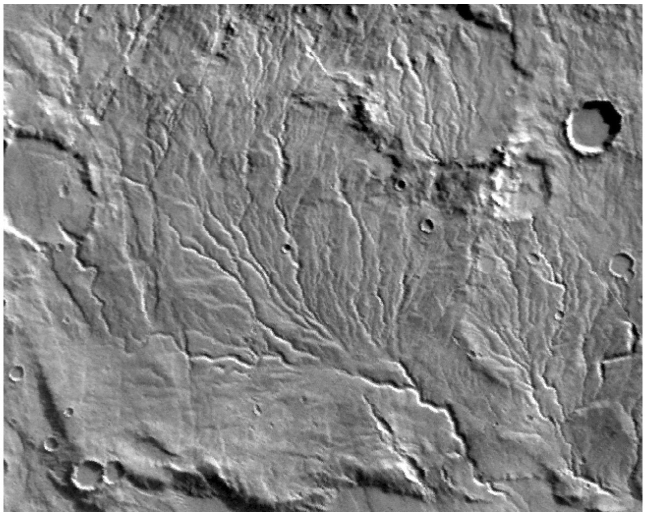

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Figure 6. Valley networks do not show evidence for catastrophic flooding as outflow channels do. It is thought that they were carved primarily by groundwater flow and so bear a closer resemblance to drainage systems on Earth where water acts at slow rates over long periods of time. The area shown is 200 km across.

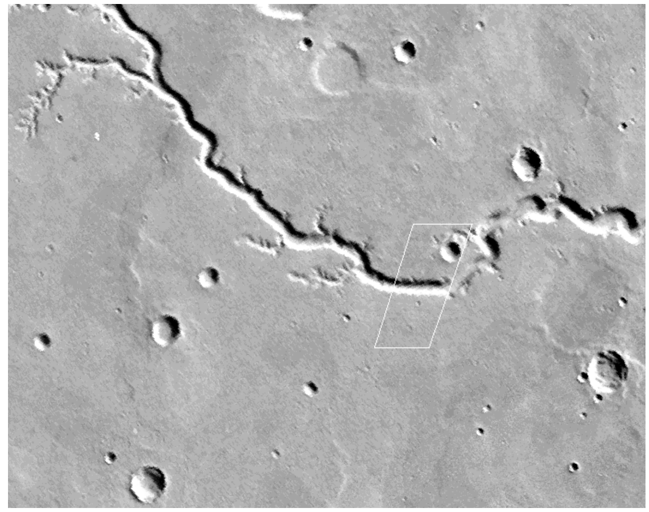

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Figure 7. Valley network. With fewer tributaries than typical terrestrial drainage systems, it is thought that the valleys were carved primarily by groundwater sapping rather than runoff from rain. Water flow in this valley would have been from left to right. This image of Nirgal Vallis was taken by the Mars Global Surveyor from an altitude of 800 km.

In addition to the outflow channels, there are Mars' "valley networks" distributed primarily in the highlands on some volcanoes near the Northern Plains (figure 6). These channels are formed by water in a process called "groundwater sapping."

A view of Valles Marineris shows tributary valleys with blunt ends, what we call amphitheater ends. These are huge things, and for perspective, the Grand Canyon would be a small part of the huge tributary channels to the main canyon. The Earth in the Colorado Plateau has the same type of morphology-amphitheater ends. As groundwater seeps out, it undermines the overlying rock and it collapses to form these amphitheater, blunt-end channels. This is exactly what we see on Mars, and everybody agrees it's due to groundwater sapping. All of this indicates a global distribution of subsurface water, so Mars is, in fact, a water planet—you just can't see it because it's below the surface.

When this was first proposed people didn't understand that there had to be a process to keep the action going. That's a profound statement, because it means that the groundwater table on Mars had to be continually recharged. The way it happens on Earth is simple—it just rains and rains and recharges the groundwater system. How does it happen on Mars? Maybe rain. There's another way of recharge through hydrothermal action, but it's very unlikely to happen on a planet-wide basis, so it may have rained on Mars as well.

The channels of Mars

One view of a valley network (figure 7) shows tributary channels much like runoff channels on Earth, except that they have the blunt ends and a morphology more similar to channels formed by groundwater sapping. These are concentrated in highland regions of Mars. There is another type of channel with one example that looks identical to the Grand Canyon, and another large valley network shows a quite different morphology, more intricate than others. One channel of this enormous network is about 2000 km long-the Grand Canyon isn't even close in size.

Yet another type of valley network is more like that associated with Valles Marineris; these networks are almost certainly due to sapping, and the amphitheater ends are prominent. The evidence for a flow of water is unambiguous—there's a delta at the end of one which indicates deposition in water. You can see other channels on Mars associated with this deltaic form: there's no question that water flowed down the valley onto the plains. There are channels at the boundary to the Northern Plains as well, very fine channels, very small, and there is also a deltaic deposit. The interesting thing about the delta at the end of one channel is that it has a steep scarp at the edge. The only way such a form evolves on the Earth is if a channel flows into water, indicating that the material was probably deposited in a standing body of water, possibly an ocean or at least a large lake.

The other type of channels on Mars, the really big ones, are called outflow channels as we mentioned previously, and they originate from chaotic terrain. Figure 8 shows the chaotic terrain and the channels going off in one direction. The source of the water is in the subsurface, and when that water pours out, the surface collapses inward to form this chaotic terrain. The water flows out into the Northern Plains, and we have views which show a portion of a channel with hydrodynamically-shaped erosional forms. Sometimes craters acted as barriers to the flow; the water flowed around them forming a streamlined shape (figure 9).

A map of the channels shows the chaotic terrain and the large canyon, Valles Marineris; the chaotic terrain shows up as stippled areas and the channels as flow lines. The channel deposits go out from them. To try to put it in perspective, just a portion of the channel deposits would have completely inundated Arizona and many adjoining states. That will give you an idea of the magnitude of the flow that must have issued through those channels. All of that water was dumped into Mars' Northern Plains.

NASA/LPI

Figure 8. Outflow channels emptying in to the Northern Plains of Chryse Planitia. Channels flowing out of chaotic terrain with abrupt beginnings and no tributaries suggest that the water that carved them was released under great pressure from underground.

Below, closeup of outflow channel originating from chaotic terrain. In outburst flooding the enormous discharge from the collapsing aquifer results in chaotic terrain.

NASA/JPL/MSSS

Water discharge a "Biblical event"

Consider what that means as far as discharge rates were concerned. You can estimate them from the shape of the channels, their depth and their slope. The estimated discharge rate in this case was enormous, and the estimated discharge rate from the outflow channels in cubic meters per second, not per minute or day or hour, was something like 1-10 billion; 10 billion is probably more realistic. Now for comparison, the discharge from the seven largest rivers on the Earth, the Amazon, Congo, Yangtze and so on, is only 370 thousand. In other words, the estimated discharge rate on Mars was about 3,000 to 30,000 times greater than the combined rate of Earth's seven largest rivers. This was not due to rainfall; this water is all disgorged from a large subsurface reservoir in a catastrophic event. The trigger was probably volcanism, and I'll return to that later.

What does this mean for the size of the Northern Plains ocean? We don't know exactly how big it was, but we can make estimates based on the contours. Zero contour would be similar to sea level on Earth, although there is no sea level on Mars. There are -1 to -2 km contours up in the Northern Plains. At the zero contour, the depth of the water would be about 1.7 km, and the equivalent amount of water would cover the entire planet to a depth of about 450 m. In other words, if you could spread that water uniformly around a flat Mars, it would cover the entire planet to about 450 m. The -1 contour would be about 1.1 km deep, -2 to about 0.7 km and so forth.

If you can estimate the discharge rate, you can also estimate the time it took to fill the Northern Plains. Based on the contours, the filling rate would be 1 billion at the bare minimum, and 10 billion would be the more realistic. At the zero contour interval filling would take about 11 weeks;

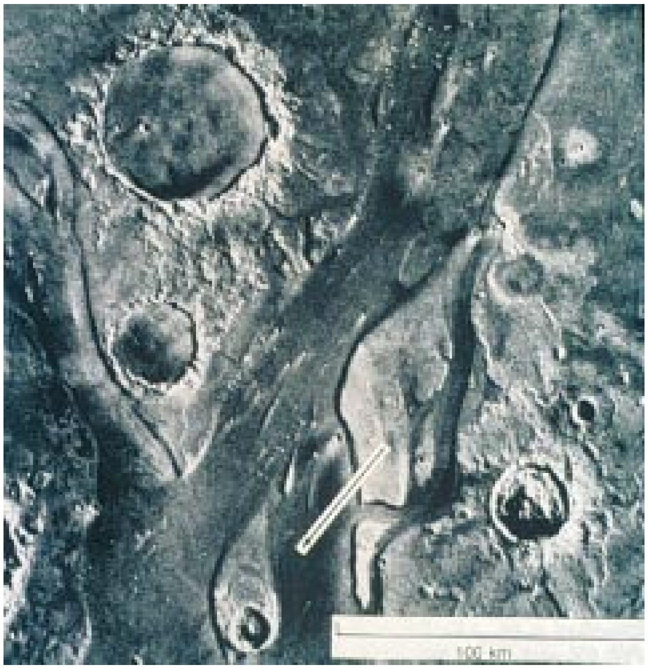

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Figure 9. Craters and other landforms were obstacles to powerful floods and consequently experienced modification as water was channeled around them. Flow ejecta can again be seen around the crater to the right.

at -1 it would take five weeks, and at -2 it would be ten days. It was a truly biblical event; remember these discharge rates are the bare minimums and probably unrealistically low. Filling could have taken anywhere from 11 weeks to ten days. It was a catastrophic release of water, huge walls of water, and there has been nothing comparable on Earth.

A drawing of the probable size of the ocean shows a line that has been interpreted to be a shoreline. It was proposed by two groups of people, one at the USGS in Flagstaff, the other at the JPL in Pasadena. A second line has also been interpreted as a shoreline; in other words there were probably at least two oceans at different times, a large one earlier and a smaller one later. They may also have been episodic; at different times in Mars' past there may have been large outflows that formed oceans of various sizes. There's good evidence, based on the crater density, that these channels did experience multiple episodes of flooding.

Ice sheets on Mars

Now I want to talk about the other side of the coin, ice sheets on Mars and the evidence for them. When you look at features in the southern hemisphere at 45 degrees latitude, you see floor features and some sinuous ridges which we'll explore in detail. There's a large impact crater called Argyre, about 1000 km in diameter; the interesting thing is that the southern rim has a morphology that is very different from the northern rim, indicating that some process has affected the southern rim and not the northern. This, in a nutshell, is the glacial geomorphic associations that we think we see on Mars. These are totally different land patterns that are all traceable to glaciers, and we think we recognize them in Argyre. There are more of these patterns east of Hellas, more in Hellas and in the Northern Plains. There were probably two ice sheets, one in the north and one in the south.

Back on Earth, the Wentworth Glacier in Alaska shows landforms that have analogues on Mars. The glacier has striations and scours which are called fluted drifts. They are scours on a glacial deposit called a ground moraine, and are caused by the movement of the glacier. Another feature is a ridge which is called an esker; it is due to the flow of water underneath the glacier. This flow when the glacier retreats leaves a ridge because sediment is packed up around the sides and floor of the glacier.

An outwash plain includes holes filled with muddy water which are called kettles. Kettles form as the glacier retreats, leaving behind chunks of ice buried in the ground moraine. When that ice melts the holes are filled, on Earth, by lakes. You've all heard of the land of 10,000 lakes in Minnesota; it's actually the land of 10,000 kettles, all from the last ice age, the Pleistocene. Finally, there is a ground moraine, a mound-shaped sediment deposit left behind by a glacier as it recedes. There are various types of moraines, but that's Geomorphology 101.

A high-resolution picture of the sinuous ridges in Argyre shows what we think are eskers (figure 10). They have a geometry which is identical to eskers on Earth, and their sizes are not too dissimilar. The surrounding mountains have extremely sharp crests which may be what are called arètes caused by glaciation; they are very common in the Alps. The northern rim of the Argyre crater is very rounded and subdued compared to the southern rim. There's quite a difference in morphology, so something has shaped the southern rim that has not acted to the north, which is at lower latitudes. We think the thing that did the shaping was ice.

Most people in the planetary community believe they see rock glaciers in the photos. These are just sloughing off of the mountains and slowly creeping down onto the plains. Rock glaciers also occur on Earth, usually associated with glaciation areas, and a lot of them have recently been cored. To the surprise of everybody the cores of these rock glaciers are ice. Are the cores of those on Mars ice as well? Maybe.

A detail of some of those sinuous ridges shows an interesting thing: they often anastomose—divide and join again. This is characteristic of eskers and is very difficult

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Figure 10. These sinuous ridges in Argyre may be glacial landforms known as eskers. (Arrow does not indicate eskers.)

to explain by anything other than flowing water. It is uncharacteristic of sand dunes: they don't anastomose. Hydrodynamic processes do anastomose on Earth and, presumably, also on Mars. These ridges were laid down by water, but they're high. The best explanation we've got is that these are, in fact, eskers. Along the top there's a trough, and this is also characteristic of eskers on the Earth.

Let's compare the geometry of some sinuous ridges on Mars, those in Argyre, with the pattern of eskers on Earth. In fact you can quantify this to a degree by measuring the amplitude of the meanders against the wavelength. When you do this for Earth eskers and for Martian sinuous ridges, you find they're identical.

Another feature which is very interesting are little mounds with a crater at the top. What are these things? They're certainly not volcanoes, but they may be pingos, another glacial feature. Pingos are very common in the arctic regions of Earth. The ground ice expands and forms domes on the surface; the centers then collapse into craters. Mars may have pingos, ground ice residuals from past glaciation.

Outwash plains from water flow

I mentioned outwash plains and there are some in Argyre. There is an impact crater that has been breached, and one can see the hydrodynamic bed forms that are certainly due to the flow of water. Where did the water come from? Everything points back accusingly to the large crater. It was probably filled by part of a glacial ice sheet that melted, and the melt water flowed out of the breach. There's no chaotic terrain in the crater, and perhaps meltwater from an ice sheet flowed out and kept going to form a visible hydrodynamic bedform, the Martian equivalent of an outwash plain. There is a terrestrial example in Iceland, an outwash plain with kettles.

The distribution of the various Martian features that we interpret as glacial are an arète area, eskers, scoured terrain, a kettle field, and the outwash plain. These occur in an ordered sequence as eskers, scoured terrain and kettles; a similar sequence occurs on glacial terrain on Earth.

The Hellas Basin on Mars is over 2,000 km across, and the topographic contours are from 4 to -5, so it is a deep area. There's a huge difference between maximum and minimum elevation, so it's very steep in some regions. If you superimpose on that some features that we see in Hellas, you detect scours, grooves cut in. The steepest part is more scoured than down below, and there are ridges which may be eskers, are there are channels. There are teardrop-shaped mounds which may be like drumlins on Earth—shaping the moraine by movement of the ice. There

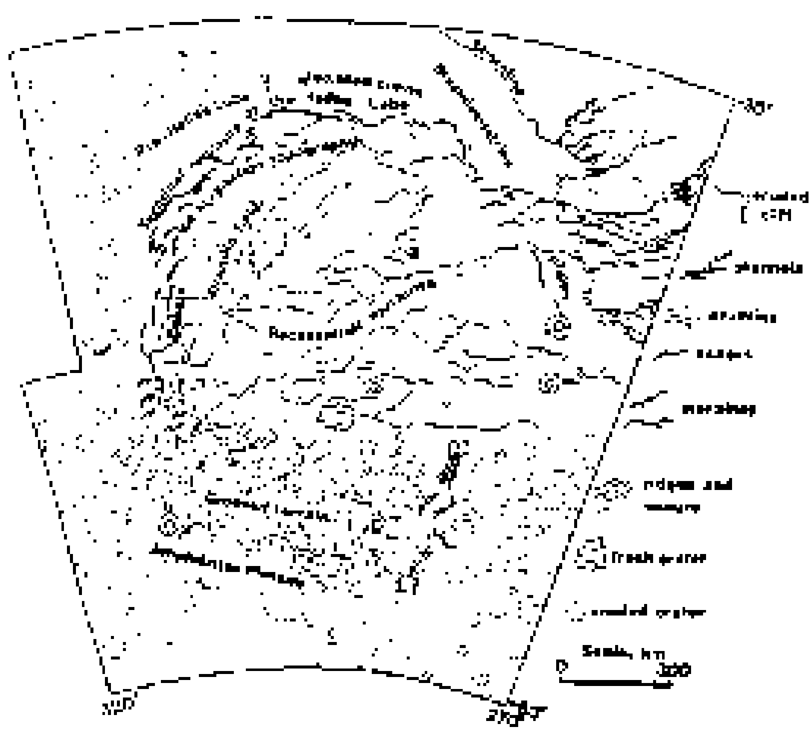

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Figure 11. A geomorphic map of Hellas showing the sequence of glacial features.

is an area which was probably a proglacier lake, and ridges which we think are terminal moraines. So there's a whole ordered sequence of geomorphic forms which are identical to glacial forms on the Earth, and which have the same ordered sequence (figure 11).

You can construct a drawing of the way a glacier might have flowed on Mars showing the terminal moraine and what would be called a proglacier lake on Earth. It would be enormous, not a glacier, but an ice sheet. One can see a dark line that would have been the northern limit; we don't know what most of the forms are at the south pole because we don't have high resolution imaging of this area yet; perhaps Global Surveyor will fill that in. Given the extent of the ice sheet in the southern hemisphere, however, it would have covered 10 to 20 percent of the surface of Mars. We think the source of the ice was the ocean, as on Earth. These events can be dated on a relative time scale by the distribution of craters on these glacial plains and also in the ocean. The relative dates of the features on the glacial plains and in the oceans are the same.

I want to go for a minute to the northern hemisphere. Dark areas seen there may be glacial forms, and there is the possible ocean and a series of channels in the Northern Plains. The complexity of these channels makes them very unlike rainwater channels or sapping channels on Earth or Mars. They have ridges down the center, and we think they are what's called tunnel valleys, also a glacial land form. A picture of a tunnel valley in Sweden, filled with water and with an esker down the center, is similar. We think that's what we're seeing on Mars—tunnel valleys with eskers down the center. Next to these features are ridges, fairly closely spaced, and it's likely they are the moraines.

Moraines point to ocean site

I'm not a glacial geomorphologist and neither are my coauthors, so we called in an expert. Some of our interpretations of the glacial features on Mars are controversial, but when we showed him these pictures, which we thought were moraines, he said they were not only moraines, but *De Geer moraines!* De Geer moraines are formed in water when a glacier flows into a lake or ocean. Remember, this is the Northern Plains, so what have you got? Perhaps the site of an ocean. It was a blockbuster of a discovery.

A map of that region shows the possible De Geer moraines and the tunnel valleys. This is in just one area in the Northern Plains, but wherever you see this type of valley, you always see ridges in the center of them, and you always see these types of moraines. Their morphologies are similar to those on Earth. A region of tunnel valleys up in Canada from the last ice age shows an intricate pattern very similar to what we think are tunnel channels on Mars.

Some researchers, Henry Moore and others from the Pathfinder team, believe they've identified conglomerates on Mars. Some rocks may show numerous sockets where pebbles resided, protrusions which look very round, and other cobble-like things that may have fallen out of the sockets. A conglomerate is made up of rounded pebbles,

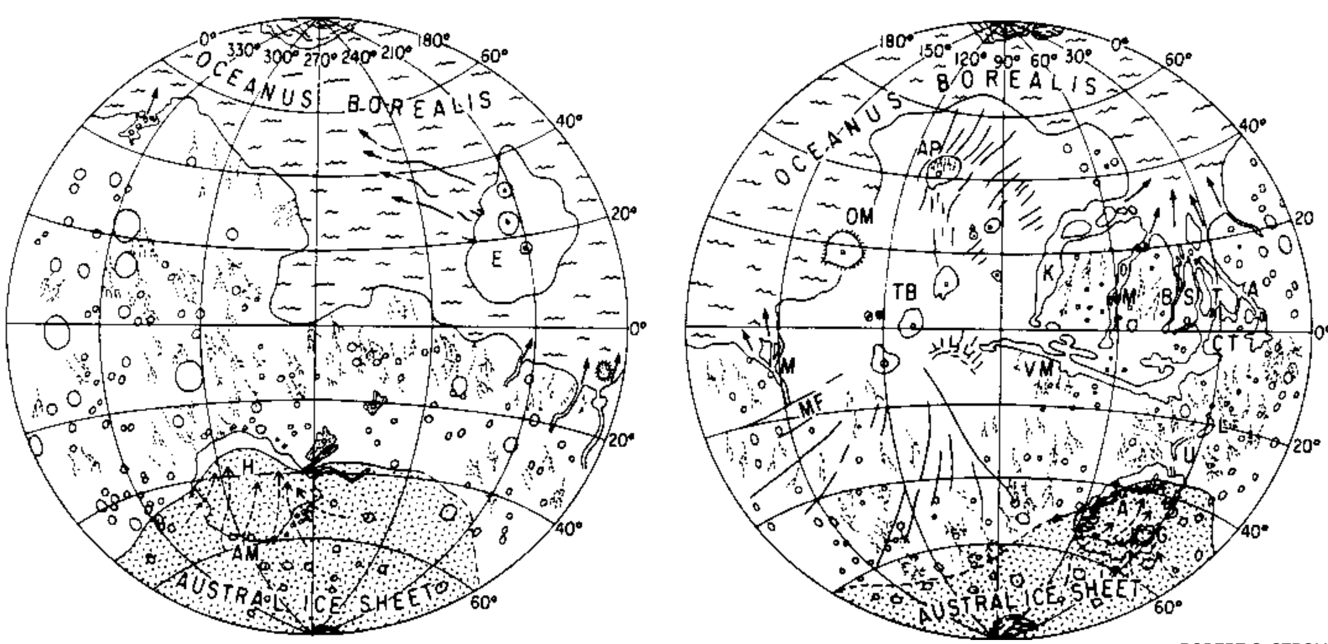

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Figure 12. Maps of Mars showing the past extent of the Northern Plains covered by ocean, the austral ice sheet, flow directions of outflow channels (arrows), and glacial landforms (dashed arrows). The dashed lines indicate the general pattern of valley networks.

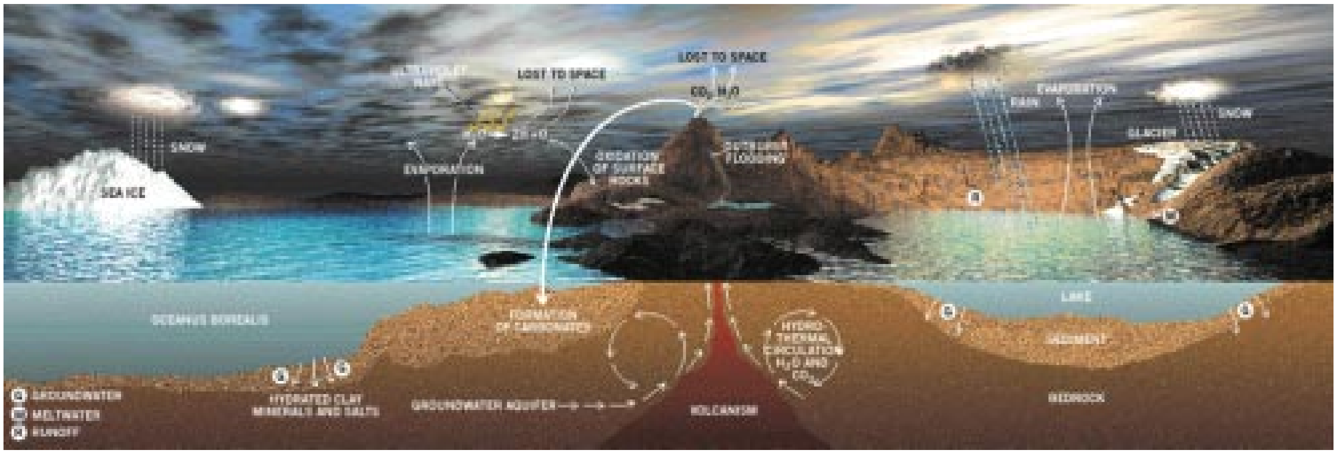


Figure 13. Model of the water cycling mechanism which may have formed oceans and ice sheets on Mars. Volcanism and resulting heat flow caused hydrothermal circulation of groundwater and triggered outburst flooding of water and carbon dioxide. The resulting water vapor and CO_2 in the atmosphere would have precipitated to form snow, glaciers and ice sheets at high latitudes, and rain at lower latitudes that recharged the aquifer. (Illustration from "Global Climatic Change on Mars," by Jeffrey S. Kargel and Robert G. Strom. Copyright ©1996 by Scientific American, Inc. All rights reserved.)

and that rounding can be due to one of two things: one is the flow of water. You could get a conglomerate of these rounded pebbles due to stream action, and remember these are at the mouth of an outflow channel.

The other way rounded pebbles are formed is by glaciation—and you can form glacial conglomerates as well. Where do these rocks come from? They were probably washed down from the highlands. One guess is that they were formed in the highlands' valley networks by stream action, which means that there had to be running water on Mars. You don't have that today, so that would mean the atmosphere was different. Or conglomerates may have been formed by glacial action.

A drawing of what we think Mars looked like during one of these wet and warmer epochs with the ice sheet helps sum up (figure 12). It shows the Austral ice sheet, and there was probably a second that produced those northern features. We're calling one of the oceans Oceanus Borealis, the northern ocean. It filled primarily the Northern Plains, and we can see the outflow channels which produced that hypothetical ocean. There are little lines marking valley networks where there has been some fluvial action.

Outburst flooding triggered by volcanic activity?

I've been describing the model that we're proposing, and remember that all of this may have been episodic. Mars' features are ephemeral, they come and go depending upon mechanisms like the outflow channels. The model appeared in the November 1996 *Scientific American*. It is a model of the mechanism by which we think the oceans and ice sheets formed (figure 13). We think that it was triggered by volcanic activity: the volcanism came up in the subsurface and reacted with the groundwater. What happened when hot lava came in contact with groundwater? It started boiling, and that may have led to the outburst flooding.

There's also a geophysical model that says that mantle overturn could have resulted in episodic volcanism extremely intense and regional in nature, and that it may have been the trigger. Episodically it would have lead to outburst flooding, produced oceans, and evaporated them. At the same time this stuff came out, probably what came with it was CO_2. In other words, it may have been more like a soda than like the water we know on Earth. If that was the case, a lot of CO_2 was released into the atmosphere; some models predict that there could have been from one to four bars of CO_2 released by this process. That would warm the atmosphere so you could have had standing bodies of water, but it would still be cold, so there might have been evaporation of H_2O. It might have rained, in fact, in low latitudes; snowed in high latitudes to produce ice sheets in both polar regions. Eventually, the precipitation would have seeped into the ground to become groundwater again.

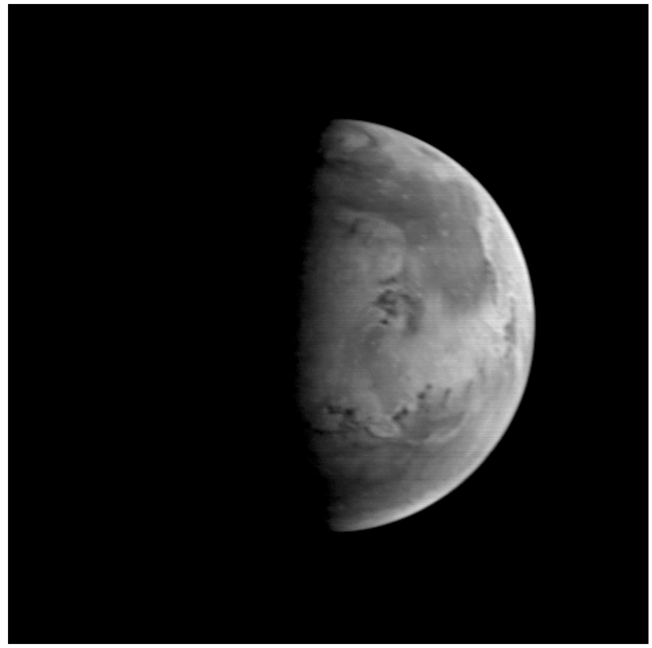
A short synopsis of the evidence shows that there are diverse features at high latitudes. By high we mean greater than +/- 35 degrees from the equator. These features have morphologies, geometries, scales and ordered distribution. They're virtually identical to glacial features formed on Earth during the Pleistocene ice age. Second, there are shorelines and other marine features that have been identified, not just by us, but by others, particularly the USGS and JPL. They occur at the margins of the Northern Plains which suggests that there was a shoreline and in fact an ocean there.

The ice sheets probably covered about 25 percent of Mars, and the oceans probably filled the Northern Plains relatively late in Martian history; we don't know how late, but perhaps a billion to 200 million years ago. All of this may have been episodic. Climatic conditions during these times had to have been vastly different than they are today: denser atmosphere and temperatures high enough to allow liquid water to exist on the surface of Mars.

The water originated in the subsurface—that's important. It was not rainwater. It existed in the subsurface, and it may have been released in catastrophic flooding caused by volcanism heating that water. There's no question that there were large amounts of water released catastrophically. A little of this water was lost to space, maybe 5-10 percent, but the rest probably still exists, residing in the subsurface.

How did the water get to the subsurface? Mars is heavily cratered, and when you form craters you fracture the surface, so that surface is probably very porous and permeable. As a consequence it's likely the ocean didn't last very long; in fact we'd have trouble explaining what we see today if it lasted for many millions of years. There would have been so much erosion that we wouldn't see any craters. The water resided on the surface for a length of time we're not sure of, and then disappeared, probably into the subsurface.

There's some recent evidence for this: one piece is the conglomerates from Pathfinder that I mentioned, and another is an extremely flat Northern Plains. This information came from the Global Surveyor within the past couple months. They did a profile through the Northern Plains and up onto a volcano, and got excited about the volcano and the implications for a flat Northern Plains. The surprise is that they are extremely flat, flatter than any surface anywhere in the Solar System except some places on Earth. A flat surface, like Lake Bonneville, is produced by sedimentation from standing bodies of water. This very



NASA/JPL

The Mars Orbital Camera took this picture in August 1997, when the Mars Global Surveyor was 3.52 million miles away. Immediately to the south of the large dark marking stretching from the right center, is the brighter area of Chryse Planitia. Many outflow channels are located here, as well as the Viking Lander I and Pathfinder landing sites. New images and data from the Global Surveyor will greatly contribute to the identification of water- and ice-formed features on Mars.

flat surface that we found on the Northern Plains is further evidence that they were caused by sedimentary deposits laid down by a large body of water.

That's the evidence; some of it, not all of it. We think it is very exciting, but I must say it is still controversial because it paints a picture of Mars that is completely different from the one we had ten years ago. But our picture has great implications for life: if life started on Mars we can gain insight as to its origins, and begin to answer the basic questions that we've been asking for hundreds of years. How did life originate? To understand life on Earth, go to Mars.