Mars: Mars has witnessed climate change over its history.

A CRATERED PAST:

Like Earth, Mars accreted from other bodies in the solar system into "plantesimal" size about 4.6 billion years ago. For the succeeding half billion years, the solar system body was pummeled intensely by bollides – asteroids and comets – growing with each impact. Accretionary heat – heat from bodies slamming into one another, and probably radioactive heat from radioactive isotopes within the rocks, allowed elements to combine and segregate – heavier ones sinking toward the planet's center.

SEGREGATION OF A SOLID CORE AND A LIQUID CORE:

MAGNETIC FIELD, PLATE TECTONICS, ACCUMULATED ATMOSPHERE, & WATER TOO:

Like the Earth, Mars probably developed a solid core, surrounded by a liquid core. Rotation of the planet combined with dynamics resulting from the liquid core crystallizing slowly and accreting onto the outer core, led to a magnetic field on Mars – one created by a geodynamo effect. This magnetic field, like Earth's, acted as a shield against solar wind. The planet's internal heat perhaps led to plate tectonic activity and volcanic activity. Large impacts also prompted volcanic emissions. These internal "belches" provided gases to Mars's atmosphere. The magnetic field prevented the solar wind from stripping this accumulating atmosphere away. Impacting bollides had a dual effect on the atmosphere. They provided some volatiles; comets have been considered a likely source for some of the original water on both Earth and Mars. Impacts also could have propelled many volatiles out to space, especially in light of Mars's weak gravitational pull – 3/8ths that of Earth's.

ATMOSPHERE AND WATER:

It can be seen that during the first half billion years of Mars's existence, it developed an atmosphere filled with carbon dioxide, sulfur oxides, water, and other volatiles. The Sun's output 4.0 billion years ago was only 30% of the output today; yet greenhouse gas quantities were apparently great enough to have allowed for a climate warmer than today's. Physical and geochemical signatures evidence a warmer climate. It has been inferred from dendritic drainage patterns on Mars's surface that liquid water readily flowed on the surface. The age of the land surface over which most of this drainage is observed has been determined by extrapolating information from the types of features crossed. Most of the features criss-crossed by these drainage patterns are craters – ones determined to be ancient, on the order of 4.0 billion years or older. The type of drainage suggests that the flow was gradual. Erosion rates during that period on Mars are estimated to have been one thousand times the rate of today, similar to erosion occurring in the arid regions on Earth.

A COOLED PLANET – LOSS OF MAGNETIC FIELD, ATMOSPHERE, AND LIQUID WATER:

A channel whose cross-section is a V indicates cutting by water. A channel whose cross-section is a U indicates cutting by ice. U-shaped valleys, determined to be about 4.0 billion years old, imply that the climate on Mars at this time began to cool dramatically. Evidence for a magnetic field in rocks younger than 3.9 to 4.0 billion years old has not been detected. From these pieces of the puzzle, scientists surmise that at this critical time for the small planet – whose radius is one-half that of Earth's – the magnetic field shut down. This was likely as a result of geothermal heat dissipating rapidly due to the small size of the planet. This cooling and cessation of a magnetic field, indicates that the outer core of the planet had likely solidified at this point. With no magnetic field to shield the atmosphere from the ever-impinging solar wind, the wind hit with a vengeance, stripping volatiles from the fragile atmosphere. This scenario finds support in the observation that Mars's atmosphere is comprised by an unusually high percentage of heavy isotopes of the volatiles within its atmosphere. We know this from spectroscopic analysis of the atmosphere and from direct testing of gases contained within meteorites that have been found on Earth that are known (from the isotopic profile) to have originated from Mars. (All of this can be found in earlier units in this series.) Solar wind would preferentially pluck out the lighter isotopes over the heavier ones. Had the atmosphere thinned mostly as a result of bollide impact, the stripping of isotopes within the atmosphere would be indiscriminate. Both processes undoubtedly occurred, but it seems that the solar wind stripping wielded the dominant influence, especially after 4.0 billion years ago. The process of stripping peaked about 3.9 billion years ago.

With a thinned atmosphere, less heat could be contained within the atmosphere. Mars rapidly became a cold and dry place. With impact frequency decreasing, especially of the really large impacting bodies, any volcanic belching of volatiles that occurred as a consequence of the cratering decreased, as well.

Atmospheric remnants tucked into reservoirs:

The remaining volatiles have been distributed among a few known reservoirs. Still some remain in the atmosphere – a thin atmosphere with a mass only 1.3% that of Earth's. Some likely reside in the lithosphere – some as permafrost, some incorporated into minerals within the crust. Some in the polar icecaps.

Ground water likely carried some water through the cracks and fissures of the ground, combining with other elements, creating carbonate-based minerals that have been seen deposited in cracks within some Martian meteorites. The famous Mars meteorite, ALH84001 – the one mentioned in an earlier unit that convinced many, rightly or wrongly, of the existence of Mars bacteria – contains trace deposits of carbonate. Ages of these carbonates are 3.9 billion years old. Not all of this activity is ancient. One meteorite contains minerals produced by the weathering of olivine, a mineral common in basalt. The mineral, known as iddingsite, is found in a 650 million-year-old meteorite by the name of the Lafayette meteorite.

Signs of "recent" liquid water activity:

Surface evidence points to more recent liquid water activity. Gullies, assumed to be carved by water or water-filled debris, cross sand dunes whose age is interpreted to be only a few million years old. Lake sedimentary features within craters suggest former crater lakes – again not ancient. Channels that reflect catastrophic type flooding align south to north, likely draining from the high terrain in the Southern Hemisphere (which is about five to six kilometers (~3 – 3.7 miles) higher than the Northern Hemisphere) to the lowlands of the Northern Hemisphere.

The polar icecaps of Mars:

The polar icecaps likely contain both carbon dioxide and water – both in the frozen state.

Current climatic conditions are asymmetric across the hemispheres of Mars. This results in differences between the polar icecaps. The northern icecap is small. In the northern winter, the icecap grows slightly. It grows as a result of carbon dioxide precipitating as frost onto the permanent icecap. During the boreal summer, the carbon dioxide sublimates (evaporates from a solid to a gas), leaving behind the residual permanent frozen water icecap. This icecap is perhaps one-eighth the size of the southern icecap.

A year in the life of an icecap on Mars:

The southern icecap is covered with frozen carbon dioxide year round. It is assumed that water ice and dust exist under the solid carbon dioxide veneer. The Southern Hemisphere experiences a much longer and colder winter than the Northern Hemisphere does because of orbital parameters and terrain differences. Summer at the Southern Hemisphere is hotter, but very short. As a consequence of this much colder winter, and shorter summer, the amount of accumulated solid carbon dioxide is greater in the south than in the north and it never completely sublimates during a Southern Hemisphere's summer.

During a hemisphere's summer, the elevation of the icecap experiencing summer reduces by 1.5 to 2.0 meters (~5 to 6 feet). It is assumed that the sublimated carbon dioxide is carried to the opposing hemisphere and deposited on the pole there. Throughout a year, Mars exchanges up to one-third of its atmospheric carbon dioxide with the surface. The seasonal re-distribution is substantial. Its effect on the atmospheric pressure is measurable. With the seasonal re-distribution of volatiles comes the seasonal fluctuation in atmosphere. But something more than seasonal sublimation seems to be taking place.

Evidence of climatic change:

Scientists, Malin et al '01, have determined through measurements that the southern icecap is eroding rapidly. Projections indicate that the southern icecap could be completely eroded within a few thousand Martian years. This finding is not typical of the past. It seems that even though the solid carbon dioxide reservoir persists throughout the year in the south, it is not in equilibrium with the overlying atmosphere. It is unknown where the sublimated CO_2 is going. Guesses include absorption into the regolith (the weathered upper portion of the bedrock) or precipitation somewhere other than the northern icecap. Some is being deposited there, but not enough to account for that being lost from the southern cap. If the excess resides within the atmosphere, this excess CO_2 could increase the mass of the Martian atmosphere by one percent per Martian decade. It appears climate change is occurring on Mars too. (Note: Mars' atmosphere is 95% CO2; this is the same percentage of CO2 as comprises Venus' atmosphere. Venus is over 460°C; Mars' surface temperature varies between -135°C and 30°C. The difference in the radiative forcing capacity lies in the difference in the densities between the two atmospheres.)

Factors influencing climate on Mars are complex – perhaps not as complex as on Earth, but complex nevertheless.

The influence of terrain:

The surface of the Northern Hemisphere is smooth and relatively devoid of craters. The Southern Hemisphere, unlike its northern counterpart, is heavily cratered. Terrain in the southern region is higher, on average five to six kilometers (~ 3 – 3.7 miles) higher than terrain north of the equator. This difference in elevation leads to differences in atmospheric pressure over the two regions. In the Southern Hemisphere, where terrain is high, atmospheric pressure is correspondingly lower. Temperatures are not as high. The difference in terrain also works with orbital parameters to affect atmospheric circulation, and therefore, transport of dust and volatiles.

The influence of orbital parameters:

Mars' orbit endures cyclical changes in its shape, just as Earth's does. Like Earth's orbit, Mars's orbit is eccentric, just more so. Earth's orbit is close to its least elliptical shape – less than 2%, where 0% is circular. Mars's orbit is over 9%. Earth's maximum degree of ellipticity is 6%.

The tilt of Mars' axis is slightly greater than that of Earth's. Earth's is currently at 23.47°; Mars' is tilted at 25.1°. The tilt of Mars is far more variable than Earth's – anywhere from 0° to 60°, in most recent times, between 15° and 40°.

Earth currently finds itself near perihelion when it experiences austral summer (in early January); Mars, too, experiences its austral summer when near perihelion. When at perihelion, Mars is 20% closer to the Sun than it is when at aphelion – a difference far greater than in Earth's case. In the cases of both planets, the austral summers are shorter than the boreal summers due to this position at perihelion – Earth's slightly so; Mars extremely so. Because a Mars year is 687 days versus Earth's 365 days, seasons are longer on Mars. The austral winter, when Mars is at aphelion, is particularly lengthy. For this reason, the Southern Hemisphere of Mars experiences a far colder and longer winter than its northern counterpart.

Summer in Mars' Southern Hemisphere is far warmer than summer in its Northern Hemisphere. In fact, insolation during the Southern Hemisphere's summer is as much as 44% higher than the insolation during the Northern Hemisphere's summer. But that intensely hot season is not long enough to have a significant impact on the southern icecap.

The orbital parameters of Mars have varied cyclically much like Earth's, only to a more extreme extent. From this recognition, many now believe that climate change on Mars is part of an ongoing pattern. Variations in orbital parameters may be THE reason for this planetary climate change, perhaps there are other reasons. Noting that changes are occurring on Pluto, Jupiter, and Triton, a moon of Neptune, perhaps there is a more unifying feature. Variability in solar output might be worthy of investigating, but remains an unknown at this point.

Hadley cell convection – not as simple as I told you it was:

Scientists have noted that climate dynamics are asymmetrical on Mars. Mars has a Hadley cell atmospheric circulation as does Earth. The Hadley cell ascends from the location over which the noonday Sun is positioned – on Earth, over the equator during equinoxes. On Earth, the "textbook Hadley" ascends from this point during the equinoxes. But, it is not always this neat and tidy. During the solstices, the pattern reorganizes.

During Earth's boreal winter, when the Sun is over the southern subtropics, the Hadley circulation is dominated by one cell instead of two; this cell ascends south of the equator and descends in the northern subtropics. The reverse is true in the boreal summer. This shift and rearrangement of the Hadley circulation is often dismissed in general discussions of atmospheric circulation on Earth because the resulting asymmetry spawns only minor climatic differences.

On Mars, the extreme eccentricity of orbit, the greater tilt, the longer seasons, and the asymmetrical terrain in the two hemispheres combine to create an intensified single Hadley cell that transports dust and gases between the hemispheres. In the austral summer, when Mars is 20% closer to the Sun than in the winter, the heating is short-lived but intense. The Hadley cell is very strong. Its winds likely transport vast quantities of dust and gases from the southern region to the northern region. This transport of dust and gases from one hemisphere to the other adds to the already existent asymmetry, and complicate interpretation of geologic features. (Nature vol 426, 3/21/02, p298-300) Whether this asymmetry plays a role in the "disappearing" carbon dioxide is unknown. Perhaps it adds positive feedback responses to other parameters that are less fixed than these are. Much research lies ahead.

The future of discovery:

With the discovery of Martian meteorites, our ability to analyze them, and with the refined measuring capacities of the Mars Orbiter Laser Altimeter (MOLA) and Doppler tracking devices, scientists will be provided with plenty of evidence to decipher and interpret for years to come. The challenge ahead for all scientists within the earth sciences field is to understand our planet, and our neighboring planets, past and present. Only then will an understanding for a possible future develop with accuracy and perspective. (Nature, vol 412, 7/12/01, p 214-253; Science, vol 294, 5549.p 2146, Malin et al. '01; Sc. Vol 294, p2141, Smith; Nature, vol 416, 3/21/02, p269 -270)