NEARBY WORLDS

CHAPTER TWO

Five billion years ago, a dark, formless nebula—a hundred million cubic light-years of diffuse gas and dust—floated within the Milky Way Galaxy's graceful spiral arms. The vast cloud was one of thousands that populated the galaxy. While some of these dispersed, others would undergo an impressive transformation, a metamorphosis that was to be the fate of this particular cloud.

Barely perceptible at first, a pocket of the cloud began to contract, perhaps recoiling from the shock wave produced by a nearby supernova—the violent death of a massive star—or possibly as the result of a merging of several clouds. Whatever triggered it, the density of the collapsing region escalated when the contraction started; atoms once comfortably separated were jostled more vigorously, generating heat. In less than 100,000 years, nebular material at least a million times the Earth's mass had collected in a zone several times wider than the present orbit of Pluto, the most remote of the sun's planets. At its heart, a seething ball of hot gas, stoked by the crushing pressure of the infalling matter, reached the ignition point for nuclear reactions: the sun was born.

Meanwhile, the cloud material in the zone surrounding the primal sun had swirled into a disc, like a miniature spiral galaxy, called the solar nebula. The disc shape emerged because whatever internal motion the original cloud had was amplified during the contraction, just as a figure skater accelerates a spin by drawing in his or her arms. The process pulled much of the infalling material into the disc. Within the nebula, atoms and molecules, now swimming at closer range than in the near-vacuum conditions of the initial cloud, began to combine into larger particles in somewhat the same way that ice crystals—the precursors of rain or snow—form in the upper atmosphere when air becomes saturated with water molecules.

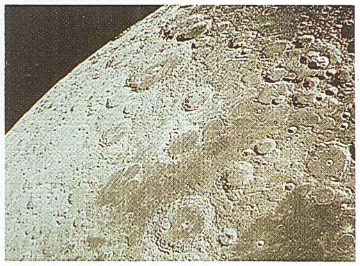
The source cloud contained abundant hydrogen and helium, lots of oxygen, nitrogen, carbon and neon, moderate quantities of magnesium, silicon, iron and sulphur and lesser amounts of all the other elements. The crucial point is that the youthful sun heated the solar nebula, leaving only solid particles of elements that did not melt. The particles combined like adhering snowflakes over the next few million years, eventually accumulating into larger and larger bodies: planets, moons, asteroids and comets. Their compositions varied depending on their distance from the sun. A bull's-eye pattern emerged. Closer in, rocks and metals survived while almost everything else vaporized and ultimately dispersed (Mercury, Venus, Earth, the moon and Mars formed here). Farther out, carbon-rich composites similar to charcoal dominated, with rock and metal mixed in (the majority of the asteroids). More distant still, reddish materials rich in carbon-nitrogen-water compounds were common (outer asteroids and small moons of Jupiter). The sector of the solar nebula beyond this was cool enough for water-ice particles to remain along with hydrogen and helium gas (Jupiter and Saturn and their major moons). The most remote realm was frigid with ammonia, methane and carbon-monoxide snow (Uranus and beyond).

At the contracting cloud's nucleus, enormous quantities of heat generated by the rapid compres-

Mankind is made of star-stuff, ruled by universal laws.

HARLOW SHAPLEY
1962

The birth of the sun and its family of planets took place 4.6 billion years ago in a dark corner of a collapsing cloud of gas and dust that was to be the genesis nebula for hundreds of new stars. The incipient sun, a dull red ember in the black mass that extends from the centre to the left, is glowing from the heat of compression as the cloud material collapses under its own weight, adding to the sun's mass. A few dozen stars in another sector of the cloud at right have just come to life through ignition of their internal thermonuclear fires. Radiation pressure from the newborn stars peels back the nebular material to expose the cloud's interior. The red trail near the centre is a cometlike effect due to nebular material being blown back by stellar radiation from a dense knot.



The crater-battered face of the moon, **above**, *is a cosmic museum dating back to an era of violent collisions that marked the first half-billion years of the solar system's existence. A young Earth,* **right**, *was bombarded just as heavily as the moon, but aeons of weathering, erosion and mountain building have erased almost all traces of the primordial concussions.*

sion of nebular material as it rushed into the blazing star produced a far more luminous sun than we see today. The outward flood of energy soon reversed the flow of infalling matter, creating a billowing wind that swept away the gases of the solar nebula but left the solid particles. The bull's-eye configuration dictated that the solar system would emerge with differences in fundamental makeup.

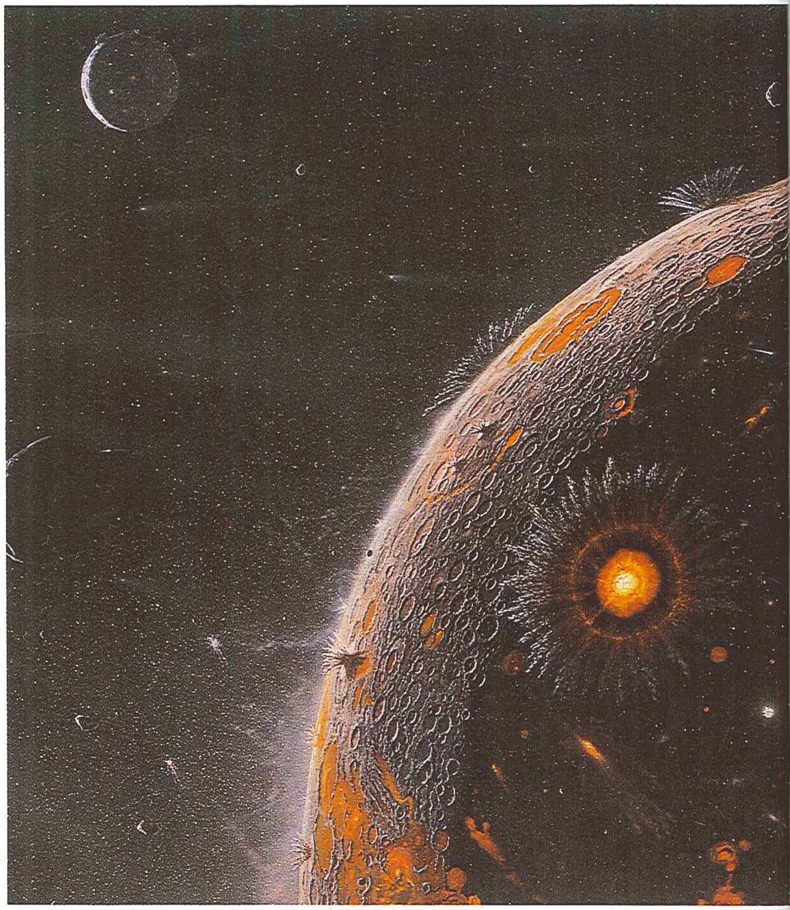
The inner zone, the region of rock and metal, is the most familiar because we are in it, along with the moon, our companion in space, and the neighbouring worlds Mars, Venus and Mercury. Robots have probed and analyzed the surfaces of Mars and Venus and have gathered high-resolution pictures of Mercury from a flyby mission. But it is the Earth-moon system that we know best.

Earth and Moon: A Gravitational Embrace

Earth and the moon are a binary planet system. If the moon were circling the sun in its own orbit, say, between Earth and Mars, astronomers would not hesitate to classify it as a planet in its own right. Its diameter is two-thirds that of Mercury, significantly larger than Pluto and a respectable one-quarter of the Earth's diameter. Yet there it is, obediently swinging around Earth. None of the other terrestrial planets have anything resembling our moon. Venus and Mercury have none, and Mars's two Manhattan-sized moons are microscopic on a cosmic scale. Even when compared with the moons of the giant outer planets, our satellite is more than respectable. Jupiter's Ganymede and Saturn's Titan are the size of Mercury, but their planets are colossal relative to Earth. Pluto, which is so small that it hardly rates planet status, is endowed with a moon half its diameter. But Pluto is different in so many ways from all the other planets that it offers a poor basis for homology.

There is still wide disagreement about precisely how the Earth-moon system emerged from the solar nebula. This is somewhat surprising, considering that in the early 1970s, the Apollo astronauts brought back nearly a ton of lunar material as well as thousands of photographs and reams of data for eager researchers. At the time, many astronomers thought the long-sought answer to the riddle of the moon's origin was at hand.

But today, nearly two decades after those historic



moon walks, the three theories in vogue prior to the Apollo missions are still being debated, and one has been added. The four theories are: *Earth's adopted cousin*—a small planet that was gravitationally captured by Earth; *Earth's sister*—simultaneously born from the solar nebula in a process called co-accretion; *Earth's daughter*—a by-product fissioned from a rapidly rotating primordial Earth; *a chip off the old block*—the final remnant of a collision between Earth and a smaller planet.

The last theory is the new one, a product of 1980s' computer simulations of the formation of the solar system. The simulations suggest that 10 million years after the solar nebula initially evolved, the material in the inner region (where Mercury, Venus, Earth and Mars were emerging) had, through accretionary collisions of smaller particles, built up thousands of mountain-sized bodies called planetesimals. Through repeated low-velocity impacts, the planetesimals continued to grow increasingly larger. As these collided with the object that was to become Earth, they in turn became part of the

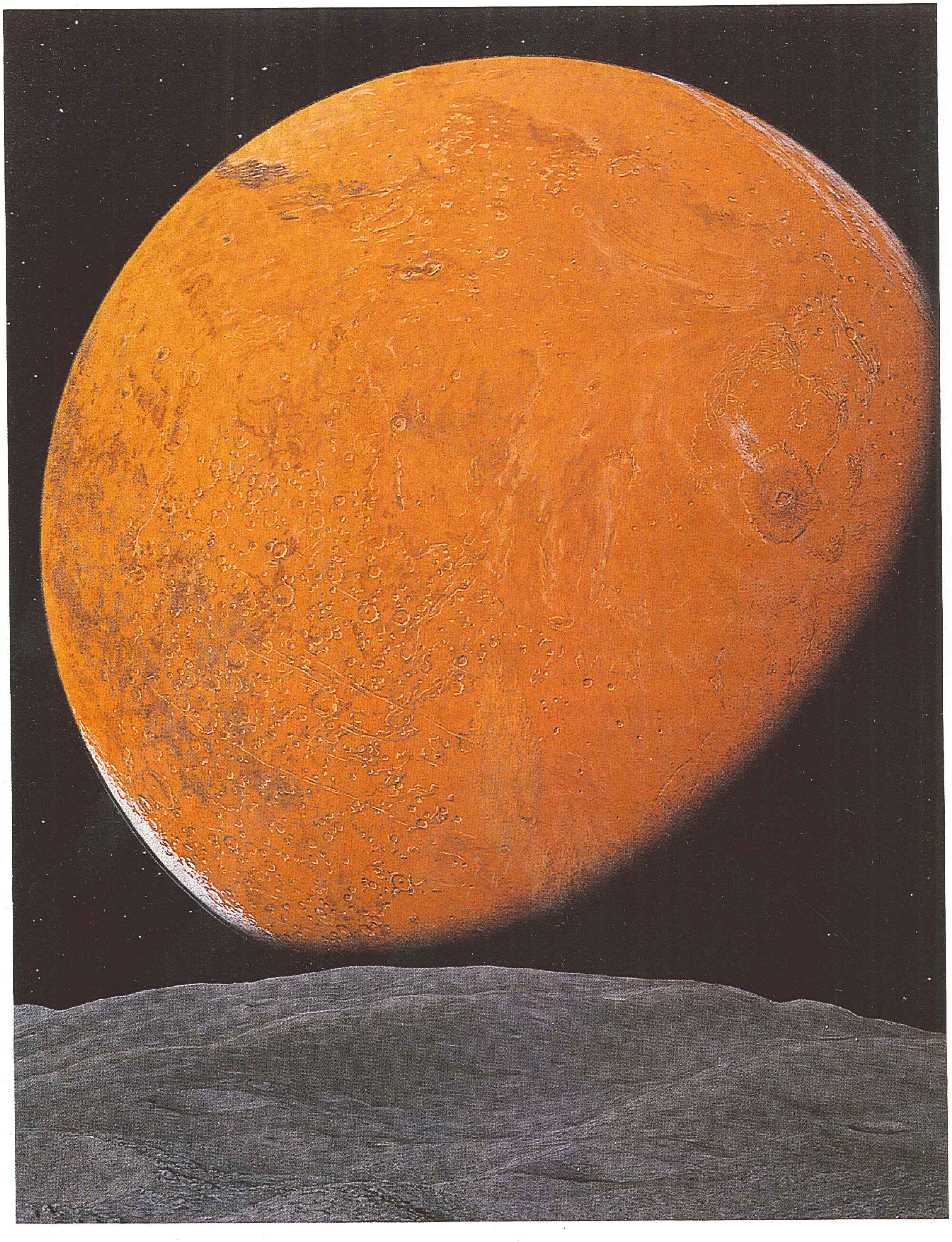
Pounded by continuous collisions with millions of chunks of debris left over from its formation and thousands of renegade comets from the outer solar system, primordial Earth glows from the impact-generated heat. Nearby, in rings of debris from its birth, the moon swings in an orbit far smaller than the one it plies today. The moon has gradually receded from Earth ever since.

planet. A few of these planetesimals might have been gargantuan, having up to three times the mass of Mars. The heat generated by colliding with something that big would have melted substantial portions of the nascent Earth. Debris from both Earth and the impacting body would have vaporized and splashed into nearby space. However, a portion of it could have lingered in the Earth's orbit, eventually coalescing into the moon.

There is some evidence to support this theory. The Apollo moon rocks reveal that while a portion of the lunar material is from an unearthly source, some does resemble the Earth's crust. The unearthly elements could have come from the projectile that hit our planet. Of the other three theories, the sister theory, suggesting that Earth and the moon were born as twins, gets fairly high marks from planetologists. In recent years, the daughter and adopted-cousin theories have had less enthusiastic reviews. There are now more theories to explain how the moon got here than there were before humans explored the lunar surface, which indicates the difficulty of unravelling specific questions of origins and destinies in the universe.

Although the moon is comparatively close in size to Earth, as satellites go, the surface conditions on the two worlds are completely different. Those now historic images of spacesuited astronauts bounding over dusty lunar plains tell much of the story. The moon is the ultimate desert: no air, no water. A grilled wasteland during the two-week lunar day, it is a freezer, almost as cold as deep space, for the two-week night. It all stems from having a relatively small mass, with its consequently weaker gravity (one-sixth Earth's). Any air or water the moon once had could not have lasted for more than a few million years. The simple heat of sunlight would give air and water molecules sufficient energy of motion to escape the weak lunar gravity and become dispersed into space.

Smaller mass also means reduced pressure of compaction on the interior of the moon, compared with Earth. Planet-wide modifications caused by volcanoes and earthquakes are drastically re-



Looming above the landscape of its inner moon Phobos, Mars is a world of contrasts: craters, valleys, sand dunes, ice fields and volcanoes. The huge volcano Olympus Mons is seen near the sunset terminator, its 70,000-foot summit creating a rare cloud on its leeward side. Phobos is one of the solar system's smallest moons—only as wide as the limits of a medium-sized city—and its gravity is so feeble that an astronaut with a strong throwing arm could put a baseball in orbit around it.

duced on the moon. It is a geologically quiet place: seismometers left by the Apollo astronauts registered vibrations from a baseball-sized meteorite striking the surface on the opposite side of the moon. Major surface-shaping forces such as plate tectonics (continental drift) and midocean ridges on Earth are completely absent on the moon. Its surface is a museum that records not internal but external processes. The craters are evidence of impacts from without—yawning bowls blasted during the solar system's exuberant youth.

Earth suffered the same bombardment. Indeed, as we have seen, the moon may have been born out of a particularly violent encounter with a planetesimal. Primitive Earth, cratered and without today's atmosphere and oceans, probably resembled the moon. Over time, steam and gas from volcanoes could have supplied our planet with water and air. More water would have arrived via impacting comets, which are largely composed of water ice. The atmosphere has evolved since then, but little escapes the Earth's gravitational grip. Atmospheric forces helped erase evidence of craters through weathering (wind, rain, rivers, glaciers), while the Earth's internal engine restructured the surface with plate tectonics, mountain building and volcanic activity. That, plus the Earth's temperature environment, which is dictated by its distance from the sun, has made it the only world in the solar system that has sustained large amounts of liquid water on its surface for billions of years. That in turn provided the crucible for life—a phenomenon which has been here for at least 3.5 billion years.

Mars: A Nice Place to Visit, but . . .

Mars is not an unfriendly place. In many ways, it is the most Earthlike planet we know about. The balmiest conditions on Mars resemble a summer day in Antarctica. But an explorer would need a spacesuit, since the air is not breathable. It is mostly carbon dioxide, and there is not much of it—its density is less than 1 percent of the Earth's atmosphere.

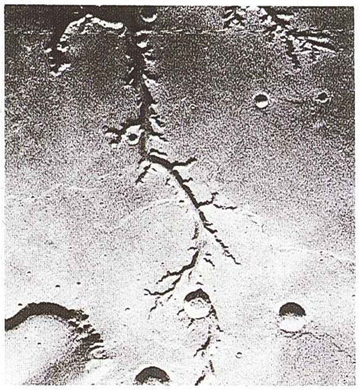
The main problem, however, is the cold. At noon on the hottest day of summer near the equator, the soil temperature might rise to 70 degrees F for a few hours; but the thin atmosphere never gets that warm. When the air temperature even approaches the freezing point of water, it is a Martian heat wave. In any case, the air pressure is too low for water to exist as a liquid. By sunset, both air and ground are as frigid as a winter day on Baffin Island. At midnight, any place in Antarctica would be warmer than Mars's equatorial zone. In the Martian polar regions in winter, the bottom really falls out, with daily *high* temperatures in the vicinity of 180 degrees F below zero. That is cold enough for the Martian air to freeze—and it does, producing a frosty blanket of dry ice (frozen CO_2) over the pole experiencing winter.

Subzero temperatures will not stop future Mars explorers, who will be outfitted in the fully heated and air-conditioned spacesuits that are available today. Getting humans to Mars and back is technologically possible, given the commitment and the funds. It would take almost three years for the round-trip, so the major hurdle is designing life-support systems for such long-duration voyages away from Earth-based supply ships.

In 1985, high-level space-programme officials in both the United States and the Soviet Union issued reports stating that landing humans on Mars was not only feasible but a reasonable goal for the early 21st century. Such a mission presents an ideal opportunity for international exploration. Perhaps several ships from various space agencies could embark together as a flotilla, for mutual safety and for sharing scientific research. In 1960, science fiction author Arthur C. Clarke, whose track record in these matters is one of the best, predicted that humans would walk on Mars before the end of the 20th century. He still thinks it could happen.

On a summer afternoon in the Martian Amazonis desert (a likely landing site), an explorer would be struck by the colour—or lack of it. Everything is shades of orange, ranging from the bright peach-coloured sky to the rusty orange dust that covers the surface. The thin atmosphere filters little sunlight, so daylight is almost as strong as it is on Earth, although the sun appears half the size due to its increased distance. On the horizon, enormous sand dunes rise and fall in a procession of frozen waves. The ground is firm and littered with pebbles that more closely resemble cinders than smooth or granitic Earth rocks. Larger versions of those cindery rocks are scattered across the low, undulating landscape. No mountains or cliffs, at least not in this region. Certain sectors of Mars have extremely rugged terrain—canyons, volcanic flows, crater walls—while huge tracts are relatively flat.

A cloud of dust stirred up by a flick of the toe would be quickly dispersed by the sharp breeze.



A mile-wide channel, almost certainly carved by water, scars a Martian plain that has not felt a drop of rain for billions of years. A flash flood from melted permafrost may account for this and hundreds of similar features, suggesting that Mars was once more Earthlike than it is today.