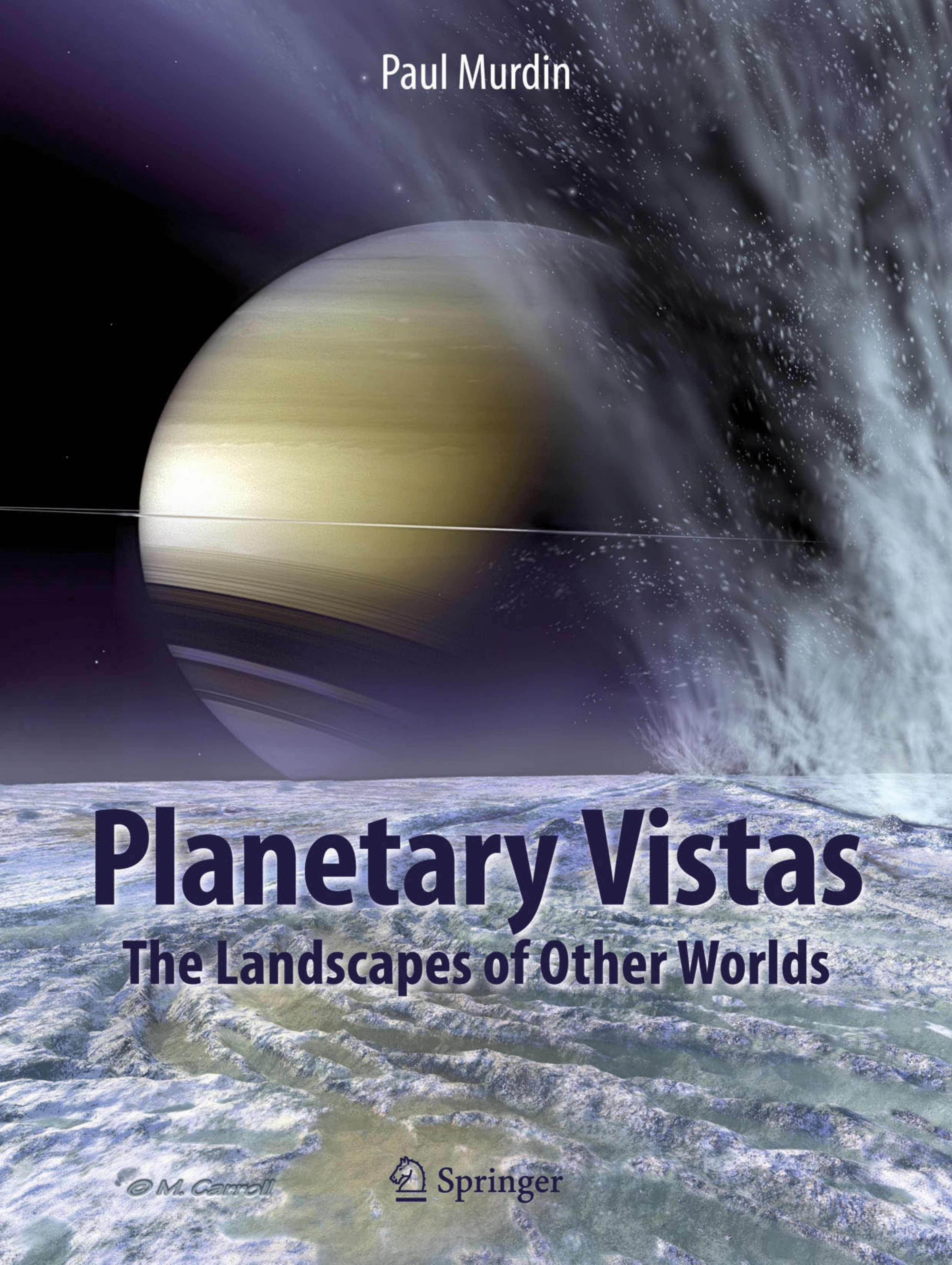
Paul Murdin

Planetary Vistas

The Landscapes of Other Worlds



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Planetary vistas on Earth and Mars: exploration and discovery.

Fig. 1 Northeastern view from the northern top of Mount Kosciusko by Eugene von Guérard (1811-1901). In 1862, von Guérard participated in an expedition to Mount Kosciusko, Australia's highest mountain, led by the Bavarian scientist Georg von Neumayer (1826-1909). The expedition served to improve the map of Australia, e.g., by measuring the heights of mountains as well as measuring Earth's magnetic field. In this painting of 1863, Neumayer is the person in the foreground, making scientific observations with an instrument, perhaps a barometer; his assistant, two guides and his dog Hector are also discernible among and against the rocks and the snow of the mountain top. Devoid of noticeable vegetation, the scene could almost be of another planet like Mars, except for the people and the cloudy, rainy sky. The picture is a painting from life, no doubt the landscape represented with painterly artifice. (The National Gallery of Australia: Wikimedia Commons, commons.wikimedia.org/wiki/File:Guerard_Mount_Townsend_1863.jpg.)

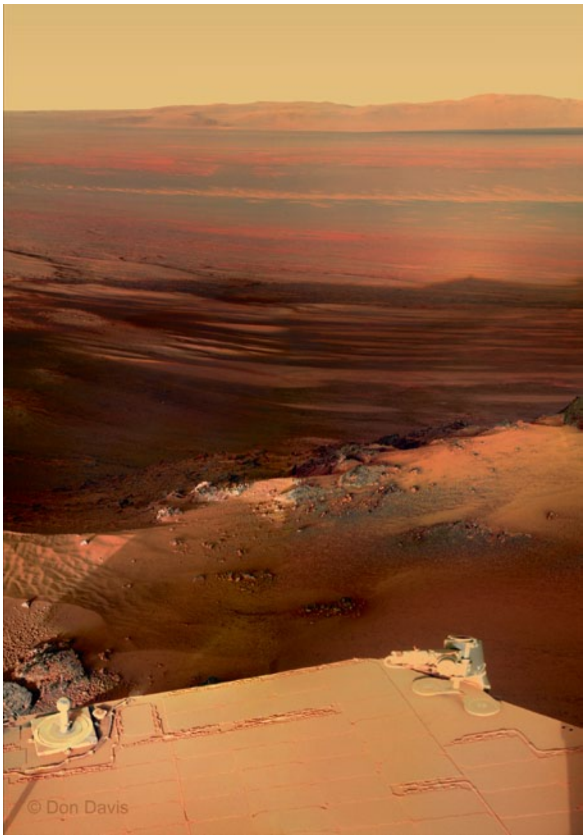

Fig. 2 Sunset at Endeavour Crater on Mars, by Cornell's Pancam team and Don Davis, 2012. The Opportunity rover, foreground, positioned on the walls of the Martian crater Endeavour, looks over the crater floor, its shadow surrounded by a solar halo. Considered against von Guérard's painting, the two pictures have the same focus on the rocky landscape, the same small human (or proxy human) foreground figures, the same composition with low sun and high horizon, the same subject of scientific exploration and the same romantic feel, although 150 years separates them. This picture uses data from a CCD camera positioned on the surface of Mars, digitally enhanced for artistic effect. (NASA/JPL-Caltech/Cornell/Arizona State University, © Don Davis, reproduced by permission.)

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For my grandchildren: Felix, Lucian, Frankie and Zoë
They will see landscapes that I can only imagine.

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I am grateful for the discussions that I have had with Frank Whitford, Alex Murdin and Valerie Shrimplin, all of whom opened my eyes to the old landscapes in fine art with which to compare the new landscapes from space science.

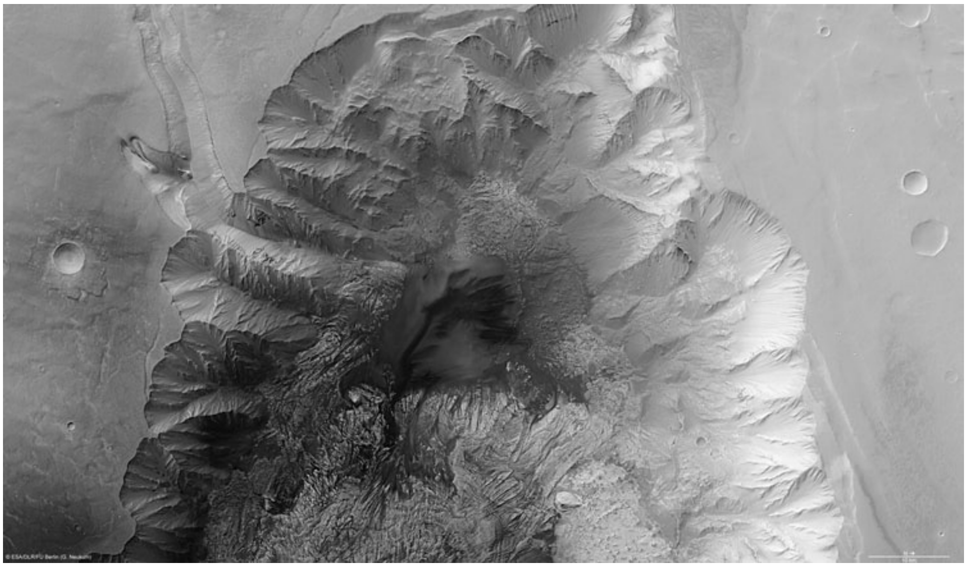
Figures 5.3 - 5.4 - 5.5 were developed from an idea by Stuart Atkinson (http://roadtoendeavour.wordpress.com/about/).

Contents

About the Author

Paul Murdin is an internationally known astronomer with a track record of well-written books and eloquent lectures about astronomy. He has been honored with an OBE in 1988, the Award of the Royal Astronomical Society for Services to [professional] Astronomy in 2011, the Eric Zucker Award of the Federation of Astronomical Societies for outreach to amateur astronomers, in 2012, and the name of asteroid 128562 Murdin.

Educated at the universities of Oxford and Rochester, NY, Paul has worked as an astronomer in the USA, Australia, England, Scotland and in Spain, where he led the operation of the Anglo-Dutch Isaac Newton Group of telescopes in the Canary Islands. He has been a research scientist (studying supernovae, neutron stars and black holes – in 1972 Paul discovered the nature of the first black hole known in our Galaxy, Cygnus X-1) and a science administrator for the UK Government and the Royal Astronomical Society. He works at the Institute of Astronomy at the University of Cambridge, England, and is Visiting Professor at John Moores University, Liverpool. He has a secondary career as a broadcaster and commentator for the BBC and CNN, as well as a lecturer and writer on astronomy, including repeat appearances on BBC Radio 4's In Our Time and at a number of literary and science festivals, like those at Hay-on-Wye and Edinburgh, and on the Cunard liner Queen Elizabeth 2. His most recent books include Secrets of the Universe: how we discovered the Universe (Thames and Hudson, 2009), Mapping the Universe (Carlton, 2011), and Are We Being Watched? The Search for Life in the Cosmos (Thames and Hudson, 2013).



Chapter 1

Landscapes on Other Worlds

Fig. 1.1 Hebes Chasma. The region is an enclosed trough situated in Valles Marineris, the Grand Canyon of Mars. It is 800 km (600 miles) wide. It is a complex region created by the collapse of the surface and subsequent landslides into huge splits in Mars caused by upwelling due to volcanic activity below. This view looks straight down, as from an overflying aircraft or spaceship. (ESA/DLR/FU Berlin-G. Neukum.) B

ALIEN LANDSCAPES

In 1543, on his deathbed, the Polish cleric Nicholas Copernicus (1473–1543) published his idea that Earth orbited the Sun, not the other way around. Earth was a planet. It was thus like the other planets of the Solar System. It was not somewhere special and different from everywhere else. The Dominican monk and philosopher Giordano Bruno (1548–1600) and the astronomer Johannes Kepler (1571–1630) immediately cast Copernicus' proposition in its logical and symmetrical reverse—if Earth was like a planet, the other planets were like Earth. This implied that the other planets were worlds like ours and probably had surfaces, as Earth does. Perhaps the other planets even had inhabitants. With the newly invented telescope, the astronomer Galileo Galilei (1564–1642) proved in 1610 that there was at least some truth in these assertions by discovering mountains and valleys on the Moon. The surface of the Moon was evidently similar to the surface of our own world.

Human beings, in person, have definitively proved that the Moon is like Earth by standing on the soil of its surface and picturing its hills, valleys and mountains. This is the only world outside Earth that has been proved by human experience to be terrestrial. However, by proxy, through the use of robots, humankind has explored, in close up and by physical presence, a number of the more distant worlds in the Solar System out to Saturn's moon Titan. Through cameras landed on mobile robots, humans have been able indirectly to venture into and picture dramatic places on these worlds. Some planets of the Solar System have been further explored by remote mapping from orbiting satellites that produce files of scientific data that can be viewed as pictures.

All this effort has built up into a number of little-known but stunning planetary landscape pictures that represent what you would see if, as a space tourist, you visited these alien worlds. So far this is not possible in actual practice, but the pictures make it possible to be a space tourist without leaving one's armchair. In this book we explore these landscapes to view the beautiful scenery of other worlds, and also to understand the scientific reality that lies behind their landscape.

The exploration of the planets of our Solar System has been driven by scientific objectives, so the scenery is the focus of the interest, pictured for geological analysis. The pictures are usually taken from above, because most spacecraft are orbiters—they fly over and therefore look down on what they orbit over. You may well have had a similar experience as a passenger in an airplane. Looking out of the window, you can likewise look down on the country you are flying over. But, as everyone who has done it knows, what you see is tantalizing—you see the country in a fascinating

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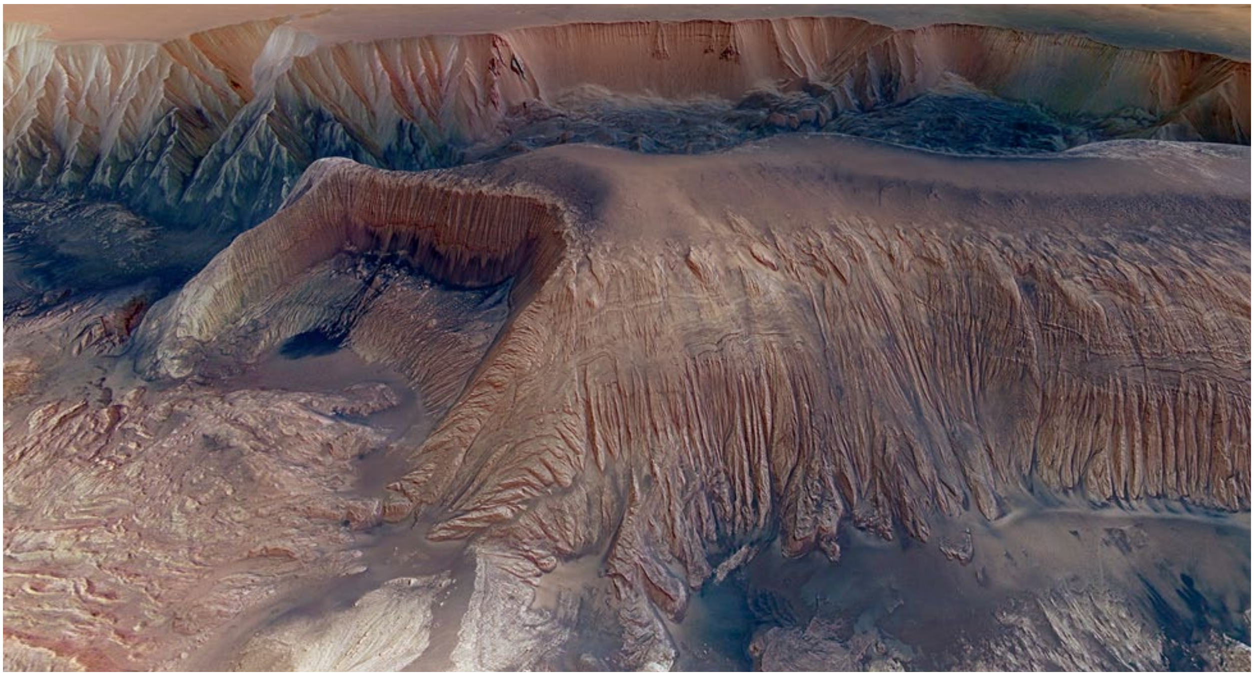
and informative way, but you do not experience it. The view engages your curiosity but not your emotions.

To experience somewhere you have to visit and be immersed in the place. A large part of this experience is looking, so an image obtained by a camera is an approximation to the experience, which is why explorers, travelers and tourists take photographs to show others back home. But, unlike most spacecraft, people do not usually take pictures that look down (Fig. 1.1). We see more naturally by looking horizontally at a scene that stretches out in front (Fig. 1.2). This is the view that we most often record as a souvenir, holding a camera up. In past times, before cameras had been invented and manufactured for a price everyone can afford, travelers might well have sketched the scene with pencil or painted it in watercolor or oils, to make a landscape picture—some travelers still do this. As human beings, looking horizontally is the way we understand scenery, a method that has developed as we have developed as a species. Photographs and pictures that represent what we see are the principal ways that we remember, investigate and re-experience the scenery after seeing it for the first time.

Artists have learned how to go beyond the mere recording of landscape. They simulate our human reaction to landscape by enhancing pictures of scenery—sketches and paintings—in characteristically artistic ways. They capture the emotion of involvement in the land, by choosing the viewpoint, subject and scope of the scenery and presenting it through some interpretation of their own choosing. Their work has become important to us and our culture—we build great galleries to display landscape pictures on the walls, and pay sometimes enormous prices to acquire them for that purpose. The reason is that, somehow, an artist's picture conveys

Fig. 1.2 Hebes Chasma Mesa. Imaged by the High Resolution Stereo Camera of ESA's Mars Express, the central mesa inside Hebes Chasma is seen in close-up detail in this perspective view. a horseshoe-shaped valley has been created as material on one side of the mound (left in this image); has slumped down onto the floor of the valley below. Melted ice could have played a role by weakening the rocks of the mesa to create the flow-like appearance of the landslip. Loose material has slid down the walls of the valley from a dark intermediate layer to pool on the valley floor. Layers along the side of the mound are a mix of wind-blown dust and ancient lake sediments. This is the oblique view that a space tourist would have from within the scene, much more engaging than the view from flying over it and looking down vertically. (Mars Express: ESA/DLR/FU Berlin, G. Neukum.) **BB**



more about the scenery than the mere facts. A landscape picture may speak of the beauty of the land, the awe that it inspires, and its meaning for us as humans. It may even speak about what lies in the scenery's past, or over the horizon in unseen lands beyond, or in its future.

Thus the word "landscape" has come to have two equally important meanings. "Landscape" is both the scenery and a picture of the scenery.

This book is principally about landscape pictures of other worlds and what they convey. In its elements, a planetary landscape picture is one that represents the scenery of another world as seen from a low viewpoint, near the ground, into a depth of field across the surface, looking horizontally.

Most of the planetary landscapes in this book have been made by men or spacecraft that have landed on the surface of another world. There have been about 40 missions in which spacecraft have landed on planets, and even roved over the planetary terrain. These missions have delivered many pictures of the scenery around them.

Some of the landscapes in this book have been made by men or spacecraft that have been in orbit but at low altitude, skimming the surface of a planet. This is a maneuver with its dangers. A small error of control or position, or an unforeseen technical glitch, could risk a crash. Low passes over the scenery are therefore not favored by cautious spacecraft controllers, especially flights over mountainous planets. Low-altitude flights are thus undertaken as a main part of a mission usually only on an approach to a landing in a flat area chosen to minimize dangers. But a low flight may be risked for some particular reason, perhaps in the last stages of a mission, after the main work has been completed. Landscape pictures from overflying spacecraft are therefore rare. But they are often very dramatic landscapes, of scenery that is otherwise inaccessible.

We have included in the book some pictures of planetary scenery made from above, where the picture has an artistic or scientific value that adds meaning to one of the principal landscape pictures.

Planetary landscapes evidence, at one and the same time, a familiarity and an otherworldliness. The same fundamental processes happen on all terrestrial planets, so the basic structure of planets is similar—differences are differences often of degree. Mountains build and are eroded in similar ways. Their various shapes are common to most terrestrial planets, as are the plains formed from erosion material. The underlying structures of the planetary landscapes in this book are the same from planet to planet. But the differences soar over the line that separates terrestrial and planetary landscapes in fundamental ways. Planetary landscapes are both literally and figuratively otherworldly.

Some planets have no air, because some worlds are small and their gravity is weak. Their air has escaped into interplanetary space. So their landscapes lie directly under space, with daytime sunlight but an incessant black sky, like terrestrial night. This is so for the Moon, whose landscapes instantly reveal the location of their scenery (Chaps. 3 and 5). Some planets have a thin atmosphere: Mars is one and its sky is wan. By contrast, Venus and Titan have thick atmospheres and their sky lowers darkly (Chaps. 2 and 7). A cerulean sky is an exclusively terrestrial beauty, although there is one other planet in the Solar System whose sky is sometimes pale blue (Chap. 9).

If there is air on a planet, there is some strength of wind, and some wind-altered landforms: sand dunes, dust-storms with drifting sand, wind-eroded rocks, as on Mars (Chap. 6). The sky over Mars is laden with dust, circulating in the Martian air, whipped up by global dust-storms (Chap. 9). There may be frost and snow (Chap. 8). If there is no air or frost there can be no Aeolian erosion, and the breakup of rocks by ice cracking is impossible. Erosion is slower. Sharp edges of the rocks may be sandpapered away not by blown sand but by the needle-sharp, intermittent impacts of tiny meteorites.

Does the planet have abundant water, standing on its surface in pools, lakes or seas? The usual answer is "no." Our own planet lies in the so-called "Goldilocks zone" of the Solar System, the restricted zone near the Sun in which the temperature is not too hot, nor too cold, but just right to allow water to remain liquid on its solid surface. (This is helped too by the properties of Earth's atmosphere.) This means that, in terrestrial landscapes, we can see the blue of standing water, the glint of sunlight and other reflections off the water-surfaces of lakes and seas and off the snaking meanders of rivers. We can see the effects of flowing water in the carving that it makes upon the landscape—river beds and gullies, the scouring effects of floods on hills and the sides of valleys, level alluvial plains formed from sediment dropped as a river reduces speed. There is nothing of the sort on any other world in the Solar System, with two exceptions. Mars, positioned on the far edge of the Goldilocks zone, has had water in the past, which has left its traces on the Martian landscape (Chap. 6). Saturn is positioned in the frigid distant regions of the Solar System, but its moon Titan has rivers, lakes and seas—not of water but of liquid methane (Chap. 2).

However, water exists not only as a liquid but as a solid, too, in different forms such as frost, ice and snow. Some cold planets have white landscapes like the poles of our Earth, and some planetary landscapes show the effects of grinding ice, including cracking ice-floes and glaciers (Chap. 8).

No planet in the Solar System, apart from Earth, has life on it as far as we can see. Water is essential to the development of life, and it is abundant in the Solar System in solid or liquid form. There is the potential for life on many planets, but on Earth alone we see things growing. In fact on Earth life is abundant. So a major feature of terrestrial landscapes is vegetation—trees, flowers and grasses that give variety to the surface of the scenery, and color—the green of leaves and the bright colors of flowers. Animals on Earth are rarer than vegetation and in pictures of terrestrial scenery give tone to the landscape: the detail of an animal in a landscape can impart savagery, domesticity, wildness or a pastoral nature. No other planet in the Solar System has landscapes with features like these, although some may have niche environments—caves or geothermal vents—in which life may have secretly developed. Like the blue sky, noticeable life is, in our Solar System, exclusively terrestrial. We may in the future be able to peer into a dark cave on Mars and see something akin to what we might see in a cave on Earth, but nothing like this is known yet. There are no planetary landscapes that are "living" in the same sense that terrestrial landscapes are.

There is a particularly strong contrast between lunar and terrestrial landscapes. Color is one main difference. The Moon is lifeless, and there is no vegetation—no green foliage, no flowers. Its rocks are in the main, very similar, whereas terrestrial rocks come from different mineral sources, some rich in metals and their colored chemical compounds from the interior of Earth, which have been brought to the surface from below the planet's rocky mantle. The metal compounds of terrestrial rocks, weathered by rain, are sometimes highly colored, often red because of rust-like chemical compounds from iron. On the Moon there are no bodies of water, so no blue lakes or sea, no white foaming waterfalls. The sky is black, because there is no air, so no blue sky, no white cloud, no sunset lighting effects. Lunar photographs could almost be taken as being black and white, unless there are colored objects in view that have been imported from Earth, like the Stars and Stripes on a flagpole or a spacesuit.

However, like the plains, canyons and volcanoes of Mars, and the black lava mountains of Venus, the gray, dusty plains and mountains of the Moon have their own stark beauty, here displayed for you as you voyage through the Solar System, an armchair space tourist viewing planetary scenery.

For this book we have selected the clearest pictures of planetary scenery. Just as we might try to read the character of the subject in a portrait of a human face, so we have tried to convey the character of the planet pictured in these landscapes. Moreover, we might infer from a portrait the history of the subject. We have tried to show how we can read what lies inside each planet from these landscapes, and infer its past. Here is a world, Mars, that suffered a global catastrophe of climate change, due to events that have taken place in its deep core. Here are two completely opposite worlds: Titan is Earth as it was a few hundred thousand years old, frozen in time; Io is by contrast a world recreated anew, again and again, resurfaced by inner material spewed out by ever-active volcanoes. Here is a world, the Moon, that suffered a heavy bombardment of large projectiles, caused by a collision that smashed two asteroids into millions or billions of pieces or by a developing planetary configuration that jostled asteroids out of their orbits. These cosmic catastrophes inevitably left their mark upon the land.

HOW REAL ARE THE LANDSCAPES IN THIS BOOK?

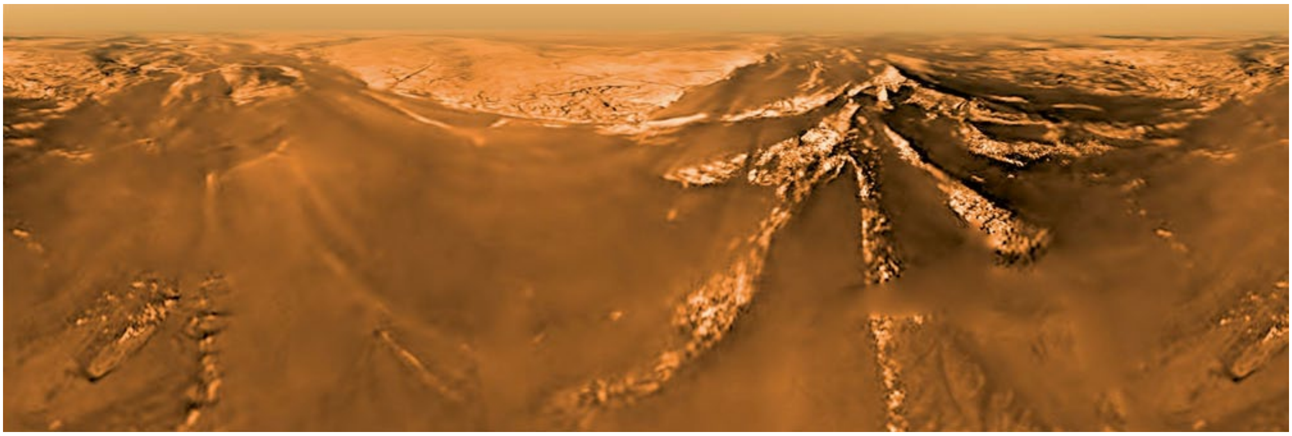
The planetary landscapes reproduced in this book have been provided by a variety of spacecraft over decades of changing technology—see Appendix 1 in this book for further details. Some of the color pictures are closer to what you would see if you stood there than others. Sometimes people wonder whether the landscapes made by space scientists are "real." A brief answer is that they are as real as any painting of a terrestrial landscape. Every picture here has reality behind it. *None* of the pictures are imaginative impressions.

To add shading to this assessment, we have given a "reality grade" to each picture in this book, along the lines of Standard and Poor's credit ratings for financial institutions or bond issues. **AAA** is as realistic as a photograph on color film or by digital photography, **AA** as realistic as a monochrome (black and white) photograph. All the subclasses of reality grade **A** are as realistic as a picture produced by an artist of what he or she sees of a scene, but as the grade is reduced to **B** or even **C** the landscape is departing from reality in ways that would be progressively jarring if the picture was held up on view and compared against the landscape, although there are many artistic landscape paintings that are equally different from reality. At grade **C** the landscapes are representative but noticeably depart from the real view in some ways. The criteria for this grading system are described in the following table, and explained in more detail in Appendix 1 of this book.

Some color pictures are reproduced in the printed version of this book in black and white; the reality grade applies to the original version (Table 1.1).

Table 1.1 Reality grades for planetary landscapes

Color	True color	Black and white	Balanced 3-color addition	Exaggerated 3-color addition	2-color	Multicolor, but invisible passbands	Synthetic colors and/or radar
Detector	Color film or TV	B/w film or TV	CCD images or similar				
A real image made by a camera on the surface	AAA	AA	AA	A	BBB	BB	
A real image made by a camera from an overflying satellite	AA	AA	A	BBB	BB	BB	B
Constructed from a contour map with a hypothetical viewpoint			A	BBB	BB	B	C
Constructed with exaggerated heights			BBB	BB	B	C	C



Chapter 2

The Lakes of Titan

Fig. 2.1 Titan's Lake District. During its descent on January 14, 2005, the Huygens probe took images of Titan's surface. From an altitude of 2 km (1.2 miles) Titan's surface shows as hilly ridges with dry river valleys. The distant landscape is made indistinct by the smog of Titan's hydrocarbon atmosphere. (Huygens: ESA/NASA/JPL/University of Arizona. Image processing by René Pascal.) **BB**

A ROBOTIC EYE AND A NEW LANDSCAPE

In January 2005, an electronic eye gazed on the fresh landscape of new land on a previously unexplored world. It saw a landscape that would, at first sight, have been familiar to many human eyes. The scenes that it recorded looked like the Lake District of northern England, the Finnish Lakeland, or the hilly areas of the Pacific Northwest, with rivers flowing through the world's hills to large lakes. One major difference between this world and ours was that this world had no life on it—no trees, no grass to cloak the shapes of the bare rock, no animals to give an air of domestic tranquility or savage wildness to the scene. What was not immediately obvious was that, underlying the scenery, behind the landscapes, was the potential for life. The landscape was like that of Planet Earth before life had arisen here. This land was a preserved fossil, like Earth was 4 billion years ago. This world was pregnant with prebiotic chemistry, literally awash with chemicals that span the gap between the inanimate and the living.

The electronic eye belonged to a robot spacecraft that was standing in cold, squelchy mud, the bottom of an almost dry lakebed. The bare shapes of the boulders that littered this level plain had been rounded by being tumbled in a stream. In the distance, across the lakebed, the robotic eye could dimly see a line of hills—the far lake shore, perhaps, or some islands. Their outlines were obscured by smog. Rain had fallen here, evaporating from the soggy ground, creating photochemical smog.

The robot was gazing at the only terrain in the Solar System, other than Earth, where there is landscape like this. But behind the familiarity of this scenery is an unfamiliar fact: the rain and the liquid in the lakes are of liquid methane, not water.

The scene was recorded on Titan, the largest satellite of the planet Saturn, second largest in the Solar System. Titan was the first satellite of a planet discovered since Galileo discovered the four largest of Jupiter's satellites in the northern winter of 1609/1610. Titan was discovered in 1655 by Christiaan Huygens (1629–1695). Huygens was born in The Hague, the son of a high-ranking civil servant, and, educated by private tutors, he at first studied law at Leiden University, in preparation for a diplomatic career. He was, however, attracted by mathematics. Traveling in France and Britain, his talent was noticed by influential scientists, and in 1666 he was invited to join the newly founded Academy of Sciences in Paris, where he remained until 1681. In the 1650s he had become interested in developing telescopes, and made larger and larger objective lenses with very long focal lengths that gave high magnifications of 50–100 times. While testing a newly made lens in 1655 he observed the planet Saturn in an attempt to find out about what at the time were called its *ansae*, or "ears." The first telescopes could see that there was something funny about the planet, which had protrusions sticking out either side, but were unable to see that

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they were part of a ring system that completely encircled the planet. Huygens was intrigued to see that the *ansae* in March 1655 were very narrow: we would now understand that the rings of Saturn were oriented edge-on. He also noticed a star that was lined up with the *ansae*. It followed the planet in its motion and Huygens realized that it was a satellite.

Huygens referred to the satellite in Latin, generically, with the simple name *Saturni Luna*, "Saturn's moon." Further moons of Saturn were discovered later in the seventeenth century and numbered in order from the planet: I, II, III, IV and so on. The numbering system kept changing as further discoveries were made, so Huygens' discovery has been known at various times as II, IV and VI. The astronomer John Herschel (1792–1871) suggested names for the seven satellites of Saturn that were known in 1847. He chose the names of Titans, brothers and sisters of Cronus, the Greek god who was the equivalent of Saturn, with Titan itself used for the largest satellite, the one discovered by Huygens.

Saturn, and therefore too its satellites, are so distant from Earth that telescopes cannot see many features on the surface of Titan, in fact very little in the way of detail. By clever techniques and detailed analysis astronomers using the Hubble Space Telescope (HST) have succeeded in finding dark areas on the surface and showed that they had not varied much over the few years that the HST has been active.

Telescopes on Earth itself can pick up the fact that the globe of Titan is shaded in such a way as to indicate that it has a substantial atmosphere. Spectroscopic analysis of the light reflected from Titan showed in 1944 that the atmosphere contained methane. The spacecraft *Pioneer 11* flew by Saturn in 1979, followed closely by *Voyager 1* (1980) and *2* (1981). These spacecraft confirmed that Titan had a cold, dense, hazy atmosphere, too opaque to see surface features. Before seeing it in 2005, astronomers had to imagine what its landscape looked like.

The close-up landscape recorded in 2005 was captured by the Huygens space probe, carried to Saturn by the Cassini space mission. This was a joint mission by NASA and the European Space Agency to explore Saturn, Titan and its other moons. The spacecraft started its journey in October 1997 from Cape Kennedy in Florida, setting out from a landscape that turned out to be not unlike its destination. This author could see the night-time launch of the Cassini spacecraft from beside a channel draining the marshland where the spaceport is located. There was plenty of life here—not only harmless vegetation. I had to keep one uneasy eye on an alligator stirring in the greasy water of the channel below my viewpoint. Even this primitive creature, with near ancestors dating back 200 million years, was far in advance of anything that Huygens was to see on Titan!

The main focus of my attention that day in 1997 was the floodlit Titan IVB/Centaur rocket on its launch pad. The rocket was the most powerful then available to space scientists, able to accelerate the massive spacecraft (5.6 m t) effectively on its long journey. The rocket's engines ignited in fiery smoke, and it lifted off into the black night sky, its bright flames il-