= Enceladus =

Enceladus (pronounced / ?n?s?l?d?s /) is the sixth @-@ largest moon of Saturn . It is approximately 500 kilometers (310 mi) in diameter , about a tenth of that of Saturn 's largest moon , Titan . Enceladus is mostly covered by fresh , clean ice , reflecting almost all the sunlight that strikes it , making its surface temperature at noon reach only ? 198 ° C (? 324 @.@ 4 ° F) . Despite its small size , Enceladus has a wide range of surface features , ranging from old , heavily cratered regions to young , tectonically deformed terrains that formed as recently as 100 million years ago .

Enceladus was discovered in 1789 by William Herschel , but little was known about it until the two Voyager spacecraft passed nearby in the early 1980s . In 2005 , the Cassini spacecraft started multiple close flybys of Enceladus , revealing its surface and environment in greater detail . In particular , Cassini discovered water @-@ rich plumes venting from the south polar region . Cryovolcanoes near the south pole shoot geyser @-@ like jets of water vapor , other volatiles , and solid material , including sodium chloride crystals and ice particles , into space , totaling approximately 200 kilograms (440 lb) per second . Over 100 geysers have been identified . Some of the water vapor falls back as " snow " ; the rest escapes , and supplies most of the material making up Saturn 's E ring . According to NASA scientists , the plumes are similar in composition to comets . In 2014 , NASA reported that Cassini found evidence for a large south polar subsurface ocean of liquid water with a thickness of around 10 km (6 @.@ 2 mi) .

These geyser observations , along with the finding of escaping internal heat and very few (if any) impact craters in the south polar region , show that Enceladus is geologically active today . Like many other satellites in the extensive systems of the giant planets , Enceladus is trapped in an orbital resonance . Its resonance with Dione excites its orbital eccentricity , which is damped by tidal forces , tidally heating its interior , and possibly driving the geological activity .

= = History = =

= = = Discovery = = =

Enceladus was discovered by Fredrick William Herschel on August 28 , 1789 , during the first use of his new 1 @.@ 2 m (47 in) telescope , then the largest in the world . Its faint apparent magnitude (HV = + 11 @.@ 7) and its proximity to the much brighter Saturn and Saturn 's rings make Enceladus difficult to observe from Earth with smaller telescopes . Like many satellites of Saturn discovered prior to the Space Age , Enceladus was first observed during a Saturnian equinox , when Earth is within the ring plane . At such times , the reduction in glare from the rings makes the moons easier to observe . Prior to the Voyager missions the view of Enceladus improved little from the dot first observed by Herschel . Only its orbital characteristics were known , with estimations of its mass , density and albedo .

= = = Naming = = =

Enceladus is named after the giant Enceladus of Greek mythology . The name , like the names of each of the first seven satellites of Saturn to be discovered , was suggested by William Herschel 's son John Herschel in his 1847 publication Results of Astronomical Observations made at the Cape of Good Hope . He chose these names because Saturn , known in Greek mythology as Cronus , was the leader of the Titans .

Features on Enceladus are named by the International Astronomical Union (IAU) after characters and places from Burton 's translation of The Book of One Thousand and One Nights . Impact craters are named after characters , whereas other feature types , such as fossae (long , narrow depressions) , dorsa (ridges) , planitia (plains) , and sulci (long parallel grooves) , are named after places . The IAU has officially named 85 features on Enceladus , most recently Samaria Rupes , formerly called Samaria Fossa .

= = Orbit and rotation = =

Enceladus is one of the major inner satellites of Saturn along with Dione , Tethys , and Mimas . It orbits at 238 @,@ 000 km from Saturn 's center and 180 @,@ 000 km from its cloud tops , between the orbits of Mimas and Tethys . It orbits Saturn every 32 @.@ 9 hours , fast enough for its motion to be observed over a single night of observation . Enceladus is currently in a 2 : 1 mean @-@ motion orbital resonance with Dione , completing two orbits around Saturn for every one orbit completed by Dione . This resonance maintains Enceladus 's orbital eccentricity (0 @.@ 0047) , which is known as a forced eccentricity . This non @-@ zero eccentricity results in tidal deformation of Enceladus . The dissipated heat resulting from this deformation is the main heating source for Enceladus 's geologic activity . Enceladus orbits within the densest part of Saturn 's E ring , the outermost of its major rings , and is the main source of the ring 's material composition .

Like most of Saturn 's larger satellites , Enceladus rotates synchronously with its orbital period , keeping one face pointed toward Saturn . Unlike Earth 's Moon , Enceladus does not appear to librate about its spin axis (more than 1 @.@ 5 °) . However , analysis of the shape of Enceladus suggests that at some point it was in a 1 : 4 forced secondary spin ? orbit libration . This libration could have provided Enceladus with an additional heat source .

= = = Source of the E ring = = =

Plumes from Enceladus , which are similar in composition to comets , have been shown to be the source of the material in Saturn 's E ring . The E ring is the widest and outermost ring of Saturn (except for the tenuous Phoebe ring) . It is an extremely wide but diffuse disk of microscopic icy or dusty material distributed between the orbits of Mimas and Titan .

Mathematical models show that the E ring is unstable , with a lifespan between 10 @,@ 000 and 1 @,@ 000 @,@ 000 years ; therefore , particles composing it must be constantly replenished . Enceladus is orbiting inside the ring , at its narrowest but highest density point , raising suspicion since the 1980s that Enceladus is the main source of particles for the ring . This hypothesis was confirmed by Cassini 's first two close flybys in 2005 .

= = Geology = =

= = = Surface features = = =

Voyager 2 was the first spacecraft to observe the surface in detail , in August 1981 . Examination of the resulting highest @-@ resolution imagery revealed at least five different types of terrain , including several regions of cratered terrain , regions of smooth (young) terrain , and lanes of ridged terrain often bordering the smooth areas . In addition , extensive linear cracks and scarps were observed . Given the relative lack of craters on the smooth plains , these regions are probably less than a few hundred million years old . Accordingly , Enceladus must have been recently active with " water volcanism " or other processes that renew the surface . The fresh , clean ice that dominates its surface gives Enceladus probably the most reflective surface of any body in the Solar System with a visual geometric albedo of 1 @.@ 38 . Because it reflects so much sunlight , the mean surface temperature at noon only reaches ? 198 ° C (? 324 @.@ 4 ° F) , making it somewhat colder than other Saturnian satellites .

Observations during three flybys by Cassini on February 17 , March 9 , and July 14 , 2005 , revealed Enceladus 's surface features in much greater detail than the Voyager 2 observations . The smooth plains , which Voyager 2 had observed , resolved into relatively crater @-@ free regions filled with numerous small ridges and scarps . Numerous fractures were found within the older , cratered terrain , suggesting that the surface has been subjected to extensive deformation since the craters were formed . Some areas contain no craters , indicating major resurfacing events in the

geologically recent past . There are fissures , plains , corrugated terrain and other crustal deformations . Several additional regions of young terrain were discovered in areas not well @-@ imaged by either Voyager spacecraft , such as the bizarre terrain near the south pole . All of this indicates that Enceladus 's interior may be liquid today , even though it should have been frozen long ago .

= = = = Impact craters = = = =

Impact cratering is a common occurrence on many Solar System bodies . Much of Enceladus 's surface is covered with craters at various densities and levels of degradation . This subdivision of cratered terrains on the basis of crater density (and thus surface age) suggests that Enceladus has been resurfaced in multiple stages .

Cassini observations provided a much closer look at the crater distribution and size , showing that many of Enceladus 's craters are heavily degraded through viscous relaxation and fracturing . Viscous relaxation allows gravity , over geologic time scales , to deform craters and other topographic features formed in water ice , reducing the amount of topography over time . The rate at which this occurs is dependent on the temperature of the ice : warmer ice is easier to deform than colder , stiffer ice . Viscously relaxed craters tend to have domed floors , or are recognized as craters only by a raised , circular rim . Dunyazad crater is a prime example of a viscously relaxed crater on Enceladus , with a prominent domed floor .

= = = = Tectonic features = = = =

Voyager 2 found several types of tectonic features on Enceladus , including troughs , scarps , and belts of grooves and ridges . Results from Cassini suggest that tectonics is the dominant mode of deformation on Enceladus , including rifts , one of the more dramatic types of tectonic features that were noted . These canyons can be up to 200 km long , 5 ? 10 km wide , and 1 km deep . Such features are geologically young , because they cut across other tectonic features and have sharp topographic relief with prominent outcrops along the cliff faces .

Evidence of tectonics on Enceladus is also derived from grooved terrain , consisting of lanes of curvilinear grooves and ridges . These bands , first discovered by Voyager 2 , often separate smooth plains from cratered regions . Grooved terrains such as the Samarkand Sulci are reminiscent of grooved terrain on Ganymede . However , unlike those seen on Ganymede , grooved topography on Enceladus is generally more complex . Rather than parallel sets of grooves , these lanes often appear as bands of crudely aligned , chevron @-@ shaped features . In other areas , these bands bow upwards with fractures and ridges running the length of the feature . Cassini observations of the Samarkand Sulci have revealed dark spots (125 and 750 m wide) located parallel to the narrow fractures . Currently , these spots are interpreted as collapse pits within these ridged plain belts .

In addition to deep fractures and grooved lanes , Enceladus has several other types of tectonic terrain . Many of these fractures are found in bands cutting across cratered terrain . These fractures probably propagate down only a few hundred meters into the crust . Many have probably been influenced during their formation by the weakened regolith produced by impact craters , often changing the strike of the propagating fracture . Another example of tectonic features on Enceladus are the linear grooves first found by Voyager 2 and seen at a much higher resolution by Cassini . These linear grooves can be seen cutting across other terrain types , like the groove and ridge belts . Like the deep rifts , they are among the youngest features on Enceladus . However , some linear grooves have been softened like the craters nearby , suggesting that they are older . Ridges have also been observed on Enceladus , though not nearly to the extent as those seen on Europa . These ridges are relatively limited in extent and are up to one kilometer tall . One @-@ kilometer high domes have also been observed . Given the level of resurfacing found on Enceladus , it is clear that tectonic movement has been an important driver of geology for much of its history .

= = = = Smooth plains = = = =

Two regions of smooth plains were observed by Voyager 2 . They generally have low relief and have far fewer craters than in the cratered terrains , indicating a relatively young surface age . In one of the smooth plain regions , Sarandib Planitia , no impact craters were visible down to the limit of resolution . Another region of smooth plains to the southwest of Sarandib is criss @-@ crossed by several troughs and scarps . Cassini has since viewed these smooth plains regions , like Sarandib Planitia and Diyar Planitia at much higher resolution . Cassini images show these regions filled with low @-@ relief ridges and fractures , probably caused by shear deformation . The high @-@ resolution images of Sarandib Planitia revealed a number of small impact craters , which allow for an estimate of the surface age , either 170 million years or 3 @.@ 7 billion years , depending on assumed impactor population .

The expanded surface coverage provided by Cassini has allowed for the identification of additional regions of smooth plains , particularly on Enceladus 's leading hemisphere (the side of Enceladus that faces the direction of motion as it orbits Saturn) . Rather than being covered in low @-@ relief ridges , this region is covered in numerous criss @-@ crossing sets of troughs and ridges , similar to the deformation seen in the south polar region . This area is on the opposite side of Enceladus from Sarandib and Diyar Planitiae , suggesting that the placement of these regions is influenced by Saturn 's tides on Enceladus .

= = = = South polar region = = = =

Images taken by Cassini during the flyby on July 14 , 2005 , revealed a distinctive , tectonically deformed region surrounding Enceladus 's south pole . This area , reaching as far north as 60 ° south latitude , is covered in tectonic fractures and ridges . The area has few sizable impact craters , suggesting that it is the youngest surface on Enceladus and on any of the mid @-@ sized icy satellites ; modeling of the cratering rate suggests that some regions of the south polar terrain are possibly as young as 500 @,@ 000 years or less . Near the center of this terrain are four fractures bounded by ridges , unofficially called " tiger stripes " . They appear to be the youngest features in this region and are surrounded by mint @-@ green @-@ colored (in false color , UV ? green ? near IR images) , coarse @-@ grained water ice , seen elsewhere on the surface within outcrops and fracture walls . Here the " blue " ice is on a flat surface , indicating that the region is young enough not to have been coated by fine @-@ grained water ice from the E ring . Results from the visual and infrared spectrometer (VIMS) instrument suggest that the green @-@ colored material surrounding the tiger stripes is chemically distinct from the rest of the surface of Enceladus . VIMS detected crystalline water ice in the stripes , suggesting that they are quite young (likely less than 1 @,@ 000 years old) or the surface ice has been thermally altered in the recent past . VIMS also detected simple organic (carbon @-@ containing) compounds in the tiger stripes , chemistry not found anywhere else on Enceladus thus far . One of these areas of " blue " ice in the south polar region was observed at high resolution during the July 14 flyby , revealing an area of extreme tectonic deformation and blocky terrain , with some areas covered in boulders 10 ? 100 m across .

The boundary of the south polar region is marked by a pattern of parallel , Y- and V @-@ shaped ridges and valleys . The shape , orientation , and location of these features suggest they are caused by changes in the overall shape of Enceladus . As of 2006 there were two theories for what could cause such a shift in shape : the orbit of Enceladus may have migrated inward , leading to an increase in Enceladus 's rotation rate . Such a shift would lead to a more oblate shape ; or a rising mass of warm , low @-@ density material in Enceladus 's interior may have led to a shift in the position of the current south polar terrain from Enceladus 's southern mid @-@ latitudes to its south pole . Consequently , the moon 's ellipsoid shape would have adjusted to match the new orientation . One problem of the polar flattening hypothesis is that both polar regions should have similar tectonic deformation histories . However , the north polar region is densely cratered , and has a much older surface age than the south pole . Thickness variations in Enceladus 's lithosphere is one explanation for this discrepancy . Variations in lithospheric thickness are supported by the

correlation between the Y @-@ shaped discontinuities and the V @-@ shaped cusps along the south polar terrain margin and the relative surface age of the adjacent non @-@ south polar terrain regions . The Y @-@ shaped discontinuities , and the north @-@ south trending tension fractures into which they lead , are correlated with younger terrain with presumably thinner lithospheres . The V @-@ shaped cusps are adjacent to older , more heavily cratered terrains .

= = = Internal structure = = =

Before the Cassini mission , little was known about the interior of Enceladus . However , flybys by Cassini provided information for models of Enceladus 's interior , including a better determination of the mass and shape , high @-@ resolution observations of the surface , and new insights on the interior .

Mass estimates from the Voyager program missions suggested that Enceladus was composed almost entirely of water ice . However , based on the effects of Enceladus 's gravity on Cassini , its mass was determined to be much higher than previously thought , yielding a density of 1 @.@ 61 g / cm3 . This density is higher than Saturn 's other mid @-@ sized icy satellites , indicating that Enceladus contains a greater percentage of silicates and iron .

Castillo et al . (2005) suggested that Iapetus and the other icy satellites of Saturn formed relatively quickly after the formation of the Saturnian subnebula , and thus were rich in short @-@ lived radionuclides . These radionuclides , like aluminium @-@ 26 and iron @-@ 60 , have short half @-@ lives and would produce interior heating relatively quickly . Without the short @-@ lived variety , Enceladus 's complement of long @-@ lived radionuclides would not have been enough to prevent rapid freezing of the interior , even with Enceladus 's comparatively high rock ? mass fraction , given its small size . Given Enceladus 's relatively high rock ? mass fraction , the proposed enhancement in 26Al and 60Fe would result in a differentiated body , with an icy mantle and a rocky core . Subsequent radioactive and tidal heating would raise the temperature of the core to 1 @,@ 000 K , enough to melt the inner mantle . However , for Enceladus to still be active , part of the core must have also melted , forming magma chambers that would flex under the strain of Saturn 's tides . Tidal heating , such as from the resonance with Dione or from libration , would then have sustained these hot spots in the core and would power the current geological activity .

In addition to its mass and modeled geochemistry , researchers have also examined Enceladus 's shape to determine if it is differentiated . Porco et al . (2006) used limb measurements to determine that its shape , assuming hydrostatic equilibrium , is consistent with an undifferentiated interior , in contradiction to the geological and geochemical evidence . However , the current shape also supports the possibility that Enceladus is not in hydrostatic equilibrium , and may have rotated faster at some point in the recent past (with a differentiated interior) . Gravity measurements by Cassini show that the density of the core is low , indicating that the core contains water in addition to silicates .

= = = = Subsurface water ocean = = = =

Evidence of liquid water on Enceladus began to accumulate in 2005 , when scientists observed plumes containing water vapor spewing from its south polar surface , with jets moving 250 kg of water vapor every second at up to 2 @,@ 189 km / h (1 @,@ 360 mph) into space . Soon after , in 2006 it was determined that Enceladus 's plumes are the source of Saturn 's E Ring . The sources of salty particles are uniformly distributed along the tiger stripes , whereas sources of " fresh " particles are closely related to the high @-@ speed gas jets . The " salty " particles are heavier and mostly fall back to the surface , whereas the fast " fresh " particles escape to the E ring , explaining its salt @-@ poor composition of 0 @.@ 5 ? 2 % of sodium salts by mass . The plumes ' " salty " composition indicates that the source is a salty subsurface ocean . Cassini also found traces of simple organic compounds in some dust grains .

Gravimetric data from Cassini 's December 2010 flybys showed that Enceladus likely has a liquid water ocean beneath its frozen surface , but at the time it was thought the subsurface ocean was

limited to the south pole . The top of the ocean proabably lies beneath a 30 to 40 kilometers (19 to 25 mi) thick ice shelf . The ocean may be 10 kilometers (6 @.@ 2 mi) deep at the south pole .

Measurements of Enceladus 's " wobble " as it orbits Saturn ? called libration ? suggests that the entire icy crust is detached from the rocky core and therefore that a global ocean is present beneath the surface . The amount of libration (0 @.@ 120 ° ± 0 @.@ 014 °) implies that this global ocean is about 26 to 31 kilometers deep . For comparison , Earth 's ocean has an average depth of 3 @.@ 7 kilometers .

A model suggests that Enceladus 's salty ocean (-Na , -Cl , -CO3) has an alkaline pH of 11 to 12 . The high pH is interpreted to be a consequence of serpentinization of chondritic rock that leads to the generation of H2 , a geochemical source of energy that can support both abiotic and biological synthesis of organic molecules such as those that have been detected in Enceladus 's plumes .

= = = South polar plumes = = =

Following Voyager 's encounters with Enceladus in the early 1980s , scientists postulated that it may be geologically active based on its young , reflective surface and location near the core of the E ring . Based on the connection between Enceladus and the E ring , scientists suspected that Enceladus was the source of material in the E ring , perhaps through venting of water vapor . Readings from Cassini 's 2005 passage suggested that cryovolcanism , where water and other volatiles are the materials erupted instead of silicate rock , had been discovered on Enceladus . The first Cassini sighting of a plume of icy particles above Enceladus 's south pole came from the Imaging Science Subsystem (ISS) images taken in January and February 2005 , though the possibility of a camera artifact delayed an official announcement . Data from the magnetometer instrument during the February 17 , 2005 , encounter provided a hint that the feature might be real when it found evidence for a planetary atmosphere . The magnetometer observed an increase in the power of ion cyclotron waves near Enceladus . These waves are produced by the interaction of ionized particles and magnetic fields , and the waves ' frequency can be used to identify their composition , in this case ionized water vapor . During the two following encounters , the magnetometer team determined that gases in Enceladus 's atmosphere are concentrated over the south polar region , with atmospheric density away from the pole being much lower . The Ultraviolet Imaging Spectrograph (UVIS) confirmed this result by observing two stellar occultations during the February 17 and July 14 encounters . Unlike the magnetometer , UVIS failed to detect an atmosphere above Enceladus during the February encounter when it looked over the equatorial region , but did detect water vapor during an occultation over the south polar region during the July encounter .

Fortuitously , Cassini flew through this gas cloud during the July 14 encounter , allowing instruments such as the ion and neutral mass spectrometer (INMS) and the cosmic dust analyzer (CDA) to directly sample the plume . INMS measured the composition of the gas cloud , detecting mostly water vapor , as well as traces of molecular nitrogen , methane , and carbon dioxide . The CDA " detected a large increase in the number of particles near Enceladus " , confirming Enceladus as the primary source for the E ring . Analysis of the CDA and INMS data suggest that the gas cloud Cassini flew through during the July encounter , and observed from a distance with its magnetometer and UVIS , was actually a water @-@ rich cryovolcanic plume , originating from vents near the south pole .

Visual confirmation of venting came in November 2005 , when ISS imaged geyser @-@ like jets of icy particles rising from Enceladus 's south polar region . (Although the plume was imaged before , in January and February 2005 , additional studies of the camera 's response at high phase angles , when the Sun is almost behind Enceladus , and comparison with equivalent high @-@ phase @-@ angle images taken of other Saturnian satellites , were required before this could be confirmed .) The November 2005 images showed the plume 's fine structure , revealing numerous jets (perhaps issuing from numerous distinct vents) within a larger , faint component extending out nearly 500 km from the surface . The particles have a bulk velocity of 1 @.@ 25 ± 0 @.@ 1 km / s . Cassini 's UVIS later observed gas jets coinciding with the dust jets seen by ISS during a non @-@ targeted

encounter with Enceladus in October 2007 .

Observations during a flyby on March 12 , 2008 , revealed additional chemicals in the plume , including trace amounts of simple hydrocarbons such as methane , propane , acetylene and formaldehyde . The plumes ' composition , as measured by the INMS , is similar to that seen at most comets .

The combined analysis of imaging , mass spectrometry , and magnetospheric data suggests that the observed south polar plume emanates from pressurized subsurface chambers , similar to Earth 's geysers , but the mechanism that drives and sustains the eruptions is unclear . The intensity of the eruption of the south polar jets varies significantly as a function of the position of Enceladus in its orbit . The plumes are about four times brighter when Enceladus is at apoapsis (the point in its orbit most distant from Saturn) than when it is at periapsis . This is consistent with geophysical calculations which predict the south polar fissures are under compression near periapsis , pushing them shut , and under tension near apoapsis , pulling them open .

Much of the plume activity consists of broad curtain @-@ like eruptions . Optical illusions from a combination of viewing direction and local fracture geometry previously made the plumes look like discrete jets .

= = = Possible heat sources = = =

During the flyby of July 14 , 2005 , the Composite Infrared Spectrometer (CIRS) found a warm region near the south pole . Temperatures in this region ranged from 85 ? 90 K , with small areas showing as high as 157 K (? 116 ° C) , much too warm to be explained by solar heating , indicating that parts of the south polar region are heated from the interior of Enceladus . The presence of a subsurface ocean under the south polar region is now accepted , but it cannot explain the source of the heat , with an estimated heat flux of 200 mW / m2 , which is about 10 times higher than that from radiogenic heating alone .

Several explanations for the observed elevated temperatures and the resulting plumes have been proposed , including venting from a subsurface reservoir of liquid water , sublimation of ice , decompression and dissociation of clathrates , and shear heating , but a complete explanation of all the heat sources causing the observed thermal power output of Enceladus has not yet been settled .

Heating in Enceladus has occurred through various mechanisms ever since its formation . Radioactive decay in its core may have initially heated it , giving it a warm core and a subsurface ocean , which is now kept above freezing through an unidentified mechanism . Geophysical models indicate that tidal heating is a main heat source , perhaps aided by radioactive decay and some heat @-@ producing chemical reactions . A 2007 study predicted the internal heat of Enceladus , if generated by tidal forces , could be no greater than 1 @.@ 1 gigawatts , but data from Cassini 's infrared spectrometer of the south polar terrain over 16 months , indicate that the internal heat generated power is about 4 @.@ 7 gigawatts , and suggest that it is in thermal equilibrium .

The observed power output of 4 @.@ 7 gigawatts is challenging to explain from tidal heating alone , so the main source of heat remains a mystery . Most scientists think the observed heat flux of Enceladus is not enough to maintain the subsurface ocean , and therefore any subsurface ocean must be a remnant of a period of higher eccentricity and tidal heating , or the heat is produced through another mechanism .

= = = = Tidal heating = = = =

Tidal heating occurs through the tidal friction processes : orbital and rotational energy are dissipated as heat in the crust of an object . In addition , to the extent that tides produce heat along fractures , libration may affect the magnitude and distribution of such tidal shear heating . Tidal dissipation of Enceladus 's ice crust is significant because Enceladus has a subsurface ocean . Scientific models of heating on Enceladus suggest that despite the increased heat from tidal dissipation , the total observed heating of Enceladus is not enough to maintain a subsurface ocean

for more than 30 million years (Enceladus is billions of years old) , even if the ocean contains other chemical components that lower its freezing point . It is thought that if Enceladus had a more eccentric orbit in the past , the enhanced tidal forces could be sufficient to maintain a subsurface ocean , such that a periodic enhancement in eccentricity could maintain a subsurface ocean that periodically changes in size . Previous models suggest that resonant perturbations of Dione could provide the necessary periodic eccentricity changes to maintain the subsurface ocean of Enceladus , if the ocean contains a substantial amount of ammonia . The surface of Enceladus indicates that the entire moon has experienced periods of enhanced heat flux in the past .

= = = = Radioactive heating = = = =

The " hot start " model of heating suggests Enceladus began as ice and rock that contained rapidly decaying short @-@ lived radioactive isotopes of aluminium , iron and manganese . Enormous amounts of heat were then produced as these isotopes decayed for about 7 million years , resulting in the consolidation of rocky material at the core surrounded by a shell of ice . Although the heat from radioactivity would decrease over time , the combination of radioactivity and tidal forces from Saturn 's gravitational tug could prevent the subsurface ocean from freezing . The present @-@ day radiogenic heating rate is 3 @.@ 2 × 1015 ergs / s , assuming Enceladus has a composition of ice , iron and silicate materials . Heating from long @-@ lived radioactive isotopes uranium U238 , U235 , thorium Th232 and potassium K40 inside Enceladus would add 0 @.@ 3 gigawatts to the observed heat flux . The presence of Enceladus 's regionally thick subsurface ocean suggests a heat flux ~ 10 times higher than that from radiogenic heating in the silicate core .

= = = = Chemistry = = = =

Because no ammonia was initially found in the vented material by INMS or UVIS , which could act as an anti @-@ freeze , it was thought such a heated , pressurized chamber would consist of nearly pure liquid water with a temperature of at least 270 K (? 3 ° C) , because pure water requires more energy to melt . In July 2009 it was announced that traces of ammonia had been found in the plumes during flybys in July and October 2008 . Reducing the freezing point of water with ammonia would also allow for outgassing and higher gas pressure , and less heat required to power the water plumes . The subsurface layer heating the surface water ice could be an ammonia ? water slurry at temperatures as low as 170 K (? 103 ° C) , and thus less energy is required to produce the plume activity . However , the observed 4 @.@ 7 gigawatts heat flux is enough to power the cryovolcanism without the presence of ammonia .

= = Shape and size = =

Enceladus is a relatively small satellite composed of ice and rock . It is a scalene ellipsoid in shape ; its diameters , calculated from images taken by Cassini 's ISS (Imaging Science Subsystem) instrument , are 513 km between the sub- and anti @-@ Saturnian poles , 503 km between the leading and trailing hemispheres , and 497 km between the north and south poles . Enceladus is only one @-@ seventh the diameter of Earth 's Moon . It ranks sixth in both mass and size among the satellites of Saturn , after Titan (5 @,@ 150 km) , Rhea (1 @,@ 530 km) , Iapetus (1 @,@ 440 km) , Dione (1 @,@ 120 km) and Tethys (1 @,@ 050 km) .

= = Origin = =

= = = Mimas ? Enceladus paradox = = =

Mimas , the innermost of the round moons of Saturn and directly interior to Enceladus , is a geologically dead body , even though it should experience stronger tidal forces than Enceladus .

This apparent paradox can be explained in part by temperature @-@ dependent properties of water ice (the main constituent of the interiors of Mimas and Enceladus) . The tidal heating per unit mass is given by the formula <formula> , where ? is the (mass) density of the satellite , n is its mean orbital motion , r is the satellite 's radius , e is the orbital eccentricity of the satellite , ? is the shear modulus and Q is the dimensionless dissipation factor . For a same @-@ temperature approximation , the expected value of qtid for Mimas is about 40 times that of Enceladus . However , the material parameters ? and Q are temperature dependent . At high temperatures (close to the melting point) , ? and Q are low , so tidal heating is high . Modeling suggests that for Enceladus , both a ' basic ' low @-@ energy thermal state with little internal temperature gradient , and an ' excited ' high @-@ energy thermal state with a significant temperature gradient , and consequent convection (endogenic geologic activity) , once established , would be stable . For Mimas , only a low @-@ energy state is expected to be stable , despite its being closer to Saturn . So the model predicts a low @-@ internal @-@ temperature state for Mimas (values of ? and Q are high) but a possible higher @-@ temperature state for Enceladus (values of ? and Q are low) . Additional historical information is needed to explain how Enceladus first entered the high @-@ energy state (e.g. more radiogenic heating or a more eccentric orbit in the past) .

The significantly higher density of Enceladus relative to Mimas (1 @.@ 61 vs. 1 @.@ 15 g / cm3) , implying a larger content of rock and more radiogenic heating in its early history , has also been cited as an important factor in resolving the Mimas paradox .

It has been suggested that for an icy satellite the size of Mimas or Enceladus to enter an ' excited state ' of tidal heating and convection , it would need to enter an orbital resonance before it lost too much of its primordial internal heat . Because Mimas , being smaller , would cool more rapidly than Enceladus , its window of opportunity for initiating orbital resonance @-@ driven convection would have been considerably shorter .

= = = Proto @-@ Enceladus hypothesis = = =

Enceladus is losing mass at a rate of 200 kg / second . If mass loss at this rate continued for 4 @.@ 5 Gyr , the satellite would have lost approximately 30 % of its initial mass . A similar value is obtained by assuming that the initial densities of Enceladus and Mimas were equal . It suggests that tectonics in the south polar region is probably mainly related to subsidence and associated subduction caused by the process of mass loss .

= = = Date of formation = = =

In 2016 , a study of how the orbits of Saturn 's moons should have changed due to tidal effects suggested that all of Saturn 's satellites inward of Titan , including Enceladus (whose geologic activity was used to derive the strength of tidal effects on Saturn 's satellites) , may have formed as little as 100 million years ago .

= = Potential habitability = =

Enceladus ejects plumes of salt water that are laced with grains of silica @-@ rich sand , nitrogen (in ammonia) , nutrients and organic molecules , including trace amounts of simple hydrocarbons such as methane (CH
4) , propane (C
3H
8) , acetylene (C
2H
2) and formaldehyde (CH
2O) , which are carbon @-@ bearing molecules . This indicates that hydrothermal activity ? an energy source ? may be at work in Enceladus 's subsurface ocean . In addition , models indicate the large rocky core is porous , allowing water to flow through it to pick up heat .

Molecular hydrogen (H
2) , a geochemical source of energy that can be metabolized by methanogen microbes to provide energy for life , could be present if , as models suggest , Enceladus 's salty ocean has an alkaline pH from serpentinization of chondritic rock .

The presence of an internal global salty ocean with an aquatic environment supported by global ocean circulation patterns , with an energy source and simple organic compounds in contact with Enceladus 's rocky core , may advance the study of astrobiology and the study of potentially habitable environments for microbial extraterrestrial life . Therefore , several robotic missions have been proposed to further explore Enceladus and assess its habitability ; some of the proposed missions are : Journey to Enceladus and Titan , Enceladus Explorer , Enceladus Life Finder , and Life Investigation For Enceladus .

= = Exploration = =

= = = Voyager missions = = =

The two Voyager spacecraft made the first close @-@ up images of Enceladus . Voyager 1 was the first to fly past Enceladus , at a distance of 202 @,@ 000 km on November 12 , 1980 . Images acquired from this distance had very poor spatial resolution , but revealed a highly reflective surface devoid of impact craters , indicating a youthful surface . Voyager 1 also confirmed that Enceladus was embedded in the densest part of Saturn 's diffuse E ring . Combined with the apparent youthful appearance of the surface , Voyager scientists suggested that the E ring consisted of particles vented from Enceladus 's surface .

Voyager 2 passed closer to Enceladus (87 @,@ 010 km) on August 26 , 1981 , allowing higher @-@ resolution images to be obtained . These images showed a young surface . They also revealed a surface with different regions with vastly different surface ages , with a heavily cratered mid- to high @-@ northern latitude region , and a lightly cratered region closer to the equator . This geologic diversity contrasts with the ancient , heavily cratered surface of Mimas , another moon of Saturn slightly smaller than Enceladus . The geologically youthful terrains came as a great surprise to the scientific community , because no theory was then able to predict that such a small (and cold , compared to Jupiter 's highly active moon Io) celestial body could bear signs of such activity .

= = = Cassini = = =

The answers to many remaining mysteries of Enceladus had to wait until the arrival of the Cassini spacecraft on July 1 , 2004 , when it entered orbit around Saturn . Given the results from the Voyager 2 images , Enceladus was considered a priority target by the Cassini mission planners , and several targeted flybys within 1 @,@ 500 km of the surface were planned as well as numerous , " non @-@ targeted " opportunities within 100 @,@ 000 km of Enceladus . The flybys have yielded significant information concerning Enceladus 's surface , as well as the discovery of water vapor with traces of simple hydrocarbons venting from the geologically active south polar region . These discoveries prompted the adjustment of Cassini 's flight plan to allow closer flybys of Enceladus , including an encounter in March 2008 that took it to within 48 km of the surface . Cassini 's extended mission included seven close flybys of Enceladus between July 2008 and July 2010 , including two passes at only 50 km in the later half of 2008 . Cassini performed a flyby on October 28 , 2015 , passing as close as 49 km (30 mi) and through a plume . Confirmation of molecular hydrogen (H
2) would be an independent line of evidence that hydrothermal activity is taking place in the Enceladus seafloor , increasing its habitability .

Cassini has provided strong evidence that Enceladus has an ocean with an energy source , nutrients and organic molecules , making Enceladus one of the best places for the study of potentially habitable environments for extraterrestrial life . By contrast , the water thought to be on Jupiter 's moon Europa is located under a much thicker layer of ice .

= = = Proposed mission concepts = = =

The discoveries Cassini has made at Enceladus have prompted studies into follow @-@ up mission concepts , including a flyby plume sample @-@ return mission by NASA , a probe flyby (Journey to Enceladus and Titan or JET) to analyze plume contents in @-@ situ , a lander by the German Aerospace Center to study the habitability potential of its subsurface ocean (Enceladus Explorer) , and two astrobiology @-@ oriented mission concepts (the Enceladus Life Finder and Life Investigation For Enceladus) . The European Space Agency (ESA) is also assessing concepts to send a probe to Enceladus in a mission to be combined with studies of Titan : TandEM (Titan and Enceladus Mission) .

Additionally , the Titan Saturn System Mission (TSSM) was a joint NASA / ESA flagship @-@ class proposal for exploration of Saturn 's moons , with a focus on Enceladus . TSSM was competing against the Europa Jupiter System Mission (EJSM) proposal for funding . In February 2009 , it was announced that NASA / ESA had given the EJSM mission priority ahead of TSSM , although TSSM will continue to be studied and evaluated .

2006 GSFC NASA Academy : ' EAGLE ' study
2006 NASA : ' Billion Dollar Box ' study
2007 NASA : ' Enceladus Flagship ' study
2007 ESA : Titan and Enceladus Mission (TandEM)
2007 JPL : Enceladus RMA Study
2008 NASA / ESA : Titan Saturn System Mission (TSSM)
2010 PSDS Decadal Survey : Enceladus Studies including the Enceladus Orbiter
2010 JPL : Journey to Enceladus and Titan (JET)
2012 DLR : Enceladus Explorer (EnEx) lander , employing the IceMole
2012 JPL : Life Investigation For Enceladus (LIFE)
2015 JPL : Enceladus Life Finder (ELF)