What does chemical weathering mean in biology

There are three types of weathering which affect rock: physical, biological, and chemical. Chemical weathering, also known as decomposition or decay, is the breakdown of rock by chemical mechanisms. Chemical weathering does not break rocks into smaller fragments through wind, water, and ice (that's physical weathering). Nor does it break rocks apart through the action of plants or animals (that's biological weathering). Instead, it changes the chemical composition of the rock, usually through carbonation, hydration, hydrolysis or oxidation. Chemical weathering alters the composition of the rock material toward surface minerals, such as clay. It attacks minerals that are relatively unstable in surface conditions, such as the primary minerals of igneous rocks like basalt, granite or peridotite. It can also occur in sedimentary and metamorphic rocks and is an element of corrosion or chemical erosion. Water is especially effective at introducing chemically active agents by way of fractures and causing rocks to crumble piecemeal. Water may also loosen thin shells of material (in spheroidal weathering). Chemical weathering may include shallow, low-temperature alteration. Let's take a look at the four main types of chemical weathering that were mentioned earlier. It should be noted that these are not the only forms, just the most common. Carbonation occurs when rain, which is naturally slightly acidic due to atmospheric carbon dioxide (CO_2), combines with a calcium carbonate ($CaCO_3$), such as limestone or chalk. The interaction forms calcium bicarbonate, or $Ca(HCO_3)_2$. Rain has a normal pH level of 5.0-5.5, which alone is acidic enough to cause a chemical reaction. Acid rain, which is unnaturally acidic from atmospheric pollution, has a pH level of 4 (a lower number indicates greater acidity while a higher number indicates greater basicity). Carbonation, sometimes referred to as dissolution, is the driving force behind the sinkholes, caverns and underground rivers of karst topography. Hydration occurs when water reacts with an anhydrous mineral, creating a new mineral. The water is added to the crystalline structure of a mineral, which forms a hydrate. Anhydrite, which means "waterless stone," is a calcium sulfate ($CaSO_4$) that is usually found in underground settings. When exposed to water near the surface, it quickly becomes gypsum, the softest mineral on the Mohs hardness scale. Hydrolysis is the opposite of hydration; in this case, water breaks down the chemical bonds of a mineral instead of creating a new material. It is a decomposition reaction. The name makes this one particularly easy to remember: The prefix "hydro-" means water, while the suffix "-lysis" means decomposition, breakdown or separation. Oxidation refers to the reaction of oxygen with metal elements in a rock, forming oxides. An easily recognizable example of this is rust. Iron (steel) reacts easily with oxygen, turning into reddish-brown iron oxides. This reaction is responsible for the red surface of Mars and the red color of hematite and magnetite, two other common oxides. Deterioration of rocks and other minerals through exposure to the elements This article is about weathering of rocks and minerals. For weathering of polymers, see Polymer degradation and Weather testing of polymers. Part of a series onGeologyScience of the solid Earth Index Outline Category Glossary History (Timeline) Key components Minerals Rock (Igneous Sedimentary Metamorphic) Bedrock Plate tectonics Strata Weathering Erosion Geologic time scale Laws, principles, theories Stratigraphic principles Principle of original horizontality Law of superposition Principle of lateral continuity Principle of cross-cutting relationships Principle of faunal succession Principle of inclusions and components Walther's law Topics Composition Geochemistry Mineralogy Sedimentology Petrology Structure of Earth Landform structures Geomorphology Glaciology Structural geology Volcanology Geologic history Geological history of Earth Research Branches of geology Geologist (List) Methods Geological survey Applications Engineering Mining Forensics Military Planetary geology Lists of geological features of the Solar System Geology of solar terrestrial planets By planet and body Mercury Venus Moon Mars Vesta Ceres Io Titan Pluto Charon Geology portalv t e A natural arch produced by erosion of differentially weathered rock in Jebel Kharaz (Jordan). Weathering is the deterioration of rocks, soils and minerals as well as wood and artificial materials through contact with water, atmospheric gases, and biological organisms. Weathering occurs in situ (on site, with little or no movement), and should not be confused with erosion, which involves the transport of rocks and minerals by agents such as water, ice, snow, wind, waves and gravity. Weathering processes are divided into physical and chemical weathering. Physical weathering involves the breakdown of rocks and soils through the mechanical effects of heat, water, ice, or other agents. Chemical weathering involves the chemical reaction of water, atmospheric gases, and biologically produced chemicals with rocks and soils. Water is the principal agent behind both physical and chemical weathering,[1] though atmospheric oxygen and carbon dioxide and the activities of biological organisms are also important.[2] Chemical weathering by biological action is also known as biological weathering.[3] The materials left over after the rock breaks down combine with organic material to create soil. Many of Earth's landforms and landscapes are the result of weathering processes combined with erosion and re-deposition. Weathering is a crucial part of the rock cycle, and sedimentary rock, formed from the weathering products of older rock, covers 66% of the Earth's continents and much of its ocean floor.[4] Physical weathering Physical weathering, also called mechanical weathering or disaggregation, is the class of processes that causes the disintegration of rocks without chemical change. It is usually much less important than chemical weathering, but can be significant in subarctic or alpine environments.[5] Furthermore, chemical and physical weathering often go hand in hand. For example, cracks extended by physical weathering will increase the surface area exposed to chemical action, thus amplifying the rate of disintegration.[6] Frost weathering is the most important form of physical weathering. Next in importance is wedging by plant roots, which sometimes enter cracks in rocks and pry them apart. The burrowing of worms or other animals may also help disintegrate rock, as can "plucking" by lichens.[7] Frost weathering A rock in Abisko, Sweden fractured along existing joints possibly by frost weathering or thermal stress. Main article: Frost weathering Frost weathering is the collective name for those forms of physical weathering that are caused by the formation of ice within rock outcrops. It was long believed that the most important of these is frost wedging, which results from the expansion of pore water when it freezes. However, a growing body of theoretical and experimental work suggests that ice segregation, in which supercooled water migrates to lenses of ice forming within the rock, is the more important mechanism.[8][9] When water freezes, its volume increases by 9.2%. This expansion can theoretically generate pressures greater than 200 megapascals (29,000 psi), though a more realistic upper limit is 14 megapascals (2,000 psi). This is still much greater than the tensile strength of granite, which is about 4 megapascals (580 psi). This makes frost wedging, in which pore water freezes and its volumetric expansion fractures the enclosing rock, appear to be a plausible mechanism for frost weathering. However, ice will simply expand out of a straight, open fracture before it can generate significant pressure. Thus frost wedging can only take place in small, tortuous fractures.[5] The rock must also be almost completely saturated with water, or the ice will simply expand into the air spaces in the unsaturated rock without generating much pressure. These conditions are unusual enough that frost wedging is unlikely to be the dominant process of frost weathering.[10] Frost wedging is most effective where there are daily cycles of melting and freezing of water-saturated rock, so it is unlikely to be significant in the tropics, in polar regions, or in arid climates.[5] Ice segregation is a less well characterized mechanism of physical weathering.[8] It takes place because ice grains always have a surface layer, often just a few molecules thick, that resembles liquid water more than solid ice, even at temperatures well below the freezing point. This premelted liquid layer has unusual properties, including a strong tendency to draw in water by capillary action from warmer parts of the rock. This results in growth of the ice grain that puts considerable pressure on the surrounding rock,[11] up to ten times greater than is likely with frost wedging. This mechanism is most effective in rock whose temperature averages just below the freezing point, −4 to −15 °C (25 to 5 °F). Ice segregation results in growth of ice needles and ice lenses within fractures in the rock, and parallel to the rock surface, that gradually pry the rock apart.[9] Thermal stress Thermal stress weathering results from the expansion and contraction of rock due to temperature changes. Thermal stress weathering is most effective when the heated portion of the rock is buttressed by surrounding rock, so that it is free to expand in only one direction.[12] Thermal stress weathering comprises two main types, thermal shock and thermal fatigue. Thermal shock takes place when the stresses are so great that the rock cracks immediately, but this is uncommon. More typical is thermal fatigue, in which the stresses are not great enough to cause immediate rock failure, but repeated cycles of stress and release gradually weaken the rock.[12] Thermal stress weathering is an important mechanism in deserts, where there is a large diurnal temperature range, hot in the day and cold at night.[13] As a result, thermal stress weathering is sometimes called insolation weathering, but this is misleading. Thermal stress weathering can be caused by any large change of temperature, and not just intense solar heating. It is likely as important in cold climates as in hot, arid climates.[12] Wildfires can also be a significant cause of rapid weathering of rocks.[14] The importance of thermal stress weathering has long been discounted by geologists,[5][9] based on experiments in the early 20th century that seemed to show that its effects were unimportant. These experiments have since been criticized as unrealistic, since the rock samples were small, were polished (which reduces nucleation of fractures), and were not buttressed. These small samples were thus able to expand freely in all directions when heated in experimental ovens, which failed to produce the kinds of stress likely in natural settings. The experiments were also more sensitive to thermal shock than thermal fatigue, but thermal fatigue is likely the more important mechanism in nature. Geomorphologists have begun to reemphasize the importance of thermal stress weathering, particularly in cold climates.[12] Pressure release See also: Erosion and tectonics Pressure release could have caused the exfoliated granite sheets shown in the picture. Pressure release or unloading is a form of physical weathering seen when deeply buried rock is exhumed. Intrusive igneous rocks, such as granite, are formed deep beneath the Earth's surface. They are under tremendous pressure because of the overlying rock material. When erosion removes the overlying rock material, these intrusive rocks are exposed and the pressure on them is released. The outer parts of the rocks then tend to expand. The expansion sets up stresses which cause fractures parallel to the rock surface to form. Over time, sheets of rock break away from the exposed rocks along the fractures, a process known as exfoliation. Exfoliation due to pressure release is also known as sheeting.[15] As with thermal weathering, pressure release is most effective in buttressed rock. Here the differential stress directed toward the unbuttressed surface can be as high as 35 megapascals (5,100 psi), easily enough to shatter rock. This mechanism is also responsible for spalling in mines and quarries, and for the formation of joints in rock outcrops.[16] Retreat of an overlying glacier can also lead to exfoliation due to pressure release. This can be enhanced by other physical wearing mechanisms.[17] Salt-crystal growth Tafoni at Salt Point State Park, Sonoma County, California. Main article: Haloclasty "Salt wedging" redirects here. Not to be confused with Salt wedge (hydrology). Salt crystallization (also known as salt weathering, salt wedging or haloclasty) causes disintegration of rocks when saline solutions seep into cracks and joints in the rocks and evaporate, leaving salt crystals behind. As with ice segregation, the surfaces of the salt grains draw in additional dissolved salts through capillary action, causing the growth of salt lenses that exert high pressure on the surrounding rock. Sodium and magnesium salts are the most effective at producing salt weathering. Salt weathering can also take place when pyrite in sedimentary rock is chemically weathered to iron(II) sulfate and gypsum, which then crystallize as salt lenses.[9] Salt crystallization can take place wherever salts are concentrated by evaporation. It is thus most common in arid climates where strong heating causes strong evaporation and along coasts.[18] Salt weathering is likely important in the formation of tafoni, a class of cavernous rock weathering structures.[19] Biological effects on mechanical weathering Main article: Bioerosion Lichens growing on concrete Living organisms may contribute to mechanical weathering, as well as chemical weathering (see § Biological weathering below). Lichens and mosses grow on essentially bare rock surfaces and create a more humid chemical microenvironment. The attachment of these organisms to the rock surface enhances physical as well as chemical breakdown of the surface microlayer of the rock. Lichens have been observed to pry mineral grains loose from bare shale with their hyphae (rootlike attachment structures), a process described as plucking,[15] and to pull the fragments into their body, where the fragments then undergo a process of chemical weathering not unlike digestion.[19] On a larger scale, seedlings sprouting in a crevice and plant roots exert physical pressure as well as providing a pathway for water and chemical infiltration.[7] Chemical weathering Comparison of unweathered (left) and weathered (right) limestone. Most rock forms at elevated temperature and pressure, and the minerals making up the rock are often chemically unstable in the relatively cool, wet, and oxidizing conditions typical of the Earth's surface. Chemical weathering takes place when water, oxygen, carbon dioxide, and other chemical substances react with rock to change its composition. These reactions convert some of the original primary minerals in the rock to secondary minerals, remove other substances as solutes, and leave the most stable minerals as a chemically unchanged resistate. In effect, chemical weathering changes the original set of minerals in the rock into a new set of minerals that is in closer equilibrium with surface conditions. However, true equilibrium is rarely reached, because weathering is a slow process, and leaching carries away solutes produced by weathering reactions before they can accumulate to equilibrium levels. This is particularly true in tropical environments.[20] Water is the principal agent of chemical weathering, converting many primary minerals to clay minerals or hydrated oxides via reactions collectively described as hydrolysis. Oxygen is also important, acting to oxidize many minerals, as is carbon dioxide, whose weathering reactions are described as carbonation.[21] The process of mountain block uplift is important in exposing new rock strata to the atmosphere and moisture, enabling important chemical weathering to occur; significant release occurs of Ca^{2+} and other ions into surface waters.[22] Dissolution Limestone core samples at different stages of chemical weathering (due to tropical rain and underground water), from very high at shallow depths (bottom) to very low at greater depths (top). Slightly weathered limestone shows brownish stains, while highly weathered limestone loses much of its carbonate mineral content, leaving behind clay. Underground limestone from the carbonate West Congolian deposit in Kimpese, Democratic Republic of Congo. Dissolution (also called simple solution or congruent dissolution) is the process in which a mineral dissolves completely without producing any new solid substance.[23] Rainwater easily dissolves soluble minerals, such as halite or gypsum, but can also dissolve highly resistant minerals such as quartz, given sufficient time.[24] Water breaks the bonds between atoms in the crystal:[25] The overall reaction for dissolution of quartz is $SiO_2 + 2H_2O \rightarrow H_4SiO_4$ The dissolved quartz takes the form of silicic acid. A particularly important form of dissolution is carbonate dissolution, in which atmospheric carbon dioxide enhances solution weathering. Carbonate dissolution affects rocks containing calcium carbonate, such as limestone and chalk. It takes place when rainwater combines with carbon dioxide to form carbonic acid, a weak acid, which dissolves calcium carbonate (limestone) and forms soluble calcium bicarbonate. Despite a slower reaction kinetics, this process is thermodynamically favored at low temperature, because colder water holds more dissolved carbon dioxide gas (due to the retrograde solubility of gases). Carbonate dissolution is therefore an important feature of glacial weathering.[26] Carbonate dissolution involves the following steps: $CO_2 + H_2O \rightarrow H_2CO_3$ carbon dioxide + water → carbonic acid $H_2CO_3 + CaCO_3 \rightarrow Ca(HCO_3)_2$ carbonic acid + calcium carbonate → calcium bicarbonate Carbonate dissolution on the surface of well-jointed limestone produces a dissected limestone pavement. This process is most effective along the joints, widening and deepening them.[27] In unpolluted environments, the pH of rainwater due to dissolved carbon dioxide is around 5.6. Acid rain occurs when gases such as sulfur dioxide and nitrogen oxides are present in the atmosphere. These oxides react in the rain water to produce stronger acids and can lower the pH to 4.5 or even 3.0. Sulfur dioxide, SO_2, comes from volcanic eruptions or from fossil fuels, can become sulfuric acid within rainwater, which can cause solution weathering to the rocks on which it falls.[28] Hydrolysis and carbonation Olivine weathering to iddingsite within a mantle xenolith. Hydrolysis (also called incongruent dissolution) is a form of chemical weathering in which only part of a mineral is taken into solution. The rest of the mineral is transformed into a new solid material, such as a clay mineral.[29] For example, forsterite (magnesium olivine) is hydrolyzed into solid brucite and dissolved silicic acid: $Mg_2SiO_4 + 4 H_2O \rightleftharpoons 2 Mg(OH)_2 + H_4SiO_4$ forsterite + water ⇌ brucite + silicic acid Most hydrolysis during weathering of minerals is acid hydrolysis, in which protons (hydrogen ions), which are present in acidic water, attack chemical bonds in mineral crystals.[30] The bonds between different cations and oxygen ions in minerals differ in strength, and the weakest are attacked first. The result is that minerals in igneous rock weather in roughly the same order in which they were originally formed (Bowen's Reaction Series).[31] Relative bond strength is shown in the following table:[25] Bond Relative strength Si–O 2.4 Ti–O 1.8 Al–O 1.65 Fe+3–O 1.4 Mg–O 0.9 Fe+2–O 0.85 Mn–O 0.8 Ca–O 0.7 Na–O 0.35 K–O 0.25 This table is only a rough guide to order of weathering. Some minerals, such as illite, are unusually stable, while silica is unusually unstable given the strength of the silicon–oxygen bond.[32] Carbon dioxide that dissolves in water to form carbonic acid is the most important source of protons, but organic acids are also important natural sources of acidity.[33] Acid hydrolysis from dissolved carbon dioxide is sometimes described as carbonation, and can result in weathering of the primary minerals to secondary carbonate minerals.[34] For example, weathering of forsterite can produce magnesite instead of brucite via the reaction: $Mg_2SiO_4 + 2 CO_2 + 2 H_2O \rightleftharpoons 2 MgCO_3 + H_4SiO_4$ forsterite + carbon dioxide + water ⇌ magnesite + silicic acid in solution Carbonic acid is consumed by silicate weathering, resulting in more alkaline solutions because of the bicarbonate. This is an important reaction in controlling the amount of CO_2 in the atmosphere and can affect climate.[35] Aluminosilicates containing highly soluble cations, such as sodium or potassium ions, will release the cations as dissolved bicarbonates during acid hydrolysis: $2 KAlSi_3O_8 + 2 H_2CO_3 + 9 H_2O \rightleftharpoons Al_2Si_2O_5(OH)_4 + 4 H_4SiO_4 + 2 K^+ + 2 HCO_3^-$ orthoclase (aluminosilicate feldspar) + carbonic acid + water ⇌ kaolinite (a clay mineral) + silicic acid in solution + potassium and bicarbonate ions in solution Oxidation A pyrite cube has dissolved away from host rock, leaving gold particles behind. Oxidized pyrite cubes. Within the weathering environment, chemical oxidation of a variety of metals occurs. The most commonly observed is the oxidation of Fe^{2+} (iron) by oxygen and water to form Fe^{3+} oxides and hydroxides such as goethite, limonite, and hematite. This gives the affected rocks a reddish-brown coloration on the surface which crumbles easily and weakens the rock. Many other metallic ores and minerals oxidize and hydrate to produce colored deposits, as does sulfur during the weathering of sulfide minerals such as chalcopyrites or $CuFeS_2$ oxidizing to copper hydroxide and iron oxides.[36] Hydration Mineral hydration is a form of chemical weathering that involves the rigid attachment of water molecules or H+ and OH- ions to the atoms and molecules of a mineral. No significant dissolution takes place. For example, iron oxides are converted to iron hydroxides and the hydration of anhydrite forms gypsum.[37] Bulk hydration of minerals is secondary in importance to dissolution, hydrolysis, and oxidation,[36] but hydration of the crystal surface is the crucial first step in hydrolysis. A fresh surface of a mineral crystal exposes ions whose electrical charge attracts water molecules. Some of these molecules break into H+ that bonds to exposed anions (usually oxygen) and OH- that bonds to exposed cations. This further disrupts the surface, making it susceptible to various hydrolysis reactions. Additional protons replace cations exposed on the surface, freeing the cations as solutes. As cations are removed, silicon-oxygen and silicon-aluminium bonds become more susceptible to hydrolysis, freeing silicic acid and aluminium hydroxides to be leached away or to form clay minerals.[32][38] Laboratory experiments show that weathering of feldspar crystals begins at dislocations or other defects on the surface of the crystal, and that the weathering layer is only a few atoms thick. Diffusion within the mineral grain does not appear to be significant.[39] A freshly broken rock shows differential chemical weathering (probably mostly oxidation) progressing inward. This piece of sandstone was found in glacial drift near Angelica, New York. Biological weathering Mineral weathering can also be initiated or accelerated by soil microorganisms. Soil organisms make up about 10 mg/cm3 of typical soils, and laboratory experiments have demonstrated that albite and muscovite weather twice as fast in live versus sterile soil. Lichens on rocks are among the most effective biological agents of chemical weathering.[33] For example, an experimental study on hornblende granite in New Jersey, USA, demonstrated a 3x – 4x increase in weathering rate under lichen covered surfaces compared to recently exposed bare rock surfaces.[40] Biological weathering of basalt by lichen, La Palma. The most common forms of biological weathering result from the release of chelating compounds (such as certain organic acids and siderophores) and of carbon dioxide and organic acids by plants. Roots can build up the carbon dioxide level to 30% of all soil gases, aided by adsorption of CO_2 on clay minerals and the very slow diffusion rate of CO_2 out of the soil.[41] The CO_2 and organic acids help break down aluminium- and iron-containing compounds in the soils beneath them. Roots have a negative electrical charge balanced by protons in the soil next to the roots, and these can be exchanged for essential nutrient cations such as potassium.[42] Decaying remains of dead plants in soil may form organic acids which, when dissolved in water, cause chemical weathering.[43] Chelating compounds, mostly low molecular weight organic acids, are capable of removing metal ions from bare rock surfaces, with aluminium and silicon being particularly susceptible.[44] The ability to break down bare rock allows lichens to be among the first colonizers of dry land.[45] The accumulation of chelating compounds can easily affect surrounding rocks and soils, and may lead to podsolisation of soils.[46][47] The symbiotic mycorrhizal fungi associated with tree root systems can release inorganic nutrients from minerals such as apatite or biotite and transfer these nutrients to the trees, thus contributing to tree nutrition.[48] It was also recently evidenced that bacterial communities can impact mineral stability leading to the release of inorganic nutrients.[49] A large range of bacterial strains or communities from diverse genera have been reported to be able to colonize mineral surfaces or to weather minerals, and for some of them a plant growth promoting effect has been demonstrated.[50] The demonstrated or hypothesised mechanisms used by bacteria to weather minerals include several oxidoreduction and dissolution reactions as well as the production of weathering agents, such as protons, organic acids and chelating molecules. Weathering on the ocean floor Weathering of basaltic oceanic crust differs in important respects from weathering in the atmosphere. Weathering is relatively slow, with basalt becoming less dense, at a rate of about 15% per 100 million years. The basalt becomes hydrated, and is enriched in total and ferric iron, magnesium, and sodium at the expense of silica, titanium, aluminum, ferrous iron, and calcium.[51] Building weathering Concrete damaged by acid rain. Buildings made of any stone, brick or concrete are susceptible to the same weathering agents as any exposed rock surface. Also statues, monuments and ornamental stonework can be badly damaged by natural weathering processes. This is accelerated in areas severely affected by acid rain.[52] Accelerated building weathering may be a threat to the environment and occupant safety. Design strategies can moderate the impact of environmental effects, such as using of pressure-moderated rain screening, ensuring that the HVAC system is able to effectively control humidity accumulation and selecting concrete mixes with reduced water content to minimize the impact of freeze-thaw cycles. [53] Properties of well-weathered soils Granitic rock, which is the most abundant crystalline rock exposed at the Earth's surface, begins weathering with destruction of hornblende. Biotite then weathers to vermiculite, and finally oligoclase and microcline are destroyed. All are converted into a mixture of clay minerals and iron oxides.[31] The resulting soil is depleted in calcium, sodium, and ferrous iron compared with the bedrock, and magnesium is reduced 40% and silicon by 15%. At the same time, the soil is enriched in aluminium and potassium, by at least 50%; by titanium, whose abundance triples; and by ferric iron, whose abundance increases by an order of magnitude compared with the bedrock.[54] Basaltic rock is more easily weathered than granitic rock, due to its formation at higher temperatures and drier conditions. The fine grain size and presence of volcanic glass also hasten weathering. In tropical settings, it rapidly weathers to clay minerals, aluminium hydroxides, and titanium-enriched iron oxides. Because most basalt is relatively poor in potassium, the basalt weathers directly to potassium-poor montmorillonite, then to kaolinite. Where leaching is continuous and intense, as in rain forests, the final weathering product is bauxite, the principal ore of aluminium. Where rainfall is intense but seasonal, as in monsoon climates, the final weathering product is iron- and titanium-rich laterite. [55] Conversion of kaolinite to bauxite occurs only with intense leaching, as ordinary river water is in equilibrium with kaolinite.[56] Soil formation requires between 100 and 1000 years, a very brief interval in geologic time. As a result, some formations show numerous paleosol (fossil soil) beds. For example, the Willwood Formation of Wyoming contains over 1000 paleosol layers in a 770 meters (2,530 ft) section representing 3.5 million years of geologic time. Paleosols have been identified in formations as old as Archean (over 2.5 billion years in age). However, paleosols are difficult to recognize in the geologic record.[57] Indications that a sedimentary bed is a paleosol include a gradational lower boundary and sharp upper boundary, the presence of much clay, poor sorting with few sedimentary structures, rip-up clasts in overlying beds, and desiccation cracks containing material from higher beds.[58] The degree of weathering of a soil can be expressed as the chemical index of alteration, defined as 100 $Al_2O_3/(Al_2O_3 + CaO + Na_2O + K_2O)$. This varies from 47 for unweathered upper crust rock to 100 for fully weathered material.[59] Weathering of non-geological materials Wood can be physically and chemically weathered by hydrolysis and other processes relevant to minerals, but in addition, wood is highly susceptible to weathering induced by ultraviolet radiation from sunlight. This induces photochemical reactions that degrade the wood surface.[60] Photochemical reactions are also significant in the weathering of paint[61] and plastics.[62] Gallery Salt weathering of building stone on the island of Gozo, Malta. Salt weathering of sandstone near Qobustan, Azerbaijan. This Permian sandstone wall near Sedona, Arizona, United States has weathered into a small alcove. Weathering on a sandstone statue in Dresden, Germany. See also Aeolian processes – Processes due to wind activity Bioerosion – Erosion of hard ocean substrates by living organisms Decomposition – Process in which organic substances are broken down into simpler organic matter Environmental chamber Eluvium Exfoliating granite – Granite skin peeling like an onion (desquamation) because of weathering Factor of polymer weathering Meteorite weathering Pedogenesis Reverse weathering Soil production function Space weathering Spheroidal weathering – Form of chemical weathering that affects jointed bedrock Weather testing of polymers – Controlled polymer and polymer coating degradation Weathering steel – Group of steel alloys designed to form a rust-like finish when exposed to weather References ^ Leeder, M. R. (2011). Sedimentology and sedimentary basins : from turbulence to tectonics (2nd ed.). Chichester, West Sussex, UK: Wiley-Blackwell. p. 4. ISBN 9781405177832. ^ Blatt, Harvey; Middleton, Gerard; Murray, Raymond (1980). 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For other uses, see Vesta (disambiguation). 4 Vesta Color image of Vesta taken by DawnDiscoveryDiscovered byHeinrich Wilhelm OlbersDiscovery date29 March 1807DesignationsMPC designation(4) VestaPronunciation/ˈvɛstə/[1]Named afterVestaMinor planet categoryMain belt (Vesta family)AdjectivesVestanVestian[a]Orbital characteristics[8]Epoch 9 December 2014 (JD 2457000.5)Aphelion2.57138 AU (384.673 Gm)Perihelion2.15221 AU (321.966 Gm)Semi-major axis2.36179 AU (353.319 Gm)Eccentricity0.08874Orbital period (sidereal)3.63 yr (1325.75 d)Average orbital speed19.34 km/sMean anomaly20.86384°Inclination7.14043° to ecliptic5.58° to invariable plane[6]Longitude of ascending node103.85136°Time of perihelion26 December 2021[7]Argument of perihelion151.19853°SatellitesNoneProper orbital elements[9]Proper semi-major axis2.36151 AUProper eccentricity0.098758Proper inclination6.39234°Proper mean motion99.1888 deg / yrProper orbital period3.62944 yr(1325.654 d)Precession of perihelion36.8729 (2343 years) arcsec / yrPrecession of the ascending node−39.5979 (2182 years) arcsec / yrPhysical characteristicsDimensions572.6 km × 557.2 km × 446.4 km[10]Mean diameter525.4±0.2 km[10]Flattening0.2204Surface area(8.66±0.2)×105 km2[b][11]Volume(7.46±0.3)×107 km3[b][12]Mass(2.59076±0.00001)×1020 kg[10]Mean density3.456±0.035 g/cm3[10]Equatorial surface gravity0.25 m/s20.025 gEquatorial escape velocity0.36 km/sSynodic rotation period0.2226 d (5.342 h)[8][13]Equatorial rotation velocity93.1 m/s[c]North pole right ascension20h 32m[citation needed]North pole declination48°[citation needed]Geometric albedo0.423[14]Temperaturemin: 75 K (−198 °C)max: 250 K (−23 °C)[15]Spectral typeV[8][16]Apparent magnitude5.1[17] to 8.48Absolute magnitude (H)3.20[8][14]Angular diameter0.70″ to 0.22″ Vesta (minor-planet designation: 4 Vesta) is one of the largest objects in the asteroid belt, with a mean diameter of 525 kilometres (326 mi).[10] It was discovered by the German astronomer Heinrich Wilhelm Matthias Olbers on 29 March 1807[8] and is named after Vesta, the virgin goddess of home and hearth from Roman mythology. Vesta is thought to be the second-largest asteroid, both by mass and by volume, after the dwarf planet Ceres,[18][19][20] though in volume it overlaps with the uncertainty in the measurements of 2 Pallas.[21] Measurements give it a nominal volume only slightly larger than that of Pallas (about 5% greater, which is the magnitude of the uncertainties in measurement), but it is 25% to 30% more massive. It constitutes an estimated 9% of the mass of the asteroid belt.[22] Vesta is the only known remaining rocky protoplanet (with a differentiated interior) of the kind that formed the terrestrial planets.[23][24][25] Numerous fragments of Vesta were ejected by collisions one and two billion years ago that left two enormous craters occupying much of Vesta's southern hemisphere.[26][27] Debris from these events has fallen to Earth as howardite–eucrite–diogenite (HED) meteorites, which have been a rich source of information about Vesta.[28][29][30] Vesta is the brightest asteroid visible from Earth. It is regularly as bright as magnitude 5.1,[17] at which times it is faintly visible to the naked eye. Its maximum distance from the Sun is slightly greater than the minimum distance of Ceres from the Sun,[d] though its orbit lies entirely within that of Ceres.[31] NASA's Dawn spacecraft entered orbit around Vesta on 16 July 2011 for a one-year exploration and left the orbit of Vesta on 5 September 2012[32] en route to its final destination, Ceres. Researchers continue to examine data collected by Dawn for additional insights into the formation and history of Vesta.[33][34] History Discovery Vesta, Ceres, and the Moon with sizes shown to scale Heinrich Olbers discovered Pallas in 1802, the year after the discovery of Ceres. He proposed that the two objects were the remnants of a destroyed planet. He sent a letter with his proposal to the British astronomer William Herschel, suggesting that a search near the locations where the orbits of Ceres and Pallas intersected might reveal more fragments. These orbital intersections were located in the constellations of Cetus and Virgo.[35] Olbers commenced his search in 1802, and on 29 March 1807 he discovered Vesta in the constellation Virgo—a coincidence, because Ceres, Pallas, and Vesta are not fragments of a larger body. Because the asteroid Juno had been discovered in 1804, this made Vesta the fourth object to be identified in the region that is now known as the asteroid belt. The discovery was announced in a letter addressed to German astronomer Johann H. Schröter dated 31 March.[36] Because Olbers already had credit for discovering a planet (Pallas; at the time, the asteroids were considered to be planets), he gave the honor of naming his new discovery to German mathematician Carl Friedrich Gauss, whose orbital calculations had enabled astronomers to confirm the existence of Ceres, the first asteroid, and who had computed the orbit of the new planet in the remarkably short time of 10 hours.[37][38] Gauss decided on the Roman virgin goddess of home and hearth, Vesta.[39] Name and symbol Vesta was the fourth asteroid to be discovered, hence the number 4 in its formal designation. The name Vesta, or national variants thereof, is in international use with two exceptions: Greece and China. In Greek, the name adopted was the Hellenic equivalent of Vesta, Hestia (4 Εστία); in English, that name is used for 46 Hestia (Greeks use the name "Hestia" for both, with the minor-planet numbers used for disambiguation). In Chinese, Vesta is called the 'hearth-god(dess) star', 灶神星 zàoshénxīng, naming the asteroid for Vesta's role, similar to the Chinese names of Uranus, Neptune, and Pluto.[e] Vesta's planetary symbol, as published in 1807 Upon its discovery, Vesta was, like Ceres, Pallas, and Juno before it, classified as a planet and given a planetary symbol. The symbol represented the altar of Vesta with its sacred fire and was designed by Gauss.[40][41] In Gauss's conception, now obsolete, this was drawn .[f] The asteroid symbols were gradually retired from astronomical use after 1852, but the symbols for the first four asteroids were resurrected for astrology in the 1970s. The abbreviated modern astrological variant of the Vesta symbol is (U+26B6 ⚶).[g] After the discovery of Vesta, no further objects were discovered for 38 years, and during this time the Solar System was thought to have eleven planets.[46] However, in 1845, new asteroids started being discovered at a rapid pace, and by 1851 there were fifteen, each with its own symbol, in addition to the eight major planets (Neptune had been discovered in 1846). It soon became clear that it would be impractical to continue inventing new planetary symbols indefinitely, and some of the existing ones proved difficult to draw quickly. That year, the problem was addressed by Benjamin Apthorp Gould, who suggested numbering asteroids in their order of discovery, and placing this number in a disk (circle) as the generic symbol of an asteroid. Thus, the fourth asteroid, Vesta, acquired the generic symbol ④. This was soon coupled with the name into an official number–name designation, ④ Vesta, as the number of minor planets increased. By 1858, the circle had been simplified to parentheses, (4) Vesta, which were easier to typeset. Other punctuation, such as 4) Vesta and 4, Vesta, was also used, but had more or less completely died out by 1949.[47] Today, either Vesta or, more commonly, 4 Vesta is used. Early measurements SPHERE image is shown on the left, with a synthetic view derived from Dawn images shown on the right for comparison.[48] Photometric observations of Vesta were made at the Harvard College Observatory in 1880–1882 and at the Observatoire de Toulouse in 1909. These and other observations allowed the rotation rate of Vesta to be determined by the 1950s. However, the early estimates of the rotation rate came into question because the light curve included variations in both shape and albedo.[49] Early estimates of the diameter of Vesta ranged from 383 kilometres (238 mi) in 1825, to 444 km (276 mi). E.C. Pickering produced an estimated diameter of 513 ± 17 km (319 ± 11 mi) in 1879, which is close to the modern value for the mean diameter, but the subsequent estimates ranged from a low of 390 km (242 mi) up to a high of 602 km (374 mi) during the next century. The measured estimates were based on photometry. In 1989, speckle interferometry was used to measure a dimension that varied between 498 and 548 km (309 and 341 mi) during the rotational period.[50] In 1991, an occultation of the star SAO 93228 by Vesta was observed from multiple locations in the eastern United States and Canada. Based on observations from 14 different sites, the best fit to the data was an elliptical profile with dimensions of about 550 km × 462 km (342 mi × 287 mi).[51] Dawn confirmed this measurement. Vesta became the first asteroid to have its mass determined. Every 18 years, the asteroid 197 Arete approaches within 0.04 AU of Vesta. In 1966, based upon observations of Vesta's gravitational perturbations of Arete, Hans G. Hertz estimated the mass of Vesta at (1.20±0.08)×10−10 M☉ (solar masses).[52] More refined estimates followed, and in 2001 the perturbations of 17 Thetis were used to calculate the mass of Vesta to be (1.31±0.02)×10−10 M☉.[53] Dawn determined it to be 1.3029×10−10 M☉. Orbit Vesta orbits the Sun between Mars and Jupiter, within the asteroid belt, with a period of 3.6 Earth years,[8] specifically in the inner asteroid belt, interior to the Kirkwood gap at 2.50 AU. Its orbit is moderately inclined (i = 7.1°, compared to 7° for Mercury and 17° for Pluto) and moderately eccentric (e = 0.09, about the same as for Mars).[8] True orbital resonances between asteroids are considered unlikely; due to their small masses relative to their large separations, such relationships should be very rare.[54] Nevertheless, Vesta is able to capture other asteroids into temporary 1:1 resonant orbital relationships (for periods up to 2 million years or more); about forty such objects have been identified.[55] Decameter-sized objects detected in the vicinity of Vesta by Dawn may be such quasi-satellites rather than proper satellites.[55] Rotation Olbers Regio (dark area) defines the prime meridian in the IAU coordinate system. It is shown here in a Hubble shot of Vesta, because it is not visible in the more detailed Dawn images.Claudia crater (indicated by the arrow at the bottom of the closeup image at right) defines the prime meridian in the Dawn/NASA coordinate system. Vesta's rotation is relatively fast for an asteroid (5.342 h) and prograde, with the north pole pointing in the direction of right ascension 20 h 32 min, declination +48° (in the constellation Cygnus) with an uncertainty of about 10°. This gives an axial tilt of 29°.[56] Coordinate systems There are two longitudinal coordinate systems in use for Vesta, with prime meridians separated by 150°. The IAU established a coordinate system in 1997 based on Hubble photos, with the prime meridian running through the center of Olbers Regio, a dark feature 200 km across. When Dawn arrived at Vesta, mission scientists found that the location of the pole assumed by the IAU was off by 10°, so that the IAU coordinate system drifted across the surface of Vesta at 0.06° per year, and also that Olbers Regio was not discernible from up close, and so was not adequate to define the prime meridian with the precision they needed. They corrected the pole, but also established a new prime meridian 4° from the center of Claudia, a sharply defined crater 700 meters across, which they say results in a more logical set of mapping quadrangles.[57] All NASA publications, including images and maps of Vesta, use the Claudian meridian, which is unacceptable to the IAU. The IAU Working Group on Cartographic Coordinates and Rotational Elements recommended a coordinate system, correcting the pole but rotating the Claudian longitude by 150° to coincide with Olbers Regio.[58] It was accepted by the IAU, though it disrupts the maps prepared by the Dawn team, which had been positioned so they would not bisect any major surface features.[57][59] Physical characteristics Relative sizes of the four largest asteroids. Vesta is second from left. Mass of Vesta compared[h] The mass of 4 Vesta (blue) compared to other large asteroids: 1 Ceres, 2 Pallas, 10 Hygiea, 704 Interamnia, 15 Eunomia and the remainder of the Main Belt. The unit of mass is ×1018 kg. Vesta is the second-most-massive body in the asteroid belt,[60] though only 28% as massive as Ceres.[22] Ceres is however believed to be an interloper from beyond Jupiter; if true, Vesta would be the most massive body that formed in the asteroid belt. Vesta's density is lower than those of the four terrestrial planets, but higher than those of most asteroids and all of the moons in the Solar System except volcanic Io. Vesta's surface area is about the same as the land area of Pakistan, Venezuela, Tanzania or Nigeria (a bit under 900,000 square kilometers).[i] It has a differentiated interior.[23] Vesta is only slightly larger (525.4±0.2 km[10]) than 2 Pallas (512±3 km) in volume,[61] but is about 25% more massive. Vesta's shape is close to a gravitationally relaxed oblate spheroid,[56] but the large concavity and protrusion at the southern pole (see 'Surface features' below) combined with a mass less than 5×1020 kg precluded Vesta from automatically being considered a dwarf planet under International Astronomical Union (IAU) Resolution XXVI 5.[62] A 2012 analysis of Vesta's shape[63] and gravity field using data gathered by the Dawn spacecraft has shown that Vesta is currently not in hydrostatic equilibrium.[10][64] Temperatures on the surface have been estimated to lie between about −20 °C with the Sun overhead, dropping to about −190 °C at the winter pole. Typical daytime and nighttime temperatures are −60 °C and −130 °C respectively. This estimate is for 6 May 1996, very close to perihelion, although details vary somewhat with the seasons.[15] Surface features Further information: List of geological features on Vesta Prior to the arrival of the Dawn spacecraft, some Vestan surface features had already been resolved using the Hubble Space Telescope and ground-based telescopes (e.g. the Keck Observatory).[65] The arrival of Dawn in July 2011 revealed the complex surface of Vesta in detail.[66] Geologic map of Vesta[67] The most ancient and heavily cratered regions are brown; areas modified by the Veneneia and Rheasilvia impacts are purple (the Saturnalia Fossae Formation, in the north)[68] and light cyan (the Divalia Fossae Formation, equatorial),[67] respectively; the Rheasilvia impact basin interior (in the south) is dark blue, and neighboring areas of Rheasilvia ejecta (including an area within Veneneia) are light purple-blue;[69][70] areas modified by more recent impacts or mass wasting are yellow/orange or green, respectively. Northern (left) and southern (right) hemispheres. The 'Snowman' craters are at the top of the left image; Rheasilvia and Veneneia (green and blue) dominate the right. Parallel troughs are seen in both. Colors of the two hemispheres are not to scale,[j] and the equatorial region is not shown. Rheasilvia and Veneneia craters Main articles: Rheasilvia and Veneneia South pole of Vesta, showing the extent of Rheasilvia crater. The most prominent of these surface features are two enormous craters, the 500-kilometre (311 mi)-wide Rheasilvia crater, centered near the south pole, and the 400 km (249 mi) wide Veneneia crater. The Rheasilvia crater is younger and overlies the Veneneia crater.[71] The Dawn science team named the younger, more prominent crater Rheasilvia, after the mother of Romulus and Remus and a mythical vestal virgin.[72] Its width is 95% of the mean diameter of Vesta. The crater is about 19 km (12 mi) deep. A central peak rises 23 km (14 mi) above the lowest measured part of the crater floor and the highest measured part of the crater rim is 31 km (19 mi) above the crater floor low point. It is estimated that the impact responsible excavated about 1% of the volume of Vesta, and it is likely that the Vesta family and V-type asteroids are the products of this collision. If this is the case, then the fact that 10 km (6.2 mi) fragments have survived bombardment until the present indicates that the crater is at most only about 1 billion years old.[73] It would also be the site of origin of the HED meteorites. All the known V-type asteroids taken together account for only about 6% of the ejected volume, with the rest presumably either in small fragments, ejected by approaching the 3:1 Kirkwood gap, or perturbed away by the Yarkovsky effect or radiation pressure. Spectroscopic analyses of the Hubble images have shown that this crater has penetrated deep through several distinct layers of the crust, and possibly into the mantle, as indicated by spectral signatures of olivine.[56] The large peak at the center of Rheasilvia is 20 to 25 km (12–16 mi) high and 180 km (112 mi) wide,[71] and is possibly a result of a planetary-scale impact.[74] Other craters Aelia Crater Feralia Planitia, an old, degraded crater near Vesta's equator (green and blue). It is 270 km (168 mi) across and predates Rheasilvia (green at bottom). Several old, degraded craters rival Rheasilvia and Veneneia in size, though none are quite so large. They include Feralia Planitia, shown at right, which is 270 km (168 mi) across.[75] More-recent, sharper craters range up to 158 km (98 mi) Varronilla and 196 km (122 mi) Postumia.[76] "Snowman craters" The "snowman craters" is an informal name given to a group of three adjacent craters in Vesta's northern hemisphere. Their official names from largest to smallest (west to east) are Marcia, Calpurnia, and Minucia. Marcia is the youngest and cross-cuts Calpurnia. Minucia is the oldest.[67] "Snowman" craters by Dawn from 5,200 km (3,200 mi) in 2011Detailed image of the "Snowman" craters Troughs The majority of the equatorial region of Vesta is sculpted by a series of parallel troughs. The largest is named Divalia Fossa (10–20 km wide, 465 km long). Despite the fact that Vesta is a one-seventh the size of the Moon, Divalia Fossa dwarfs the Grand Canyon. A second series, inclined to the equator, is found further north. The largest of the northern troughs is named Saturnalia Fossa (≈ 40 km wide, > 370 km long). These troughs are thought to be large-scale graben resulting from the impacts that created Rheasilvia and Veneneia craters, respectively. They are some of the longest chasms in the Solar System, nearly as long as Ithaca Chasma on Tethys. The troughs may be graben that formed after another asteroid collided with Vesta, a process that can happen only in a body that, like Vesta, is differentiated.[77] Vesta's differentiation is one of the reasons why scientists consider it a protoplanet.[78] A section of Divalia Fossa, with parallel troughs to the north and southA computer-generated view of a portion of Divalia Fossa Surface composition Compositional information from the visible and infrared spectrometer (VIR), gamma-ray and neutron detector (GRaND), and framing camera (FC), all indicate that the majority of the surface composition of Vesta is consistent with the composition of the howardite, eucrite, and diogenite meteorites.[79][80][81] The Rheasilvia region is richest in diogenite, consistent with the Rheasilvia-forming impact excavating material from deeper within Vesta. The presence of olivine within the Rheasilvia region would also be consistent with excavation of mantle material. However, olivine has only been detected in localized regions of the northern hemisphere, not within Rheasilvia.[33] The origin of this olivine is currently unknown. Features associated with volatiles Pitted terrain has been observed in four craters on Vesta: Marcia, Cornelia, Numisia and Licinia.[82] The formation of the pitted terrain is proposed to be degassing of impact-heated volatile-bearing material. Along with the pitted terrain, curvilinear gullies are found in Marcia and Cornelia craters. The curvilinear gullies end in lobate deposits, which are sometimes covered by pitted terrain, and are proposed to form by the transient flow of liquid water after buried deposits of ice were melted by the heat of the impacts.[68] Hydrated materials have also been detected, many of which are associated with areas of dark material.[83] Consequently, dark material is thought to be largely composed of carbonaceous chondrite, which was deposited on the surface by impacts. Carbonaceous chondrites are comparatively rich in mineralogically bound OH.[81] Geology Cut-away schematic of Vestan core, mantle, and crust Eucrite meteorite There is a large collection of potential samples from Vesta accessible to scientists, in the form of over 1200 HED meteorites (Vestan achondrites), giving insight into Vesta's geologic history and structure. NASA Infrared Telescope Facility (NASA IRTF) studies of asteroid (237442) 1999 TA10 suggest that it originated from deeper within Vesta than the HED meteorites.[24] Vesta is thought to consist of a metallic iron–nickel core 214–226 km in diameter,[10] an overlying rocky olivine mantle, with a surface crust. From the first appearance of calcium–aluminium-rich inclusions (the first solid matter in the Solar System, forming about 4.567 billion years ago), a likely time line is as follows:[84][85][86][87][88] Timeline of the evolution of Vesta 2–3 million years Accretion completed 4–5 million years Complete or almost complete melting due to radioactive decay of 26Al, leading to separation of the metal core 6–7 million years Progressive crystallization of a convecting molten mantle. Convection stopped when about 80% of the material had crystallized Extrusion of the remaining molten material to form the crust, either as basaltic lavas in progressive eruptions, or possibly forming a short-lived magma ocean. The deeper layers of the crust crystallize to form plutonic rocks, whereas older basalts are metamorphosed due to the pressure of newer surface layers. Slow cooling of the interior Vesta is the only known intact asteroid that has been resurfaced in this manner. Because of this, some scientists refer to Vesta as a protoplanet.[89] However, the presence of iron meteorites and achondritic meteorite classes without identified parent bodies indicates that there once were other differentiated planetesimals with igneous histories, which have since been shattered by impacts. Composition of the Vestan crust (by depth)[90] A lithified regolith, the source of howardites and brecciated eucrites. Basaltic lava flows, a source of non-cumulate eucrites. Plutonic rocks consisting of pyroxene, pigeonite and plagioclase, the source of cumulate eucrites. Plutonic rocks rich in orthopyroxene with large grain sizes, the source of diogenites. On the basis of the sizes of V-type asteroids (thought to be pieces of Vesta's crust ejected during large impacts), and the depth of Rheasilvia crater (see below), the crust is thought to be roughly 10 kilometres (6 mi) thick.[91] Findings from the Dawn spacecraft have found evidence that the troughs that wrap around Vesta could be graben formed by impact-induced faulting (see Troughs section above), meaning that Vesta has more complex geology than other asteroids. Vesta's differentiated interior implies that it was in hydrostatic equilibrium and thus a dwarf planet in the past, but it is not today.[71] The impacts that created the Rheasilvia and Veneneia craters occurred when Vesta was no longer warm and plastic enough to return to an equilibrium shape, distorting its once rounded shape and prohibiting it from being classified as a dwarf planet today. Regolith Vesta's surface is covered by regolith distinct from that found on the Moon or asteroids such as Itokawa. This is because space weathering acts differently. Vesta's surface shows no significant trace of nanophase iron because the impact speeds on Vesta are too low to make rock melting and vaporization an appreciable process. Instead, regolith evolution is dominated by brecciation and subsequent mixing of bright and dark components.[92] The dark component is probably due to the infall of carbonaceous material, whereas the bright component is the original Vesta basaltic soil.[93] Fragments Some small Solar System bodies are suspected to be fragments of Vesta caused by impacts. The Vestian asteroids and HED meteorites are examples. The V-type asteroid 1929 Kollaa has been determined to have a composition akin to cumulate eucrite meteorites, indicating its origin deep within Vesta's crust.[29] Vesta is currently one of only seven identified Solar System bodies of which we have physical samples, coming from a number of meteorites suspected to be Vestan fragments. It is estimated that 1 out of 16 meteorites originated from Vesta.[94] The other identified Solar System samples are from Earth itself, meteorites from Mars, meteorites from the Moon, and samples returned from the Moon, the comet Wild 2, and the asteroids 25143 Itokawa and 162173 Ryugu.[30][k] Exploration Animation of Dawn's trajectory from 27 September 2007 to 5 October 2018 Dawn · Earth · Mars · 4 Vesta · 1 Ceres First image of asteroids (Ceres and Vesta) taken from Mars. The image was made by the Curiosity rover on 20 April 2014. Animation of Dawn's trajectory around 4 Vesta from 15 July 2011 to 10 September 2012 Dawn · 4 Vesta In 1981, a proposal for an asteroid mission was submitted to the European Space Agency (ESA). Named the Asteroidal Gravity Optical and Radar Analysis (AGORA), this spacecraft was to launch some time in 1990–1994 and perform two flybys of large asteroids. The preferred target for this mission was Vesta. AGORA would reach the asteroid belt either by a gravitational slingshot trajectory past Mars or by means of a small ion engine. However, the proposal was refused by the ESA. A joint NASA–ESA asteroid mission was then drawn up for a Multiple Asteroid Orbiter with Solar Electric Propulsion (MAOSEP), with one of the mission profiles including an orbit of Vesta. NASA indicated they were not interested in an asteroid mission. Instead, the ESA set up a technological study of a spacecraft with an ion drive. Other missions to the asteroid belt were proposed in the 1980s by France, Germany, Italy and the United States, but none were approved.[95] Exploration of Vesta by fly-by and impacting penetrator was the second main target of the first plan of the multi-aimed Soviet Vesta mission, developed in cooperation with European countries for realisation in 1991–1994 but canceled due to the dissolution of the Soviet Union. Artist's conception of Dawn orbiting Vesta In the early 1990s, NASA initiated the Discovery Program, which was intended to be a series of low-cost scientific missions. In 1996, the program's study team recommended a mission to explore the asteroid belt using a spacecraft with an ion engine as a high priority. Funding for this program remained problematic for several years, but by 2004 the Dawn vehicle had passed its critical design review[96] and construction proceeded. It launched on 27 September 2007 as the first space mission to Vesta. On 3 May 2011, Dawn acquired its first targeting image 1.2 million kilometers from Vesta.[97] On 16 July 2011, NASA confirmed that it received telemetry from Dawn indicating that the spacecraft successfully entered Vesta's orbit.[98] It was scheduled to orbit Vesta for one year, until July 2012.[99] Dawn's arrival coincided with late summer in the southern hemisphere of Vesta, with the large crater at Vesta's south pole (Rheasilvia) in sunlight. Because a season on Vesta lasts eleven months, the northern hemisphere, including anticipated compression fractures opposite the crater, would become visible to Dawn's cameras before it left orbit.[100] Dawn left orbit around Vesta on 4 September 2012 11:26 p.m. PDT to travel to Ceres.[101] NASA/DLR released imagery and summary information from a survey orbit, two high-altitude orbits (60–70 m/pixel) and a low-altitude mapping orbit (20 m/pixel), including digital terrain models, videos and atlases.[102][103][104][105][106][107] Scientists also used Dawn to calculate Vesta's precise mass and gravity field. The subsequent determination of the J2 component yielded a core diameter estimate of about 220 km assuming a crustal density similar to that of the HED.[102] Dawn data can be accessed by the public at the UCLA website.[108] Observations from Earth orbit Albedo and spectral maps of 4 Vesta, as determined from Hubble Space Telescope images from November 1994 Elevation map of 4 Vesta, as determined from Hubble Space Telescope images of May 1996 Elevation diagram of 4 Vesta (as determined from Hubble Space Telescope images of May 1996) viewed from the south-east, showing Rheasilvia crater at the south pole and Feralia Planitia near the equator Vesta seen by the Hubble Space Telescope in May 2007 The 2006 IAU draft proposal on the definition of a planet listed Vesta as a candidate.[109] Vesta is shown fourth from the left along the bottom row. Observations from Dawn Vesta comes into view as the Dawn spacecraft approaches and enters orbit: Vesta from 100,000 km(1 July 2011) Vesta from 41,000 km(9 July 2011) In orbit at 16,000 km(17 July 2011) In orbit from 10,500 km(18 July 2011) The northern hemisphere from 5,200 km(23 July 2011) In orbit from 5,200 km(24 July 2011) In orbit from 3,700 km(31 July 2011) Full rotation(1 August 2011) Composite greyscale image Cratered terrain with hills and ridges(6 August 2011) Densely cratered terrain near terminator(6 August 2011) Vestan craters in various states of degradation, with troughs at bottom(6 August 2011) Hill shaded central mound at the south pole of Vesta(2 February 2015) True-color images Detailed images retrieved during the high-altitude (60–70 m/pixel) and low-altitude (~20 m/pixel) mapping orbits are available on the Dawn Mission website of JPL/NASA. Visibility Annotated image from Earth's surface in June 2007 with (4) Vesta Its size and unusually bright surface make Vesta the brightest asteroid, and it is occasionally visible to the naked eye from dark skies (without light pollution). In May and June 2007, Vesta reached a peak magnitude of +5.4, the brightest since 1989.[110] At that time, opposition and perihelion were only a few weeks apart.[111] It was brighter still at its 22 June 2018 opposition, reaching a magnitude of +5.3.[112] Less favorable oppositions during late autumn 2008 in the Northern Hemisphere still had Vesta at a magnitude of from +6.5 to +7.3.[113] Even when in conjunction with the Sun, Vesta will have a magnitude around +8.5; thus from a pollution-free sky it can be observed with binoculars even at elongations much smaller than near opposition.[113] 2010–2011 In 2010, Vesta reached opposition in the constellation of Leo on the night of 17–18 February, at about magnitude 6.1,[114] a brightness that makes it visible in binocular range but generally not for the naked eye. Under perfect dark sky conditions where all light pollution is absent it might be visible to an experienced observer without the use of a telescope or binoculars. Vesta came to opposition again on 5 August 2011, in the constellation of Capricornus at about magnitude 5.6.[114][115] 2012–2013 Vesta was at opposition again on 9 December 2012.[116] According to Sky and Telescope magazine, this year Vesta came within about 6 degrees of 1 Ceres during the winter of 2012 and spring 2013.[117] Vesta orbits the Sun in 3.63 years and Ceres in 4.6 years, so every 17.4 years Vesta overtakes Ceres (the previous overtaking was in April 1996).[117] On 1 December 2012, Vesta had a magnitude of 6.6, but it had decreased to 8.4 by 1 May 2013.[117] 2014 Conjunction of Ceres and Vesta near the star Gamma Virginis on 5 July 2014 in the Constellation of Virgo. Ceres and Vesta came within one degree of each other in the night sky in July 2014.[117] See also 3103 Eger 3551 Verenia 3908 Nyx 4055 Magellan Asteroids in fiction Diogenite Eucrite Former classification of planets Howardite Vesta family (vestoids) List of tallest mountains in the Solar System Notes ^ Marc Rayman of the JPL Dawn team used "Vestian" (analogous to the Greek cognate Hestian) a few times in 2010 and early 2011 in his Dawn Journal, and the Planetary Society continued to use that form for a few more years.[2] The word had been used elsewhere, e.g. in Tsiolkovsky (1960) The call of the cosmos. However, otherwise the shorter form "Vestan" has been used by JPL.[3] Most modern print sources also use "Vestan".[4][5] Note that the related word "Vestalian" refers to people or things associated with Vesta, such as the vestal virgins, not to Vesta herself. ^ a b Calculated using the known dimensions assuming an ellipsoid. ^ Calculated using (1) the known rotation period (5.342 h)[8] and (2) the equatorial radius Req (285 km)[10] of the best-fit biaxial ellipsoid to Asteroid 4 Vesta. ^ On 10 February 2009, during Ceres perihelion, Ceres was closer to the Sun than Vesta, because Vesta has an aphelion distance greater than Ceres's perihelion distance. (10 February 2009: Vesta 2.56 AU; Ceres 2.54 AU) ^ 維斯塔 wéisītǎ, with an obscure ī, is the closest Chinese approximation of the Latin pronunciation westa. ^ Some sources contemporaneous to Gauss invented more elaborate forms, such as and .[42][43] A simplification of the latter from ca. 1930, ,[44] never caught on. ^ This symbol can be seen in the top of the most elaborate of the earlier forms, . It dates from 1973, at the beginning of astrological interest in asteroids.[45] ^ The objects elsewhere in the Solar system with well-defined masses that are within a factor of 2 of Vesta's are shown at right. No moons are in this range: the closest, Tethys (Saturn III) and Enceladus (Saturn II), are over twice and less that half Vesta's mass. Mass of Vesta compared (cont.) Vesta compared to objects within a factor of 2 of its mass: Pallas, Varda, G!kúnǁʼhòmdímà, Salacia. The unit of mass is ×1018 kg. ^ Or a quarter greater than the US state of Texas; a within 10% of New South Wales in Australia and British Columbia in Canada; the combined size of the three largest Indian states of Rajasthan, Madhya Pradesh and Maharashtra; two thirds the size of South Africa and over three times the size of New Zealand or the UK. ^ that is, blue in the north does not mean the same thing as blue in the south. ^ Note that there is very strong evidence that 6 Hebe is the parent body for H-chondrites, one of the most common meteorite types. References

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