

すばる望遠鏡によって得られた火星 CO₂ 同位体分布 Global mapping of the CO₂ isotopologues in the Martian atmosphere as observed Subaru/IRCS

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We investigated Martian CO₂ isotopic ratios at 2-4 micron spectra observed by Subaru IRCS.

The determination of the isotopic ratios on Mars is important to study atmospheric evolution. The relative abundance of isotopes of CO₂ provides insight into the loss of Mars primordial atmosphere. In addition, the distributions and variations of C and O isotopes can constrain the information about the magnitude and distribution of sources and sinks of CO₂, i.e. the global coupling between surface, aerosols, and atmosphere. Photochemical reaction, condensation into the polar caps and aerosols, soil and subsurface reservoir respiration impart C and O isotope signals to the atmosphere that can be used as a tracer at various temporal and spatial scales.

High-resolution global imaging spectroscopy of Martian CO₂ isotopologues has been achieved at 2-4 micron (2970-3050 cm⁻¹) by IRCS with Subaru telescope on 30 November 2011 (Ls=37), 4-5 January 2012(Ls=52), and 12 April 2012 (Ls=96). Owing to its wide wavelength coverage, our measurements obtained a comprehensive dataset of CO₂ isotopes (626, 627, 628, and 636) & water vapor isotopes (H₂O and HDO) simultaneously, providing a global perspective on their near-surface distributions.

Spectra were collected in the northern hemisphere at a spectral resolution of R=20,000. The diameter in these periods of Mars was more or less 9 arcsec. The seeing was 0.5-0.8 arcsec (pixel scale: 0.06 arcsec). We used two slit positions. The slit along the N-S direction on Mars covered the region between the northern polar cap and the equator, in order to investigate the sublimation of the polar cap and condensation into the CO₂ ice clouds at mid-latitude. The W-E direction of the slit position was also selected in order to clarify the local-time dependence surrounding of sub-solar area. The mud volcanic regions, Utopia/Isidis Nilli Forssae, Sytris Major, were also covered by these observing runs.

Terrestrial absorptions were reduced using standard-star calibrations in order to retrieve the Martian isotope lines. After that, we could successfully obtained clear CO₂ isotopes (626, 627, 628) absorptions in the range of 3330-3380 cm⁻¹ for 626, 2620-2640 cm⁻¹ for 627, and 2630-2660 cm⁻¹ for 628, respectively. The 3400 cm⁻¹ range shows lines of 636. Finally, the chosen spectral range involves plenty good enough lines of the Martian CO₂ isotopes.

In this paper, we will present these isotopologues, their distributions, and seasonal variations. Their S/N will be quantitatively discussed.

キーワード: 同位体, 二酸化炭素, 火星

Keywords: Isotope, carbon dioxide, Mars

火星大気大循環モデルで表現される火星中層大気子午面循環 Meridional circulation of Martian middle atmosphere represented by a Mars general circulation model

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Observations by Mars Climate Sounder (MCS) onboard Mars Reconnaissance Orbiter spacecraft provided the meridional temperature structure of Martian middle atmosphere up to about 90 km altitude. These observations enable us to compare the model produced middle atmosphere with observational ones and examine the nature of Martian middle atmosphere. In this study, structure of Martian middle atmosphere is investigated by use of a Mars General Circulation Model (GCM).

A planetary atmosphere GCM, dcpan, is used in this study. Dynamical core of dcpan solves the primitive equation system by use of spectral transform method with the finite difference method in vertical direction. The included physical processes are the radiative process, the turbulent mixing process, and the surface processes. Further, a condensation scheme of CO₂ is included. By the use of a "Mars mode" of this model, several experiments have been performed. In the experiments, the dust distribution in the atmosphere is prescribed. In the vertical direction, the Conrath-type distribution is assumed. In the horizontal direction, the optical depth is prescribed in two ways. Those distributions will be described below. The resolutions used for this study is T21L32, which is equivalent to about 5.6 degrees longitude-latitude grid and has 32 vertical levels. Under these conditions, the model is integrated for 5 Mars years from an initial condition of isothermal atmosphere at rest. The result during the last Martian year is analyzed.

The model is evaluated by comparing the temperature structure simulated by the model with that observed by the MCS. In the simulation, the dust optical depth is prescribed based on the "climatology", which has been created by averaging dust optical depth observed by Thermal Emission Spectrometer onboard Mars Global Surveyor spacecraft. It is found that the gross features of temperature structure observed by MCS are represented by the model, such as the strong latitudinal temperature gradient at southern middle latitude, and the latitude of highest near surface temperature. However, some differences can also be observed. One of that is the strength of temperature increase in southern middle and high latitude at about 1 Pa pressure level (~60 km). This temperature increase is caused by adiabatic heating in a descending branch of meridional circulation. The difference of this temperature increase between the model and observation implies the failure in representing strength of meridional circulation in the model. One of plausible explanations for the failure would be the lack of representation of the effects of subgrid scale atmospheric waves, such as gravity waves. Similar biases were observed in Earth's atmosphere models without (non-orographic) gravity wave drag parameterization.

In order to examine the driving mechanisms of meridional circulation in the middle atmosphere, three experiments are performed: (I) an experiment with Rayleigh friction in the middle atmosphere, (II) an experiment with diurnally mean solar insolation, and (III) an experiment with zonally averaged surface topography, albedo, and thermal inertia. Those three experiments are intended to examine the effects of subgrid scale atmospheric waves, such as gravity wave, thermal tides, and orographically related waves, such as topographic Rossby waves, respectively. The Rayleigh friction coefficient in the experiment (I) is chosen to reproduce the middle atmospheric polar temperature increase observed by MCS roughly. The difference in peak values of mass stream function at 1 Pa pressure level between each experiment and control experiment at northern winter are 0.2e8, 0.15e8, and 0.15e8 kg/s, respectively. This result implies that the subgrid scale atmospheric waves, the thermal tides, and the orographically related waves contribute to middle atmospheric meridional circulation by the similar degree.

キーワード: 惑星大気, 大気大循環モデル, 火星, 中層大気

Keywords: planetary atmosphere, general circulation model, Mars, middle atmosphere

火星の Amazonis Planitia における最近の火山活動の検討 Recent magmatism in Amazonis Planitia, Mars

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On Mars, several young volcanic fields have been discovered such as at Tharsis region, Acidalia Planitia, Utopia Planitia, Isidis Planitia, Elysium Planitia, and Amazonis Planitia (e.g. Fagents and Thordarson, 2007, Jaeger et al., 2010). Some of these volcanic field seem to consist of flood lava plain and volcanic cones (e.g. Jaeger et al., 2007, Hamilton et al., 2010). It is interesting whether the recent magmatism is different from those of large edifice-build-up type. For example, in Central Elysium Planitia, there exist vast smooth plain. Since a lot of cones are found on this plain, which are identified as rootless cones, the surface is interpreted to be covered by young fluidic lava, which emanated from Cerberus Fossae (e.g. Jaeger et al., 2007, Noguchi and Kurita, 2012). But there exist quite few investigation focusing on the style of recent magmatism except Central Elysium Planitia. In this report we describe the style and extent of recent magmatism at Amazonis Planitia.

Amazonis Planitia is also famous for its young smooth plain, although only a few paper stated its origin. Fuller and Head, 2002 stated Southern Amazonis Planitia (SAP) is covered with lava flow from Tharsis region in Early Amazonian, while Northern Amazonis Planitia (NAP) is occupied with lava from Cerberus Fossae via Marte Valles in Early Amazonian to Mid Amazonian. On the other hand, Tanaka et al., 2005 and Harmon et al., 2012 stated that SAP lava should have a local source. While its young origin has been well documented by crater chronology, identification of the volcanic origin seems insufficient such as the point whether the smooth plain is fluidic lava flow or not. Volcanic cones are important morphology for the inspection of flood lava magmatism on Mars. Types, distributions, and shapes of volcanic cones tell us its volcanic origin rather than mud flows, and the style of the magmatism. In this presentation, we focus on the volcanic cone morphologies in Amazonis Planitia. We surveyed its spatial distribution and the size by using CTX and HiRISE images.

キーワード: 火星, 火山, 火砕丘, 溶岩平原, ルートレスコーン

Keywords: Mars, volcano, volcanic cone, lava plain, rootless cone

惑星の大きさがプレートテクトニクス・熱史に与える影響：火星への応用 Large Effect of Small Planet on Plate Tectonics and Thermal Evolution: Application to Mars

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The likelihood of plate tectonics on other planets has been investigated especially in the last two decades (e.g., Solomatov and Moresi, 1997). In terms of a larger planet than the Earth, a super-Earth is an instance. Geodynamicists have analyzed the probability that plate tectonics operates on its surface, and some results claim that the plate tectonics is conceivable (Valencia et al., 2007). As regards a smaller planet than the Earth, Mars is a representative example. Although several observations of the Martian surface indicate the existence of plate tectonics for the first ~500 Myr, calculated thermal history with plate tectonics (Nimmo and Stevenson, 2000) seems inconsistent with other observations (e.g., Baratoux et al., 2011) and, as a result, the early Martian plate tectonics was concluded to be unlikely (Breuer and Spohn, 2003). To those planets, this study applies the thermal evolution model of the Earth, which has been investigated much more than the other planets, and especially follows a recently proceeded theory about thermal evolution with plate tectonics on Earth (Korenaga, 2006). In addition to the application, focusing on the effect of gravity, in particular small gravity of Mars, this study provides its thermal history, which shows the early Martian plate tectonics conceivable.

Calculation of thermal history mainly follows the theory developed by Korenaga (2006), which includes the effect of plate thickness generated at the mid-ocean ridge by decompression melting. This thermal history model is consistent with geochemical or petrological data of the Earth (Korenaga, 2008; Herzberg et al., 2010). I applied the theory to different-size planets on the assumption that plate tectonics is operating on their surface. I focus on the influence of thickening plate due to the small gravity on a small planet, like Mars, since the effect helps keep the heat of small planet.

First, in order to clarify the effect of plate thickness variation on the Martian early thermal history, I calculate the initial time rate of change of temperature, $dT(t=4.5\text{Ga})/dt$, with variation of planet size, which shows that a planet smaller than the critical size, ~ 1.1 Earth size, such as the Earth and Mars, first increases the temperature, though a larger planet decreases the temperature as we conventionally expected. Secondly, I calculate the early thermal evolution of Mars with plate tectonics to 4.0 Ga and then employ the stagnant-lid convection (Schubert and Spohn, 1990) from 4.0 Ga to the present, which shows two important results. The first one is that the application of the Earth's thermal history with plate tectonics to Mars enables us to reproduce a conceivable Martian thermal history. Second, if the plate tectonics ceased at 4.0 Ga, the cessation occurred in a hotter condition than the initial one, though the mantle must have convected more vigorously than ever.

Whereas those results depends on some uncertain parameters, such as the initial temperature and the geometry of subducting slab, those uncertainties do not change the essence, that is, Mars with plate tectonics tends to keep the heat in. It means that, if there was plate tectonics in the early stage of Mars, the drastic temperature drop shown in a conventional theory (Nimmo and Stevenson, 2000) is unlikely, which results in a realistic temperature evolution after the cessation of plate tectonics. In addition, plate tectonics cessation with the hot mantle at 4.0 Ga means that other factors than temperature are indispensable to retain plate tectonics, such as liquid water on the surface. As future works, we should consider other observational data, such as Martian morphology, to constrain this thermal model of Mars.

キーワード: 火星, プレートテクトニクス, 熱史

Keywords: Mars, Plate tectonics, Thermal Evolution

火星における Recurring Slope Lineae の地形学的特徴と成因 On the formational processes of Recurring Slope Lineae on Mars

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近年急速に進む火星探査によって、火星が完全に乾燥しきった天体ではなく、現在においてもごく短い時間であれば液体の水が流出している可能性があること、示唆されるようになった。その一例として、マーズリコネサンスオービター搭載の HiRISE カメラの高解像度画像の解析結果から明らかになった、Recurring Slope Lineae (RSL) と呼ばれる一連の微地形がある。

RSL は、火星の南半球の中緯度にある Newton Crater などの斜面に広範囲にわたって認められ、液体が流れたような跡を形成することが知られている (McEwen et al. 2011)。RSL は春から秋の温暖な季節に現れ、冬には消えるという挙動を年毎に繰り返すと考えられている。火星にはアウトフローチャネルなどの水成地形があることが知られているが、これらは 30 億年以上前に形成されたものである。一方、現在でも活動しているとみられる RSL は液体の水が現存することを示唆する極めて重要な地形であるといえる。もし RSL が液体の水が流れて形成されたものであったならば、火星が液体の水を保持していることを意味し、現在も活動的であることを示す。

寒冷な火星表層に水が液体のまま残されている要因として、塩による凝固点降下が考えられる。しかし、RSL の成因や水源、季節性の理由など、詳しいことはわかっていない。

そこで本研究では、緯度 - 20 度から - 50 度を中心に、全経度にわたり約 100 個の HiRISE の衛星画像について、RSL およびその可能性のある地形を徹底的に探し出し、一部においては新たに HiRISE ステレオ画像から構築した高解像度高度データ (DEM) を対比することで、RSL の勾配や分布の傾向、流れの特徴などの性質について、定量的な調査を行った。その結果、約 30 度の勾配のものが多く、緯度 - 40 度付近に多く分布している (経度には目立った傾向はなくばらついている)。1 つ 1 つの流れの幅は 1 - 5m (太く見えるものは合流しているから) 流長は長いものでも約 500 m で、それ以上は延伸しない という傾向がみられることがあきらかになった。これらは RSL が液体の水で形成されたとする指摘と調和的である。

キーワード: 火星, 地質, 水, 衛星画像, 生命探査

Keywords: Mars, Geology, Water, Orbiter images, Life exploration

火星のアシダリア平原におけるピットドコーンの超高解像度地形解析 HiRISE-based topographic analysis of pitted cones in the Acidalia Planitia on Mars

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The presence or absence of liquid water within the martian sub-surface for the past ~ 2.0 Gy is still under debate. Low-relief circular mounds with summit pits, called as pitted cones, are commonly identified on the early Amazonian-aged surface in the martian northern lowlands. Although pitted cones are previously interpreted as rootless cones, cinder cones, pingoes, or mud volcanoes [Tanaka et al., 2005], high-resolution images obtained by the recent observations indicate that these pitted cones are likely sedimentary features formed by the fluid flow [Oehler and Allen, 2010]. However, physical characteristics of the materials forming the pitted cones are not critically estimated.

Using the HiRISE stereo pairs, we develop high-resolution (up to 1 m/pix) DEMs (Digital Elevation Models), which enables us to accurately measure the relative heights and basal diameters of the pitted cones. We study 140 pitted cones in the southern Acidalia Planitia, known as the early Amazonian terrain. As a result, we find that these pitted cones have the relative heights of 7 to 64 m (median 22 m) and the basal diameters from 222 to 1377 m (median 579 m).

The high-resolution DEMs are used to calculate the yield strengths and the viscosities of the materials forming the pitted cones. Assuming that the materials have Bingham rheology [Hulme, 1974; Major and Pierson, 1992], we can obtain 10^2 - 10^4 Pa for the yield strengths and the range of 10^1 to 10^6 Pa s for the viscosities for those materials forming the pitted cones. This result strongly indicates that pitted cones are formed by the mud-volcanic activities. Applying a simple buoyancy model to these potential mud volcanoes [Murton and Biggs, 2003], we estimate that the depths to mud sources range from 27-247 m with a median value of 86 m (std. dev. 40 m). In summary, we conclude that (i) liquid water had been preserved in ~ 40 m-thick reservoir layers formed about 86 m under the surface in southern Acidalia Planitia and (ii) after that, the fluidized mud erupted from the mud source layers formed mud volcanoes on the surface of Mars.

キーワード: 火星, アシダリア平原, ピットドコーン, 数値標高モデル, 泥火山
Keywords: Mars, Acidalia Planitia, pitted cone, digital elevation model, mud volcano