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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 isotoplogues 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/Isidid 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.

Keywords: Isotope, carbon dioxide, Mars

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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, dcpam, is used in this study. Dynamical core of dcpam 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.

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

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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.

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

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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 Sphon, 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=4.5Ga)/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.

Keywords: Mars, Plate tectonics, Thermal Evolution

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On the formational processes of Recurring Slope Lineae on Mars

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Results of recent exploration of Mars indicate that liquid water may exist near its surface at depth at present day. Small surficial features, known as Recurring Slope Lineae (RSL), found by the observations using HiRISE camera onboard Mars Reconnaissance orbiter support the above view.

RSLs are identified on the slopes of a lot of craters in the mid latitude of the southern hemisphere and leave traces like water flow (McEwen et al. 2011). In addition, RSL are thought to be recurrently developed from spring to autumn but fade out in winter. Importantly, RSLs are the currently active events possibly related to the existence of liquid water on Mars. Note that most other surface features considered to be formed by water flows, such as outflow channels and valley networks, are formed during Noachian or Hesperian periods, over 3 billion years ago.

In this work, we study about 100 HiRISE images in the latitudes from 20 to 50 S. We also contrast high resolution Digital Elevation Models in this region. We map out RSLs found on these images and perform a statistical study, particularly focusing on their geomorphology features, such as the gradients the distributions and states of flow. As a result, we find that RSLs are numerously exist on about 30 degree slope at the latitudes around 40S and that the width of a single RSL is generally from 1 to 5 m and the length is up to 500m or so. In this presentation, we will discuss that these results are consistent with the idea that their formations are related to liquid water.

Reference

McEwen, A. S. et al., 2011. Seasonal flows on warm martian slopes. Science 333, 740-743.

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

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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.

Keywords: Mars, Acidalia Planitia, pitted cone, digital elevation model, mud volcano