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Microporosity and thermophysical properties of cometary ices and their relation to outbursts of cometary nuclei

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Abstract

In a previous paper [1], we show that melting of cometary ices can occur in the near-surface of some cometary nuclei where escape of volatiles is restricted by a *microporous* matrix held together by surface tension forces: the 'wetted layer'. Cometary grains are likely to be assemblages of submicrometre-sized particles, including clays porous at the 1–10 nm scale. Given melting of cometary ices, the subsurface should exhibit certain properties characteristic of partially-saturated soils such as described by Fredlund [2]. Diurnal rotation of the nucleus generates alternate positive and negative temperature gradients in the immediate subsurface. The net effect in some slowly-rotating nuclei will be to form a consolidated mantle, in which the composition of volatile ices will be significantly altered and the lowest melting point mixtures will tend to accumulate at some depth below the surface where solutions of gases can reach high degrees of supersaturation provoking cometary outbursts.

As indicated in paper [3] presented at this conference, at 4-10 AU heliocentric distance a 'hydrophobic' environment may exist, where the melting of hydrocarbons (HC) and especially ethane (C_2H_6) ice is likely to dominate. Whereas at ~1.5-4.0 AU, oxygenated, 'hydrophilic' species (especially methanol (CH_3OH) and aqueous CH_3OH) are more likely to exist in the liquid phase. Here, we provide additional information about the strength of the consolidated mantle and thermophysical properties of gases, especially carbon monoxide (CO) and carbon dioxide (CO_2), when dissolved in liquids near their freezing point. We also illustrate how, in comets receding from perihelion, volatile ices can migrate outwards within a microporous matrix having a wide distribution of pore sizes.

1. Properties of the 'wetted layer'

Wetting of the microporous cometary matrix by liquid species, such as for instance C_2H_6 at ~100 K, will result in capillary action and surface tension forces acting through liquid menisci, which bind particles with increasing force as pore size decreases. In the discipline of soil mechanics, the term suction is used to describe a soil particle-liquid system, implying pressure deficiency. Such pressure deficiency is equivalent to a negative pore-liquid pressure, which in turn makes a positive contribution to the effective particle-to-particle stress. Particularly in partially-saturated soils, such as a fine microporous HC-wetted cometary matrix, suction pressure can easily reach 10^5 Pa and can impart considerable strength and, as with terrestrial soils, lead to reduced permeability, consolidation, and reduced void ratios in areas so affected [2]. Capillary suction also has the potential to enhance heat transfer via capillary wetting in low-gravity, and modify surface topography, e.g. forming flat-bottomed features.

2. Outbursts of 29P/SW1: role of CO

Comet 29P/Schwassmann-Wachmann occupies a near-circular orbit at r_h = 6.2 AU and is unique in its outburst activity. Spitzer observations indicate a possible nucleus rotation period of ~60 days [4].

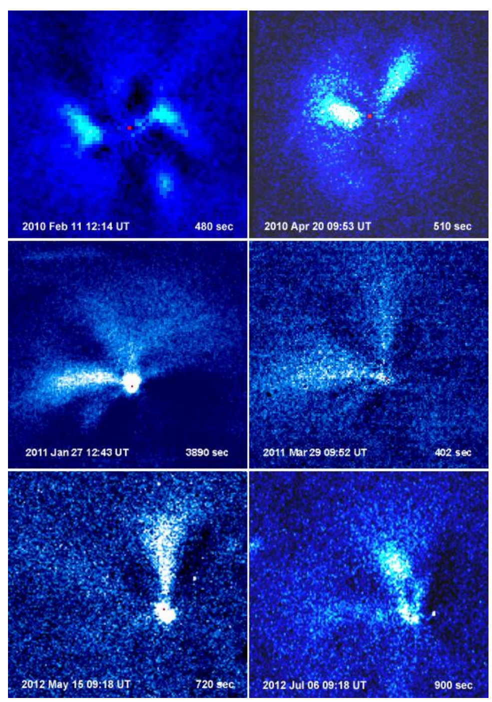

Figure 1: Pairs of rotational-gradient filtered images of the inner coma of comet 29P (fov ~20") taken in 2010 (Feb 11, Apr 20); 2011 (Jan 27, Mar 29) and 2012 (May 15 and Jul 06) depicting similar patterns of outflowing material. (2.0-m Faulkes telescopes)

Comparing the chronology of the particular events shown above, we find that the initial outbursts were separated in time by; 64.3±0.5 day in 2010; 58.0±1.5 day in 2011 and 58.0±2.5 day in 2012 confirming the ~60-day rotation period. Exposure to extended periods of insolation facilitates subsurface melting, and long exposure to low temperatures on the night-side enhances compositional changes and stratification, potentially forming low-melting HC reservoirs at depths of the order of ~10 m. C_2H_6 is the most likely HC to exist in the liquid phase at temperatures of 90-110 K given the low-pressure environment within the nucleus. CO gas is unusually soluble in liquid C_2H_6 (and in liquid CH_4) especially near the triple point temperature/freezing point. The negative temperature coefficient for CO dissolving in CH_4 and C_2H_6 (see Figure 2) is unusually high and so these liquids can readily become supersaturated in CO, resulting in sudden releases of gas driving outbursts from beneath consolidated layers.

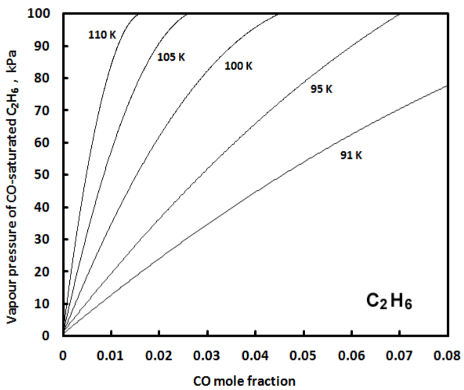

Figure 2 - Thermophysical vapour pressure data interpolated from measurements of CO solubility in liquid CH_4 and in C_3H_8 reported in the literature.

The observed behaviour of this comet fits a model where dust and gas escape from the periphery of strong surface layers able to withstand sudden pressure increases as CO escapes from solution in subsurface reservoirs, and where repeat outbursts can arise from the same active regions of the nucleus.

3. Outbursts of 17P/Holmes: role of CO_2

Comet 17P/Holmes is reknowned for super-outbursts in 1892 and 2007. Other less energetic outbursts of this comet have also taken place, for example in 2009 January, and in 2012 May, whilst relatively far from perihelion [3]. The wetted-layer mechanism can be invoked to explain the outburst characteristics of this Jupiter-family comet, which occupies heliocentric distances of 2.1-5.2 AU. Slow diurnal cycling in a hydrophilic environment can produce aqueous liquid-phase mixtures. In low-temperature environments, CH_3OH-H_2O mixtures dissolve large amounts of CO_2 (Fig. 3). If supersaturation occurs, the abrupt release of CO_2 can potentially generate a cometary outburst.

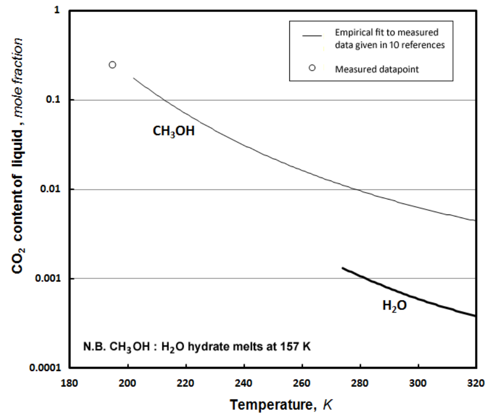

Figure 3 - Solubility of CO_2 in pure CH_3OH and pure H_2O at 101 kPa pressure reported in the literature.

We also outline how microporosity and the role of adsorption isotherms and hysteresis in pore filling and pore emptying tends to cause volatile ices to migrate towards the surface where significant heat is lost by thermal emission to space whilst on the night-time side. Nyctogenic processes may explain not only cometary outbursts far from perihelion but also the existence of detectable H_2O ice at the surface of an outer Main-Belt asteroid such as (24) Themis.

Acknowledgements

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