FOCUS ON THE PROCESSES OCCURRING IN BRINES FREEZING UNDER CERES SURFACE. M. Pedone¹, E. Ammannito¹, C. Plainaki¹, M. C. De Sanctis², A. Raponi², S. De Angelis², M. Ciarniello², M. Ferrari², A. Frigeri² and F. G. Carrozzo³, ¹ASI, Agenzia Spaziale Italiana, via del Politecnico s.n.c., 00133, Rome, Italy, (corresponding author e-mail address: maria.pedone@est.asi.it), ²IAPS, Istituto di Astrofisica e Planetologia Spaziali-INAF, Via del Fosso del Cavaliere, 100, 00133, Rome.

Introduction: In the dwarf planet Ceres, a residual ocean at shallow depth may still exist today in the form of localized reservoirs [1]. We constrained the physico-chemical properties of initial aqueous fluids, characterizing potential reservoirs, located under two craters: Kupalo (39.6°S, 173°E) and Juling (36°S, 168.3°E), located in the eastern part of Toharu Quadrangle Ac-H-12 [2, 3]. Our simulations allowed us to speculate on whether different surface composition patterns - in terms of different carbonates contents as obtained with VIR spectral analysis [4] - reflect different composition and differentiation of the initial aqueous solutions feeding the two craters under study. VIR is the VIS-IR spectrometer of the Dawn mission [5].

This work: We selected the region of Kupalo and Juling for the morphological and mineralogical aspects characterizing the area. These two craters are close to each other but are morphologically and compositionally different. By a morphological point of view, Kupalo crater hosts well-preserved pitted materials, fractures, channels, and a central peak/ridge [6]; instead, Juling is characterized by the presence of fractures, and no pits and peaks are visible on its surface [6]. By a mineralogical point of view, the two craters have different carbonates: Na-carbonates (Kupalo) and Ca-Mg-carbonates (Juling). Juling crater is also characterized by the presence of water ice in shadowed regions [7] while in Kupalo there is no such evidence.

We think that the distinct geology of the two craters may be the result of the freezing of different subsurface aqueous reservoirs, characterized by different compositions and initial P-T conditions. We assumed that a potential Ceres’ reservoir is characterized by the presence of brines having the same physical properties as the ones summarized in literature in terms of T-pH-alkalinity range. The pH value of our solutions is ~10 as suggested from [8], and the alkalinity is ~1.2 equivalents/kg of water.

Then, we characterized the initial composition of the solutions which, after freezing/precipitation processes, delivered the minerals which can better approximate the surface compositions found by VIR in the Juling and Kupalo craters. The two potential brines are alkaline aqueous solutions, and they differ for the initial concentration of Na- and Cl- ions. Based on the surface composition measured by VIR, we assumed that the solutions producing the Kupalo-like mineralogy have an initial higher concentration of such ions with respect to the one producing the Juling-like mineralogy.

We used the FREZCHEM code [9] under the fractional crystallization pathway to simulate the brines’ freezing processes by decreasing temperature value from the initial T=273 K to final T=243 K.

![Fig. 1: Results deriving from the freezing simulations applied to aqueous solutions under Kupalo crater at 1 bar. The amounts of the solids precipitated (left y-axis), expressed in log₁₀ moles + 10, were calculated starting from the initial water content of 1000 g at Tᵢ=273 K decreasing to 0.1 g at the eutectic final temperature. Water ice amounts, expressed in moles, are plotted in the right y-axis (in blue).](image_url)

In our simulations, 5K of decreasing temperature step, between the initial and the final T value, was selected. The 5K and 1K (Fig. 1) modelling steps have given similar results in terms of T-range in which each solid precipitated from the solution, and in terms of order of precipitation of solids during the freezing. In this work, we used the 5K T-step, which was a good compromise to find differences (if any) in the freezing processes beneath the two craters, and we achieved results which, as shown as follows, where comparable, turned out in line with the findings of other authors. Pressure values of 1, 1.5, and 30 bar were considered in our models, which correspond to a depth value from 300 m to 10 km (at an initial density of about 1000 kg/m³ at 273 K, and g=0.28 m/s²).

At each temperature step, under different pressure, the code calculated the amounts of solid phases (minerals and water ice expressed in moles) that precipitated from the initial solutions.

Results and Discussions: In our simulations, carbonates have been the first solids to precipitate, followed by the formation of water ice, sulphates, and, last, Cl-bearing salts. The precipitation of MgCO₃ and
CaMg(CO$_3$)$_2$ is thermodynamically favored. However, we compared the equilibrium constant of dissolution/precipitation reaction ($k$ constant, derived by FREZCHEM) with the IAP (Ion Activity Product), to show if the precipitated carbonates are stable during the precipitation from solutions. The $k$ constant and the IAP have the same formula: they are the product of the solutes’ activities. The difference is that the first refers to the dissolution/precipitation reaction at equilibrium, but the latter refers to the measured activities (different from the ideal condition at equilibrium). By comparing $k$ and IAP, we showed that MgCO$_3$ and CaMg(CO$_3$)$_2$ precipitation is inhibited at a lower temperature at a shallower depth (below T=273 K and P=1 bar).

According to our simulations, the formation of hydrated sodium carbonate (natron, Na$_2$CO$_3$·10H$_2$O) is highly favored in Na-enriched solution (anhydrous sodium carbonate has been detected in Kupalo [2]); instead, it could form only after water ice precipitation in Na-depleted solutions.

Natrite (Na$_3$CO$_3$) was found on Kupalo’s surface, and, in our simulations, it did not directly precipitate from the solutions. We suggest that it could have derived from natron and nahcolite (Na$_2$CO$_3$·10H$_2$O and NaHCO$_3$ respectively) at 1 bar of total pressure. We can emphasize that, alternatively, at higher pressure values, natrite could only derive from dehydration of natron since nahcolite could not have formed.

We investigated the transport dynamics in terms of brines’ viscosity and density, and geometry of the potential reservoirs. We suggest that, already in the subsurface, there could be the physical properties to bring the solids (precipitated from the solutions) to the surface. Under a laminar regime, in a conduit of radius ranged 10-50 m, the brines with a density of 1140 kg·m$^{-3}$ (average from the code’s output) and with a viscosity ranged 1-10 Pa·s, could reach velocities ranging between a minimum value of 1.7-8.7·10$^{-3}$ m/s and a maximum 1.2-1.7·10$^{-1}$ m/s.

When the solid fraction increases, another driving force may occur. For example, the emission of trapped gases may be another possible way of bringing carbonate-rich materials to the surface [10].

Low-pressure boiling of solutions and the gas-driven transport may be a more efficient process for bringing 1) high-density solids (as sodium carbonate particles), and 2) ice-dominated grains to the surface.

Gases exsolution can be favored in a high-salinity condition, under shallower layers, facilitating the transport of material to the surface.

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Data deriving from the mission Dawn are available at repository PDS (Planetary Data System) at url: https://sbn.psi.edu/pds/resource/dawn/dwncvirL1.html and also https://sbn.psi.edu/data/PDS-Ceres/about.html.

FREZCHEM code is free and available at url: https://www.dri.edu/frezchem.