VAPO-DIFFUSION ORIGIN (CONDENSATION-ADSORPTION) IN ICE-CEMENTED PERMAFROST SPANNING THE LAST 135.5 KA YEARS IN UNIVERSITY VALLEY, DRY VALLEYS OF ANTARCTICA. Denis Lacelle¹, Alfonso F. Davila², David Fisher³, Regina DeWitt⁵, Wayne H. Pollard⁶, Dale Andersen², Jennifer Heldmann, Margarita M. Marinova³ and Christopher P. McKay³

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Introduction: The McMurdo Dry Valleys (MDV) are the largest ice-free region in Antarctica. Climatically, the MDV are all considered cold and arid environments, but an elevation-controlled climate gradient exists [1,2]. The lower valleys (< 400 m a.s.l.) are the warmest and wettest, whereas the upper valleys (>1000 a.s.l) are the coldest and driest with summer air temperatures nearly always below 0°C. According to [3], ground ice in the MDV occurs as 3 main types: i) ice-cemented sediments, ii) massive ground ice bodies, and iii) saline frozen ground associated with the presence of brines. Massive ground ice bodies occur predominantly as ice wedges or buried relict glacial ice [4–6]. Even though ice-cemented permafrost occupies approximately 55% of the upper 1 m in the landscape of the MDV, little is known regarding its nature, origin and stability.

In this study, we investigate the age, origin, recharge mechanism and stability of ice-cemented sediments in University Valley, one of the valleys situated at high elevation in the MDV (Fig. 1). This objective is reached by obtaining a 65 cm long core, describing its cryostratigraphy and measuring the water-soluble ions and stable O-H isotopes of the ice-cemented sediments. The age-depth profile of the core is derived from optically stimulated luminescence (OSL) dating of sediments in an adjacent 95 cm long core; the first reported OSL ages from ice-cemented permafrost in the MDV. To account for the observed trends, we applied a model of water transport through sediments that includes diffusive migration and phase changes driven by seasonal temperature variations. Finally, the long-term preservation of the ice-cemented sediments in a cold and dry environment is discussed.

University Valley: University Valley is located within the “stable upland” micro-climatic zone defined by [2]. In December 2009, we installed in University Valley (1677 m), an automated Campbell meteorological station equipped with air and soil temperature, relative humidity, solar radiation and wind speed sensors. The December 2009 to December 2010 data reports a mean annual air temperature and relative humidity of –24.3°C and 48%, respectively. Even though summer air temperatures were always below the freezing point, near-surface soil temperatures raised above 0°C during the summer due to solar heating, with maximum penetration of the soil 0°C isotherm approaching depths of 10 cm at the meteorological station site. These climatic conditions results in layer of dry soils overlying ice-cemented soils.

Fig 1: A) Satellite image showing Beacon Valley (1200 m a.s.l.) and University Valley (1700 m a.s.l.) in the MDV of Antarctica. B) Aerial view of University Valley with a stable glacier at the head of the valley. Subsamples of a core of vapour-deposited ground ice obtained in 2009 near the glacier.
Results: Sediments throughout the core have a light-brown color and consist mainly of medium sand-sized particles (sandy-clay loam). A slight increase in the clay fraction is observed with depth. The volumetric ice content rapidly increases from 25% at the surface to 84% at 11 cm depth (Fig. 2). Below this depth, the ice content in the sediments progressively decreases to 30%. Based on volumetric ice content values, the ground ice can be classified as ice-rich sediments, corresponding to the two zones where ice content is < 50%, and sediment-rich ice, where the ice content is > 50% between 6 and 28 cm. Five OSL ages obtained from the adjacent ice-cemented sediments core vary between 17 ± 3 ka at 2-7 cm depth to 149.7 ± 16.2 ka at 92-95 cm below the surface.

![Image](image.png)

Fig 2: Volumetric ice content, conductivity and oxygen-18 profiles obtained from the ground ice core. IRS: Ice-rich sediments; SRI: Sediment-rich ice.

The δ18O composition of the ice-rich sediments and sediment-rich ice varies between −24.6 to −27.8‰. There is an increase in δ18O values from the surface to 6 cm, where the maximum value is reached. Below 6 cm, δ18O values rapidly decreases to a minimum value at 28 cm depth, after which the δ18O composition progressively increases (Fig. 2). In a δD-δ18O diagram, the samples appear to be distributed along three distinct regression slopes. The samples within the uppermost 6 cm are distributed along a slope value of −0.2 (δD = −0.2 δ18O − 237.5; r² = 0.004); samples between 6 and 27 cm are distributed along a slope value of 7.0 (δD = 7.0 δ18O − 64.7; r² = 0.91); and samples below 27 cm plot along a slope of −0.2 (δD = −0.2 δ18O − 267.9; r² = 0.003). These three groupings correspond closely to the ice-rich sediments and sediment-rich ice cryofacies defined by the ice content.

![Image](image.png)

Fig 3: δD-δ18O relations in ground ice core.

Discussion and conclusion: The geochemical (not shown) and stable O-H isotope composition of the ground ice and OSL dating of the sediments provides valuable insights into the origin and age of the ground ice. Based on OSL dating and linear interpolation between the 5 ages, the sediments of the lower ice-rich sediments cryofacies (65-27 cm) were deposited between ca. 135.5 and 105 Ka, those in the middle sediment-rich ice cryofacies (27-6 cm) accumulated between ca. 105 and 21.5 Ka, and the upper ice-rich sediments (6-0 cm) since 21.5 Ka years ago. As such, the three cryofacies corresponds very closely to inter-glacial-glacial periods. In addition, although in δD-δ18O diagram, the ground ice samples form 3 distinct clusters that correspond to the three cryofacies observed in the core, the two ice-rich sediments cryofacies have similar regression slope values (−0.2) with poor correlation (Fig. 3). Considering that both ice-rich sediments cryofacies corresponds closely to interglacial periods (MIS5e and MIS1), this suggests that the three cryofacies have different origins or have undergone different evolutions following their formation under changing large-scale climate conditions. Using a model of long-term vapor diffusion and thermal cracking of the frozen sediments [7], our data fits reasonably well with the modeled data. Overall, our results indicate that large-scale climate variations affect, to a large extent, the origin and stability of ground ice, and that air temperatures at the site have been less than 0°C, at least for the last 135.5 Ka years.