**Introduction:** The polar regions of Mars bear massive (kilometers thick) layered deposits (PLD; NPLD and SPLD for the North and South, respectively) made mostly of H$_2$O ice. A widely accepted scenario is deposition of both PLD during a period $6-4$ Ma ago in response to a major climate change [1]. Geologically recent climate change on Mars is driven by changes of three spin/orbit parameters: orbit eccentricity $e$, spin axis obliquity $\theta$ relative to the orbit plane, and season of perihelion $L_p$ [2]. Of the three parameters, obliquity is the main driver of climate in the polar regions; it undergoes quasi-periodic oscillations with a period about 110 ka (thousands of earth years); their amplitude varies reaching +/-10$^\circ$, and the long-time average decreased from ~35$^\circ$ before ~5 Ma ago to ~25$^\circ$ after ~3 Ma ago. The latter change caused overall migration of H$_2$O ices from low- and mid-latitude regions to the polar regions and formation of the PLD [1].

Ground-penetrating radar data revealed three unusual layers in the upper horizons within the SPLD interpreted as layers of solid CO$_2$ [3,4]. Their thickness is hundreds of meters and they are interleaved with H$_2$O ice deposits tens of meters thick. No such deposits have been identified in the NPLD. The total mass of these CO$_2$ deposits is equivalent to 610 Pa pressure [4], almost the same as the planet-average year-average present-day atmospheric pressure. Assuming that the main stack of the PLD layers was formed 5 – 3 Ma ago, as discussed above, the deposits should be younger than ~4 Ma. Before formation of these deposits the atmosphere was a factor of two denser. It is logical to associate their formation with low obliquity periods, because the atmospheric collapse at low obliquity [e.g., 5-8] it is the only way to form massive CO$_2$ deposits. Location of the deposits in the upper parts of the PLD stack is reasonable, because in the early stages of the PLD formation, before ~4 Ma, when the lower PLD layers were forming, obliquity has never been significantly lower than now, and atmospheric collapse was unlikely. It is not obvious, however, why there are three layers, why they are in the SPLD, and why there are no similar layers in the NPLD. Moreover, simple considerations predict that during the atmosphere collapse, CO$_2$ should be deposited in the north pole, and not on the south [4] (see below). In [4] an advanced 1D energy balance model [8] was used to trace details of atmospheric collapse and obtained a few recent (younger than 1 Ma) episodes of CO$_2$ deposit formation in the South. However, this model was essentially based on empirically postulated very specific seasonal behavior of CO$_2$ frost albedo, which is essentially different in the north and in the south. While this model reproduces the present-day conditions well, its applicability to different epochs is not grounded, because there is no any reason to extrapolate the specific present-day peculiarities of CO$_2$ ice microphysics.

Here we propose a conceptual model that naturally explains the presence of a few layers of CO$_2$ in the SPLD and absence of CO$_2$ layers in NPLD without involvement of assumptions about different properties of ices on the North and South.

**Dynamics of atmospheric collapse at low obliquity:** We used simple energy balance model [6] to understand dynamics of atmospheric collapse at low obliquity (Fig. 1). CO$_2$ deposition starts in both polar areas and occurs at approximately equal rate. However, when atmospheric pressure becomes low, accumulation in the S polar area stops, because the surface temperature does not reach the frost point in winter. On the N polar area, however, accumulation continues, because its elevation is lower, atmospheric pressure is higher, and the frost point occurs at a higher temperature. This leads to migration of CO$_2$ from the S to the N polar area. When obliquity increases, the CO$_2$ deposit on the N sublimates. Therefore, during atmospheric collapse CO$_2$ deposits at the S polar area are transient; they disappear unless they are protected by overlying deposits.

**Conceptual model:** Our conceptual model of CO$_2$ layer formation is schematically illustrated in Fig. 2, which shows variations of obliquity from [2], calculated summer pole insolation on the basis of [2], and amount of CO$_2$ in the atmosphere and sequestered in the PLD (schematically) for the last 4 Ma (time goes from the right to the left).

To be preserved, the CO$_2$ deposit formed at low obliquity should be buried by H$_2$O ice. Such burial is possible, because perennial CO$_2$ deposits are cold traps in the summer, they inevitably accumulate some H$_2$O ice from the atmosphere; this ice can form a protective lag, when CO$_2$ sublimes. This mechanism can potentially protect CO$_2$ deposits on both PLD: on SPLD protective lag would form early, when obliquity still decreasing, but atmospheric pressure already dropped, while on NPLD it would form when obliquity is increasing. Accumulation of H$_2$O ice is most effective, when atmospheric H$_2$O vapor is abundant, which is likely, when some H$_2$O ice deposits still exist at low
latitudes, that is earlier in the PLD formation. Therefore, the best conditions for sequestration of CO$_2$ in the PLD occur during the very first obliquity minima and atmosphere collapse episodes, 3.19, 3.07, and 2.94 Ma ago. We suggest that the observed CO$_2$ layers in the SPLD formed that time; three layers might correspond to those 3 obliquity minima. However, if some CO$_2$ was sequestered in the SPLD, almost inevitably a CO$_2$ layer would also form in the NPLD.

We suggest that thick CO$_2$ layers indeed were formed in the NPLD ~3 Ma ago, sequestering almost all present-day CO$_2$ inventory. However, this sequestered CO$_2$ was returned to the atmosphere later, during high obliquity periods. It is seen in Fig. 2 that during obliquity maxima 1.86 and 0.63 Ma ago, the summer-time insolation in the N polar region was noticeably higher than ever in the S polar region during the last 3 Ma, after the hypothesized CO$_2$ sequestration episodes. During these warm periods migration of H$_2$O ice from the NPLD to lower latitudes [1] could lead to exposure of sequestered CO$_2$ and its quick sublimation. We hypothesize that the same did not occur at the SPLD, because peak insolation was lower. The difference in the insolation patterns between N and S occurred coincidentally due to specific evolution of $\theta$ and $L_P$. Re-sequestration of the released CO$_2$ has not occurred because there were no deep obliquity minima after the 0.63 Ma maximum, as well as because the low-latitude H$_2$O reservoir was likely smaller than ~3 Ma ago, H$_2$O vapor was less abundant, and H$_2$O ice lag was insufficient to protect newly forming CO$_2$ deposits.

Some variations of this model are possible, for example, some additional layers of CO$_2$ might be deposited and removed from both PLD at other obliquity minima and maxima; Fig. 2 actually shows one of such variants.

**Conclusion:** Our conceptual model naturally explains the presence of the CO$_2$ layers in the SPLD and their absence in the NPLD. It predicts that the CO$_2$ deposits are older than suggested in [4], likely ~3 Ma old and were deposited in the earliest low obliquity/atmospheric collapse episode. It also predicts very low atmospheric pressure ~ 2 Ma – 3 Ma years ago, and might be even later, before the CO$_2$ deposits in the NPLD were released.

Our conceptual model perfectly consistent with observation of extinct CO$_2$ glaciers [9]: the most extensive CO$_2$ glaciers were the oldest stratigraphically; they were likely formed during the first obliquity minimum, before some CO$_2$ was sequestered in both PLD, and atmospheric CO$_2$ reservoir was the largest. Our model is also consistent with observation of small impact crater clusters in Tharsis that suggest a lower mean atmospheric pressure 1-2 Ma ago [10].

**References:**