The puzzle of the early Martian climate
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The aim of this activity is to discover more about sedimentary processes, mineralogy, geochemistry and climate science and to think through an interesting problem in planetary science - the nature of the early Martian climate. The major puzzle of the early Martian climate is this: the geological record of Mars preserves abundant evidence for the presence of liquid water in the form of sedimentary deposits, landforms, etc. However, Earth Scientists and physicists who study climate processes do not understand how the early Martian climate was able to stabilise liquid water. This is because billions of years ago the ancient sun was less bright and therefore less able to warm planetary surfaces, so intense "greenhouse effects" of certain gases are required. But which ones, and how?

The principles developed here are introduced in first and second year Earth Sciences at Cambridge where sedimentary geology, geochemistry, and climate science feature more prominently in the curriculum. Also, its a fascinating subject!

Many of the questions below can be addressed by consulting various sources of information but one very important source is *The Climate of Early Mars*, written by Robin Wordsworth for Annual Reviews in Earth and Planetary Sciences in 2016. The paper contains a lot of information, but it is exceptionally clear and most of it should be accessible at the first year University level - do your best to absorb this information!

Consider the following questions:

- The Martian surface features some enormous impact craters (i.e., the Isidis, Hellas and Argyre basins). What role do you think they played in shaping the early climate evolution of Mars?

- Why is evidence for crater lakes important from a climate perspective? What crater lake deposits have been explored by previous landed missions to Mars?

- The mineralogical composition of the Martian crust (which contains sedimentary rocks) has been constrained by orbiting instruments and by rover-based analyses. Why is it important to bear this information in mind when considering global or long-term climate trends?

- What are "phyllosilicates"? Name some examples. What are some ways in which they form and how is this helpful in understanding the climate on ancient Mars?

- Some minerals found at the martian surface indicate "acidic" and "oxidising" conditions. Which ones, and why?

- Why is the apparent absence of carbonate minerals exposed at the surface a problem? What are some potential explanations for this?

- Why is an ancient atmosphere composed only of CO_2 unable to increase the mean surface temperature above the melting point of liquid water? What does this result mean for the nature of the early atmosphere?

- Was Mars warm and wet, cold and dry, or somewhere in between? Summarise some of the current hypotheses for the nature of the early martian climate, including the "icy highlands hypothesis".

- As I discussed in the talk, the Mars 2020 *Perseverance* rover (https://mars.nasa.gov/mars2020/) has landed at Jezero Crater. Why is this a scientifically interesting landing site? What observations should the rover be making to achieve its goals?

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