The Effect of Pressure on the Prebiotic Carbon of the Early Solar System: Ribose and Deoxyribose on Early Earth

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Abstract: High pressures, along with thermal processes and irradiation, have a measurable effect on carbonaceous compounds which are found throughout the solar system. High pressure environments such as impacts occur frequently during the evolution of the solar system, and the effects of these environments on the carbonaceous material present can influence the subsequent chemistry of the body. In situ high pressure synchrotron source Fourier Transform Infrared (FTIR) spectroscopy coupled with computational models has been used to directly study the effect of pressure on carbonaceous material. Our work using these techniques demonstrates that the structural sugars ribose and deoxyribose have differing responses to the high pressures. These particular carbonaceous materials play a key role in the prebiotic chemistry of the early Earth as key constituents of the bioinformational molecules ribonucleic acid (RNA) and deoxyribonucleic acid (DNA) respectively. Ribose is substantially less stable than deoxyribose at pressures exceeding 14 GPa and shows less recovery on decompression. Our results imply that the modest impacts experienced throughout the solar system could substantially alter the carbonaceous payload of many bodies, with consequences for any prebiotic chemistry.

Conclusions:

There is a period of ~0.7 Ga when high pressure and temperature conditions (transient and static) due to impacts and nascent tectonics coincided with the earliest evidence of "organic" carbon. (Context)

Experimental studies (Figure 1) have shown that the biologically significant sugar molecules ribose and deoxyribose respond differently to these pressures.

Compared to deoxyribose, ribose is amorphosed at substantially lower pressures with less recovery on decompression (Figures 2, 4-5).

This experimental result is consistent with computational studies (Figure 3) indicating that the binding energy differences from the molecular fragment of deoxyribose became greater than that of ribose at pressures greater than 5 GPa. The enthalpy is greater at 10 GPa. This is most likely due to differences in H-bonding in these molecules.

Understanding the response of the meteoritic/interplanetary dust particle organic payload to planetary formation and evolution pressures will further constrain the timescale and possible reactions of prebiotic chemistry.

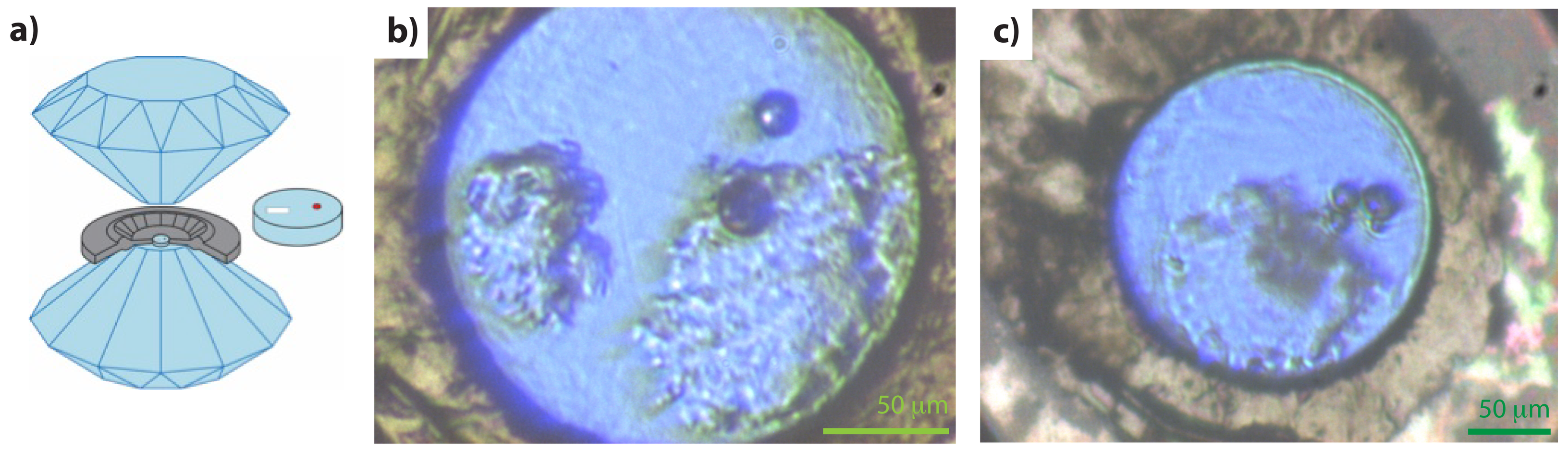

Figure 1: a) Diamond anvil cell (DAC) schematic[3] b) ribose and c) deoxyribose loaded into DAC.

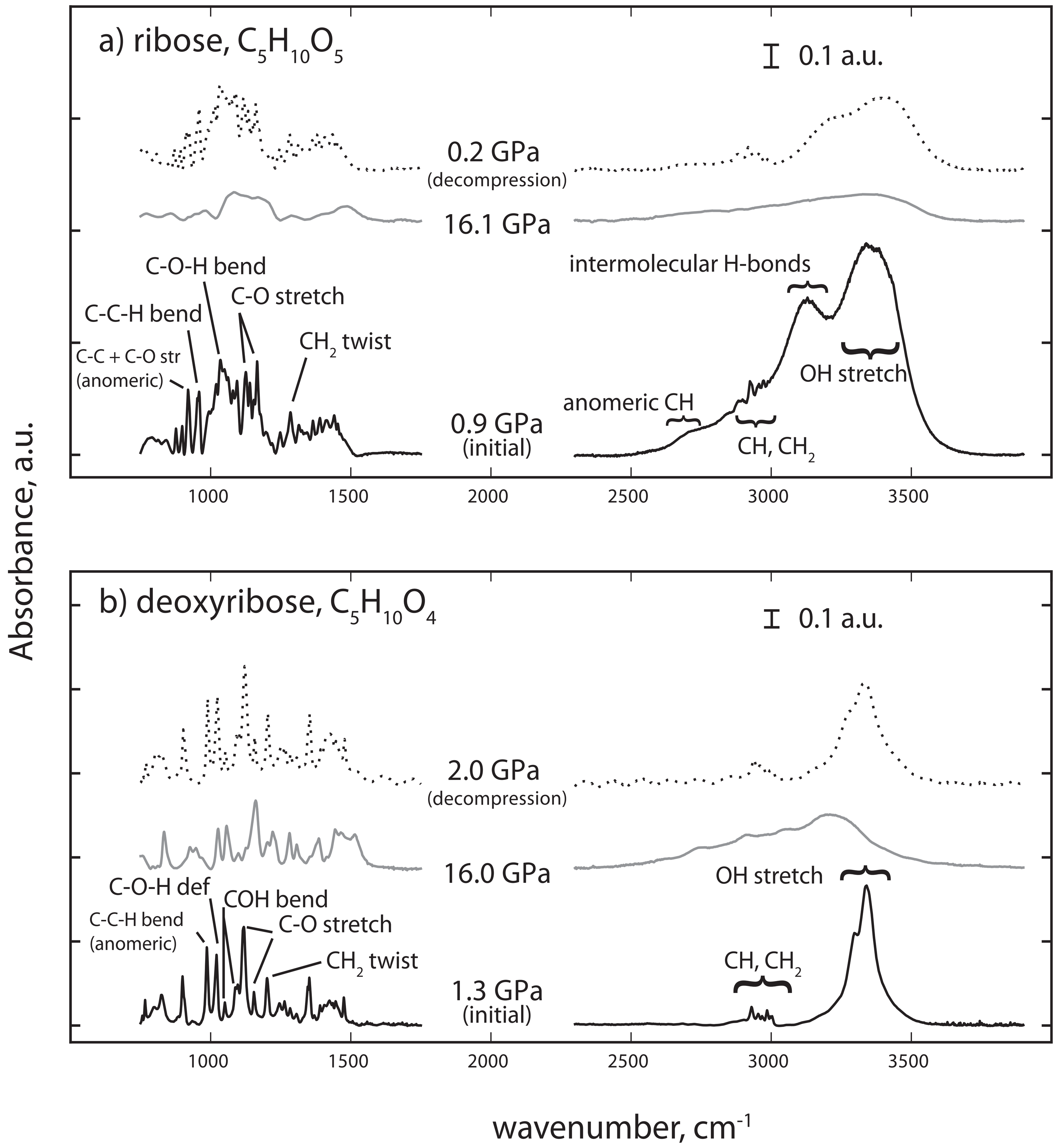

Figure 2: Experimental FTIR spectra of ribose and deoxyribose at pressures ranging from 0.9 GPa to 16.1 GPa. Spectra collected on decompression are indicated by dashed lines. Spectra are presented on a relative scale; significant loss of peak height and area is observed.

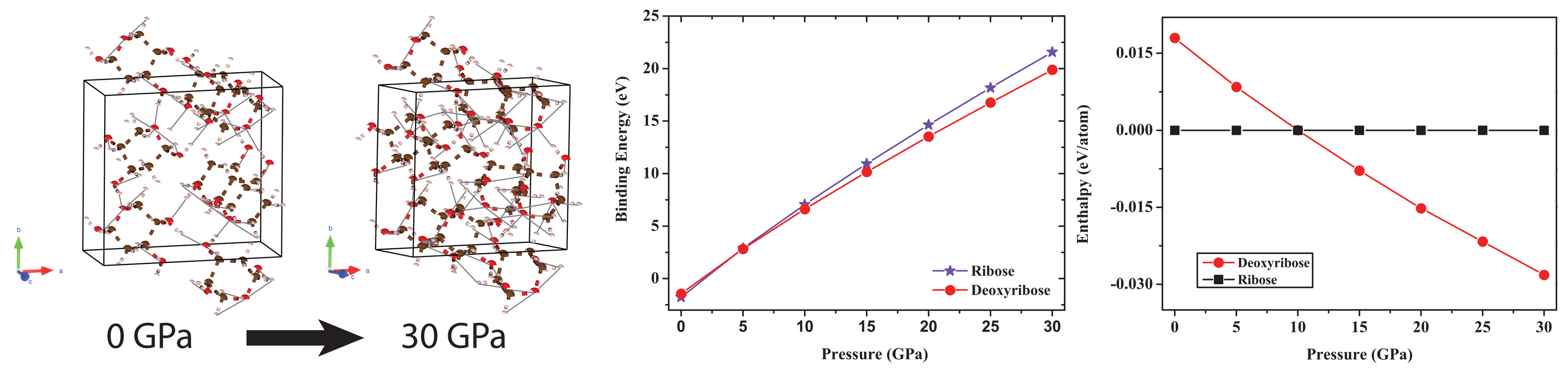

Figure 3: Computational studies of binding energy and enthalpy with increased pressure of ribose and deoxyribose. Left part of figure shows the formation of H-bonds within the deoxyribose crystal at high pressures. Right part of figure shows binding energy differences from the molecular fragment of deoxyribose became greater than that of ribose at pressures greater than 5 GPa and the enthalpy is greater at 10 GPa.The calculations were performed with the projected augment wave potentials with a plane wave basis set using VASP.

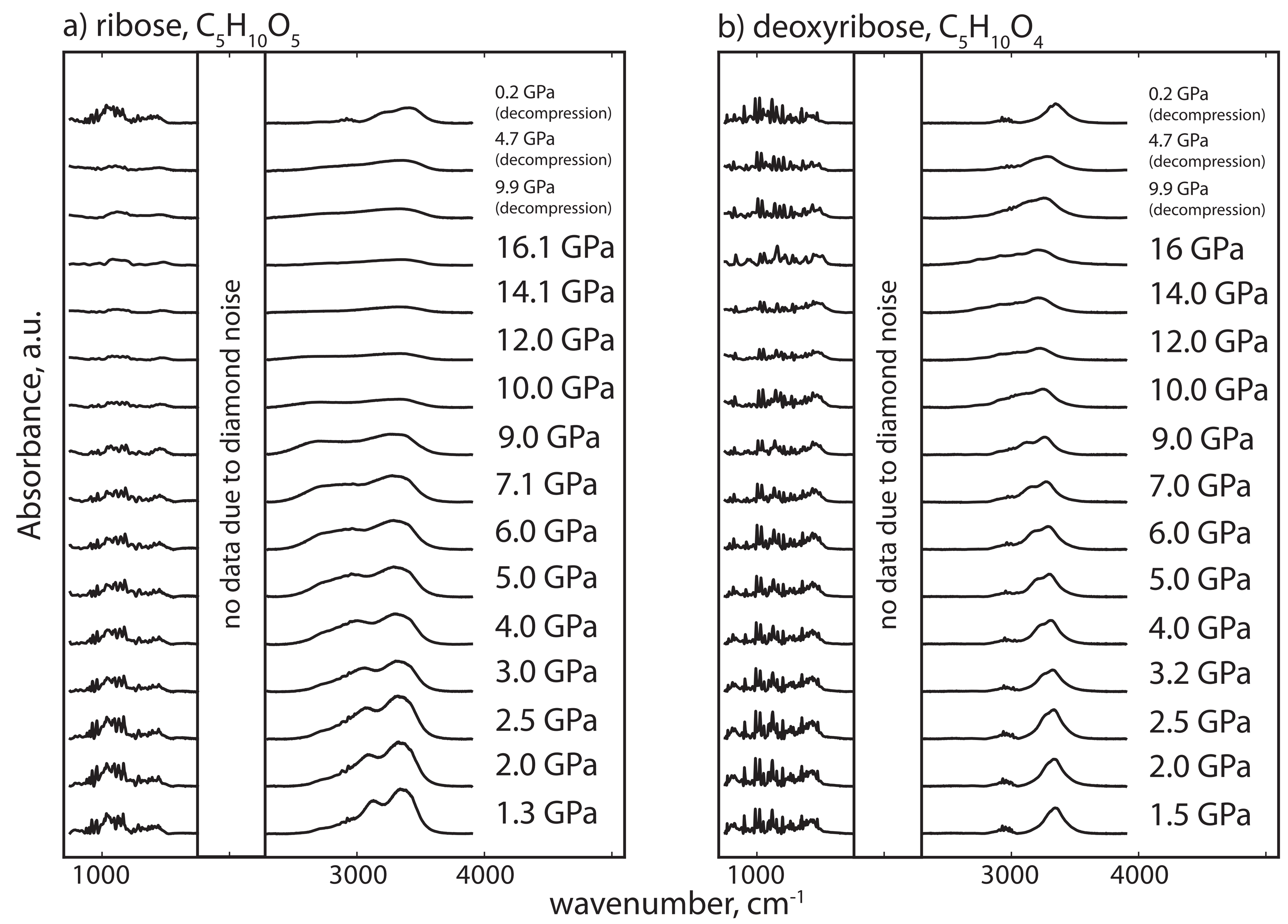

Figure 4: FTIR spectra of ribose and deoxyribose at pressures up to 16 GPa. Ribose peaks disappear at 10 GPa, while deoxyribose peaks persist to higher pressures.

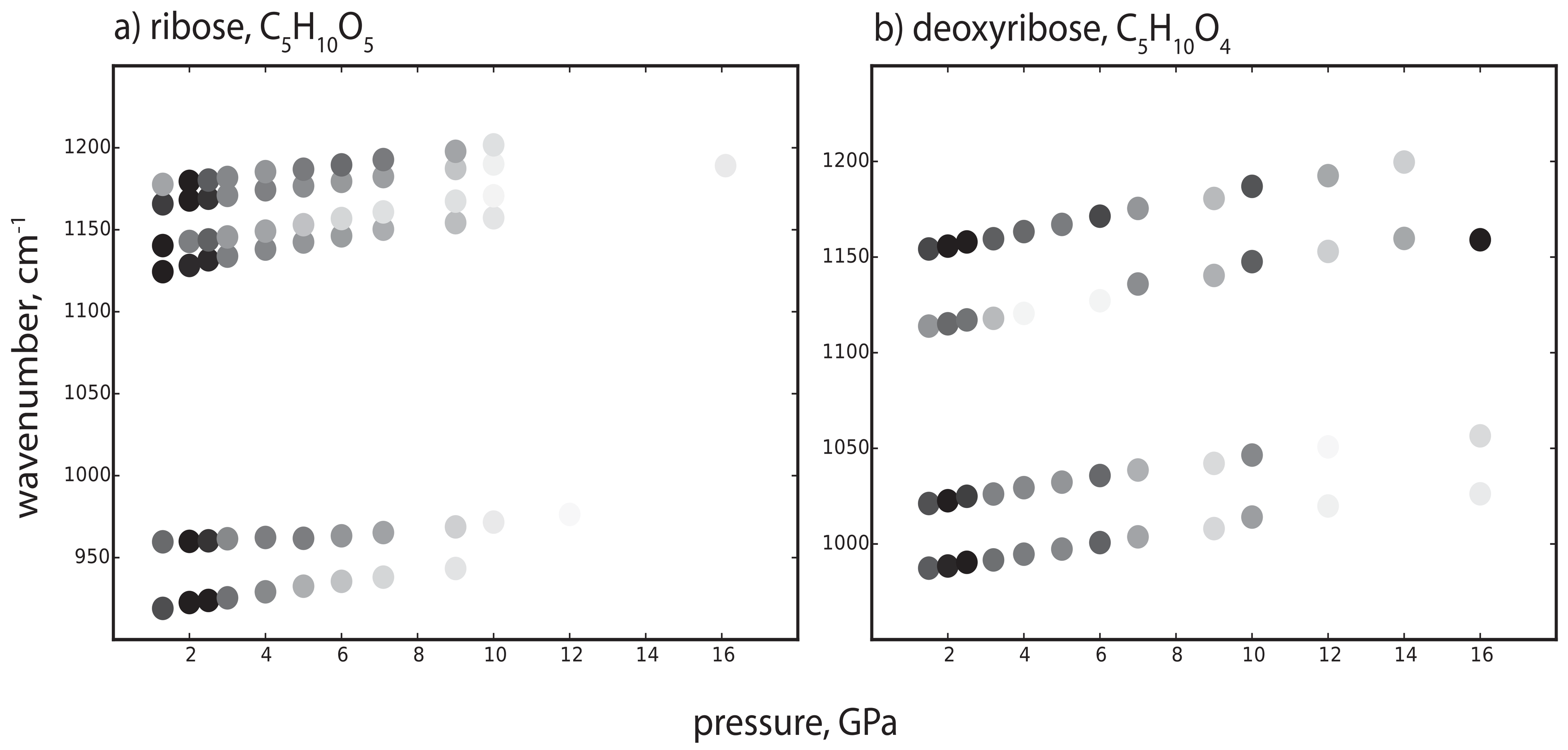

Figure 5: Pressure evolution of peak centers on compression. Intensity of dot indicates percentage of initial peak height. Ribose peaks disappear at 10 GPa, while deoxyribose peaks persist to higher pressures.

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