**Porous ceramic rod #2**

**Summary of Results:**

Dry measurements were conducted at the very beginning, after nitrogen saturated measurements, and after CO2 saturated measurements. The elastic wave velocity of the dry rock changed between each set of dry measurements, where the velocity of each set of measurement is progressively lower than the previous. This change is not attributed to closing of cracks or pores, since velocity is not increasing with the sets of measurements.

**Nitrogen**

After the first set of dry measurements, the sample was saturated with nitrogen. Measurements were done at room temperature and at T=40C. Measurements were done for constant differential pressure (Pd) at 15MPa, and constant confining pressure (Pc) at 40MPa while pore pressure varied. For the heated nitrogen measurements, signals were collected as temperature of the vessel increased.

Pd=15MPa N2: As pore pressure increases the velocity of the rock decreased. Since differential pressure is constant, this reflects purely the effect of pore fluid. Comparing the results of room temperature nitrogen and that of 40C nitrogen, the velocity of the room temperature nitrogen is higher than that of the heated nitrogen at any given pore pressure.

This higher T=23C velocity than T=40C velocity is also notable for where the measurements were conducted for constant confining pressure and pore pressure was allowed to vary. Pc was the same for both set of temperature measurements, then at any given differential pressure the velocity difference observed is be solely due to the effect of temperature, since the same pore pressure will be required to produce the same differential pressure if the confining pressure is the same.

This higher velocity of T=23C measurements versus that of the T=40C measurements can be attributed to the weakening of the frame of the host rock and can be illustrated from measurements taken as the sample was heated up from room temperature to 40C. The pore pressure and confining pressure were maintained as the temperature of the vessel increased. The changes in velocities is due to temperature effects on the host rock and the pore fluid (viscosity effect?)

This sample was also saturated with only 0.5MPa of nitrogen in the pore space, while confining pressure was varied. This result is plotted on the first graph with dry measurements. Comparing this measurement taken on March 31st to the dry results taken the day after, April 1st, it is seen that even with a small amount of N2 in the pore space, the velocity of the overall rock will drop.

**Carbon Dioxide**

Measurements were conducted for temperatures of 23C (room temperature), 28C, 40C, 45C, and 55C (incomplete). At each of these temperatures, measurements were taken at constant Pd=15MPa and constant Pc=40MPa. For all temperatures except room temperature, measurements were taken as the pressure vessel was heated to the desired temperature. All pressures (Pc, Pp, and Pd) were maintained as the temperature rose. Pd=15MPa for all sets of heating up measurements, while Pp varied between each set of heating up measurements.

**Heating UP**

T=28C: Pd=15MPa, Pp=6.8MPa (Phase transition: liquid to gas)

T=40C: Pd=15MPa, Pp=10MPa (Phase transition: liquid to supercritical)

T=45C: Pd=15MPa, Pp=25MPa (Phase transition: liquid to supercritical)

T=55C: Pd=15MPa, Pp=6.8MPa (Phase transition: liquid to gas)

Only for T=55C heating up measurements was the phase transition obvious from the velocity change (signal strength increased drastically once in the gas regime).

For all the other set of heating up measurements, the resulting velocity increased with temperature., however the change is very moderate (~15m/s overall change). Same trend can be seen with S-wave. Increase in velocity with increasing temperature is expected if we considered that the shear modulus is not affected by the behaviour of the pore fluid, because the shear modulus will stay the same the same sample regardless of the condition and density will decrease with higher temperature thus resulting in increasing velocity with temperature.

Below is a comparison of the different pore pressures maintained as temperature went up during heating for each of the set of measurements. It appears that at a given temperature, the higher the pore pressure inside the rock the lower the velocity and is not due to differential pressure difference between each set because Pd=15MPa for all of them.

Phase change is most apparent for Pp=6.9MPa heating up to 55C. Phase change is somewhat apparent for the Pp=25MPa, for heating up to 45C in the graph below. This slight step up in velocity with temperature for this set is not obvious when this set of measurements were graphed only by itself. The scale of the graph highlights this change that was unnoticed before.

**Pd=15MPa at constant Temperature**

Pd=15MPa at constant temperature measurements were done at T=23C, 28, 40, and 45C. At 55C, Pd=15MPa were only partially completed (gas phase state only). As pore pressure increases for any of the temperature sets, the velocity decreased. Phase change is evident from the large drop in velocity for both gas to liquid and gas to supercritical phase states. Gas to liquid phase change is notably different than gas to supercritical. Gas to liquid consist of a steep drop, unlike the gradual nature of the gas to supercritical phase change. Also, the drop in velocity occurs at a lower pore pressure for gas to liquid, than gas to supercritical. This is expected since the vapour liquid boundary (phase change position of gas to liquid as a function of temperature and pressure) occurs at a lower pressure than the critical pressure for any substance. The occurrence of the velocity changes between gas and liquid and gas and supercritical is somewhat close to predicted.

**Pc=40MPa at constant Temperature**

Similar to Pd=15MPa at constant temperature, we observe a drop in velocity due the phase change of the pore fluid. And it appears, just like Pd=15MPa, higher temperatures have higher velocity than that of the lower temperatures, particularly at high pore pressure. At high pore pressure, the pore fluid can be a liquid or a supercritical fluid. Which phase state occurs is dependent on what the temperature is. At higher temperatures, the phase state is supercritical which has a lower density than the liquid phase state which occurs at lower temperatures. This higher velocity of supercritical fluid is then explainable, because supercritical fluids have lower density than that of a liquid phase state.

Note in the diagram below, comparison in velocity among a given temperature measurement set is affected by pore pressure and differential pressure and does not reflect solely the pore fluid or the rock response to pressure because Pc is constant, Pd and Pp both would vary. However, comparison is valid at any given pore pressure between the different set of measurements and would yield the effects of the pore fluid. Pc=40MPa for all temperature sets, so for a given pore pressure Pd is the same for all sets of measurement, thus eliminating the effect of the Pd on the velocity comparison. The changes in velocity between the different temperatures is solely due to the pore fluid, IF we are comparing at one pore pressure.

**Heating Dry Sample**

Measurements were also done on the dry sample while heated to illustrate frame weakening due to temperature and is shown below. As temperature increases, the velocity of the dry frame decreases while the confining pressure is held constant throughout the heating. This works in opposite of what was seen when the sample was saturated and heated. If the frame did not weaken with temperature (ie decrease in velocity), the increase of velocity of the saturated rock containing CO2 with increasing temperature would be more enhanced.