Introduction: Feldspar is the most abundant mineral at the surface of the Earth and is a dominant mineral in the crusts of Mars and the Moon. Feldspars also are common in meteorites, suggesting that it is abundant on the surfaces of asteroids. Feldspars, particularly plagioclase, are known to undergo a series of structural transformations in response to pressure, and therefore have been used as indicators of shock processes across the Solar System [1-2]. Specifically, these transformations manifest as a systematic loss of crystallinity forming an amorphous material (sometimes referred to as either “diaplectic glass” or “maskelynite”) [3-5]. Under certain conditions, plagioclase will undergo a decomposition to higher density or higher coordinated phases, such as jadeite-structured phases [6]. However, the specific mechanisms behind these transitions are not fully understood [7-8]. Additionally, these transitions are not just pressure dependent, but also depend on temperature, strain rate, deviatoric stress, and shear [8-9]. Therefore, in order to correctly interpret P/T conditions from shocked samples, it is important to have a complete understanding of the high-pressure pathways and stability fields of plagioclase.

Samples: All experiments were conducted on andesine separated from an anorthosite collected near St. Urbain province in Quebec, Canada [10]. This sample has been used previously for shock experiments and subsequent spectroscopic studies [10-11].

Methods: Diamond anvil cell experiments were conducted using diamond anvils with a 450 μm culet with salt (NaCl) as pressure medium. The sample was crushed slightly by hand and individual ~50 μm sized grains were loaded into the cells. Pressures were obtained using the ruby fluorescence method [12]. Errors on pressure measurements are 0.2-0.3 GPa. All analyses were conducted in the Center for Planetary Exploration at Stony Brook University. Micro-Raman spectra were collected using a WiTec alpha300R confocal imaging system equipped with 532 nm Nd YAG laser with 2.24 mW nominal power at the sample surface, and a 50X objective (spot size of 763 nm). Each analysis consisted of 240 1-second integrations.

Experiment 1: The first experiment incrementally increased pressure on the sample to 17.9 GPa (in 7 steps over the course of 45 minutes), and then pressure was stepped down to 0 GPa (in 5 steps over 20 minutes). Results are shown in Figures 1-2. There is a narrow peak seen at 311 Δcm⁻¹, that is an instrumental artifact and is present in all samples and standards. Between 0 and 12 GPa, there is an increasing disorder, noted by the decrease in intensity of the 485 Δcm⁻¹ peak, and slight broadening of the 514 Δcm⁻¹ peak. Additionally, the peak position of the 514 Δcm⁻¹ peak increases in wavenumber. Above 14.9 GPa, the sample is no longer crystalline. Upon decompression the sample reverts to a crystalline phase. Interestingly, there are slight differences between the pre- and post-compression samples, as shown by slightly lower peak intensities and a higher 485/514 Δcm⁻¹ peak ratio in the post-compression sample.

Experiment 2: Andesine was compressed directly to 17.9 GPa, and then quenched immediately. “Quenched” here refers to a single step decompression of the cell. Results are shown in Figure 3. As with experiment 1, the sample reverts to its crystalline form upon decompression.

Experiment 3: Andesine was compressed incrementally to 18.1 GPa, let sit at high pressure for 2 months, and then quenched. Results are shown in Figure 4. This sample remained amorphous after decompression. This sample was monitored for 9 months after quench and the sample remained amorphous the entire time.

Experiment 4: Andesine was compressed to 20.3 GPa, and then quenched immediately. Results are shown in Figure 5. This sample remained amorphous after decompression.
Discussion: Our results indicate that andesine undergoes two transitions in response to compression: one reversible transition to an amorphous material above ~14 GPa, and a second irreversible transition to fully amorphous material between ~18 and ~20 GPa. Similar behavior has been observed in pure anorthite [8], but this had not previously been documented in less calcic plagioclase.

The pressures associated with both transitions in our experiments for andesine are the same as those reported for anorthite [8].

This is contrary to the known trend where more calcic feldspars transform under lower pressures. This is likely due to a secondary effect on transformations in feldspar – deviatoric stress and the degree of isotropy of the compression. These experiments were conducted with a less-hydrostatic medium (salt) than the experiments on anorthite (ethanol). Under the same pressure transmitting medium, the transformation pressures in andesine and anorthite would likely follow the predicted trends. We are currently working to do similar experiments with albite and bytownite all using the same mounting medium.

Importantly, experiment 3, staying at high pressure for 2 months, suggests that there is an additional variable involved in the transformations to amorphous material – time. The overall level of deformation required to transform andesine to a fully amorphous, non-recoverable material likely depends on not just pressure, but also temperature, time, and deviatoric stress. Based on this experiment, we suggest that there is a point (likely by ~18 GPa) where there is a metastability field at high pressure, such that in order to cross the threshold for an irreversible transformation an increase in pressure, or time is needed. This time dependency may be critical to applying static compression experiments to natural systems – both shock and traditional metamorphic environments. Shock events are significantly shorter than DAC experiments, while metamorphic events are significantly slower than DAC experiments, and therefore we should consider the time components when interpreting DAC data.

Acknowledgements: PG&G grant NNX14AN33G.