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RESEARCH AND ENGINEERING HIGHLIGHTS FROM THE ADVANCED PHOTON SOURCE AT ARGONNE NATIONAL LABORATORY

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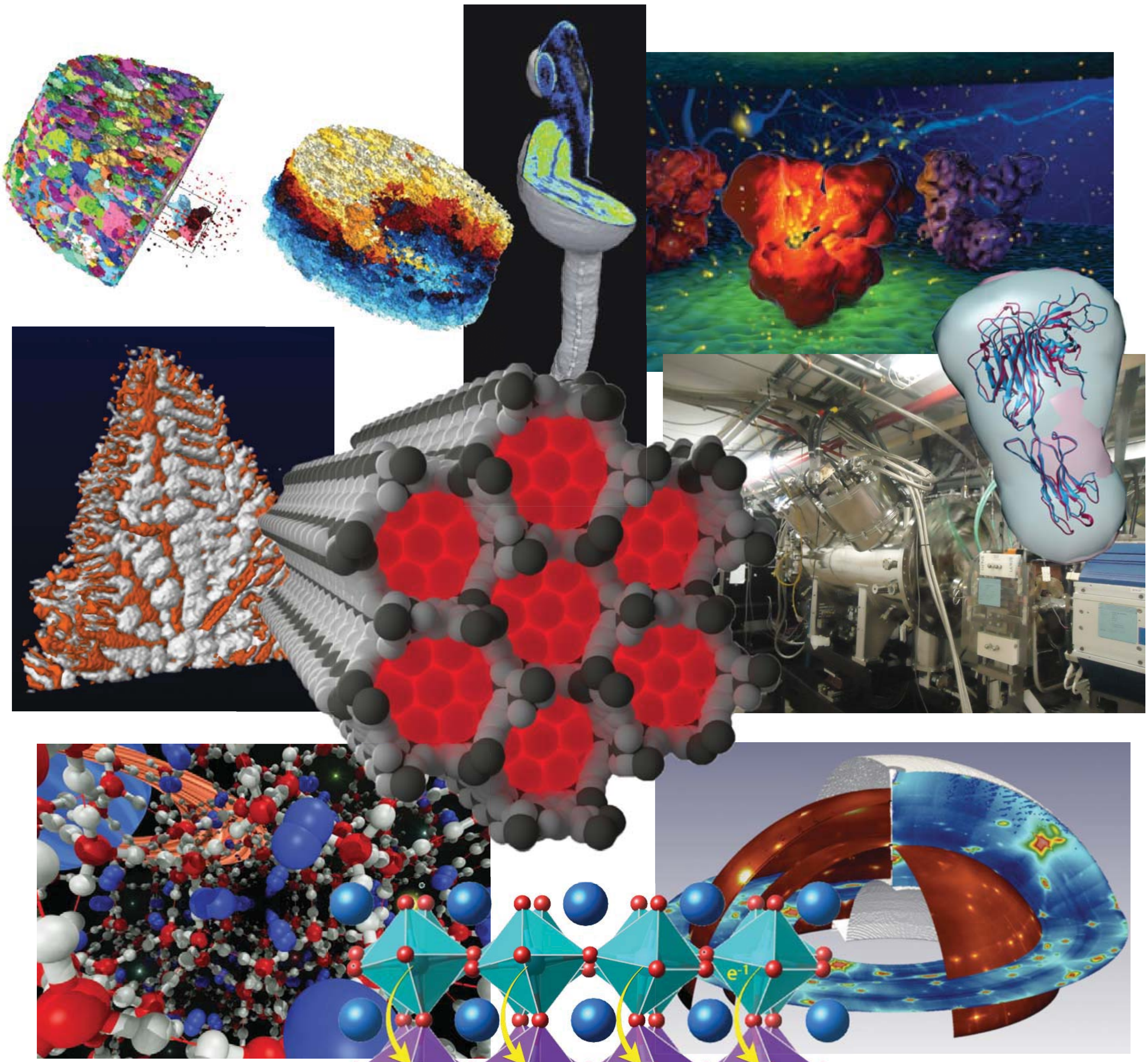

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ENHANCING OUR UNDERSTANDING OF MANTLE MELT FRACTION

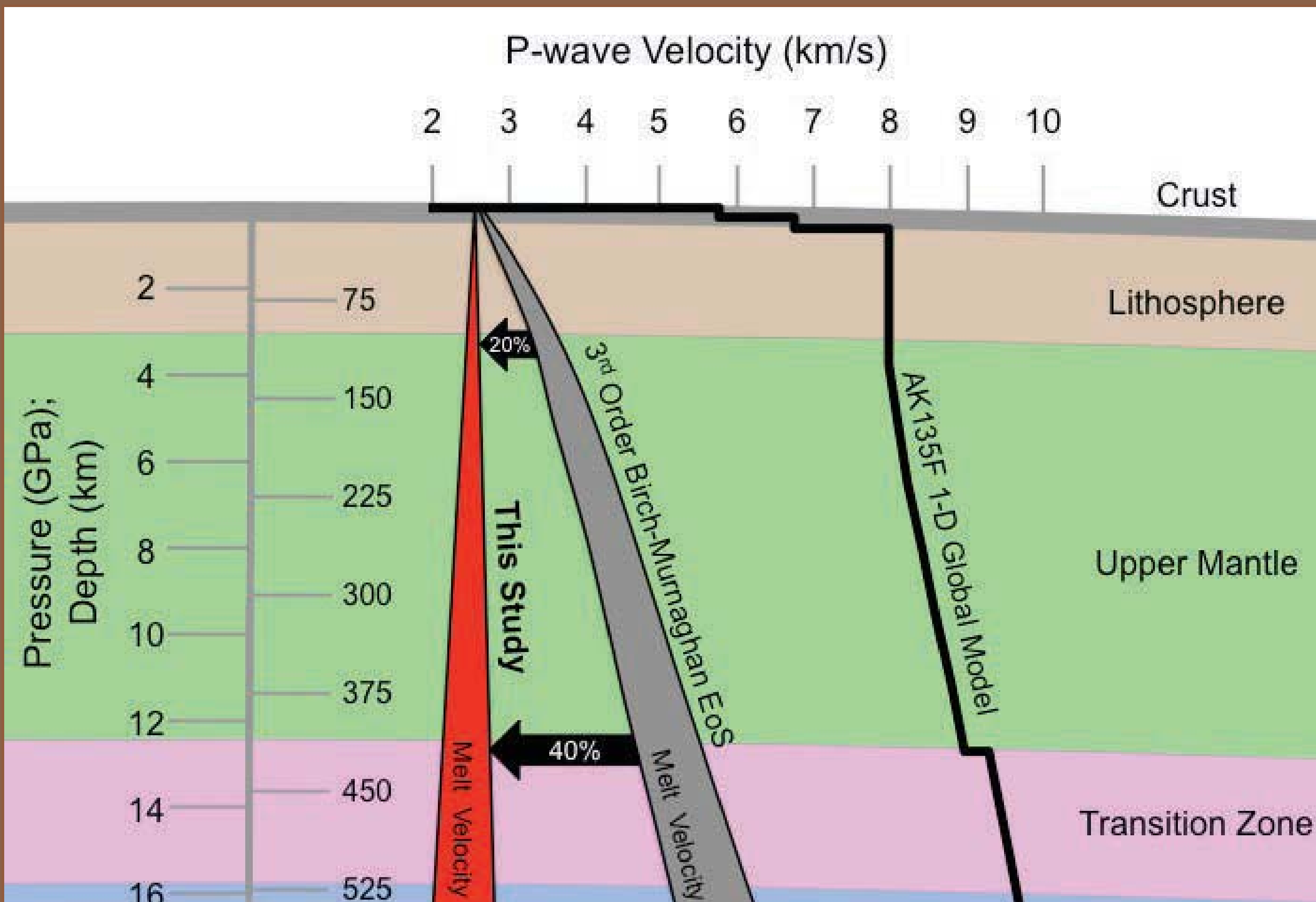

Fig. 1. *P*-wave velocity as a function of depth for this new data, compared with two preexisting velocity-pressure relationships: a global Earth computational model and the extrapolation of Birch's Law (labeled 3rd Order Birch-Murnaghan Equations of State). The new results give considerably lower velocities than the other models due to the amorphous structure of glass.

Scientists study how seismic waves change while traveling through rocks to determine the composition and physical state of the materials that comprise Earth's interior. The current theory relating seismic wave velocities and the materials in the mantle relies on results from challenging-to-conduct laboratory experiments manipulating crystalline solids; consequently, most scientists utilize extrapolations of these existing measurements for other physical states such as glasses and melts. In research at the APS, an international team discovered that melts do not exhibit the behavior predicted by these extrapolations. They further found that existing extrapolative relationships might overestimate the amount of melt in the Earth's upper mantle. This overestimation impacts our current understanding of key concepts in plate tectonics, such as the amount of coupling between the plates and the mantle.

In this new work, a team of researchers from the University of California, Davis, Aarhus University (Denmark), Northwestern University, and The University of Chicago found that melts do not follow the relationship prescribed by Birch's Law: that the velocity of pressure waves, also called *P* waves, increases in denser rocks. Instead, melts slow down the seismic waves at depths corresponding to the Earth's crust and upper mantle. To reach this conclusion, the team combined ultrasonic and tomographic data from basalt glass to determine the relationship between the elasticity and density of the glass.

The team used United States Geological Survey standard basalt glass from the Columbia River flood basalt province as their experimental sample. They began by taking volumetric measurements of the basalt glass using high-pressure x-ray microtomography at the GSECARS beamline 13-BM-D at the APS. From this, they determined the density of the glass as a function of pressure.

Next, they measured acoustic wave travel times using gigahertz-ultrasonic interferometry at Northwestern University. By combining the tomographic and ultrasonic results, the team determined how *P* wave velocity, adiabatic bulk modulus, and shear modulus vary as a function of pressure.

The values determined for these pressure-dependent characteristics were unexpected. Unlike a highly structured silicate network in a mineral, which repeats periodically over a mineral's volume, a glass has a more flexible structure because it consists of disordered regions: differently sized rings and randomly oriented chains of silica polyhedra. The team concluded that the amorphous structure of the silicate rings and chains in the basalt glass were what produced the unexpected values for these characteristics: the rings and chains bend, twist, and buckle when compressed, unlike the shortening of interatomic bonds, which occurs during compression of highly ordered silicate minerals.

Another of the team's conclusions was that seismic waves move more slowly through melts than previously thought; seismic wave velocities decrease in basalt glass even in increasing pressure. Figure 1 shows *P* wave velocity as a function of depth for three sets of data, allowing for a visual comparison of how this new data yields much lower velocities than those calculated by previous studies.

The implications of this conclusion are that most models overestimate the amount of melt associated with the low seismic velocity zone near the boundary between the plastically deforming portion of the mantle and the rigid shell above it, which is comprised of both crust and mantle. This overestimate impacts many existing theories, including plate tectonics, which assumes a high volume of silicate melts that allow the rigid plates to slide without friction over the malleable mantle, with little coupling. A smaller amount of melt would require the theory to include friction between the plates and the mantle. This requirement would increase the complexity of the theory, but also empower it to better account for plate subduction since friction between the plates would induce coupling and help explain the downward forces acting on the plates.

Seismic wave velocities and plate coupling are only two examples of large-scale events affected by the small-scale amorphous structure of basalt glasses. These new results show that the behavior of basalt glass under pressure offers an updated picture of Earth's interior and ongoing geophysical processes.

— Mary Alexandra Agner

See: Alisha N. Clark[1*‡], Charles E. Lesher[1,2], Steven D. Jacobsen[3], and Yanbin Wang[4], "Anomalous density and elastic properties of basalt at high pressure: Reevaluating of the effect of melt fraction on seismic velocity in the Earth's crust and upper mantle," J. Geophys. Res. Solid Earth **121**, 4232 (2016). DOI: 10.1002/2016JB012973.

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