Broadband seismic stations record ground shaking produced by both nearby and teleseismic sources, making them quintessentially multi-purpose tools for investigating earthquake processes and Earth structure throughout the globe. USArray will gather an immense seismic data set that can be exploited for many new research applications as the TA migrates across the United States, as the fixed ANSS Backbone accumulates data, and as deployments of dense arrays of FA stations occur for times scales from days to years. In combination with US regional network stations, these USArray data collection efforts will provide unprecedented aperture and wave field sampling that will enable new approaches and insights to fundamental problems.

Figure 1: The deep mantle corridor sampled by paths from deep South American events to the initial TA deployment in the western US is shown on the left. S and ScS observations were migrated to form the image on the right along profile A’-A, which is interpreted as having a reflector above the CMB caused by post-perovskite phase transition in a cold, folded and piled relic Farallon slab. [Hutko et al., 2006].

Figure 2: Paths to USArray TA stations in the western U.S. from deep focus events in the Tonga-Fiji region (A), illuminate the lowermost mantle beneath the central Pacific (B) in a region of lower than average shear velocities (red regions). (C) Stacking of broadband SH waves aligned on the core-reflection ScS (top right), reveals reflectivity (black lines) in the lowest 300 km of the mantle, modeled (red lines) by small velocity increases and decreases for the velocity profiles shown on the lower right. A lens of post-perovskite material that thins toward the northeast is one interpretation of the velocity structure. In this scenario, the double intersection with the phase boundary provides an estimate of the regional temperature gradient, and by assuming a thermal conductivity, the heat flow through the CMB can be estimated [Lay et al., 2006].
While the principle scientific focus of USArray data collection is centered on earthquake processes and crustal, lithospheric, and upper mantle structure beneath the continental United States, a host of exciting investigations of other parts of the globe are possible using USArray data. These include studies of remote earthquake sources, as well as imaging of Earth structure far from North America, from the crust down to the planet’s center. The density and quality of the USArray data are primary factors in the types of studies that are enabled. Here we highlight how USArray data can address fundamental questions in Earth science beyond those associated with the North American continent. Among a long list of possible applications, USArray can contribute significantly to our understanding of the nature of great earthquakes, the mode and style of mantle convection, the fate of subducting slabs, the genesis of mantle plumes, heat flux across the core-mantle boundary (CMB), the age and rotation rate of the inner core, the nature of Earth’s magnetic field, and the mineralogical and petrological structure of the planet.

The global distribution of earthquake sources intrinsically ensures that USArray data have seismic wave paths that extensively sample Earth structure outside of the continental US. Seismologists have developed many approaches for isolating near-source, deep path, and near-receiver contributions to the seismic signals. Well-sampled wave fields with large spatial aperture are key to isolating the effects, and the TA plus ANSS backbone satisfies both criteria to an extent never before achieved. Global distributions of seismic observations are critical to many studies, and the concentration of North American observations provides particularly good sampling and signal-to-noise enhancement over a range of paths for studies of global mantle tomography, earthquake source mechanism inversions, and studies of deep Earth structure. The open access and high quality of the USArray data ensures its incorporation into such research applications. In this sense, the USArray broadband observations augment the global station distributions of the GSN and FDSN, and all the USArray recordings of larger earthquakes around the world can and will be routinely incorporated into important research efforts.

The more innovative value of USArray observations is their collective use in array approaches, which directly exploit the dense wavefield sampling. For example, investigations of deep Earth structure are commonly focused on localized corridors through the Earth sampled by specific earthquake and station concentrations. For studies that use deep earthquake sources, the well-illuminated corridors are limited; USArray in particular provides dense sampling of corridors under the Central Pacific, under Central America, and under Alaska and the Aleutians. Each of these three corridors has regions of deep seismicity at ideal distances from the US for analyses of seismic waves (e.g., direct and diffracted S and P, ScS, PcP SKS, SKKS, SPdKS, and PKiKP) that sample the lowermost mantle (D" Region), the core-mantle boundary, and the outer core. As the TA migrates, the well-sampled corridors will expand spatially, unraveling structure over increasing length scales. This is a particularly exciting prospect, as it will transform tantalizing limited exposures to broadly sampled domains that can be more robustly interpreted.

Deep South American events recorded by the initial deployment of TA stations in the western US sample D" beneath the Cocos plate and Central America. Studies of P and PcP and S and ScS phases in this corridor reveal complex lowermost mantle structure (Figure 1). Differential travel time analysis, differential shear wave splitting of ScS relative to S, and wavefield stacking and migrating algorithms that utilize the array aperture to isolate ray-parameter dependent behavior of the wavefield are some of the methods used to isolate deep mantle structure in this corridor. The seismic wave reflector above the core-mantle boundary imaged by stacking of broadband data from the western US in Figure 1 is commonly attributed to the phase change from perovskite to post-perovskite phase predicted to exist some 200 to 400 km above the CMB, with the abrupt offset in the reflector interpreted as the result of folding and piling of cold Farallon slab material that has penetrated to the base of the mantle. As the TA migrates eastward, it will expose a broader region to high resolution imaging, allowing the folded slab interpretation to be tested. The TA data are already being incorporated into massive migrations of all seismic recordings sampling the deep mantle beneath the Caribbean that will resolve the details of what may be a large slab graveyard below North America.

Deep events in the Tonga-Fiji region recorded by USArray provide paths through the lower mantle beneath the central
Pacific (Figure 2), allowing detailed investigation of the large low shear velocity province (LLSVP) under the Pacific. This LLSVP and that beneath Africa, appear to be massive chemically distinct regions in the lower mantle. Past studies have suggested a variety of structures beneath the Pacific LLSVP including changes in anisotropy related to the root of the Hawaiian plume, ultra-low velocity zone (ULVZ) layering right at the CMB, containing partial melt and giving rise to plume instabilities, as well as strong lateral gradients near the edges of the LLSVPs. Figure 2 shows array stacking of USArray data and synthetic modeling to image a layered D* structure which is interpreted as having a velocity drop at the top of the LLSVP, an entrance into (velocity increase) and exit from (velocity decrease) a lens of post-perovskite phase, and a mild ULVZ at the CMB. The laterally varying post-perovskite lens structure was used to infer regional heat flux through the core-mantle boundary of about 80 mW/m². Approaches like this that draw upon seismic, mineral physics, and geodynamics constraints are a promising tool for resolving major problems in deep Earth geophysics.

Isolation of near-source structure can be done by designing the seismic analysis appropriately. Reflections from structure above the deep focus sources in the Tonga-Fiji regions are detected by migrations of P and SH waves in Figure 3. The dense sampling of the wavefield by TA stations plays an important role in forming these images, with additional coverage being provided by other global broadband stations. Imaging like that in Figures 2 and 3 is greatly enhanced by having large numbers of recordings for individual events because that allows elimination of source rupture characteristics and great signal-to-noise enhancement by stacking.

The large number of available stations in USArray and regional seismic networks provides resolution of Earth structure from single event studies – usually this is not possible with sparse data sets. Figure 4 shows an example of stacking data from a recent teleseismic event (January 30, 2007) to study precursors of the SS wave. SS precursors have been demonstrated to be sensitive to upper mantle discontinuity structure – topography on the 410 and 660 km depth discontinuities (schematics are shown in the inset panels, for synthetic seismograms of the PREM model), and have the ability to resolve fine scale structure. (d) Double array stacking of the data in (a) are shown versus distance, aligned on the SS wave (at time = 0). Travel times of dominant precursors are shown, with the waveforms for the stack of the entire data set shown to the right. Both the '410' and '660' precursors are clearly recovered, and sub-array analyses for this event would reveal the lateral variations of the discontinuity topography (Schmerr and Garnero, 2006).

These examples highlight just a few of the many exciting possibilities for using USArray data in studies of global structure and earthquake source retrieval. As the TA rolls east, new structures will be imaged, old structures will be viewed through a larger lens, and new earthquake processes will be revealed. These analyses will bring a deeper understanding to how Earth works as a system – how the evolution, structure, and dynamics of the interior relates to the tectonic processes manifested at Earth's surface.


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