BOOK REVIEW

POST-PEROVSKITE: THE LAST MANTLE PHASE TRANSITION. K. Hirose, J. Brodholt, T. Lay, D. Yuen, Eds. (2007) American Geophyscial Union, Geophysical Monograph Series, 174. 350 pages, hardbound. ISBN 13: 978-0-87590-439-9. $104.00 (AGU Member Price: $72.80).

We live in interesting times. It used to be that mantle phase transitions were so few in number that even a child could become an expert—but my childhood is long past. Now even seismologists invoke obscure phase transitions to elicit favorable publishing decisions whenever an unexpected wiggle arises in a seismogram, and even mineral physicists routinely discuss seismic anisotropy. (Note to self: good reason not to drop optical mineralogy from a syllabus.) This surprising broadening of knowledge arose from the singular alliance of large-scale facilities provided by synchrotron light sources, supercomputers, and seismological data facilities like IRIS. Kei Hirose, John Brodholt, Thorne Lay, and David Yuen marshal the forces of this effort in their collection of papers, *Post-perovskite, The Last Mantle Phase Transition,* which highlights the knowns and unknowns of the *Pbnm* to *Cmcm* transition in $MgSiO_3$ perovskite (pv) to post-perovskite (ppv). One known is that the seismic features in D" are largely attributable to it. Oh, D"? That's the bottom of the Earth's mantle, a place where Birch's famous warning applies: "Language undergoes a transformation to high pressure forms." Now reread the prepenultimate sentence.

Possible hype notwithstanding, the editors provide a nice disciplinary packaging of the papers: experimental and theoretical mineral physics, seismology, and dynamics. The experimental section begins with two histories of high-pressure experimentation, a more general one by Yagi on mantle phase transitions, and a more ppv-centric one by Hirose. Their thrill of discovery is evident. While reading, I kept wondering what Ringwood would say. "You mean, you didn't investigate analogues *first*?" was my surmise (but I imagine less politely put).

Graff Jewelers (Bond Street, London) report that wealthy Russian shoppers prefer yellow diamonds (source: *International Herald Tribune*). This is good news for the consumable budgets of DAC labs everywhere. I'm sure that Mao et al. expended a few in their study of the effect of Fe on ppv: its transition pressure, wave speed, and density. The main result is that there is no thermal expansivity difference but a reduction in transition pressure, wave speeds, and an increase in density. Li examines the likely role of a spin transition on the lower mantle and ppv. Answer? Minor, due to high temperature. Yamazaki and Karato summarize possible fabric development in ppv, of interest to seismologists due to observed D" anisotropy. They conclude that ferropericlase is the most likely contributor, but not our last—latest?—phase transition product.

A neat trio of papers on the mineralogical properties of pv and ppv follows. The first will please university students trolling the web for essay-padding material. For a nice set of color structural figures, see Wentzcovitch et al.'s contribution. Not for results, though—they mainly point to other group publications. But if you're keen on computational details—GGA, LDA, and so on—this one's for you, largely because it lays out a justification for using the QHA (quasi-harmonic approximation).

Stackhouse and Brodholt's paper in the mineralogical series brings home the bacon: lists of moduli, density, and elastic constants, with which they argue for a (surprisingly cool 2700 K) pyrolitic D" that has sufficient anisotropy and v_P/v_S variation to keep seismologists happy. The anisotropy treatment is good because it incorporates fabric, which always reduces single-crystal anisotropy estimates. Even though they justify (at length) the computational approach, it is a good reference for mineralogical properties.

Caracas and Cohen complete the hat trick with a refreshing study of the pv-ppv phase boundary, blessedly spare in computational details. They acknowledge that in the natural system Al_2O_3-$MgSiO_3$-$FeSiO_3$ the reaction is not univariant and present transition interval widths at a range of temperatures. It narrows at high temperatures, making the transition pseudo-univariant. There must be silicon meltdown (Intel silicon, that is) at what I consider to be a more D"-like temperature, 3800 K; otherwise, I can't account for the 1500–3000 K temperatures they chose. Might GGA, LDA, or QHA be the reason? Or—heavens—is ppv in the mantle at all, X-ed out by banishment to core pressures? Whatever. They give very good physical insight on the geometric mechanism underlying the transformation, as well as the preference of ppv for Al and Fe over pv where Mg largely remains. Caracas and Cohen also calculate the single-crystal anisotropy of the phases, though it is larger than what Stackhouse and Brodholt find, as well as being at 0 K.

Between our book covers the seismologists now process. Except for the bright orange color, I thought I had picked up a missal when reading Lay and Garnero's sepulchral "...with no realistic prospect of ever having a hand-sample to provide ground truth." This is a readable and exquisitely skeptical examination of the question of whether the seismological observations require a phase change in D", given their uncertainty. Their Figure 1 is a super cartoon showing how mineralogical and seismological properties are linked (notwithstanding omissions: at top left, the authors neglect distinguishing thermodynamic components from fixed composition). They conclude the exegesis by pronouncing the evidence favoring (but not requiring) a role for ppv but only in combination with lateral compositional changes. Simplicity eludes us again.

Sun et al. write a forward-looking paper on data to be recovered in the next half-decade, reflecting on the 30 years [sic] that passed since Lay and Helmberger (1983) first modeled the discontinuity atop D". They test hypotheses of uniform compositional model affected by lateral temperature changes and of a chemically variable model as well. The details will puzzle and frustrate readers (outcome expertise-dependent), but the picture

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that emerges will be more satisfying to advocates of changing chemistry: Go Slabs!

You think dropped pennies are too cheap to pick up these days? Not if they're in the lower mantle! Wookey and Kendall summarize studies of seismic anisotropy in and near D" showing how hexagonally symmetric material with a variably oriented axis can confound verdicts delivered via traditional relative SH vs. SV arrival times. If the penny's sixfold (well, $\infty/m \approx 6/m$) symmetry axis tips around 45° from vertical, woe! They then use ppv elastic constant and slip system mobility estimates to calculate deformation fabrics and the resultant bulk anisotropy likely in a ppv-rich D". The observations exclude some proposed slip systems; a table summary could help.

The questions that Houser addresses in her seismological study are whether normal mode, long-period, and shorter-period seismic wave signals carry any information about ppv's existence in D". The answers to these questions are no, half, and partly. *No* means the stuff is unresolvable, *half* is the lower part of D" that might locally contain ppv, and *partly* is whether ppv explains the signal in tomographic travel time residuals.

This would be the right place for convection studies to spring up, and sure enough a slightly dissonant quartet of them do. Peltier reviews the large-scale effects that an inviscid lower boundary causes in mantle convection by increasing the mean mantle temperature and enhancing convection with vertical scales smaller than mantle depth. (In an interesting aside, Peltier swears to a discovery of D" prior to Bullen's!) Tackley et al. see less of an influence on average mantle temperature (below 150 K) and suggest that lateral variations in ppv abundance may contribute to long-wave length heterogeneity at the CMB. Only if the ppv phase boundary is composition-dependent will it extend into down-welling material regions; otherwise, it is too cool to develop there.

Yuen et al. explore the combined effects of ppv, depth-dependent thermal expansivity, and enhanced radiative heat transport. Variety may be life's spice but it makes the significance of any single effect harder to assess. Yuen et al. find a change in convective style, and, intriguingly, a stiffer lower mantle that could serve to anchor whole-mantle plumes fed by a relatively inviscid, ppv-rich D". Petford et al. argue that core material may be drawn up into D" due to flow-induced shear dilatancy in D". They follow the implications of this interesting scenario through to (1) iron enrichment of silicates, (2) compositional control of the pv-ppv boundary, and (3) chemical anchoring of rising plumes from the core-mantle boundary.

Overall, I got a good sense of where the knowledge gaps are regarding D" properties. Fabric is one, transition pressure and temperature is another; the pressure scale problem is perplexingly yet unsolved. And why so computationally cold? Seismologists always want more data, but USArray help awaits the strong swimmers in the data flood. I have high hopes that the themes voiced in this book could provide the kernel of a fine multidisciplinary proposal of the seismic, convective, and material properties of the core-mantle boundary. (Oops, there goes another NSF grant!)

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