
Diamond melting in shock compression experiments at 1 TPa pressures

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S1. Methods: Steady shock experiments

S1.1. Target design

The data reported here were collected during three experimental campaigns at the Laboratory for Laser Energetics (LLE) Omega Extended Performance (EP) laser facility at the University of Rochester, NY.

We used one dimensional radiative-hydrodynamic simulations (see Fig. S1) with the HYADES code (47) to design the target assembly. A $\sim 150 \mu\text{m}$ thick Be ablator provided efficient ablation pressure to launch strong 6-12 Mbar shocks into a $\sim 100 \mu\text{m}$ thick, 2mm diameter disk of microcrystalline diamond grown by microwave plasma assisted chemical vapor deposition (48, 49) and purchased from Diamond Materials GmbH. Some targets (see Extended Data Table 1) incorporated a $0.5\text{-}1 \mu\text{m}$ Au preheat and photo-ionization shield between the Be and the diamond sample. Most targets included a $\sim 50 \mu\text{m}$ thick α -quartz window (30975 had no window, 32645 had a $\sim 120 \mu\text{m}$ polystyrene window) providing an in-situ reference (42) for shock velocity, reflectivity and temperature determination (see Extended Data Table 1). Because commercially available Be foils can exhibit significant surface roughness, with peak-to-valley values reaching several μm , both sides of the Be ablators are polished to achieve a root-mean-square (rms) roughness of approximately 200 nm. A 150 nm thick Ti mirror coating is deposited on the laser-drive side of the diamond sample to provide an initial reflectivity of about 40%, which is comparable to the expected reflectivity of the shocked diamond, quartz and polystyrene plates. This approach optimizes the intensity dynamic range for the velocimetry measurement. To reduce spurious ghost VISAR fringes caused by reflections at the diamond/window interface, anti-reflection dielectric coatings are applied to the surface of the diamond plates facing the velocimetry system. The target packages containing the diamond samples were assembled with thin ($\sim 1 \mu\text{m}$) epoxy bonds and then centered on a 300-500 μm diameter pinhole on a 10 mm x 10 mm, 57 μm thick Pt foil. This assembly was then positioned and secured on the front face of a PXRDIP box (see

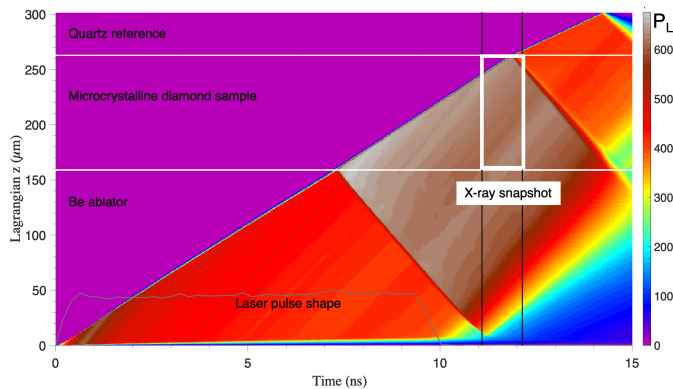


Fig. S1 1D hydrodynamic simulation of a steady shock experiment. Longitudinal stress colormap (in GPa) as a function of Lagrangian position along the shock propagation direction and time, overlaid with the laser pulse shape. The target package includes a $\sim 150 \mu\text{m}$ Be ablator, a $\sim 100 \mu\text{m}$ diamond sample and a $\sim 50 \mu\text{m}$ thick quartz reference plate.

Ref.(23)).

Secondary targets were used to produce a x-ray flash for the x-ray diffraction measurements. Two experiments (30589 and 30595) used a $2 \times 2 \text{ mm}$, $\sim 6 \mu\text{m}$ thick Cu foil. The other experiments used a $\sim 6 \mu\text{m}$ thick Ge film deposited onto $2 \times 2 \text{ mm}$, $\sim 100 \mu\text{m}$ thick graphite substrates.

S1.2. Experimental configuration: drive lasers and x-ray source

Each planar sample packages was placed on the front plate of a Powder X-Ray Diffraction Image Plate (PXRDIP) metallic box (see Ref.(23)). We used Omega EP Long Pulse configuration, with four individually controlled laser beams delivering several kJ of 351 nm light in precisely temporally shaped pulses (50), at a 23.2 degree incidence. Except for 30979 which used two beams, all experiments used one beam to drive the sample with a $\sim 10 \text{ ns}$ long pulse with a total energy between ~ 2000 and 5500 J . EP SG8-1100 super-gaussian distributed phase plates (DPPs) were used for the drive beams. The laser intensity in the best focus plane of these DPPs can be accurately modeled as $I(r) = I_0 \exp(-\frac{r}{r_0})^\eta$ where $I(r)$ is the laser intensity as a function of the distance from the beam center r , I_0 is the peak intensity, $r_0 = 483 \mu\text{m}$ and $\eta = 8.57$. Having a $\sim 1000 \mu\text{m}$ diameter uniform intensity area – *i.e.* three times larger than the $\sim 300 \mu\text{m}$ total thickness of the Ablator+Sample package – enabled us to achieve a highly planar one-dimensional dynamic compression.

Two or three additional laser beams were tightly focused (down to $\sim 200 \mu\text{m}$ beam size, without phase plates) onto the secondary target to produce a x-ray flash for the x-ray diffraction measurement (32). Each beam delivered $\sim 1250 \text{ J}$ in a super-gaussian 1 ns flat-top pulse – an irradiance of $\sim 3 \times 10^{15} \text{ W/cm}^2$ – with a co-timing accuracy better than 100 ps. This produces strong pulses of x-ray emission dominated by the He- α lines and results in quasi-monochromatic radiation with a 40 eV bandwidth near 10.249 keV (1.2097 Å) for Ge and a 89 eV bandwidth near 8.3680 keV (1.4816 Å) for Cu. For the XRD analysis, we assume that the x-ray pulse has a constant intensity and turns on (and off) 50 ps after the rise (and after the fall) of the laser pulse: we use Hill's equation fits to determine the rising and falling edges of the total delivered laser pulse as measured by the UV ROSS diagnostic.

We used 125 μm of black Kapton and either 100 μm of aluminum (for Ge x-ray sources) or 12.5 μm of copper (for Cu x-ray source) to filter out a significant fraction of the soft x-ray spectrum generated by the drive ablation plasma (see Ref.(23)).

A full suite of laser diagnostics record the precise pulse shape and relative timing of the various laser beams. Typical laser pulse shapes are reported on Figs. S10(A) through S11(A).

The drive laser intensity here is only moderately high near $1 \times 10^{14} \text{ W/cm}^2$. This is a consequence of the high efficiency of the Beryllium ablator that we chose here. In addition the large shock impedance-mismatch between the Be ablator and the stiffer and denser diamond sample lowers the ablation pressure needed to reach up to $\sim 1200 \text{ GPa}$ in the sample. Finally, considering the ambient-condition mass attenuation length (51) of diamond and Be (both low atomic number materials) reveals that the thick Be ablator will efficiently absorb soft x-rays below

1.5 keV while diamond will have a significant absorption only between ~ 1.5 and 8 keV. We note that no significant level of preheat was observed in laser-driven ramp compression experiments of metals (52). We also note that no fringe motion due to thermal expansion is observed prior to the arrival of the main shock into the diamond sample and that no noticeable thermal expansion is detected in the observed diffraction lines for the unshocked diamond.

S1.3. XRD data analysis

S1.3.1. Workflow

We described our methodology for PXRDIP data analysis in Ref.(23) which builds on the PXRDIP data analysis methods (22) as well as refinements developed for the TARDIS diffraction diagnostic developed at the NIF (33) to implement additional detailed corrections on the data focused towards improving the fidelity of the powder x-ray diffraction intensity determination.

Briefly, we load, crop and combine the data from different image plate panels, then mask spurious features and project the data into $2\theta - \phi$. For each shot we compute three projections corresponding to the signal scattered by the shocked sample, by the ambient diamond ahead of the shock and by the platinum pinhole reference and apply specific intensity corrections (23).

We apply a 2D Statistics-sensitive Non-linear Iterative Peak-clipping (SNIP) algorithm to estimate and subtract the background (33, 53, 54). Here we use a 2D SNIP with constant 2θ lines. These experiments used three different pinhole diameters: 300, 400 and 500 μm . We find that the SNIP kernel size which appears optimum to retrieve the sample peak area is equal to 41 for a 300 μm diameter pinhole, 51 for a 400 μm pinhole and 71 for a 500 μm diameter pinhole (see Fig. S2).

For each experiment, we compute three XRD intensity lineouts by averaging the background subtracted projection over a common range of ϕ for each of the $2\theta - \phi$ projections, after masking spurious features. While the lineout would ideally be averaging the full extent of the ϕ coverage enabled by our diffraction geometry, the presence of strong background due to the hot ablation plasmas (generated at the sample and at the x-ray source) significantly affects the signal over background ratio in some portions of the image plates. We therefore take the lineout over the azimuth range where the relevant lines are visible in the background subtracted image (see full set of complete and masked images in Figs. S24 through S47).

The area, position and linewidth of relevant peaks of interest are determined with a gaussian fit after removing a residual background with a third-order polynomial function of $\log(2\theta)$. To provide an in-situ reference for the instrumental sensitivity, we track the intensity of the pinhole lines in the vicinity of the most intense line from the compressed sample. Because the 111 line for ambient Pt may overlap with the 002 line for ambient unshocked diamond, we focus on the Pt 022 and 113 lines at 51.71° and 61.51° . Because we do not consistently observe more than one peak originating from the shocked sample, we focus on the most intense peak which we assign to the 111 reflection of compressed diamond near $42-44^\circ$. In most shots, we also observe two or three spotty lines from ambient conditions

diamond ahead of the shock front. Because the unshocked diamond 002 line overlaps with the Pt 111 line, we focus on the diamond 022 line near 57.32° for the intensity analysis.

At Omega EP, we find high level of repeatability in the x-ray emission in the He- α line when keeping the requested laser parameters (energy, beam focus) and position of the x-ray source constant. Using x-ray spectrometer measurements of the Ge and Cu XRS emission at Omega EP (32), we find that the standard deviation of the conversion efficiency for a day-long campaign is typically better than 10% so that using an uncertainty of $\pm 20\%$ on the brightness of the x-ray source appears reasonable.

S1.3.2. Uncertainty on the diffraction angle 2θ

We use a gaussian fit of a lineout of the sample $2\theta - \phi$ projection to determine the position of the center of the compressed

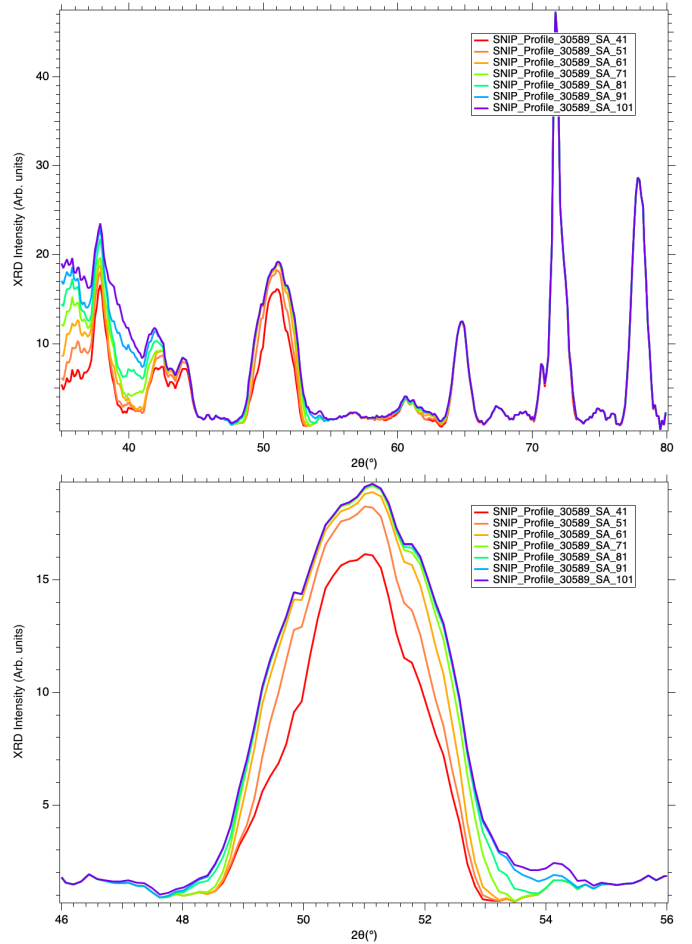


Fig. S2 Influence of the SNIP kernel width. Series of lineouts of a portion of the sample $2\theta - \phi$ projection for experiment 30589 with a 500 μm diameter pinhole taken by varying the kernel size from 41 to 101: (Top) Broad 2θ range. (Bottom) Magnified scale around the sample peak. While narrow kernels reduce the peak width, thus affecting the determination of the XRD intensity, a 71 kernel appears optimum to retrieve the sample peak. A high background is present below 40 degrees. In this work we use three different pinhole diameters: 300, 400 and 500 μm . For a 300 μm diameter the compressed sample line is unchanged when the kernel is equal or greater than 41, while the appropriate size is 51 for 400 μm .

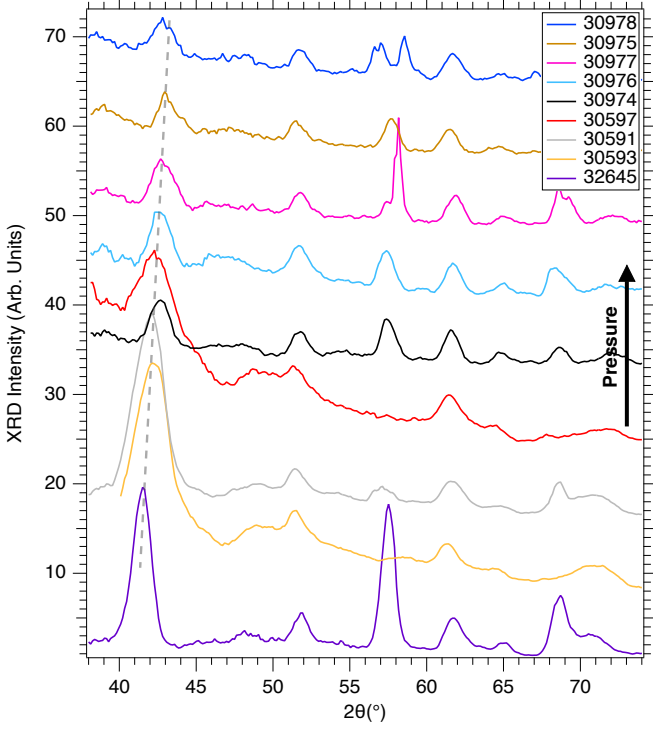


Fig. S3 Evolution of the XRD pattern with increasing pressure for the experiments using a Ge x-ray source. Background subtracted XRD intensity lineouts are sorted by increasing pressure and offset vertically. The dashed gray line serves as a guide to the eye to follow the evolution of the compressed diamond peak.

sample most intense Bragg peak 2θ . To estimate the uncertainty $\sigma_{2\theta}$ we consider contributions from the experimental uncertainty on the geometry calibration, peak fitting and sample offset distance.

Geometry calibration: Because we use the Pt pinhole diffraction lines to calibrate the diffraction geometry (see details in (23)) we estimate the fidelity of the projection into $2\theta - \phi$ by comparing the actual and expected position of the Pt lines for each shot. For each line of the Pt with an expected position ($2\theta^i$), we compute the standard deviation of the actual position of the various flags, relative to $2\theta^i$. We obtain a relative uncertainty $\sigma_{2\theta}^i/2\theta^i$ for each line. Averaging over the different lines we obtain an estimate of the relative uncertainty $(\sigma_{2\theta}/2\theta)^{\text{Cal}}$ for each experiment.

Peak fitting: We use the standard deviation of the peak position determined by the gaussian fit algorithm to compute a relative uncertainty $(\sigma_{2\theta}/2\theta)^{\text{Fit}}$.

Sample offset: We use the uncertainty on the sample offset O_A determined from the analysis of the velocimetry and pyrometry data to estimate a relative uncertainty $(\sigma_{2\theta}/2\theta)^{\text{Offset}}$.

We then combine these three relative contributions in quadrature to obtain the total relative uncertainty $(\sigma_{2\theta}/2\theta)^{\text{Total}}$ from which we infer the total absolute uncertainty on 2θ : $\sigma_{2\theta}^A$. This represents only the uncertainty in determining the Bragg peak diffraction angle and does not account for the distribution of stress and strain in the sample.

Using Bragg's law $\lambda = 2d \sin \theta$ we determine the d-spacing

d^A and its uncertainty σ_d^A :

$$\sigma_d^A = \frac{\lambda |\cos \theta|}{4 \sin^2 \theta} \sigma_{2\theta}^A \quad (1)$$

S1.3.3. Density determination and absence of evidence for BC8 structure

We observe only one diffraction peak for the compressed sample. This prevents us from uniquely determining the atomic structure from the diffraction data. In order to constrain the atomic structure, we assume a given peak corresponds to a certain (hkl) reflection for a given structure and calculate the corresponding density. We then compare with the expected density value from other measurements or simulations. Assuming that the most intense peak corresponds to the 111 reflection of the CD Diamond structure (see Extended Data Fig. 6 and Fig. S4) yields density values very close to previous observations based on impedance-matching measurements (3, 35) (see Figs. 4A and Fig. S18(Top)). In this work, the uncertainty on the density was conservatively set to two times the value obtained from propagating from $\sigma_{2\theta}$.

The BC8 structure with space group $\text{Ia}\bar{3}$ (T_h^7 , No. 206) shown on Fig. S4 has been predicted to become the most energetically favorable structure for carbon above ~ 1 TPa (13, 38–41) before being superseded by simple cubic structures SC1 and/or SC4 upon further compression above ~ 2 TPa. We consider the possibility that our sample may be partially or fully transformed into this structure upon shock compression up to ~ 1 TPa. For BC8 the atomic positions of the 16 atoms in the conventional unit cell are described (41) with the parameter x . Following previous work (21, 41), we assume that $x = 0.1001$ to compute the expected XRD patterns for the BC8 cubic structure and note that in the 2θ range of interest here (20–100 degrees), the theoretical XRD pattern for BC8 with $x = 0.1001$, $x = 0.1010$ and $x = 0.1500$ are essentially indistinguishable so that our findings are not affected by the choice of this particular value of x .

Assuming that the density of the BC8 structure is close to that of the diamond phase, we compute and report the expected XRD pattern for BC8 carbon having the same density than the compressed diamond on Figs. 2 and Extended Data Fig. 6 (black ticks and labels). No clear evidence for the sample being transformed into BC8 is apparent in the data. We also compute the density assuming that the most intense XRD peak originating from the compressed sample corresponds to the 002 or 112 reflections of the BC8 structure. As shown on Fig. S5 (Center) and (Bottom), this yields density values that are either $\sim 30\%$ lower or $\sim 30\%$ higher than previous observations based on impedance-matching measurements (3, 35) and therefore highly unlikely.

We also report on Fig. S7 the predicted density difference between the Diamond (CD) and BC8 structures according to the multi-phase model of Ref.(9) which suggests that the density of the BC8 phase should be about $\sim 2.8\%$ higher than the density of the CD diamond near 1TPa. Because the density variation could be a little different than this prediction and because the BC8 phase could nucleate at a slightly different pres-

sure/density than the CD phase we also illustrate the expected density dependence of the most intense reflections of the Diamond (CD) and BC8 structures on Fig. S8. This provides a rapid graphical means of estimating the expected location of the BC8 lines if the density was a little different than that of the diamond phase.

S1.3.4. Could a small amount of BC8 be present?

We show on Fig.3A that we observe a $\sim 10\times$ drop in XRD intensity upon increasing shock velocity from 21 to 24 km/s. Inspection of the XRD data shown e.g. on Fig. 2E and the lineouts on Fig.S5: reveals that we maintain a signal to noise of about 10 at the highest pressure. Combining these observations therefore suggests that we should be able to detect a line for the BC8 phase if about 1% of the sample transformed into this phase (provided the crystallites are large enough see below).

S1.3.5. Could nanocrystalline BC8 be present?

In these challenging experiments we cannot unambiguously detect the weak diffuse scattering from liquid carbon (34) due to a strong background. Similarly we estimate that we may fail to detect weak Bragg peak that are broadened beyond ~ 5 -10 degrees of full width at half maximum. Such peaks would be produced by nanocrystalline material with crystallites smaller than ~ 1 nm in diameter (see Fig.S6).

However, coexistence of nanocrystalline BC8 with CD is unlikely under our experimental conditions because our XRD snapshot is acquired after most of the sample has been at peak shock pressure for more than 2 ns, whereas molecular dynamics (19, 20) and metadynamics (55, 56) simulations indicate that once BC8 nucleates at P,T conditions within its predicted stability field, it should overtake CD in well under 1 ns.

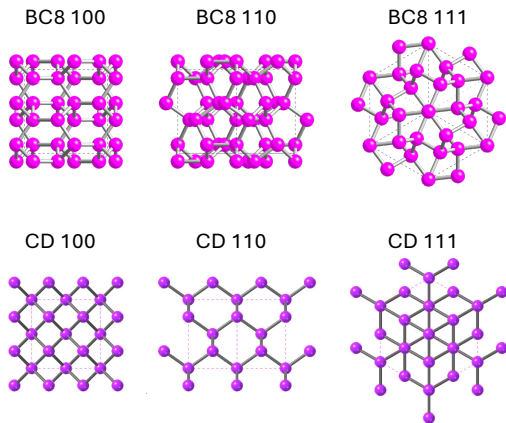


Fig. S4 Ball-stick model visualization of the predicted body centered cubic (BC8) structure for carbon compared to the cubic diamond (CD) structure. **Top:** BC8 structure viewed from the 100, 110 and 111 directions. **Bottom:** CD structure viewed from the 100, 110 and 111 directions.

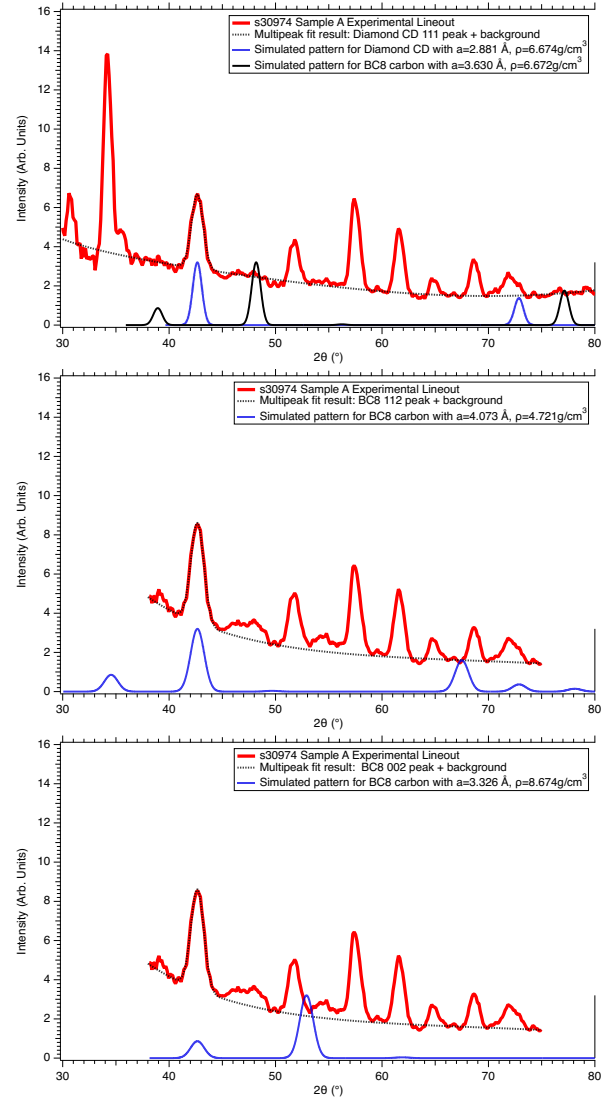


Fig. S5 Diamond (CD) and BC8 structure fits to 30974 data. For each panel the red curve represents the compressed sample (Sample A) x-ray diffraction lineout. The result of the fits shown as the sum of the background baseline and the most intense peak for the sample (black dash). The simulated patterns are calculated assuming a gaussian shape with a full width at half-maximum of 1 degree and $T = 0$ K (blue and black). **(Top)** Assigning the most intense peak to the 111 reflection of the diamond (CD) structure yields a density of $\rho = 6.677 \text{ g/cm}^3$ (blue). Comparison with the simulated pattern for the BC8 structure at the same density (solid black) reveals that the 112 reflection should be expected near 48 degrees. While the lineout exhibits a broad peak in this area, inspection of the full pattern clarifies that this broad peak is due to ablation plasma background not completely removed by the SNIP algorithm (see Figs. S34 and S35). **(Center)** Assigning the most intense measured peak to the 112 reflection of the BC8 structure yields a density of $\rho = 4.722 \text{ g/cm}^3$ and reveals that the 123 reflection should be visible near 67.5 degrees (see Extended Data Fig. 6 for the theoretical XRD pattern for BC8). **(Bottom)** Assigning the most intense measured peak to the 002 reflection of the BC8 structure yields a density of $\rho = 8.674 \text{ g/cm}^3$ and reveals that the 112 reflection should be visible near 53 degrees.

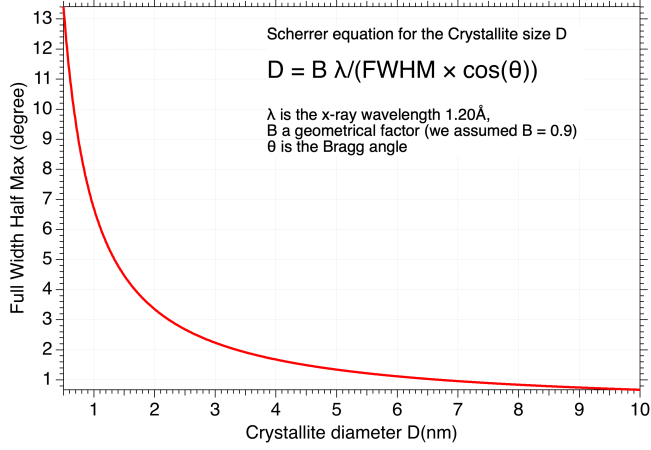


Fig. S6 Minimum crystallite diameter according to the Scherrer equation (57). Here we consider a diffraction angle near 43 degrees consistent with the data near 10 Mbar, and the Ge x-ray source near 10.2 keV. Crystallite smaller than 1 nm in diameter are expected to produce broad diffraction peaks with a full width at half maximum in excess of 7 degrees.

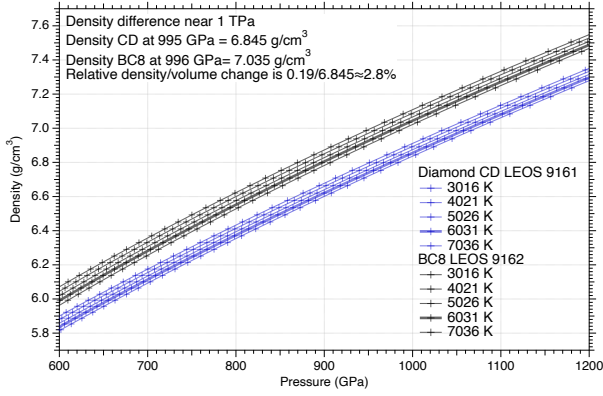


Fig. S7 Predicted density difference between the Diamond (CD) and BC8 structures. We show here several high temperature isotherms of the Diamond (CD) and BC8 structures in the EOS tables LEOS 9161 (CD) and 9162(BC8). These tables for two individual solid phases of carbon represents free-energy model fits to DFT-MD simulations (see (9) and (15) for details on these EOS tables). According to these EOS tables, the density of the BC8 phase is expected to be about ~ 2.8% higher than the density of the CD diamond near 1TPa.

S1.4. Velocimetry and pyrometry

S1.4.1. Experimental configuration and data calibration

We combine a two-channel line-imaging Doppler Velocimetry Interferometer System for Any Reflector (VISAR) (28) operating at 532 nm and a line-imaging Streaked Optical Pyrometer (SOP) (29) (collecting visible light with a wavelength $\lambda > 590\text{nm}$) to diagnose the compression state for each shot. We show an example VISAR image on Fig. S9, and two typical VISAR and SOP datasets together with the spatial and temporal variation of inferred quantities on Figs. S10 through S11. We used fused silica etalons having a thickness of 16.030 mm (VISAR1) and 6.431 mm (VISAR2), producing a vacuum velocity per fringe VVPF1= 3.1062km/s/fringe and VVPF2= 7.743km/s/fringe. The streak camera sweep durations were 30,

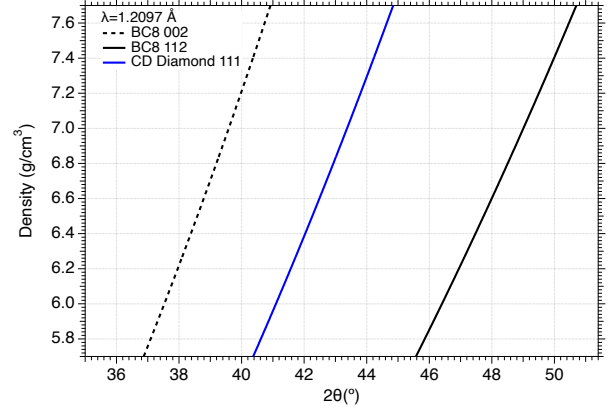


Fig. S8 Density dependence of the most intense reflections of the Diamond (CD) and BC8 structures. We illustrate how the most intense 002 and 112 lines of the BC8 structure and the 111 line of the diamond structure shifts with increasing density, assuming a Ge x-ray source. This provides a rapid graphical means of locating the expected position of the BC8 lines if the density was a little different than that of the diamond phase (see Fig. S7.)

16 and 19 ns for VISAR1, VISAR2 and SOP. The VISAR laser probe delivers up to 10 mJ in 50 or 100 ns long flat-top pulses.

Raw images are sheared by -0.8 degree for VISAR1 and 0.2 degree for VISAR2 to align isochrones with the vertical axis of the images. A non-linear time versus pixel relationship is then determined by locating the pixel center positions for the pulses generated by an oscillator with a very stable and precisely known frequency (near 2 GHz) (see Fig. S9). This non-linear relationship is used for the analysis while VISAR and SOP images are scaled with an approximate linear time versus pixel relationship for visualization purposes only. An additional, independent series of eight timing pulses provides an unambiguous means to infer – using previously determined calibrations – the absolute timing of the streak record relative to the Omega EP laser beams and therefore to the timing of the x-ray pulse for the XRD snapshot. Scaling along the spatial imaging dimension used nominal calibration values, *i.e.* 0.67 $\mu\text{m}/\text{pixel}$ for the VISAR using the ~ 500 μm field of view configuration and 1.54 $\mu\text{m}/\text{pixel}$ for the SOP. The origin was chosen arbitrarily to approximate the center of the collimating aperture.

S1.4.2. Photo-ionization

From previous work (2, 4, 5), we expect shock compressed diamond to become weakly optically reflecting ($R > 1\%$) above ~ 21 km/s and strongly reflecting ($R > 10\%$) above 23 km/s. In either cases, we also expect the corresponding shock transmitted to the quartz window to transform it into a strongly reflecting state (24, 58). Panels (B) on Fig. S10 and S11 show the VISAR and SOP streak images for two shots 30589 and 30977 in which the shock velocity in the diamond sample is respectively near 21 km/s and 24 km/s. The time origin corresponds to the beginning of the drive laser pulse shown on panel (A). The VISAR probe initially reflects primarily off the Ti coating on the drive side of the diamond sample. As illustrated on Fig. S9, a rapid drop in intensity is often observed within 200

ps after $t=0$. This is likely due to photo-ionization blanking of the diamond sample. To mitigate this effect and enable tracking the reflecting shock front in the diamond, a 0.5 to 1 μm layer Au (with a thin 0.15 μm Ti adhesion layer) was included in the target packages after the first experimental shot day (experiment greater than 30900).

We note that, even though we observe photo-ionization, we do not expect significant preheat. The drive laser intensity here is only moderately high near 10^{14} W/cm^2 . This is a consequence of the high efficiency of the Beryllium ablator that we chose here. In addition the large shock impedance-mismatch between the Be ablator and the stiffer and denser diamond sample lowers the ablation pressure needed to reach ~ 1200 GPa in the sample. Finally, considering the ambient-condition mass attenuation length (51) of diamond and Be (both low atomic number materials) reveals that the thick Be ablator will efficiently absorb soft x-rays below 1.5 keV while diamond will have a significant absorption only between ~ 1.5 and 8 keV. We note that no significant level of preheat was observed in laser-driven ramp compression experiments of metals (52). We also note that no fringe motion due to thermal expansion is observed prior to the arrival of the main shock into the diamond sample and that no noticeable thermal expansion is detected in the observed diffraction lines for the unshocked diamond. Further we see no significant systematic difference in the steady shock temperature measurements between experiments using targets with or without a Au layer.

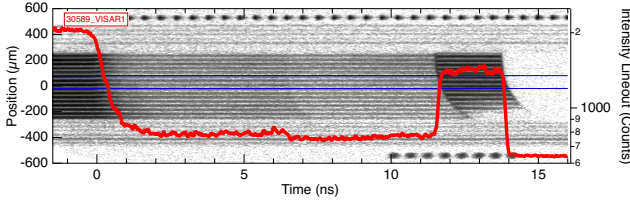


Fig. S9 Example VISAR image with partial photo-ionization. VISAR1 image for 30589 and signal intensity lineout taken between the blue horizontal lines (red, right scale). For this experiment the target package did not include a Au layer (see Extended Data Table 1). A rapid, $\sim 70\%$ drop in intensity that is likely due to photo-ionization blanking of the diamond sample begins at $t=0$, *i.e.* as soon as the drive laser turns on. A 2 GHz comb (near the top of the image) enables determining the relative time vs pixel relationship, while a series of eight pulses provides access to the absolute timing of the streak record relative to the Omega EP laser.

S1.4.3. Transit time velocity and shock planarity

In this work, we combine multiple pieces of information encoded in the VISAR and SOP data to account for spatial and temporal variations in determining a best estimate of the shock velocity and an associated uncertainty. Because the XRD measurements probe a large fraction of the volume of the sample and is time integrated over about 1 ns, we choose to account not only for both systematic and statistical uncertainties in determining the shock velocity at each position and each instant but also for the non-uniformity in space and time. In other words,

our velocity average and uncertainty value for each shot aims at accurately describing the distribution of shock states probed by the diffraction measurement.

The line-imaging VISAR and SOP diagnostics collect streak camera images representing the time dependence of the 1D image along the x axis of the planar target (see Fig. 2 and (23) for a sketch of the coordinate system). First, for each of the three streak images collected for each shot we determine the spatial variation of the transit-time velocity by determining the timing of the shock arrival into, and exit from the diamond sample as a function of the position x . From these we infer the spatial variation of the time-averaged velocity $U_{STT}(x)$ by dividing the transit time at each position x by the known thickness of the diamond sample: see the thick solid lines with 1σ uncertainty bands as shaded areas for each image on the panel (c) of Figs. S10 through S11. We then compute a spatial, weighted average of the three $U_{STT}(x)$ profiles to determine an average velocity (dotted line) where the weight is inversely proportional to the streak camera sweep duration for each channel. The spatial extent for the average is determined from the analysis of the region of interest of the x-ray diffraction data for each shot and is represented by the grey shaded area on panel (C).

S1.4.4. Reflecting shock velocity and shock steadiness

In addition, we also detect fringe motion that can be unambiguously attributed to the reflection of the VISAR probe at the shock front during its transit through the quartz or polystyrene window for all shots, as well as during the transit through the diamond sample in several shots (see for example Fig. S11). For this observation to be possible the shock velocity in the diamond needs to be large enough to induce significant reflectivity at the shock front (typically $U_S > 22 \text{ km/s}$). Photo-ionization of the diamond must also not be so large as to rendering it totally opaque to the VISAR probe (thanks to the thin Au coating). In some cases, the fringes associated with the reflecting shock only become visible during a fraction of the transit through the partially opaque diamond, *i.e.* when the attenuation length near 532 nm becomes larger than the thickness of the photoionized, unshocked diamond layer ahead of the shock front.

The velocity information is encoded in the fringe phase shift. If necessary, we first remove static ghost fringes due to spurious reflections at the diamond/quartz and or quartz/vacuum interfaces prior to fringe unwrapping. Unwrapping the fringe phase with a 1D fast Fourier transform (FFT) algorithm for each time pixel and combining the data from the VISAR1 and VISAR2 to resolve fringe jump ambiguities (28) enables us to obtain a two dimensional (2D) map of the apparent velocity U_{app} as a function of spatial position (x) and time (t). We use a reference image collected right prior to the shot to normalize the phase and amplitude maps.

Dividing U_{app} by the refractive index of the unshocked diamond ($n_D(532 \text{ nm}) = 2.426$) and quartz ($n_Q(532 \text{ nm}) = 1.547$) yields the two dimensional map of the shock velocity $U_S(x, t)$ (see Ref.(28) for a discussion of the VISAR correction for reflecting shocks). We then take a lineout of the two dimensional map of the shock velocity $U_S(x, t)$ over the spatial area where there is a good fringe contrast for the reflecting shock in the

diamond to determine the time history of the reflecting shock velocity $U_S(t)$ shown in tan in panel (D) on Extended Data Fig. 1 and Figs. S10, through S11. We typically estimate the uncertainty on the reflecting shock velocity to be better than 5% of the VPF of the most resolving etalon. Because we use thick etalons resulting in a high velocity sensitivity, the reflecting shock velocity is determined much more precisely and accurately than the transit time measurements.

Next we compute a time average of the reflecting shock velocity U_{SAvg} , between the arrival of the shock in the diamond sample and the mid-point of the x-ray flash duration (grey shaded on panel (E)), shown as the thick solid black line on panel (C). We finally linearly scale the time-averaged velocity $U_{STT}(x)$ of the most resolving channel so that taking the spatial average of that scaled profile $U_{SSC}(x)$ over the region where we computed the reflecting shock lineout matches U_{SAvg} . That scaled profile $U_{SSC}(x)$ is shown as the long dash-dot black curve on the panel (C) of Extended Data Fig. 1 and Figs. 2 and S11.

The average and standard deviation of $U_{SSC}(x)$ over the region of interest of the x-ray diffraction data for each shot yields our estimate of the most representative value U_S of the shock velocity corresponding to the XRD measurement which are reported in Extended Data Table 3 and shown as a long dashed line on panel (C) and short dotted line on panel (D). If reflecting shock measurements are not possible we use the average of the transit time measurements from the three different channels, weighted by the inverse of the sweep duration of each channel.

To most directly compare our measurements with the predictions from numerical simulations in the temperature-pressure plane, we use the $U_S - u_p$ relationship of the multiphase Hugoniot for diamond calculated in Ref.(15) to compute a pressure (P) for each shock velocity U_S datum.

S1.4.5. Post-processing of the VISAR and SOP data

Due to variations in the timing of the XRD snapshot relative to the transit of the shock through the sample (as well as small variations of diamond sample initial thickness) the thickness of the sample that has been shock compressed at the mid-point of the x-ray flash duration varies shot-to-shot.

Neglecting the small variations of the planarity of the one-dimensional drive, we assume that the radial dimension of the shocked sample contributing to the diffraction is identical in all the experiments reported here. We compute an effective thickness for the shocked and unshocked fractions of the sample. To do this we integrate U_S between the spatially averaged arrival and exit time into the diamond sample (highlighted with short vertical dash dot black lines on the panel (E) of Extended Data Fig. 1 and Figs. S10, 2 and S11) to determine the shock front position as a function of time and calculate the Lagrangian thickness of the sample (tt_A) that was shocked at the mid-point of the x-ray flash duration (vertical long dash grey) from which we infer the unshocked thickness tt_B .

In a few experiments such as 30589 (see Fig. S10), the breakout from the diamond to quartz occurs before the end of the x-ray flash so that the Lagrangian thickness of the sample that was released to lower pressure is subtracted from the La-

grangian thickness of the sample that was shocked at the mid-point of the x-ray flash.

We also compute the Eulerian position of the mid-point of the shock and unshocked fractions of the sample at the mid-point of the x-ray flash duration to accurately determine $2\theta_{SAmA}$ and $2\theta_{SAmB}$ (see Ref.(23) for details).

S1.5. Steady shock temperature measurements

We analyze the SOP data similarly to the description provided in the Supplementary Material of (24) using quartz as an in-situ reference. Briefly the shock temperature T is obtained as:

$$T = \frac{T_0}{\ln\left(1 + \epsilon \frac{A}{I}\right)} = \frac{T_0}{\ln\left(1 + (1 - R) \frac{A}{I}\right)} \quad (2)$$

where T_0 and A are calibration constants, I is the SOP intensity counts (29, 59) and ϵ is the emissivity. We assume that thermal emission can be well described as a grey body, with an emissivity independent of wavelength. We neglect absorption and determine the emissivity with $\epsilon = 1 - R$, R being the reflectivity obtained from the VISAR data analysis.

As T_0 essentially captures the spectral response of the SOP system, and because T depends only weakly on this parameter, we assume it is constant: $T_0 = 1.91$ eV. We use the SOP signal as a function of shock velocity during the shock transit in the quartz as an in-situ reference to invert Eq. 2 and obtain an effective A for each individual experiment.

We analyze the SOP in the steady shock experiments having a quartz plate embedded in the target assembly. As shown on Fig. 2D we focus on the signal immediately prior to breakout into the quartz plate to extract one $T(U_S)$ datum per experiment. The results are summarized in Table S3 and shown in Fig. 3A and Fig. 4B.

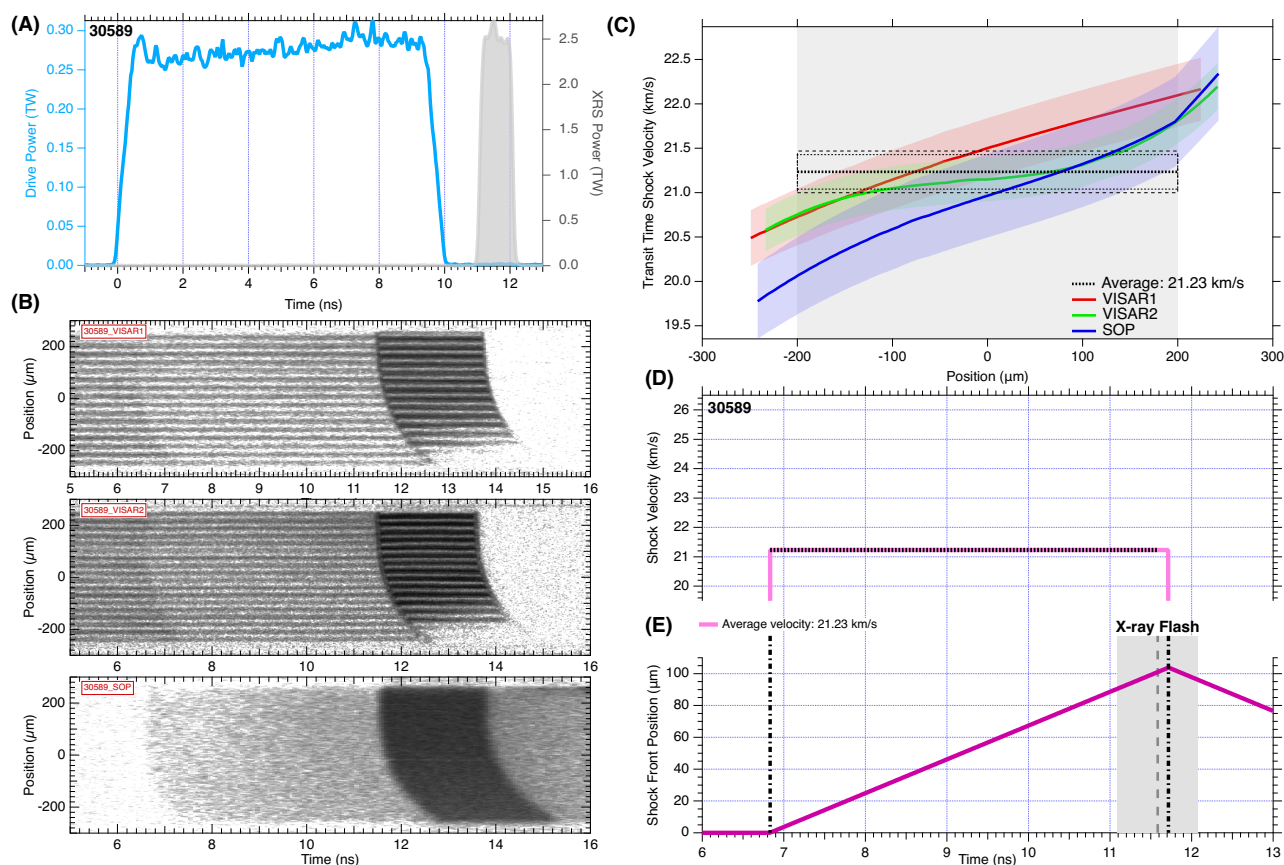


Fig. S10 Pulse shapes, velocimetry and pyrometry images and analysis for 30589. (A) Measured total power delivered to drive the sample (Left axis, blue) and generate the pulsed x-ray source (right axis, grey). (B) Streak images for VISAR1, VISAR2 and SOP. (C) Spatial variation of the transit time velocity (solid curves, see legend) and inferred averaged value and uncertainty (dashed and dotted, see legend). Grey shaded area: spatial extent of the velocimetry average. (D) Time-averaged velocity between the shock arrival in the sample and the midpoint of the x-ray flash (dot black line). (E) Time history of the Lagrangian position of the shock front (and leading edge of rarefaction fan) (solid magenta). Dash-dot vertical lines: sample shock arrival and break out times. Shaded area: duration of x-ray flash (Dash vertical line indicates mid-point). For this shot the target package did not include a Au layer (see Extended Data Table 1).

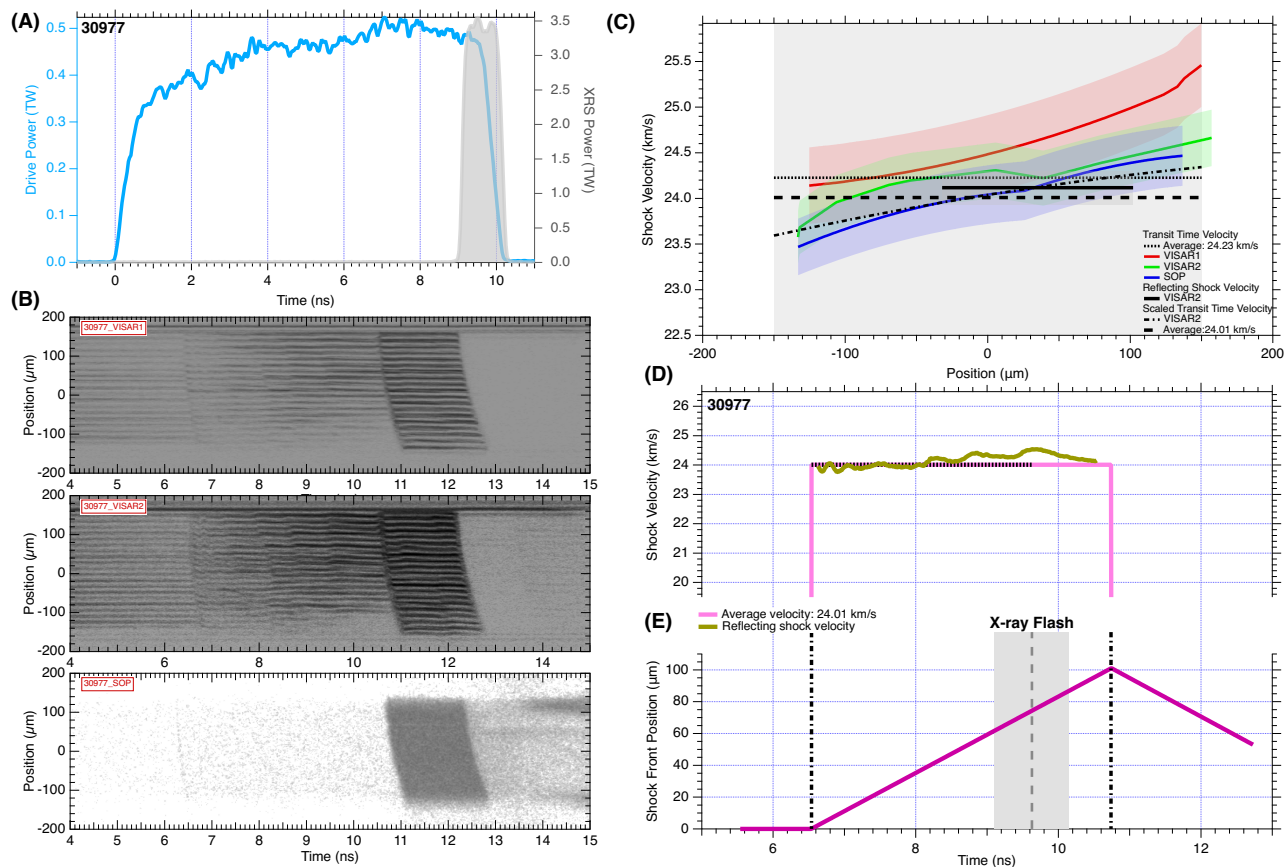


Fig. S11 Pulse shapes, velocimetry and pyrometry images and analysis for 30977. (A) Measured total power delivered to drive the sample (Left axis, blue) and generate the pulsed x-ray source (right axis, grey). (B) Streak images for VISAR1, VISAR2 and SOP. (C) Spatial variation of the transit time velocity (solid curves, see legend) and inferred averaged value and uncertainty (dashed and dotted, see legend). Grey shaded area: spatial extent of the velocimetry average. (D) Time history of the shock velocity in the diamond sample (tan solid line), and time-averaged velocity between the shock arrival in the sample and the midpoint of the x-ray flash (dot black line). (E) Time history of the Lagrangian position of the shock front (and leading edge of rarefaction fan) (solid magenta). Dash-dot vertical lines: sample shock arrival and break out times. Shaded area: duration of x-ray flash (Dash vertical line indicates mid-point). For this shot the target package included a $0.5 \mu\text{m}$ Au layer (see Extended Data Table 1)

S1.6. Combining the velocimetry, pyrometry and x-ray diffraction data

We show on Extended Data Fig. S3 the evolution of the XRD lineouts for the shocked sample projection with increasing shock pressure (restricted to the experiments with a Ge x-ray source). Ref.(23) describes our methodology to analyze the XRD data in order to quantitatively evaluate the evolution of the intensity of the XRD signal from the shocked sample and determine the solid fraction. As shown on Extended Data Fig. 7 we report the results from multiple approaches.

We report the intensity of the shocked sample XRD 111 peak scaled by the x-ray source brightness and the thickness of the shocked layer on Extended Data Fig. 7A. We also show a linear fit (black dotted line).

We report the intensity of the shocked sample scaled by the thickness of the shocked sample and the observed intensity of the Pt pinhole 002 and 113 lines on (Extended Data Fig. 7D). We also compute the scaled intensity of the Pt signal relative to the expected brightness of the x-ray source similarly to Ref.(23) and report the variation in Extended Data Fig. 7E. This reveals that the signal of the Pt reference remains visible beyond 25 km/s despite a rapid increase of the background with increasing shock pressure which is due to the increase of the ablation pressure.

Given that the XRD snapshot was captured before the entire sample was shock compressed, XRD signal from the un-compressed portion is often apparent and can be compared to the signal from the shocked sample. We report the intensity of the unshocked fraction scaled by the x-ray source brightness and the thickness of the unshocked layer on Extended Data Fig. 7C. To quantitatively compare the signal of the shock and unshocked fraction to estimate the remaining solid fraction in the shocked sample, it is important to account for the combined effects of increased density and temperature to modify the XRD intensity per unit volume. We approximate the effects of increased density and temperature on the XRD line intensity with a Debye-Waller approach (see detail in Ref.(23)). Due to the overlap of the 111 peak with the 002 Pt line, we focus on the 022 reflection and extract its area from the gaussian fit $A_{Diam022}$. We compute the expected ratio between the intensity of the 022 line of unshocked diamond and the 111 line of the shocked diamond R_{Diam}^{DW} . We then normalize the measured intensity of the 111 peak from the shocked sample by the scaled intensity of the 022 peak from the unshocked sample scaled by $A_{Diam022}/R_{Diam}^{DW}$ where $A_{Diam022}$ is the undriven 022 area from the gaussian fit.

Dividing A by the effective thickness for the shocked fraction of the sample tt_S and $A_{Diam022}/R_{Diam}^{DW}$ by the effective thickness for the unshocked fraction of the sample tt_U therefore yields an absolute estimate of the solid fraction (SF):

$$SF_{Diam022} = \frac{A/tt_S}{A_{Diam022}/(tt_U * R_{Diam}^{DW})} \quad (3)$$

S1.7. Debye temperature for compressed Diamond

Advanced numerical simulations based on the density functional theory (DFT) have been used to model the thermodynamic properties of diamond at high pressure. In particular,

Refs.(8, 9) used the general gradient approximation (GGA) of the DFT with the PBE exchange correlation functional to compute the phonon density of state (PDOS) of diamond at high pressure and temperature. This revealed that the PDOS is highly structured and is better approximated by a double Debye model rather than a simple Debye model. In addition, DFT-based molecular dynamics calculations reported in Refs.(8, 9) also reveal that anharmonic effects warrant the addition of a correction term to the free-energy. Fig. 5 in Ref.(8) summarizes the volume dependence of the two Debye temperatures for the diamond. From the ambient density value 1860 K (volume per atom near $5.7 \text{ \AA}^3/\text{at}$), the Debye temperature θ_A representing low energy modes decreases slowly with increasing density down to about 1500 K while the Debye temperature θ_B representing the high energy modes increases to about 3700 K near $3 \text{ \AA}^3/\text{at}$ (near 6.6 g/cm^3). Independently, Ref.(60) used DFT calculations in the local-density approximation (LDA) from Ref.(61) to parameterize a Debye model with one transverse and two longitudinal modes. In that study the transverse Debye temperature is nearly constant near 2000K up to 1000 GPa, while the longitudinal Debye temperature rises quite rapidly from 1500 K at ambient to 3500K near 800 GPa.

In the Debye-Waller analysis in this work (see Section S1.6), we use a Debye temperature $T_D = 3000 \pm 500 \text{ K}$ for the shock compressed state and $T_{D0} = 1860 \text{ K}$ as the Debye temperature at ambient conditions (9, 62).

S2. Methods: Decaying Shock Experiments

S2.1. Target Design

The decaying shock targets are planar packages mounted on the back of a 10 mm outer diameter, 2 mm inner diameter, 250 μm thick CH washers. These large CH washers contribute to shielding the diamond sample from the laser drive ablation plume. A 50 μm thick tantalum washer, with a 600 μm inner diameter and an outer diameter larger than 3 mm was positioned on the back of the sample package, facing the VISAR/SOP telescope. These Ta washers restrict optical light transmission and they are designed to be sufficiently thick so that their free-surface (facing the SOP) remains near room temperature or at least below the detection threshold of the SOP near 3000K during the shock transit through the sample and the quartz reference layers, *i.e.* until the leading shock eventually breaks out of the Ta. The region of the streak images corresponding to the ambient temperature Ta surface therefore provides an in-situ reference region to identify spurious (*e.g.* due to stray light) background in the SOP data.

As illustrated on Fig. S12 and summarized in Extended Data Table 2 we use 40-50 μm thick microcrystalline diamond (or Kapton) ablators. A 10 μm thick gold shielding layer is deposited on top of a 150 nm thick titanium layer either on the quartz-I or diamond sample. While the Au layer aims at minimizing photo-ionization of the diamond and quartz plates, the Ti mirror is used to ensure that the pre-shot initial reflectivity of the target is close to that of the reflecting shocks, enabling us to optimize the VISAR fringe intensity dynamic range.

The diamond samples are microcrystalline plates grown by

microwave plasma assisted chemical vapor deposition (48, 49) and purchased from Diamond Materials GmbH. We assume full density $\rho_0 = 3.515 \text{ g/cm}^3$ and a refractive index of 2.426 at 532 nm. We use either one or two z-cut α -quartz reference plates either upstream (labeled Quartz-I) or downstream (labeled Quartz-II) from the diamond sample. These provide in-situ reference for the shock front reflectivity (VISAR) and shock temperature (SOP) measurements (24, 30, 42), as well as shock EOS and release behavior. We use a density $\rho_0 = 2.648 \text{ g/cm}^3$ and a refractive index of 1.547 at 532 nm. The planar packages are assembled with thin ($\approx 1 \mu\text{m}$) epoxy bonds. Anti-reflection coatings are deposited onto the diamond samples to match the neighboring media index (*i.e.* $n = 1$ for the free surface or $n \approx 1.55$ for the epoxy bond to the quartz plates).

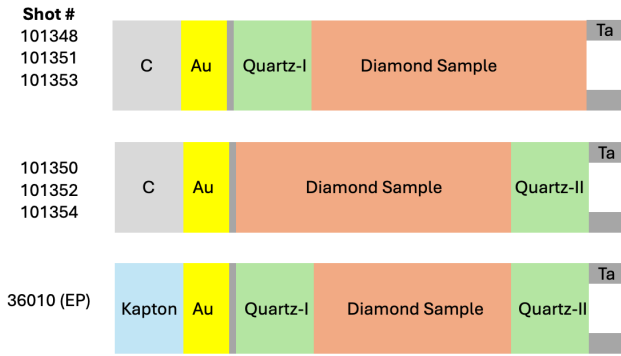


Fig. S12 Target packages for the decaying shock experiments. Not to scale. Actual package diameter is 2 mm. See details in Extended Data Table 2

S2.2. Drive laser configuration

Six experiments (101348-101354) were conducted during a 1-day experimental campaign at the Omega 60 Laser Facility, and one (36010) was executed at the Omega EP Laser Facility, both at the Laboratory for Laser Energetics (LLE) at the University of Rochester, NY. At Omega 60 we used five beams at a 23.2 degree incidence, each delivering up to 390 J of 351 nm light (see Extended Data Table 2) in a 1 ns super-gaussian flat-top pulse. At EP we used two beams at a 23.2 degree incidence, each delivering $\sim 1850 \text{ J}$ of 351 nm light in a 2 ns super-gaussian flat-top pulse. Super-gaussian distributed phase plates (DPPs) were used to spatially smooth and shape the laser intensity on target to achieve a planar one-dimensional dynamic compression. The laser intensity in the best focus plane of these DPPs can be accurately modeled as $I(r) = I_0 \cdot \exp(-\frac{r}{r_0})^\eta$ where $I(r)$ is the laser intensity as a function of the distance from the beam center r , I_0 is the peak intensity, r_0 is the flat-top radius, and η is the power of the super-Gaussian. At Omega 60 we used SG8-FLAT with $r_0 = 438 \mu\text{m}$ and $\eta = 5.8$. At EP we used EP SG8-1100 with $r_0 = 483 \mu\text{m}$ and $\eta = 8.57$.

S2.3. VISAR Velocimetry and SOP Pyrometry Diagnostics and data pre-processing

We combine a two-channel line-imaging Doppler Velocimetry Interferometer System for Any Reflector (VISAR) (28) op-

erating at 532 nm and a line-imaging Streaked Optical Pyrometer (SOP) (29) (collecting visible light with a wavelength $\lambda > 590 \text{ nm}$). The VISAR and SOP instruments at Omega 60 and EP share the same design and use ROSS streak cameras.

At Omega 60 we used fused silica etalons having a thickness of 22.866 mm (VISAR1) and 9.184 mm (VISAR2), producing a vacuum velocity per fringe $\text{VVPF1} = 2.1776 \text{ km/s/fringe}$ and $\text{VVPF2} = 5.4217 \text{ km/s/fringe}$. The streak camera sweep durations were 27, 45 and 46 ns for VISAR1, VISAR2 and SOP. Raw images are sheared by -0.4 degree for VISAR1 and -0.7 degree for VISAR2 to align isochrones with the vertical axis of the streaked images.

At EP we used a thickness of 18.199 mm (VISAR1) and 7.366 mm (VISAR2), producing a vacuum velocity per fringe $\text{VVPF1} = 2.7361 \text{ km/s/fringe}$ and $\text{VVPF2} = 6.7601 \text{ km/s/fringe}$. The streak camera sweep durations were 27, 50 and 46 ns for VISAR1, VISAR2 and SOP. Raw images are sheared by -0.8 degree for VISAR1 and 0.2 degree for VISAR2.

A non-linear time versus pixel relationship is then determined by locating the pixel center positions for the pulses generated by a frequency comb (see Fig. S9). This non-linear relationship is used for the analysis while VISAR and SOP images are scaled with an approximate linear time versus pixel relationship for visualization purposes only. An additional, independent series of eight pulses provides an unambiguous means to infer – using previously determined calibrations – the absolute timing of the streak record relative to the Omega 60 or EP laser beams.

Neutral density filters of $\text{ND}=0.3$ for 101351 and 36010 and $\text{ND}=0.6$ for 101348 and 101353 were used to attenuate the SOP signal and minimize instrumental non-linearity (due to the strong signal from the reflecting shock in the quartz-I plate).

For the scaling along the spatial imaging dimension we used nominal calibration values, *i.e.* $1.45 \mu\text{m/pixel}$ for the Omega 60 VISAR using the $\sim 1000 \mu\text{m}$ field of view configuration, $0.67 \mu\text{m/pixel}$ for the Omega EP VISAR using the $\sim 500 \mu\text{m}$ field of view configuration and $1.54 \mu\text{m/pixel}$ for the SOP at both Omega 60 and EP. The origin was placed approximately at the center of the Ta shielding washer aperture.

When the shock velocity decreases below 21 km/s, the optical reflectivity at the shock front is near or below 1% and becomes comparable to spurious reflections

S2.4. VISAR analysis

The line-imaging VISAR and SOP diagnostics collect streak camera images representing the time dependence of the 1D image along the transverse x axis of the planar target. The velocity information is encoded in the fringe phase shift.

If necessary, we first remove the static ghost fringes due to spurious reflections at the diamond/quartz and or quartz/vacuum interfaces prior to fringe unwrapping, using as a reference the fringe pattern before shock breakout or after the loss of reflecting fringes when U_s decreases below $\sim 21 \text{ km/s}$ in the diamond.

Unwrapping the fringe phase with a 1D fast Fourier transform (FFT) algorithm for each time pixel and combining the data from the VISAR1 and VISAR2 to resolve fringe jump ambiguities (28) we obtain a two dimensional (2D) map of the ap-

parent velocity U_{app} as a function of spatial position x and time t . We use a reference image collected right prior to the shot as a reference to normalize the phase and amplitude maps. A lineout of the two dimensional map of the apparent velocity $U_{app}(x, t)$ over about $120 \mu\text{m}$ near the center of curvature of the shock front provides the time history of the 1D compression. Dividing U_{app} by the refractive index of the ambient condition diamond ($n_D(532\text{nm}) = 2.426$) and quartz ($n_Q(532\text{nm}) = 1.547$) during the transit in each layer reveals the reflecting shock velocity $U_S(t)$ (see Ref.(28) for a discussion of the VISAR correction for reflecting shocks).

We typically estimate the uncertainty on the reflecting shock velocity to be better than 5% of the VPF of the most resolving etalon. Because we use thick etalons the reflecting shock velocity is determined to a very high precision.

The fringe amplitude encodes information about the optical properties of the diamond sample and quartz reference plates during the experiment including the reflectivity of the shock front and losses due to transient partial opacity. We use our calibration of the reflectivity of the shock front in quartz as a reference (42).

To most directly compare our measurements with the predictions from numerical simulations in the temperature-pressure plane, we use the $U_S - u_p$ relationship of the multiphase Hugoniot for diamond calculated in Ref.(15) to compute a pressure (P) for each shock velocity U_S datum.

S2.5. Photo-ionization model

Despite the use of $10 \mu\text{m}$ thick Au shielding layers between the ablators and the diamond samples, some photo-ionization is still present and affects both the reflectivity and temperature measurements. Here we develop a simple model assuming that the photo-ionization is induced by the absorption of hard x-rays generated by laser-plasma interactions in the drive ablation plasma plume. Considering the ambient-condition mass attenuation length (51) of diamond and gold, we compute (see Fig. S13) the spectrum of x-rays that get absorbed in a $400 \mu\text{m}$ thick diamond after being transmitted through a $10 \mu\text{m}$ thick gold slab. We find that the absorption has a well defined maximum near 10 keV and a roughly flat response above 25 keV. Considering the attenuation length of diamond in this range represented in red short dash (right scale) we find an attenuation length $d_1 \sim 1000 \mu\text{m}$ near 10 keV while above 25 keV the attenuation length is longer than several millimeters.

We assume that transient optical absorption in the visible is caused by x-ray activated color centers. We approximate the attenuation length as being proportional to the number of activated color centers that we estimate as being proportional to the deposited x-ray energy into the diamond as a function of position along the shock propagation, which is also the line-of-sight of the pyrometer. We consider two contributions from x-rays near 10 keV, for which the density of color centers will decay exponentially as $\exp(-z/d_1)$, and from higher-energy x-rays for which the density of color centers is uniform and can be described by a single attenuation length value d_2 which can vary depending on the laser-drive conditions.

We illustrate how we correct the VISAR fringe amplitude for shot 36010 on Fig. S14. Assuming an x-ray attenuation length $d_1 = 1000 \mu\text{m}$ and varying d_2 , we find that an optical attenuation length of $d_2 \sim 12000 \mu\text{m}$ yields consistent reflectivity versus U_S during the shock transit through the two quartz plates. This photo-ionization correction is also applied to correct the measured radiance time history data from the SOP. Note that the absorption is two-pass for the VISAR data (probe beam and reflected beam) and one-pass for SOP.

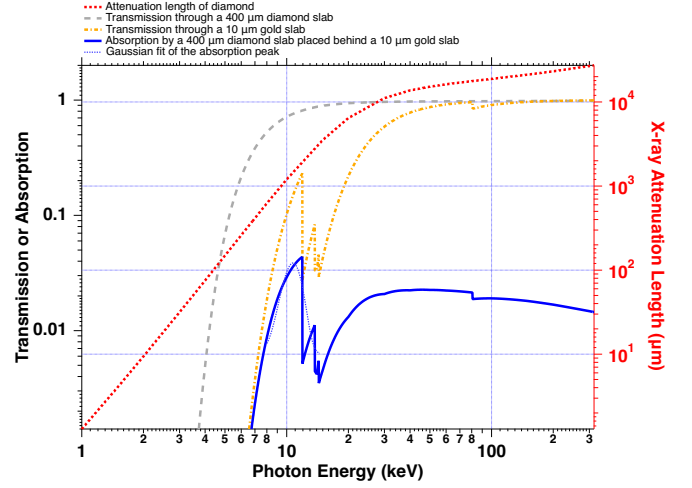


Fig. S13 X-ray transmission and absorption in diamond (see legend). All calculations use cold mass attenuation lengths from Ref.(51).

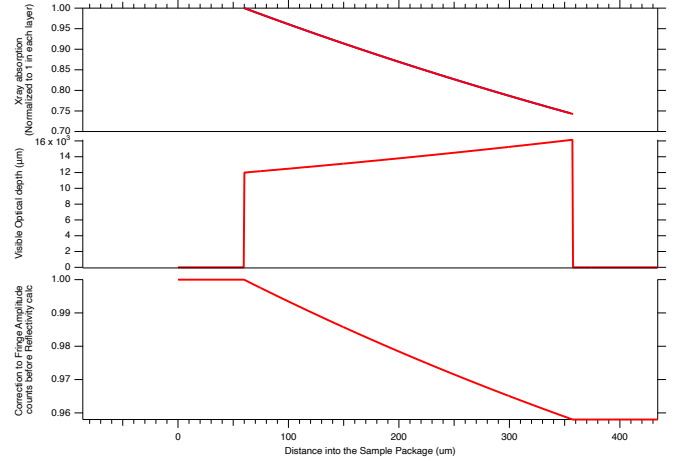


Fig. S14 Photo-ionization correction for the reflectivity of diamond for 36010. Assuming an x-ray attenuation length $d_1 = 1000 \mu\text{m}$ and an optical attenuation length of $d_2 \sim 12000 \mu\text{m}$ the photo-ionization is quite weak and the relative correction is limited to less than 4% in fringe amplitude.

S2.6. Decaying shock temperature

Similarly to the steady shock measurements (see Section S1.5), we use a grey-body approximation with the emissivity ϵ determined by the shock reflectivity (R): $\epsilon = 1 - R$, and the quartz as an *in-situ* reference to determine the shock temperature in the decaying shock measurements. The methods are

similar to those described in Ref. (26). In addition to Fig. 3 we also report the decaying shock data on Extended Data Fig. 4 where we use different symbol colors for each of the seven decaying shock experiments.

We note that Fig. 3 shows the decaying shock data restricted to the range of shock velocity (U_S) for which we can detect a reflecting shock and determine its velocity from the VISAR fringe phase shift. In addition, we also report in Extended Data Fig. 4 the decaying shock temperature measurements below the reflectivity onset near $U_S = 21$ km/s. To obtain these measurements we modeled the shock velocity decay and extrapolated U_S until the shock breakout time using constraints from (1) the known thickness of the diamond sample and (2) either the observed transmitted velocity in the quartz for the experiments with a quartz plate downstream from the diamond sample (using the diamond - quartz release calibration see Section SS4.1), or the breakout time of the inelastic wave at the free surface. The good reproducibility of the data between the different experiments validates the velocity extrapolation approach below the reflectivity onset near 21 km/s.

Since the reflectivity (R) increases with increasing shock velocity from 21 km/s to 24 km/s, the emissivity ($\epsilon = 1 - R$) decreases in that range. If the SOP signal stayed constant in that U_S range such an emissivity decrease would cause the temperature to *increase* with increasing U_S , in contrast with the observed small *decrease*. In other words the observed decrease in shock temperature upon increasing shock velocity between ~ 21 and 24 km/s cannot be attributed to the rise of shock reflectivity (as previously noted in Ref. (4).)

The quantitative SOP analysis to extract the shock temperature versus shock velocity is conducted in a $\sim 80 \mu\text{m}$ wide band in the central planar region of the record, as illustrated with the thin dashed black lines in Fig. 2C and in Figs. S20 and S21.

We note that, even though we observe some photo-ionization, we do not expect significant preheat. Even though, in these experiments, the drive intensity is higher than in the steady shock experiments because the initial shock is stronger, the use of a $10 \mu\text{m}$ thick Au shield layers enables significantly reducing the level of potential preheat from the ablation plasma. We note that the preheat was conservatively estimated to be less than 1000K in the previous study using similar and higher laser drive intensities and targets having a $50 \mu\text{m}$ thick plate of Al instead of a preheat shield (4) (neglecting the Au M-band the x-ray attenuation of $50 \mu\text{m}$ of Al is similar to that of $2 \mu\text{m}$ of Al below 10 keV). The good agreement between the shock temperature measurements of the target having or not a Quartz plate upstream of the diamond sample is another indication that no significant preheat is at play (see Fig. S12 and Extended Data Fig. 4).

S3. Additional Methods

S3.1. Shock front reflectivity, Attenuation Length and Optical Conductivity

While static compression experiments (63) reported that the refractive index of diamond decreases with increasing pressure up to 40 GPa, it is expected from numerical simulations that

the evolution depends strongly on the compression method (*e.g.* uniaxial or hydrostatic). Gas gun shock compression experiments (64) reported a particle velocity VISAR correction (28, 65) for diamond $a \sim 2$ at 532 nm. This suggests that the index increases with increasing shock pressure. We construct a simple Gladstone-Dale model for the evolution of the refractive index with density:

$$n_{GD}(\rho) = a + \frac{n_0 - a}{\rho_0} * \rho \quad (4)$$

where $n_0 = 2.426$ is the index at the ambient density $\rho_0 = 3.515 \text{ g/cm}^3$. As shown on Fig. S15, the Gladstone-Dale model is in good agreement with recent measurements with laser-driven shocks up to 170 GPa (66). The increase in refractive index described by the Gladstone-Dale model induces a small Fresnel reflectivity at the shock front:

$$R_{GD} = \frac{(n - n_0)^2}{(n + n_0)^2} \quad (5)$$

However, because of the high index of diamond at ambient conditions, such reflectivity is very small and increases slowly with increasing density reaching only $R_{GD} \sim 0.5\%$ near 6.5 g/cm^3 (dashed curve and right scale on Fig. S15).

The observation of significant shock front reflectivity indicates that the optical properties of the shock compressed material are significantly different from the material at rest ahead of the shock. If the shock compressed complex refractive index is $\tilde{n} = n + ik$ while the index at ambient conditions is $\tilde{n}_0 = n_0$ (*i.e.* neglecting optical absorption so that the imaginary part $k_0 = 0$) we can compute the optical reflectivity at the shock front as:

$$R = \frac{(n - n_0)^2 + k^2}{(n + n_0)^2 + k^2} \quad (6)$$

Following an approach similar to that described in the Supplementary Material of Ref.(30) we assume that the real part of the index in the shock state follows the trend observed below 200 GPa, while the onset of electronic conduction yields a rapidly increasing imaginary part k or equivalently the absorption coefficient $\alpha = 2\omega k/c$ where ω is the angular frequency of the VISAR probe beam and c is the velocity of light. We recall the attenuation length $d = 1/\alpha$. As illustrated on Extended Data Fig. 5 we can then relate the observed increase in the reflectivity with the absorption coefficient (or the attenuation length) as:

$$R = \frac{(n_{GD} - n_0)^2 + ((\alpha c)/(2\omega))^2}{(n_{GD} + n_0)^2 + ((\alpha c)/(2\omega))^2} \quad (7)$$

S3.2. Low adiabat ICF implosions

In this work, we demonstrate that a first shock near 24.5 km/s would be sufficiently strong to completely melt a micro-crystalline diamond ablator. From our previous in-situ measurements of the relative impedance mismatch between the diamond ablator material and cryogenic fluid D_2 using shock-timing experiments (28, 36, 58) at the National Ignition Facility, we can estimate that a 24.5 km/s first shock in the diamond

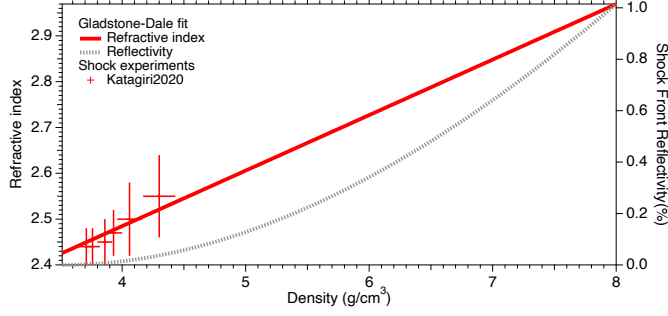


Fig. S15 Diamond refractive index under shock compression. Comparison of a Gladstone-Dale model based on Ref.(64) with the experiments of Ref.(66). The reflectivity of the shock front if the real part of the refractive index follows the Gladstone-Dale model and the imaginary part is zero is reported on the right scale and does not exceed 0.5% near 6.5 g/cm^3 . See Section S3.1.

would launch a first shock near 28 km/s in fluid D_2 shock timing experiments. In contrast, current ICF implosion designs aiming at achieving a 1.2 TPa first shock induce a 33-34 km/s transmitted first shock measured in fluid D_2 .

There is therefore an opportunity to lower the entropy of the DT fusion fuel by reducing the strength of the first shock near 1.05 TPa. Using the scaling from Ref.(67) a reduction of the first shock velocity in D_2 from 33 to 28 km/s corresponds to a 13% reduction of the DT fuel entropy at peak compression. In other words this would reduce the minimum shock adiabat from 1.56 to 1.36. Such a reduced DT fuel entropy enables the implosion to reach a higher areal density because the fuel would be more compressible. One dimensional ICF implosion modeling indicate that higher compression leads to higher yield by increasing the fraction of DT fuel transformed into helium. From the scaling of Ref.(14) (Fig. 4) a 10% reduction in the in-flight adiabat is linked to a three-fold increase in the amount of energy released by the nuclear fusion reaction.

S3.3. Sketches illustrating the evolution of the solid fraction

The sketches in Fig. 1C are qualitative in nature and do not illustrate details of the melting mechanism in the microcrystalline sample. The initial state is obtained by computing the Voronoi tessellation from a random generated array of seed point and consider the output as representative of grain boundaries. We then illustrate the increase the liquid fraction by assuming that melting begins at the grain boundaries, and progressively expand these boundaries. Above a threshold of liquid fraction *e.g.* we illustrate that entire grains may melt at once, while continuing to slowly expand the liquid region at the boundaries.

S4. Supplementary Discussion

S4.1. Shock and Release measurements

The VISAR data for several of the XRD experiments provide opportunities for additional analysis. In particular, we extract useful data documenting the relationship between the incident shock velocity in diamond and the transmitted shock in

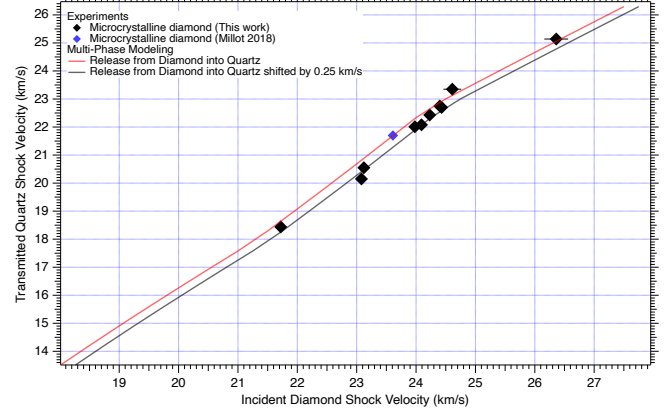


Fig. S16 Impedance-mismatch between diamond and quartz. Experimental data collected in this work document the velocity of the shock transmitted into a α -quartz plate U_{SQ} as a function of the incident shock velocity in microcrystalline diamond U_{SC} (see Table S2). A shift of the multi-phase modeling curve (solid red) by +0.25 km/s in U_{SC} appears to better reproduce the experimental trend when $U_{SC} < 24.5 \text{ km/s}$ and was used to constrain the extrapolation of the shock velocity below 21 km/s in the decaying shock experiments. One datum from our previous work (58) is also reported here.

the quartz window, similar to our previous studies(36, 58). We focus on the experiments for which we collected high quality VISAR fringes tracking the reflecting shock in the diamond right prior the shock breakout into the quartz window. We determine the reflecting shock velocity history around the instant t_{BO} at which the shock is transmitted from diamond to quartz and use linear fits of $U_S(t)$ just before and after t_{BO} to determine the incident shock velocity in the diamond U_{SC} and the transmitted shock velocity U_{SQ} in the quartz by extrapolating these fits to t_{BO} . The new data points, and one datum obtained during the decaying shock experiment 36010 (at the shock breakout from the diamond sample into the quartz-II reference plate) are reported in Table S2 and in Fig. S16.

We also report the theoretical U_{SC} versus U_{SQ} relationship from the multi-phase modeling (15). For a collection of shocks with a range of shock velocity a pressure-particle velocity ($P - u_p$) release curve can be calculated to generate a $U_{SC} - U_{SQ}$ point by finding the intersection of the release curve with the quartz Hugoniot (see (15) for detail). For quartz we use $\rho_0 = 2.648 \text{ g/cm}^3$, and the fit to the Hugoniot data from Refs.(68, 69) *i.e.* $U_S = a + b * u_p - c * \exp(-d * u_p)$ with $(a, b, c, d) = (5.477, 1.242, 2.453, 0.4336)$ where velocities are expressed in km/s . We compare the experimental data with the multi-phase calculation in Fig. S16. A shift of the multi-phase modeling curve (solid red) by +0.25 km/s in U_{SC} appears to better reproduce the experimental trend when $U_{SC} < 24.5 \text{ km/s}$ and was used to constrain the extrapolation of the shock velocity below 21 km/s in the decaying shock experiments.

S4.2. Free-surface breakouts: evidence for melting

As previously described in (24, 31), the observed VISAR signal upon shock breakout at a free-surface is qualitatively different whether the shock compressed material behind the shock

is solid or liquid. If it is solid, there is a high likelihood that it will remain solid upon release to near-zero pressure. The free-surface will therefore continue to reflect the VISAR laser probe so that VISAR fringes are usually maintained after breakout for at least a few hundred picoseconds after shock breakout.

In contrast, if the shock compressed material is liquid it is likely that it will vaporize into a partially ionized plasma upon release to near-zero pressure. The released material will generate a steep mass-density gradient towards the VISAR detector within 10-100 ps. For strong shock waves capable of melting full density materials, this mass-density gradient will be optically thick for the VISAR laser probe, so that the fringes are quickly extinguished.

The VISAR signal for the three decaying shock experiments without a Quartz-II plate (101348, 101351 and 101353) are characterized by the recovery of fringes when the shock breaks out of the diamond free surface (Fig. S21). This constitutes unambiguous evidence that the shock wave amplitude right prior to breakout ($U_S \sim 19 \text{ km/s}$) is insufficient to melt a significant fraction of the sample (24, 31).

In contrast, the VISAR fringes disappear abruptly upon shock breakout from the diamond sample surface for 30975 (2) revealing that a significant fraction of the sample is transformed to the fluid phase when the shock velocity determined right prior to breakout with $U_S \sim 24.6 \pm 0.1 \text{ km/s}$ ($\sim 1100 \text{ GPa}$).

S4.3. Free-surface breakouts: evidence for two-wave shock structures

The observation of two fringe jumps in rapid succession (less than 0.5 ns) when the shock breaks out of the diamond free surface (Fig. S21) can be interpreted as evidence for a two-wave shock structure in the decaying shock experiments without a Quartz-II plate (101348, 101351 and 101353). The observed signal is similar to previous Omega Laser Facility experiments reported in Ref.(4, 5) which also investigated the shock response of microcrystalline diamond sample grown by chemical vapor deposition. While the response of diamond to uniaxial shock compression is likely quite complex, it is useful to consider the intuitive picture of an elastic precursor wave followed by an inelastic wave.

Following Ref.(5), we determine the critical shock velocity $U_{S,Crit}$ above which the elastic precursor is overdriven by assuming that the wave splitting occurs when the shock amplitude decays to $U_{S,Crit}$ and that the elastic precursor velocity is constant at $U_{S,Crit}$. We evaluate a range of values for $U_{S,Crit}$ between 19 and 23 km/s and search for the value that reproduces the timing of the elastic precursor and inelastic wave arrivals at the free surface t_E and t_I considering the velocity history of the (inelastic) shock velocity across the sample $U_S(t)$ and the observed free surface velocity U_{FSE} for the elastic wave. In this analysis we compute explicitly the Eulerian position of the inelastic shock front by integrating $U_S(t)$. To do this we extrapolate linearly the decay of the inelastic wave velocity after breakout and ignore the small change in its shock velocity when the inelastic wave interacts with the release waves stemming from the elastic wave arrival at the free surface. We

estimate the uncertainty on $U_{S,Crit}$ by propagating the uncertainty on the timings t_E and t_I and velocities $U_S(t)$ and U_{FSE} with a Monte-Carlo algorithm. We find that the three experiments yield very similar values and a weighted average yields $U_{S,Crit} = 20.66 \pm 0.32 \text{ km/s}$. Alternatively, one can assume that $U_S(t)$ decays linearly with time and obtain an analytical formula for $U_{S,Crit}$ (see Eq. 6 in Ref.(5)). Such an analysis yield similar results near 20.6 km/s.

Fig. S17 illustrates the wave splitting for experiment 101348 for which our simplified analysis yields $U_{S,Crit} = 20.59 \pm 0.28 \text{ km/s}$. Computing the difference in Eulerian position between the elastic and inelastic waves reveals that the thickness of the elastically compressed sample is less than $10 \mu\text{m}$.

We find that the free-surface velocity of the elastic precursor is near 2.5 km/s for experiments 101348, 101351 and 101353. Such a wave amplitude is insufficient to induce a reflecting shock after transmission into a quartz plate position downstream from a diamond sample. One would instead expect quartz to become opaque (no VISAR fringes) after the transmission of the elastic wave, and to recover VISAR fringes after the merger with the stronger shock resulting from the transmission of the inelastic wave. Because the fringe disappear prior to breakout due to the loss of reflectivity in the diamond, it is difficult to assess directly whether a two-wave shock structure is present in experiments 101350, 101352 and 101354 having a quartz-II plate but the data do not preclude that there is a wave splitting (see Fig. S20)

In the fourth experiments having a quartz-II plate (36010), the velocity does not decay below 21.7 km/s. No signature for a two-wave structure is observed (Extended Data Fig. 3).

S4.4. Shock pressure-density EOS measurements

For the experiments which include a Quartz-I plate, we can measure the shock EOS of the diamond relative to the quartz. Focusing on the reflecting shock velocity history around the instant t_{BO} at which the shock is transmitted from the quartz to the diamond we use linear fits of $U_S(t)$ just before and after t_{BO} to determine – by extrapolating these fits to t_{BO} – the incident shock velocity in the quartz-I U_{SQ} and the transmitted shock velocity U_{SC} in the diamond. Using an impedance matching procedure (see details in Ref.(36)) with the fit for the quartz $U_S - u_p$ Hugoniot from Ref.(69) and a Mie-Gruneisen model with a constant Gruneisen parameter $\Gamma = 0.64 \pm 0.05$ for the reshock of the quartz (35) we determine the transmitted shock pressure P and particle velocity u_p . The density ρ is then computed with the Rankine-Hugoniot equation $\rho = \rho_0 * U_S / (U_S - u_p)$. We obtain four new data points. See detailed results in Table S1 and a comparison with previous studies (3, 35, 36) and the multi-phase modeling in Fig. S18.

A 5th polynomial fit to the $U_S - u_p$ data in km/s units from Refs.(35, 36, 70) yields the following parameters: 1.0379, 5.0783, -0.531754, 0.0302076, -0.000688916, 3.91042e-06. This fit is essentially for visualization purposes, the polynomial functional form is not expected to be meaningful outside the range of the data: U_S from 20 to 25 km/s.

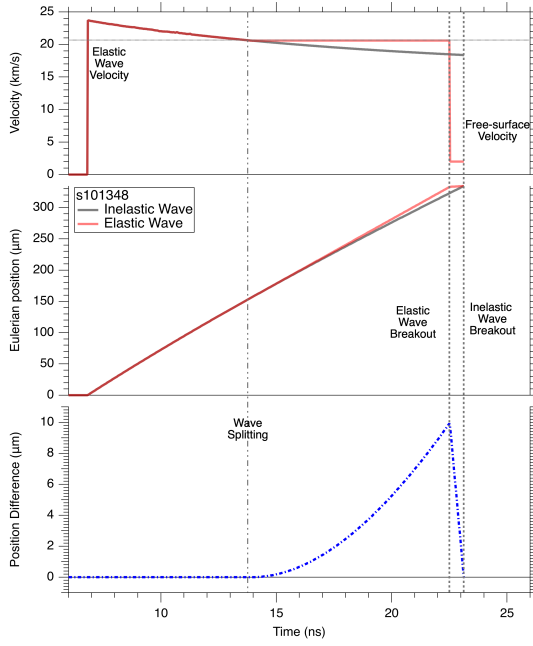


Fig. S17 Two-wave structure analysis for 101348. **Top:** Velocity history. The observed shock velocity (extrapolated when fringe disappear below $\sim 21 \text{ km/s}$) is assigned to the inelastic wave. The elastic wave is assumed to travel at the critical shock velocity $U_{S,Crit}$ until shock breakout. After breakout, the free-surface velocity U_{FSE} is reported. **Center:** Corresponding Eulerian position for the leading elastic and inelastic shock waves. **Bottom:** Difference in Eulerian position between the elastic and inelastic shocks.

S4.5. Curvature of the temperature reversal on the space-time streaked SOP images

Following the analysis framework we described in Ref.(25) we use the line-imaging capability of the SOP to obtain additional information on the observed sharp temperature reversal near $U_S \sim 24 \text{ km/s}$. Considering the full space-position streaked SOP image on Fig. S19 reveals that the shock breakout into the quartz near 18-19 ns is observed at slightly earlier time near the center of the sample compared with the top and bottom of the streaked image. This is consistent with the shock being less affected by edge rarefaction waves, and therefore faster, near the center of the sample. If we were to draw the position of the shock breakout onto the space-position image we would obtain an arc with a center of curvature located at later time than the time of the shock breakout in the center of the sample.

In contrast, the spectral radiance minimum (*i.e* the temperature reversal near 7 ns) occurs slightly earlier near the top and bottom of the image. In other words, if we were to draw the position of the temperature reversal in the position-time streaked image we would obtain an arc with a center of curvature located at earlier time than the time of the temperature reversal in the center of the sample. This reveals that the SOP minimum is a signature for a material dependent behavior at a well-defined shock velocity/pressure and not a spurious artifact due for example to a wave reverberation.

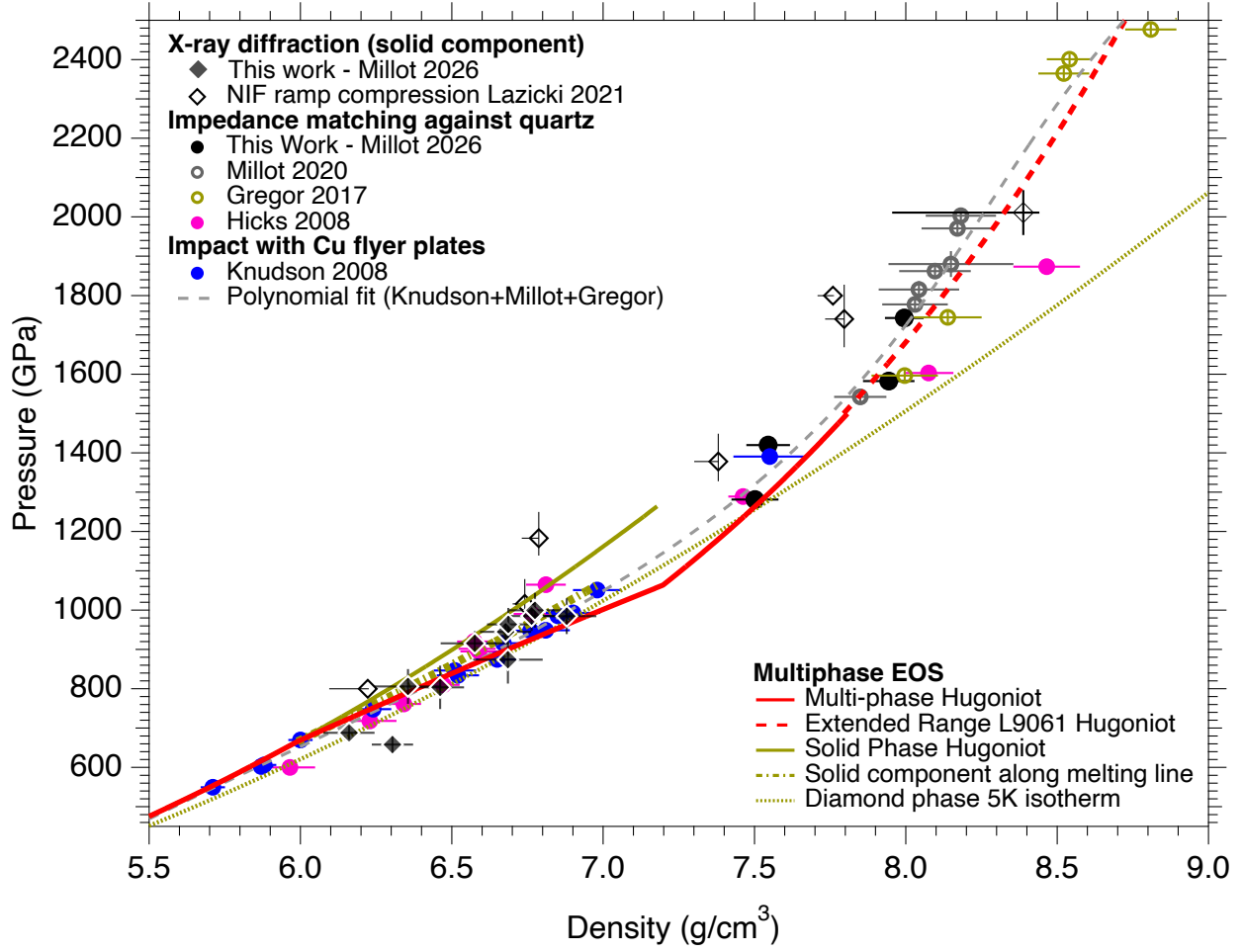


Fig. S18 Extended range Pressure-Density response of dynamically compressed diamond. X-ray diffraction data include shock compression (this work) and ramp-compression at the National Ignition Facility (21). Impedance matching experiments with a quartz standard include new data from this work, our previous work (36) and earlier Omega data (35, 70), all reanalyzed using the same quartz shock and reshock model. Impact data with a copper flyer plate represent averages over several samples for each experiment (3). Together with the multi-phase Hugoniot computed using the solid EOS, liquid EOS and melting line tables (see Ref.(15)) which do not extend beyond 20 000 K, we also report the diamond Hugoniot computed with the flattened, extended range LEOS 9061 table (dash red) and the 5 K isotherm of the diamond phase (dot tan).

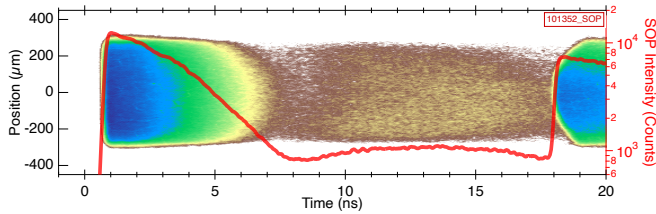


Fig. S19 Position-time curvature of the SOP minimum for s101352. Complete dataset is shown in Fig. S20. The minimum of the logarithmic color scale used here is set to 600 counts to enhance the visibility of the minimum in the SOP near 7- 8 ns. See Ref.(25) for more detail on the interpretation.

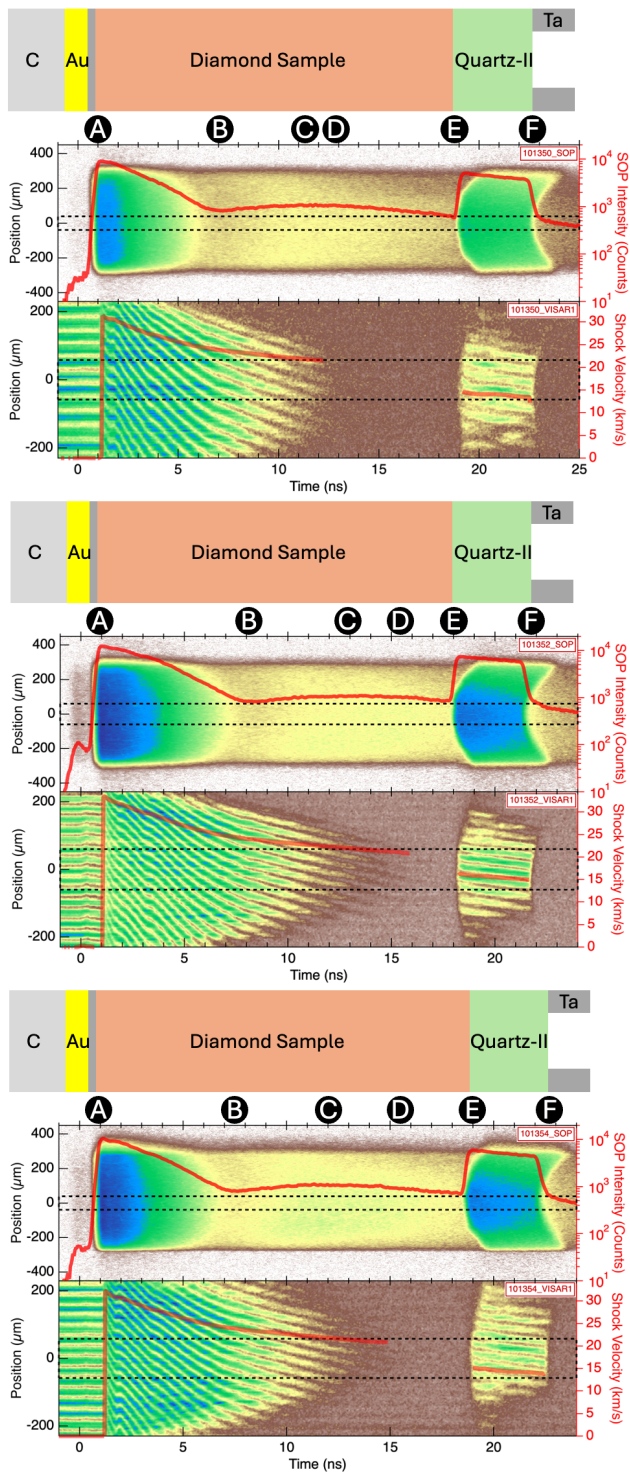


Fig. S20 Decaying shock SOP and VISAR data for 101350, 101352 and 101354. **Top:** Sketch of the target package (not to scale). **Bottom:** False colors SOP and VISAR1 streak images (log color scales, ghost fringes subtracted) with approximate linear time scale. Red curves (right axis, approximate linear time scale) represent the time history of the SOP intensity and inferred reflecting shock velocity near the center of curvature of the shock front (averaged between the dashed black lines). **A:** Shock arrival into diamond sample; **B:** SOP intensity exhibits a minimum while the shock velocity continues to decrease; **C:** SOP intensity exhibits a maximum; **D:** Loss of the reflecting shock VISAR fringes. **E to F:** Shock transit in quartz-II.

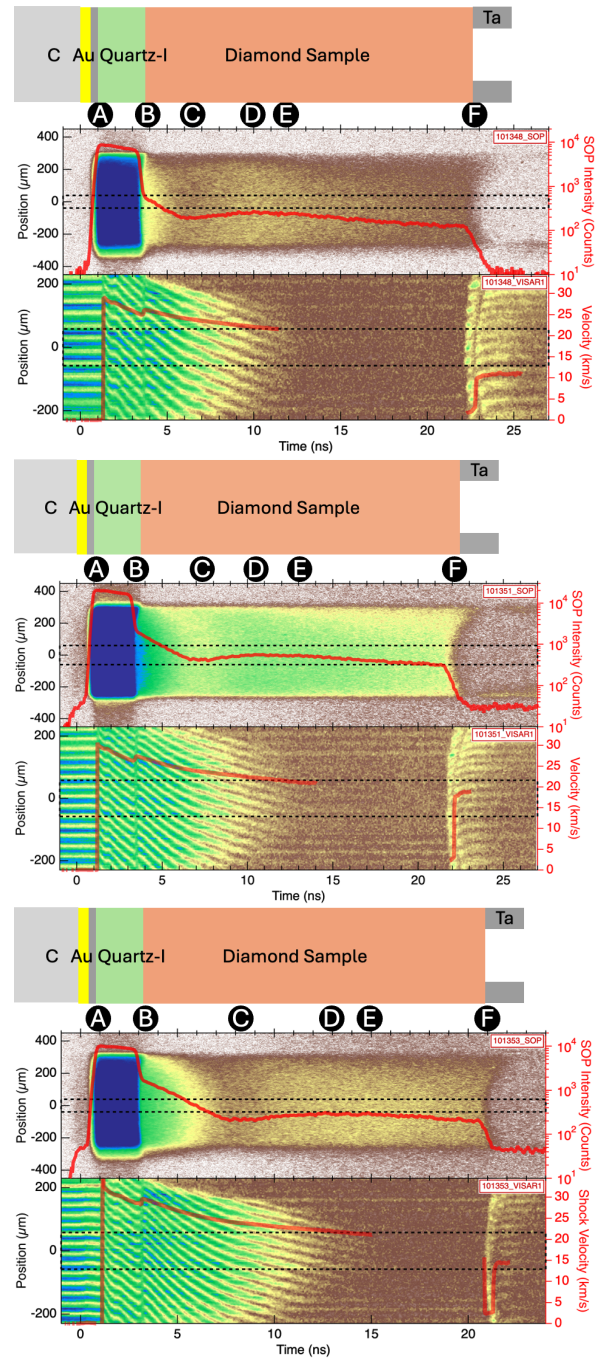


Fig. S21 Decaying shock SOP and VISAR data for 101348, 101351 and 101353. **Top:** Sketch of the target package (not to scale). **Bottom:** False colors SOP and VISAR1 streak images (log color scales, ghost fringes subtracted) with approximate linear time scale. Red curves (right axis, approximate linear time scale) represent the time history of the SOP intensity and inferred velocity near the center of curvature of the shock front (averaged between the dashed black lines). **A:** Shock arrival into quartz-I; **B:** Shock arrival into diamond sample; **C:** SOP intensity exhibits a minimum while the shock velocity continues to decrease; **D:** SOP intensity exhibits a maximum; **E:** Loss of the reflecting shock VISAR fringes; **F:** Recovery of strong fringes upon shock breakout at the diamond free-surface suggests the presence of a solid surface. The two-step velocity jump suggests a two-wave structure (see Section S4.3). Between **A** and **E** the VISAR tracks the reflecting shock velocity. After **F**, VISAR records the free-surface velocity.

S4.6. Summary of theoretical melting lines for carbon

Fig. S22 presents a comparison of a few melting lines from DFT simulations (9, 12, 13, 16). In Ref.(16) the melt curves of diamond and post-diamond carbon phases were calculated using the two-phase solid/liquid coexistence method, employing density-functional-theory molecular dynamics (DFT-MD). The Perdew-Burke-Ernzerhof (PBE) generalized gradient approximation was used along with projector augmented-wave (PAW) pseudopotential with a very large unit cell containing more than 500 atoms and stringent electronic convergence criteria.

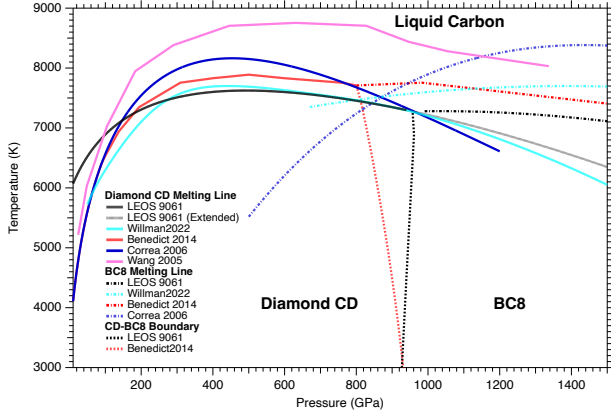


Fig. S22 Carbon melting line Comparison of predicted melting lines (9, 13, 16) for the CD Diamond and the post-diamond BC8 phases of carbon. Note that the melting line in the flattened EOS table LEOS 9061 differs from the phase boundaries reported in the publication describing the multi-phase EOS model (9).

S4.7. Comparison with Eggert 2010

The previous decaying shock study by Eggert *et al.*, used both microcrystalline and [110] oriented single crystals (4). The experiments were conducted at the Omega Laser Facility in 2006 and utilized an earlier implementation of the streaked optical pyrometry diagnostic (59). We show in Fig. S23 pyrometry and velocimetry images from two decaying shock experiments on chemical vapor deposition grown microcrystalline diamond samples from this previous study (4). While the shock temperature reversal is clearly apparent, the SOP signal does not decrease at late time even after the shock velocity decreases below the onset of optical reflectivity. Although the shock breakout from the diamond is not observed in the SOP data, preventing definitive conclusions, we speculate that a spurious contribution from stray light originating from reflections off the target chamber walls or instruments may become significant at late time (the target chamber diameter is ~ 3.3 m so that the light time-of-flight from the target chamber center to the wall and back is about 10 ns) and could have contributed to the higher melting temperature measurements in Ref.(4) relative to the present work.

Indeed, the data reported in this work was collected after several upgrades to the SOP system including the use of a higher fidelity ROSS streak camera with a P510 streak tube (29) and a time gated-photocathode which contributes to reduce

background signal due to target chamber glow while the mechanical shutter is still open. In addition, a higher performance optical telescope designed to minimize chromatic aberrations and significantly enhance stray light rejection using baffles in the telescope tube was deployed in 2018, *i.e.* prior to the experiments reported in this work (abstract BAPS.2018.DPP.BP11.4 at the 2018 APS DPP Meeting [link](#)). Optical modeling suggests that while the previous telescope allowed $\sim 2.2\%$ of any scattered light incident on the f/3.3 first lens to exit the telescope, the new design reduces this amount to $\sim 0.01\%$.

In addition, including quartz as an in-situ pyrometry reference contributes to minimizing shot-to-shot variations and provides a means to document partial loss of transparency due to photo-ionization (see Section S2.5 and Fig. S13). Finally, the use of a Ta washer with an internal diameter smaller than the VISAR and SOP field of view (see Section S2.1) enables us to document the potential presence of stray light and identify spurious background for each experiment.

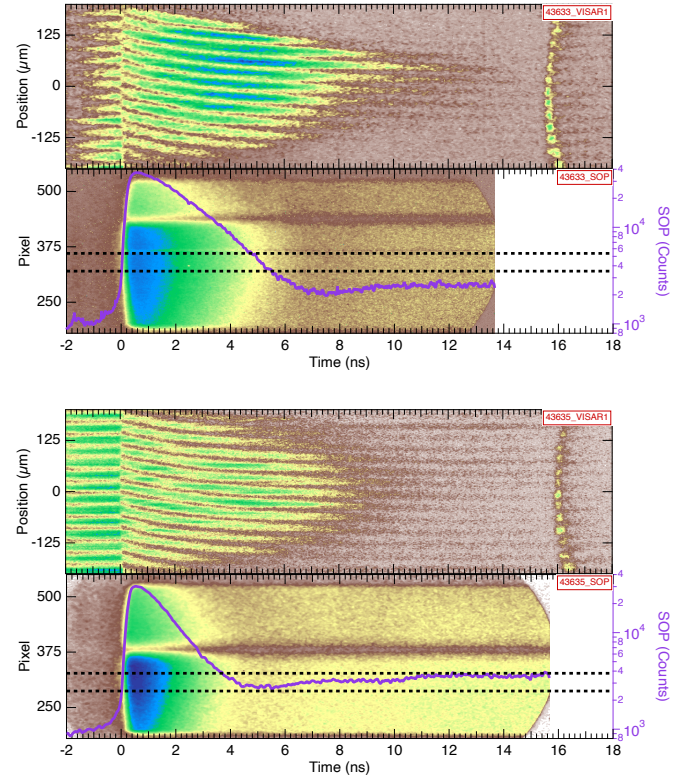


Fig. S23 VISAR and SOP data from the Eggert *et al.*, decaying shock study (4). Pyrometry and velocimetry images for shock compressed microcrystalline diamond collected at the Omega Laser Facility in 2006. Time scale is approximate (for visualization only) and relative to the shock breakout into the diamond sample. A lineout of the SOP (right scale) averaged between the dashed horizontal lines reveals a clear minimum in the radiance near 7 ns (43633 Top) and 5 ns (43635 Bottom), but the breakout from the diamond sample is not captured in these records.

Shot ID	U_{SQ} (km/s)	$\sigma(U_{SQ})$ (km/s)	U_{SC} (km/s)	$\sigma(U_{SC})$ (km/s)	u_p (km/s)	$\sigma(u_p)$ (km/s)	ρ (g/cm ³)	$\sigma(\rho)$ (g/cm ³)	P (GPa)	$\sigma(P)$ (GPa)
36010	27.41	0.12	28.42	0.09	15.84	0.12	7.944	0.085	1583	12
101348	24.84	0.12	26.19	0.08	13.92	0.11	7.502	0.078	1281	11
101351	25.96	0.11	27.50	0.08	14.69	0.11	7.545	0.072	1420	11
101353	28.59	0.07	29.75	0.09	16.67	0.08	7.995	0.064	1743	9

Table S1 Shock EOS measurements obtained with microcrystalline diamond samples. We report the observed shock velocity in the quartz U_{SQ} and in the diamond U_{SC} and their statistical uncertainties, as well as the results of the impedance-matching calculations including the particle velocity u_p , the mass density ρ and the pressure P , and their statistical uncertainties.

Shot ID	U_{SC} (km/s)	$\sigma(U_{SC})$ (km/s)	U_{SQ} (km/s)	$\sigma(U_{SQ})$ (km/s)
36010	21.72	0.06	18.44	0.09
30591	23.08	0.07	20.15	0.10
30593	23.12	0.07	20.55	0.10
30595	23.98	0.07	22.01	0.10
30974	24.09	0.07	22.08	0.11
30597	24.23	0.07	22.43	0.10
30977	24.40	0.15	22.75	0.10
30976	24.43	0.07	22.70	0.10
30978	24.61	0.20	23.35	0.10
30979	26.36	0.07	25.14	0.11

Table S2 Shock and release measurements obtained with microcrystalline diamond samples. We report the observed incident shock velocity in the diamond U_{SC} and the transmitted shock velocity in the quartz U_{SQ} , and their statistical uncertainties. See Fig. S16.

Shot ID	U_S km/s	$\sigma(U_S)$ km/s	P GPa	$\sigma(P)$ GPa	T K	$\sigma(T)$ K	ϵ	Notes
30589	21.2	0.3	656	32	7404	370	1	Transit time velocity
30591	22.9	0.1	867	14	7482	374	0.91	
30593	23.14	0.12	900	17	7394	370	0.93	
30595	23.77	0.12	993	18	7160	358	0.78	
30597	23.96	0.14	1021	22	7668	383	0.75	
30974	24.03	0.16	1024	25	7891	395	0.75	No quartz window
30975								
30976	24.33	0.11	1073	12	7810	390	0.71	
30977	24.44	0.11	1085	13	7968	398	0.70	Strong photoionization
30978								
30979	25.99	0.16	1269	20	11999	600	0.64	No quartz window
32645								

Table S3 Steady shock measurements results. Shock velocity (U_S), pressure (P), shock Temperature (T) and emissivity ϵ inferred from the VISAR and SOP analysis. Note that unless indicated in the Notes column, the shock velocity is determined just prior to the shock breakout (as indicated in Fig. 2D) which corresponds to the portion of the SOP record that is used to determine the temperature. The gray-body emissivity is determined as $\epsilon = 1 - R$ where R is the shock front reflectivity except for 30589 where we assume $\epsilon = 1$.

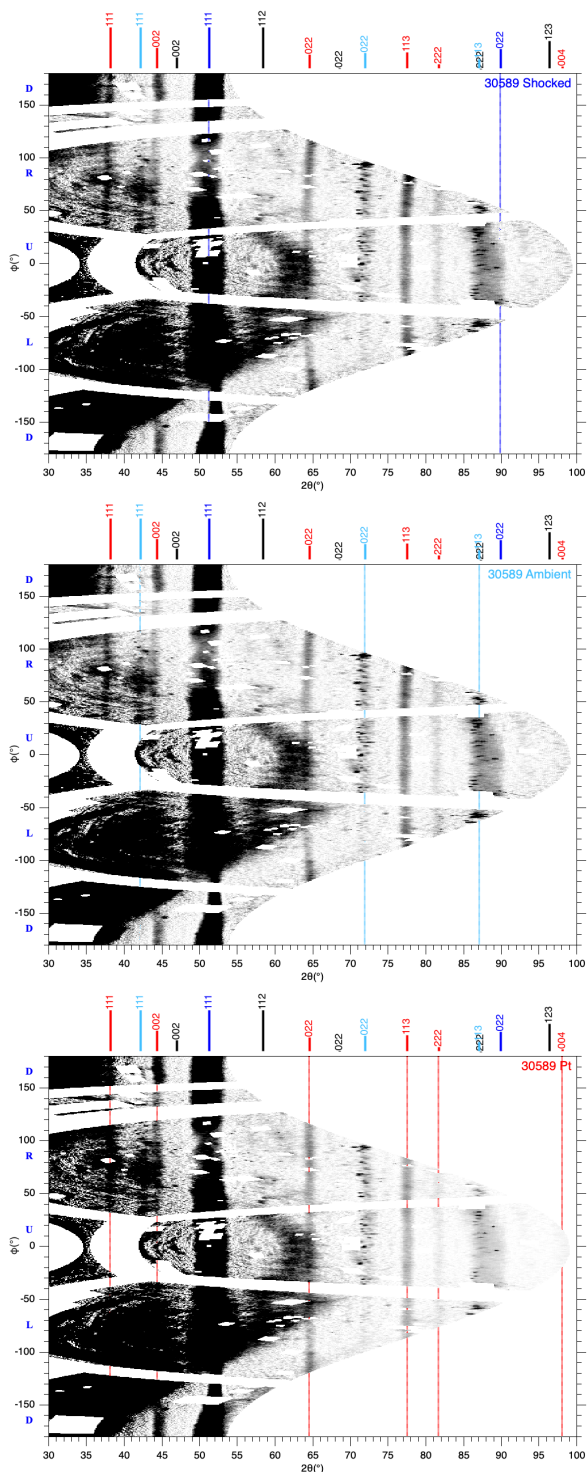


Fig. S24 XRD data for 30589 after SNIP background subtraction. Tick marks and Miller indices are similar to Extended Data Fig. 6.

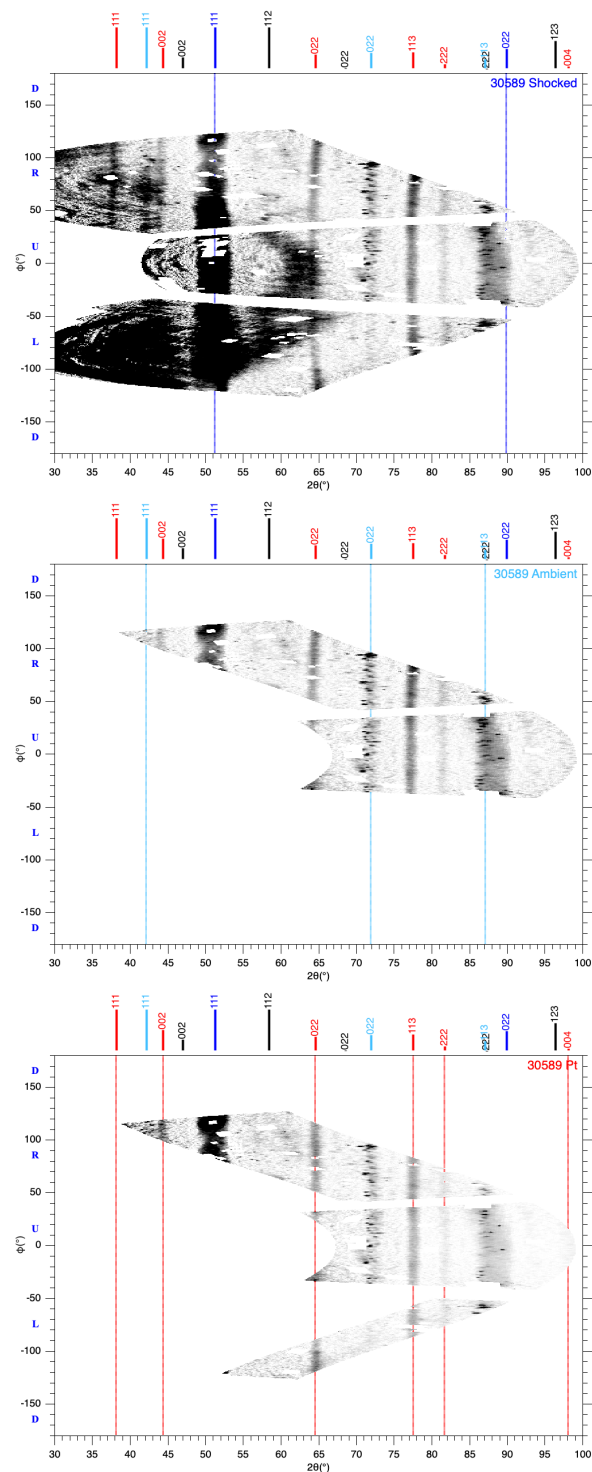


Fig. S25 Cropped XRD data for 30589 for intensity lineouts. Tick marks and Miller indices are similar to Extended Data Fig. 6.

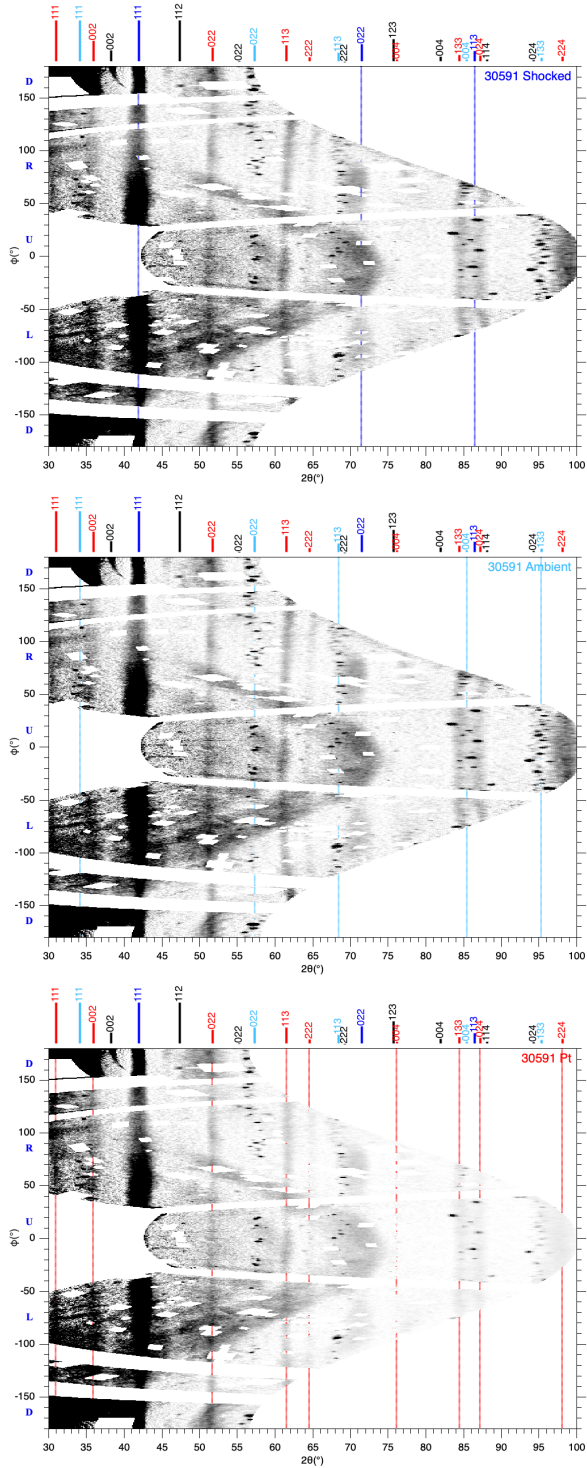


Fig. S26 XRD data for 30591 after SNIP background subtraction. Tick marks and Miller indices are similar to Extended Data Fig. 6.

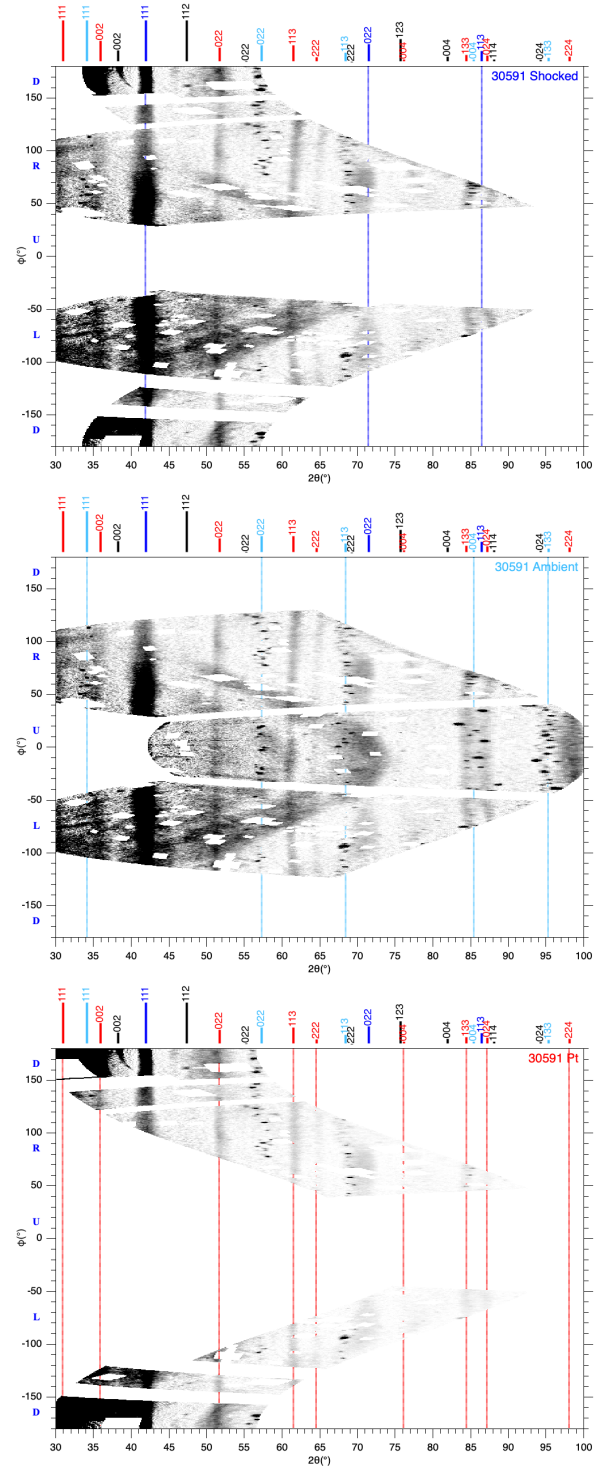


Fig. S27 Cropped XRD data for 30591 for intensity lineouts. Tick marks and Miller indices are similar to Extended Data Fig. 6.

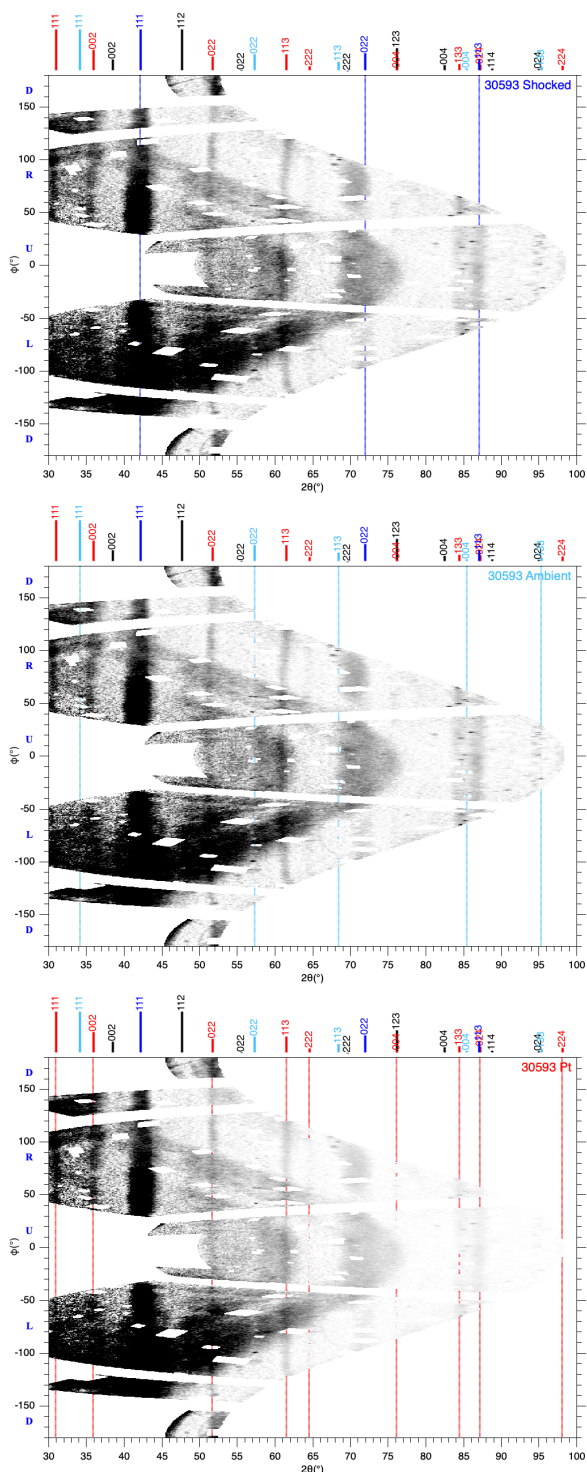


Fig. S28 XRD data for 30593 after SNIP background subtraction. Tick marks and Miller indices are similar to Extended Data Fig. 6.

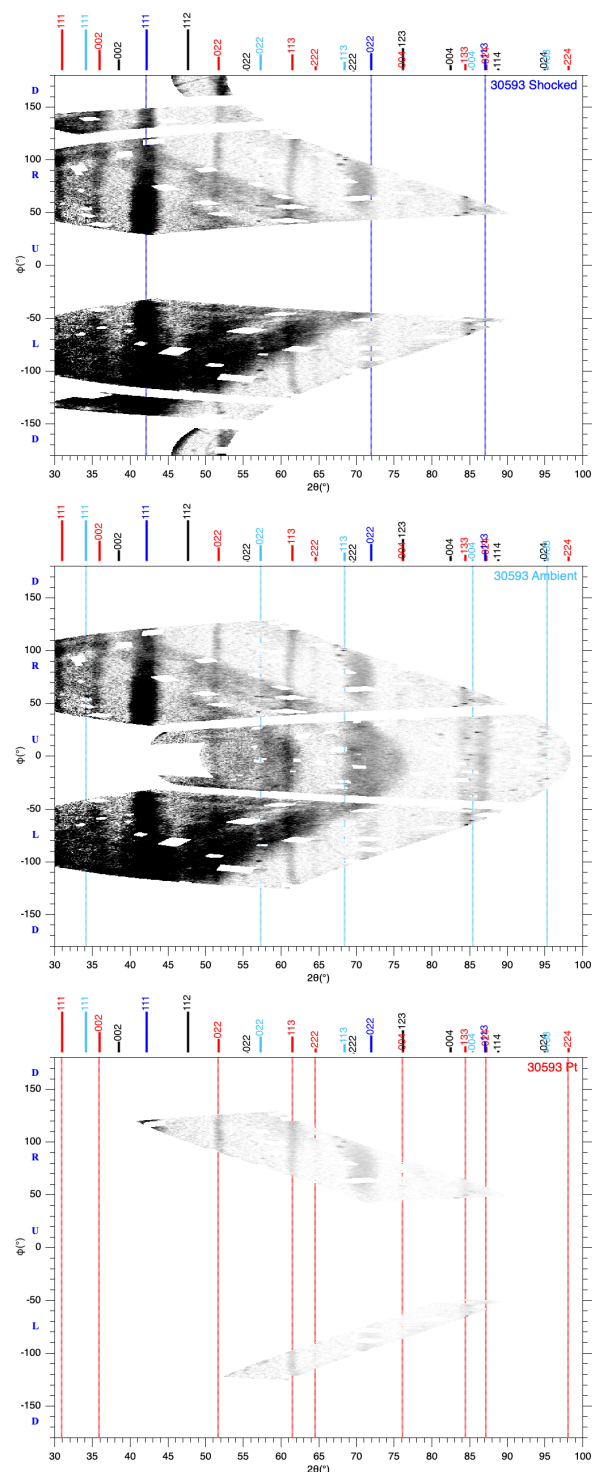


Fig. S29 Cropped XRD data for 30593 for intensity lineouts. Tick marks and Miller indices are similar to Extended Data Fig. 6.

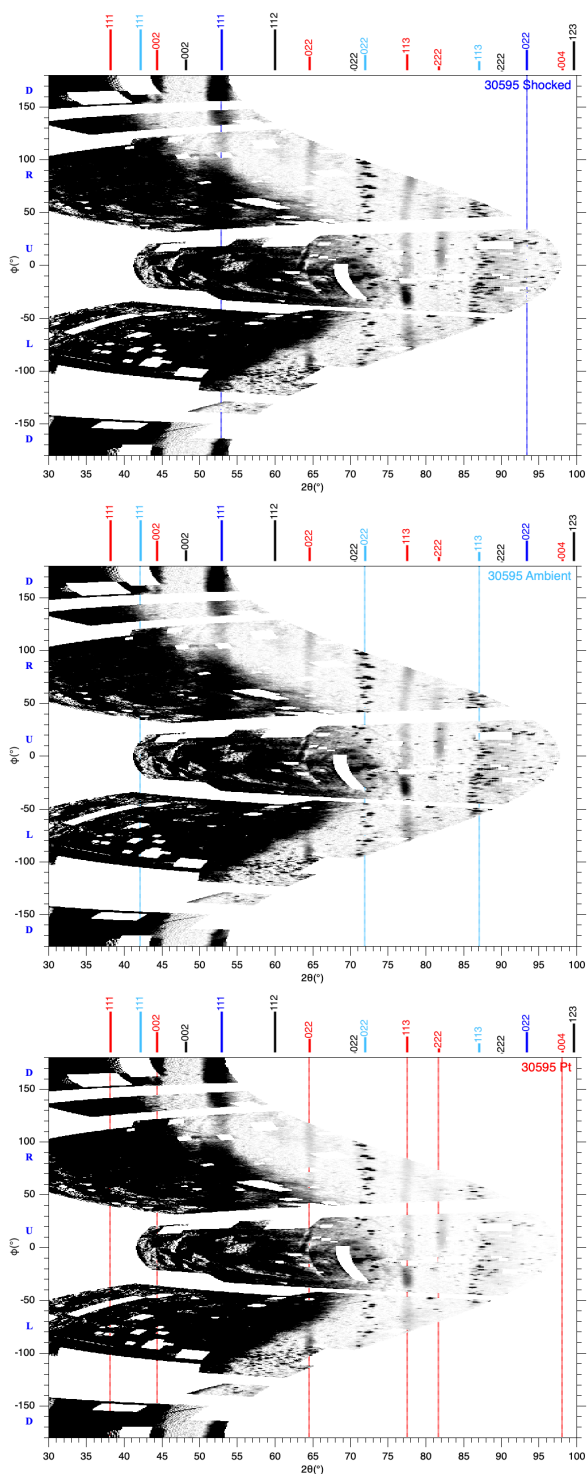


Fig. S30 XRD data for 30595 after SNIP background subtraction. Tick marks and Miller indices are similar to Extended Data Fig. 6.

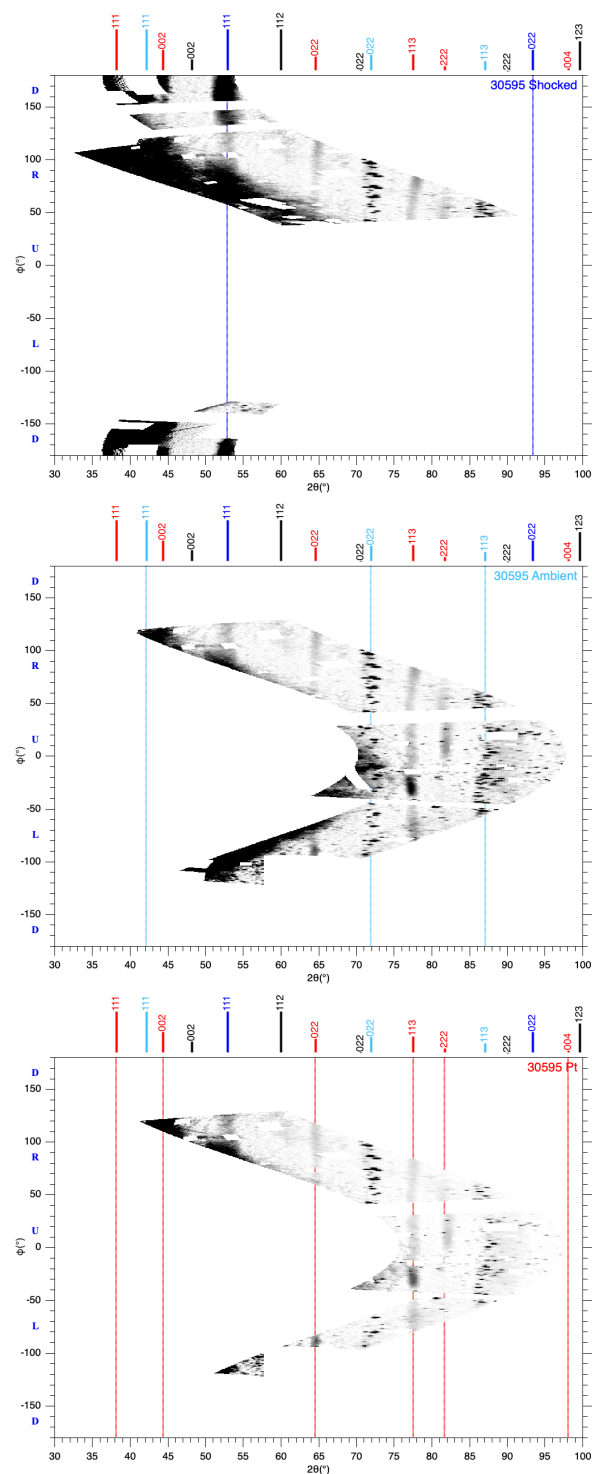


Fig. S31 Cropped XRD data for 30595 for intensity lineouts. Tick marks and Miller indices are similar to Extended Data Fig. 6.

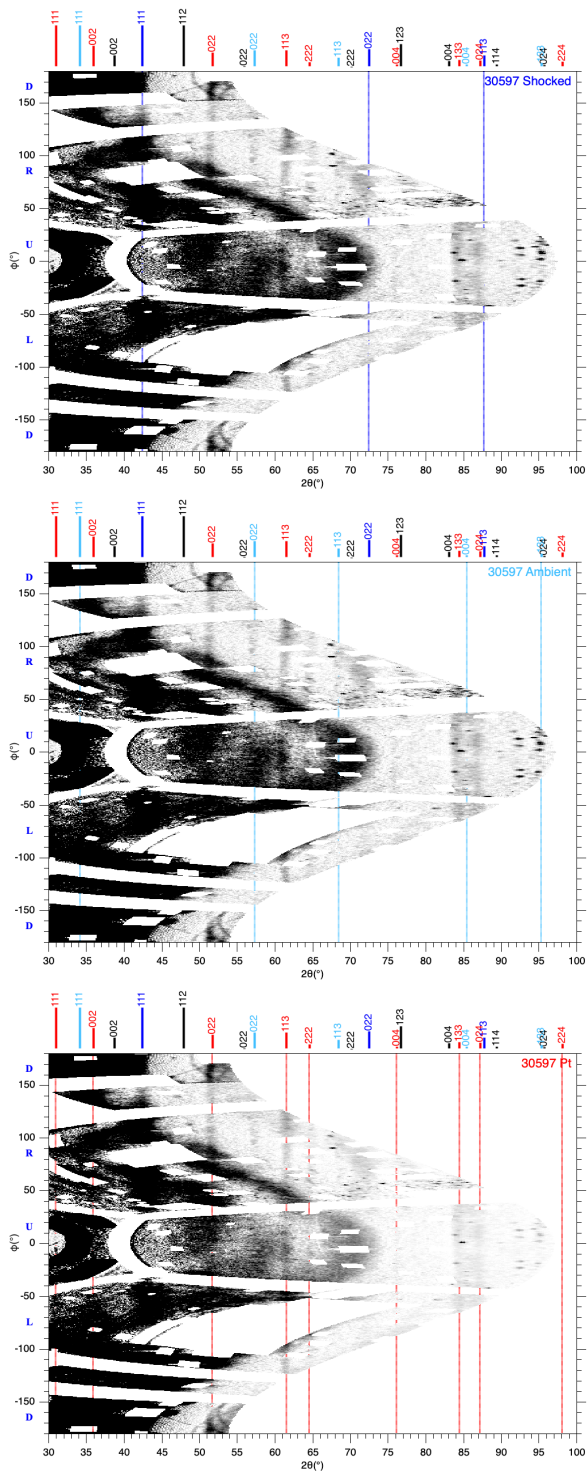


Fig. S32 XRD data for 30597 after SNIP background subtraction. Tick marks and Miller indices are similar to Extended Data Fig. 6.

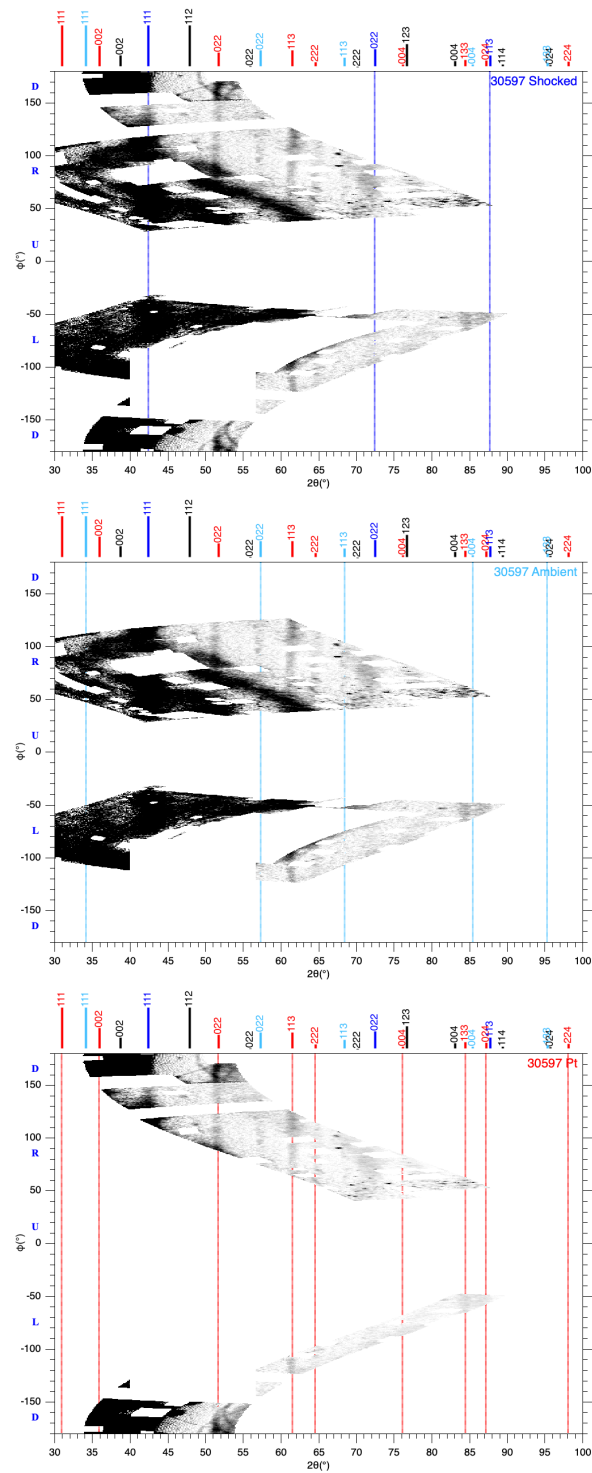


Fig. S33 Cropped XRD data for 30597 for intensity lineouts. Tick marks and Miller indices are similar to Extended Data Fig. 6.

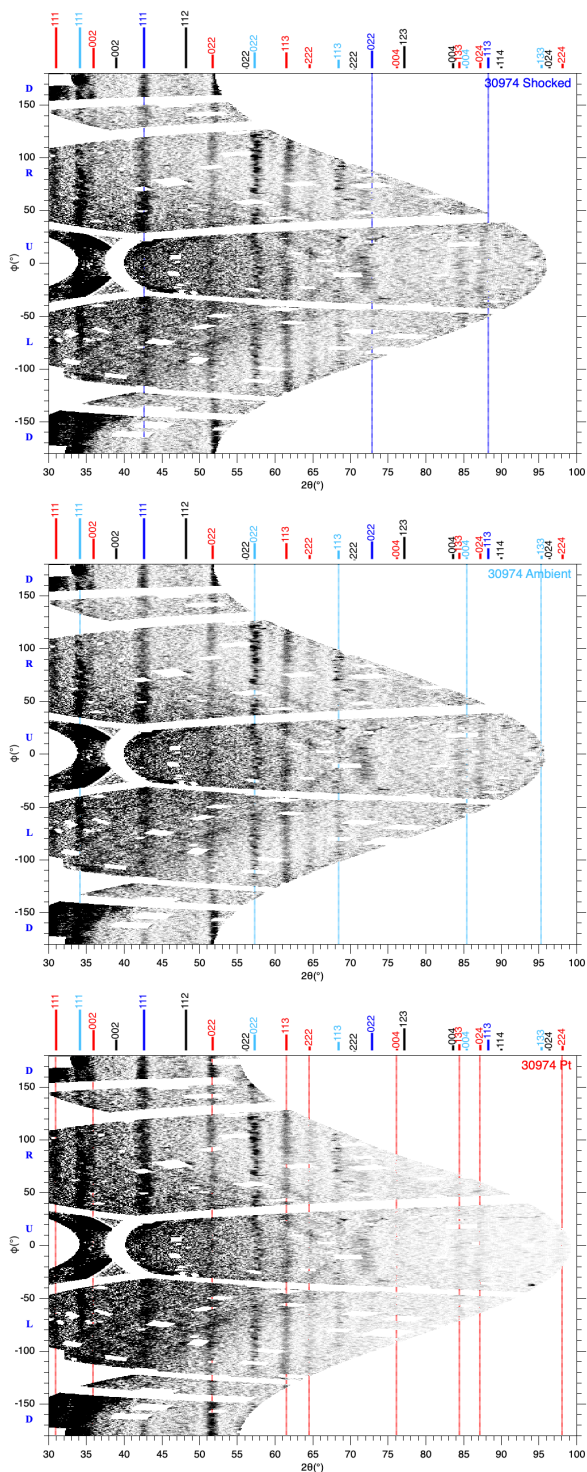


Fig. S34 XRD data for 30974 after SNIP background subtraction. Tick marks and Miller indices are similar to Extended Data Fig. 6.

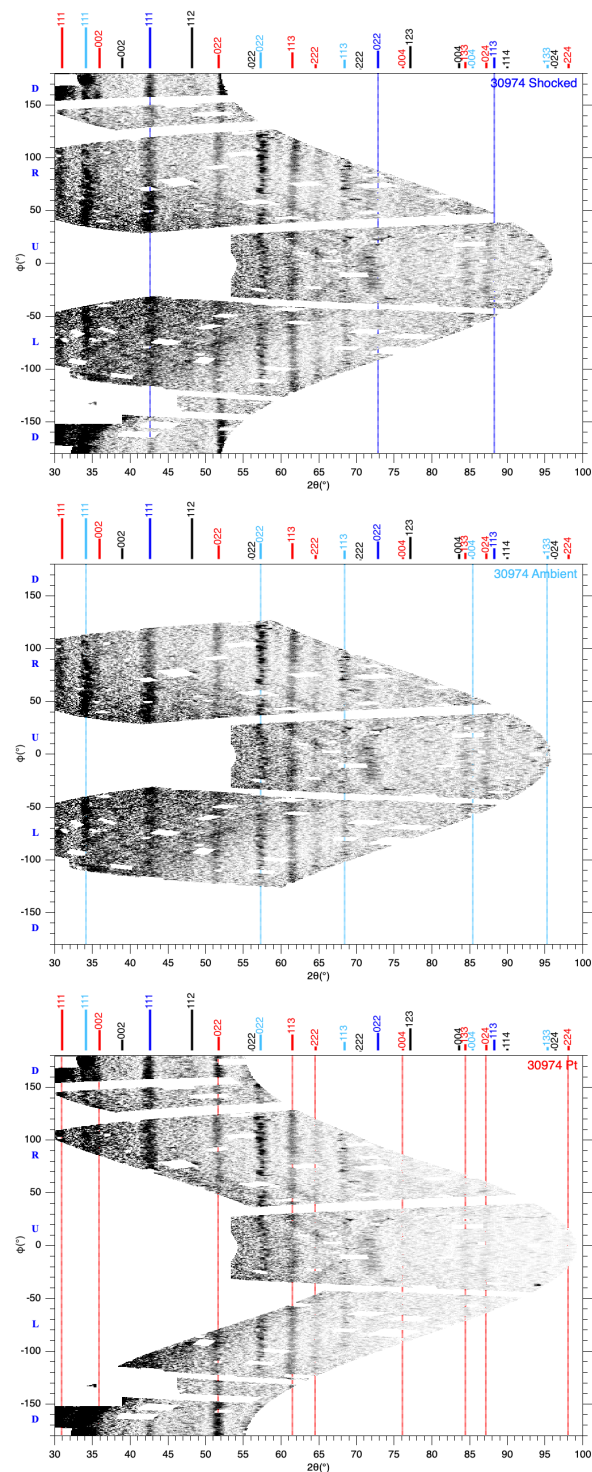


Fig. S35 Cropped XRD data for 30974 for intensity lineouts. Tick marks and Miller indices are similar to Extended Data Fig. 6.

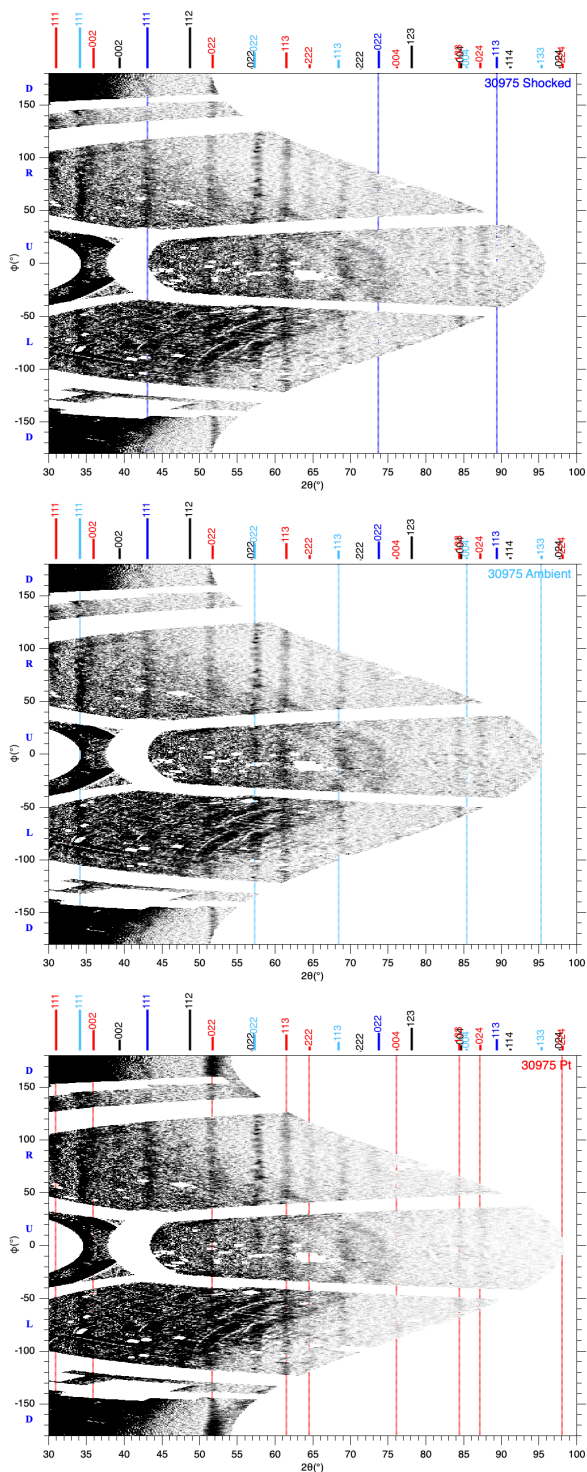


Fig. S36 XRD data for 30975 after SNIP background subtraction. Tick marks and Miller indices are similar to Extended Data Fig. 6.

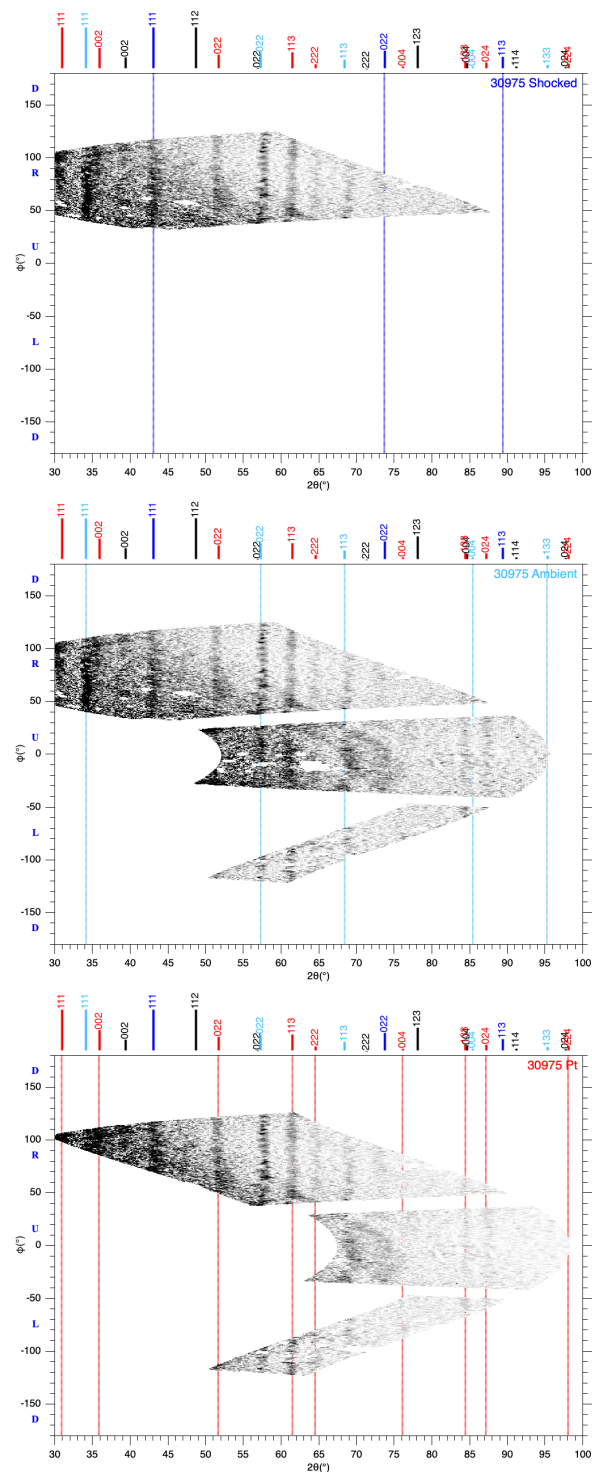


Fig. S37 Cropped XRD data for 30975 for intensity lineouts. Tick marks and Miller indices are similar to Extended Data Fig. 6.

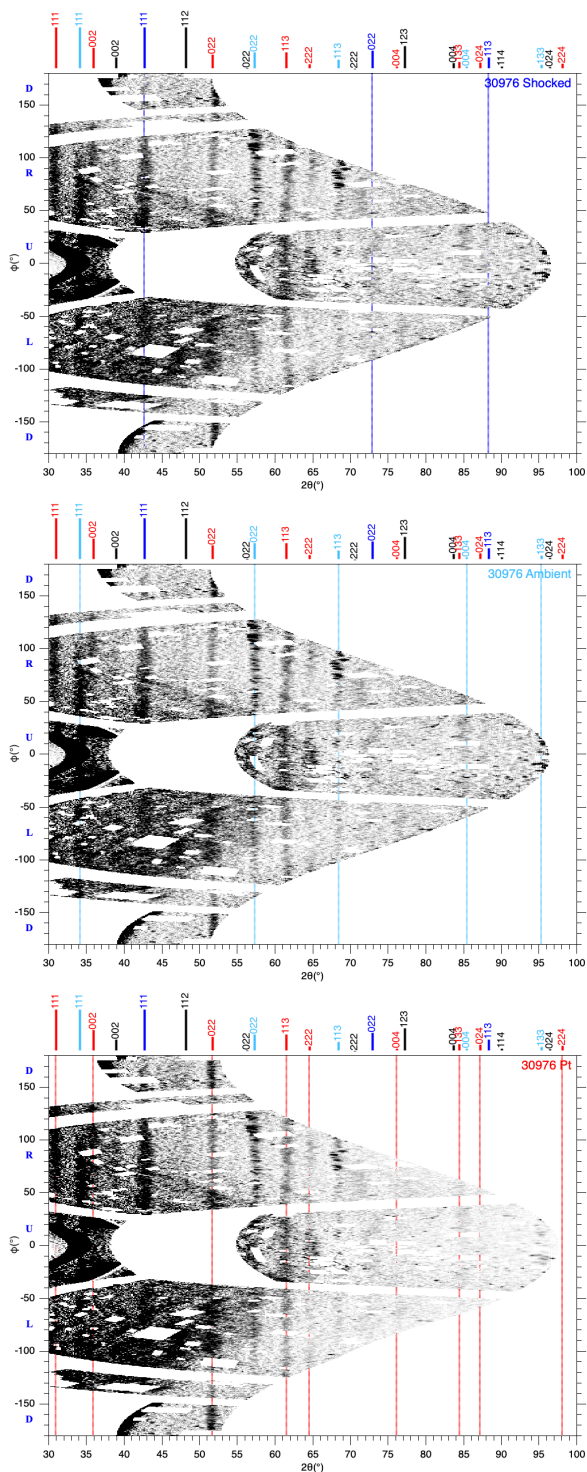


Fig. S38 XRD data for 30976 after SNIP background subtraction. Tick marks and Miller indices are similar to Extended Data Fig. 6.

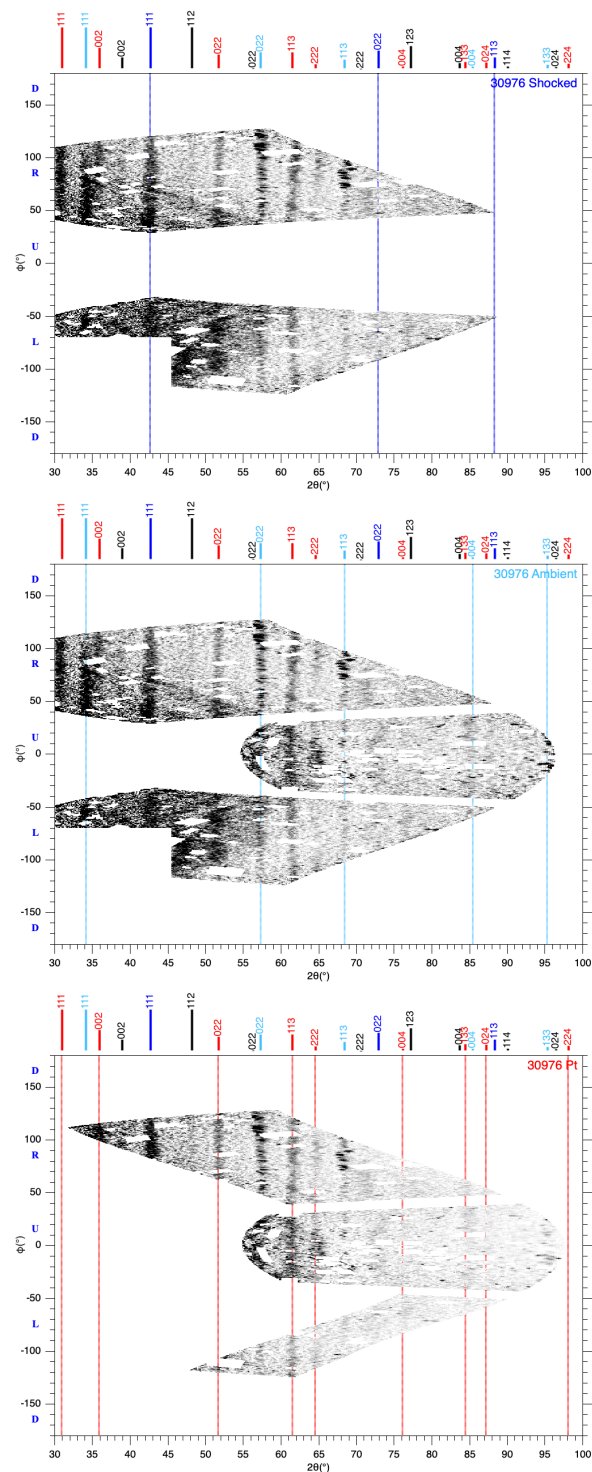


Fig. S39 Cropped XRD data for 30976 for intensity lineouts. Tick marks and Miller indices are similar to Extended Data Fig. 6.

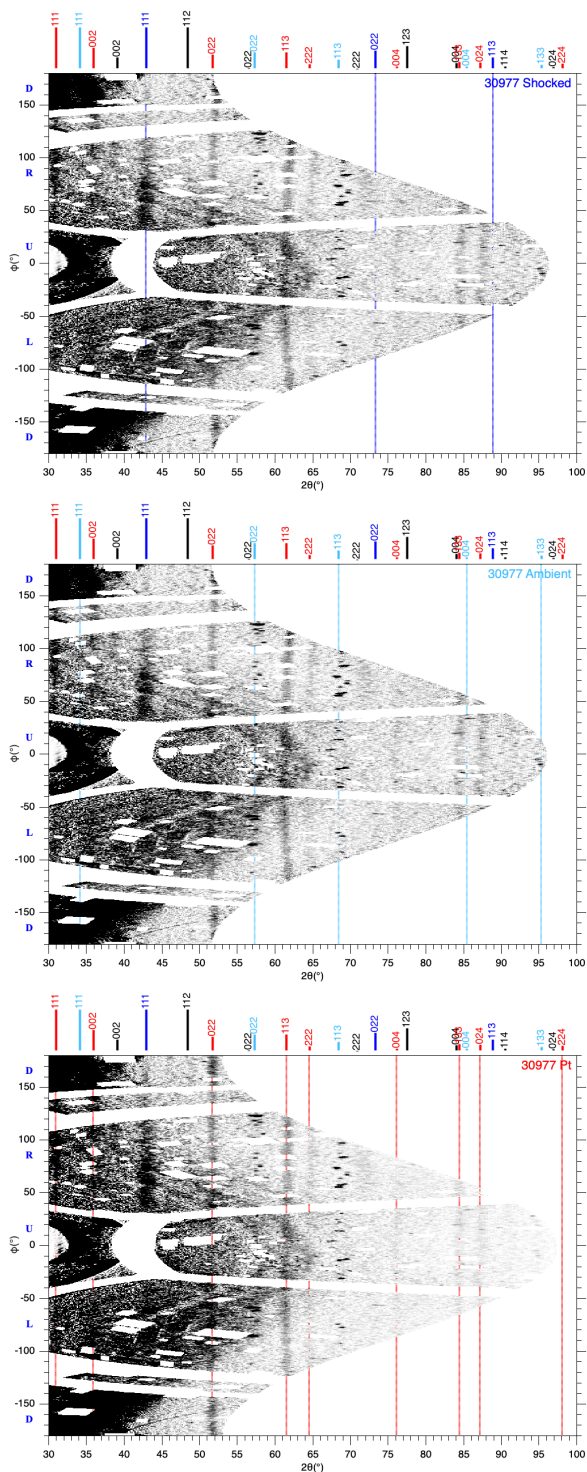


Fig. S40 XRD data for 30977 after SNIP background subtraction. Tick marks and Miller indices are similar to Extended Data Fig. 6.

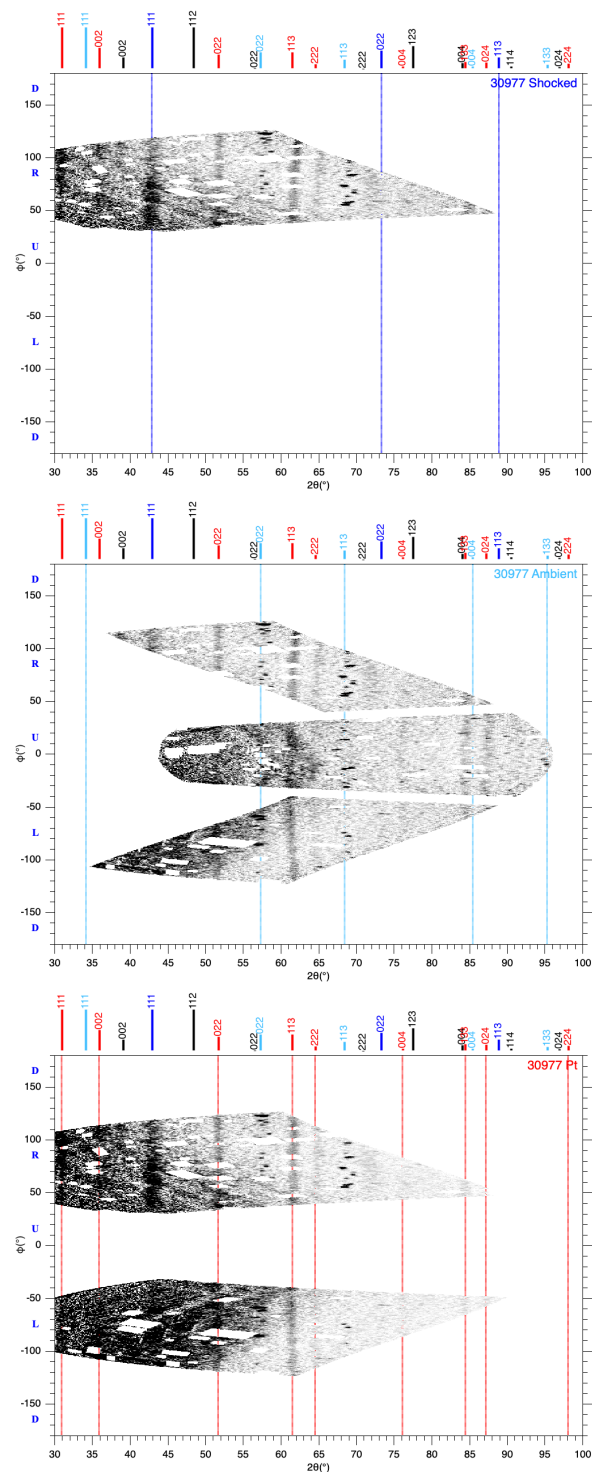


Fig. S41 Cropped XRD data for 30977 for intensity lineouts. Tick marks and Miller indices are similar to Extended Data Fig. 6.

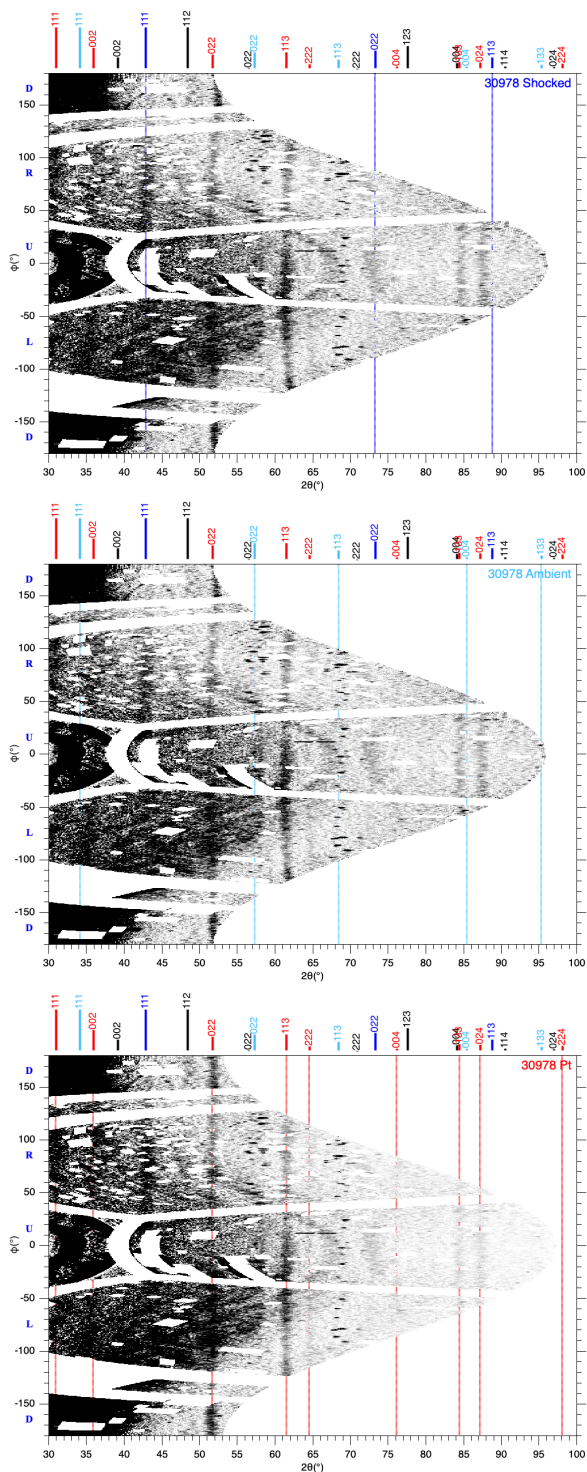


Fig. S42 XRD data for 30978 after SNIP background subtraction. Tick marks and Miller indices are similar to Extended Data Fig. 6.

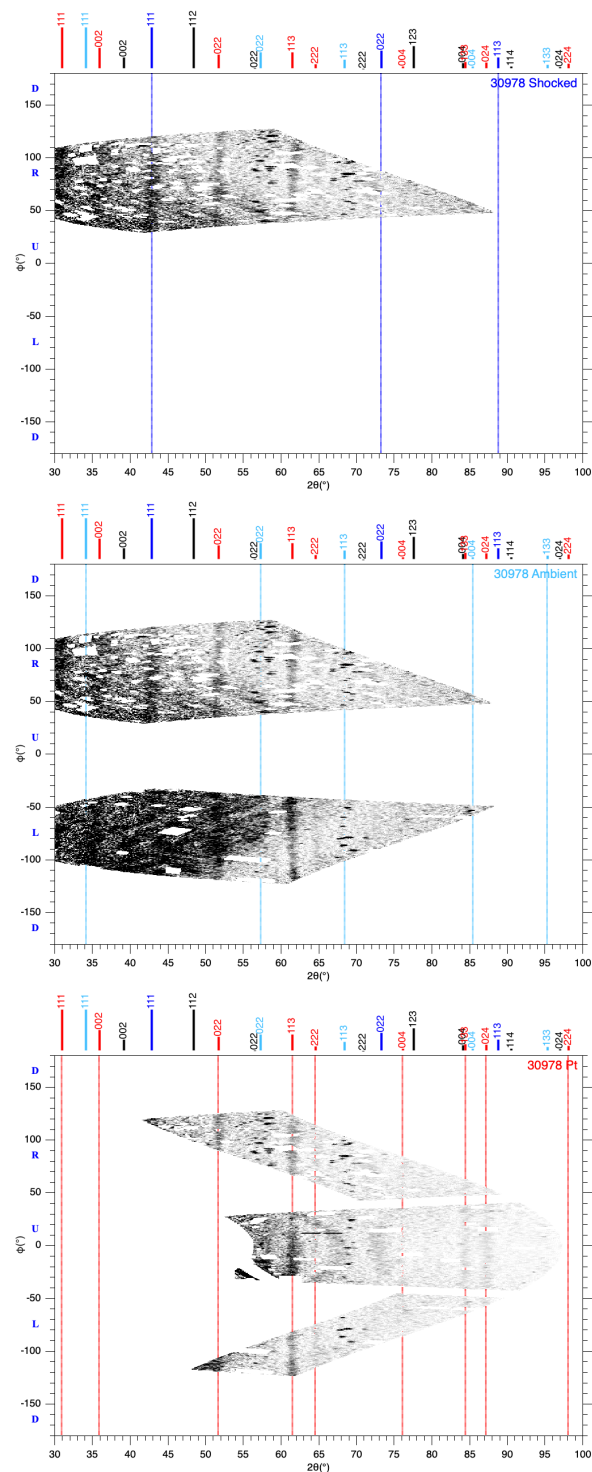


Fig. S43 Cropped XRD data for 30978 for intensity lineouts. Tick marks and Miller indices are similar to Extended Data Fig. 6.

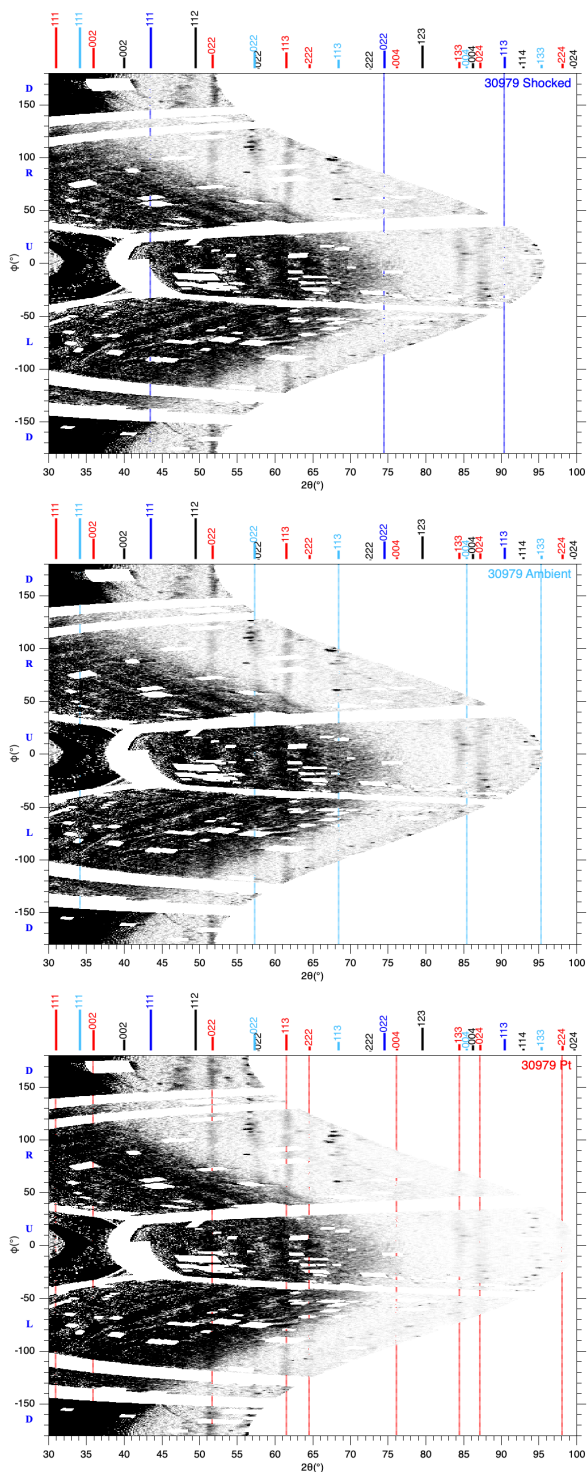


Fig. S44 XRD data for 30979 after SNIP background subtraction. Tick marks and Miller indices are similar to Extended Data Fig. 6.

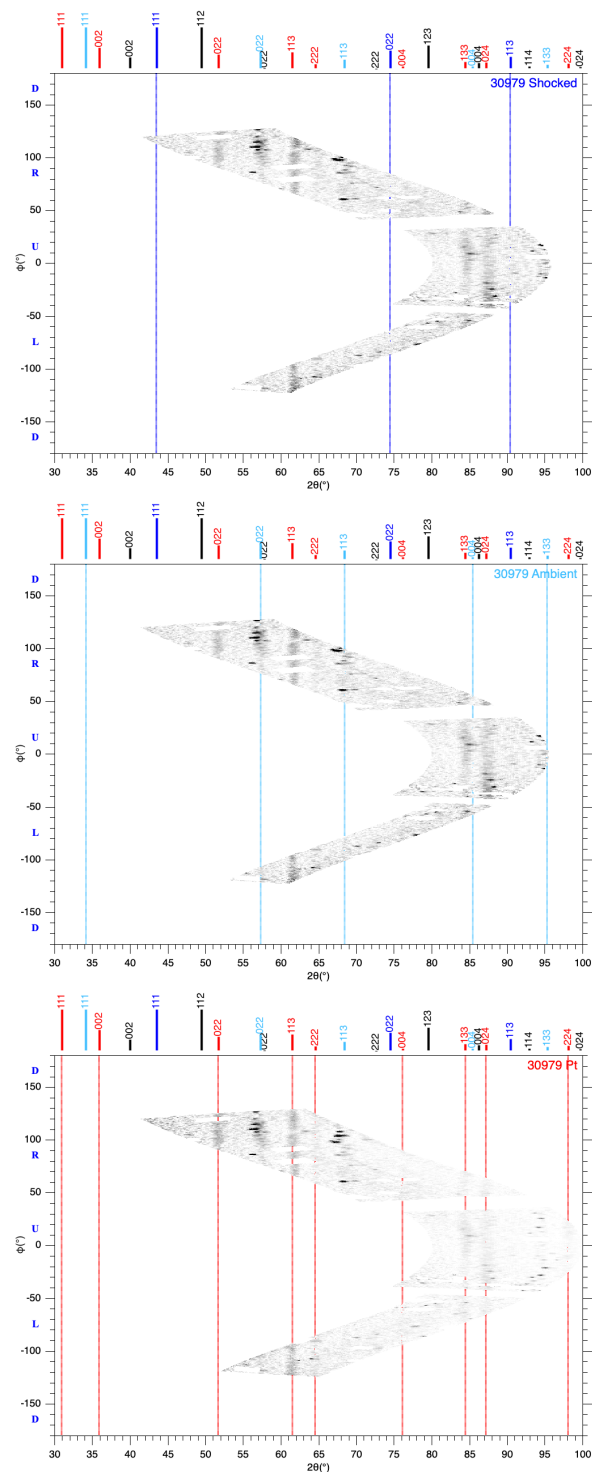


Fig. S45 Cropped XRD data for 30979 for intensity lineouts. Tick marks and Miller indices are similar to Extended Data Fig. 6.

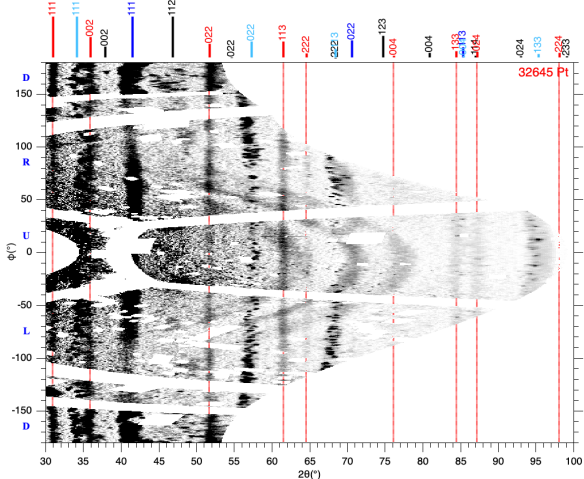


Fig. S46 XRD data for 32645 after SNIP background subtraction. Tick marks and Miller indices are similar to Extended Data Fig. 6.

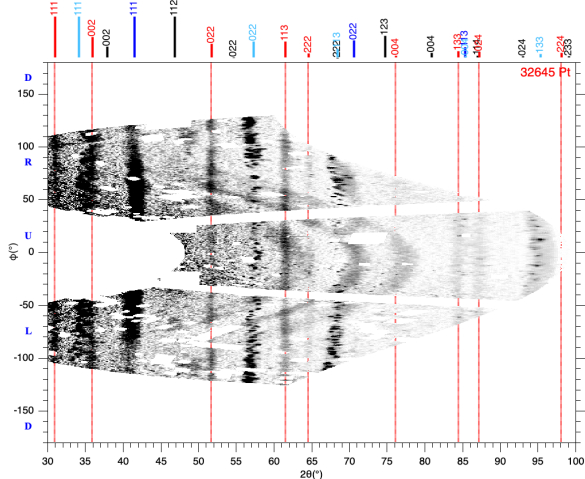


Fig. S47 Cropped XRD data for 32645 for intensity lineouts. Tick marks and Miller indices are similar to Extended Data Fig. 6.

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