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Microtexture and formation mechanism of impact diamonds from the Popigai crater, Russia

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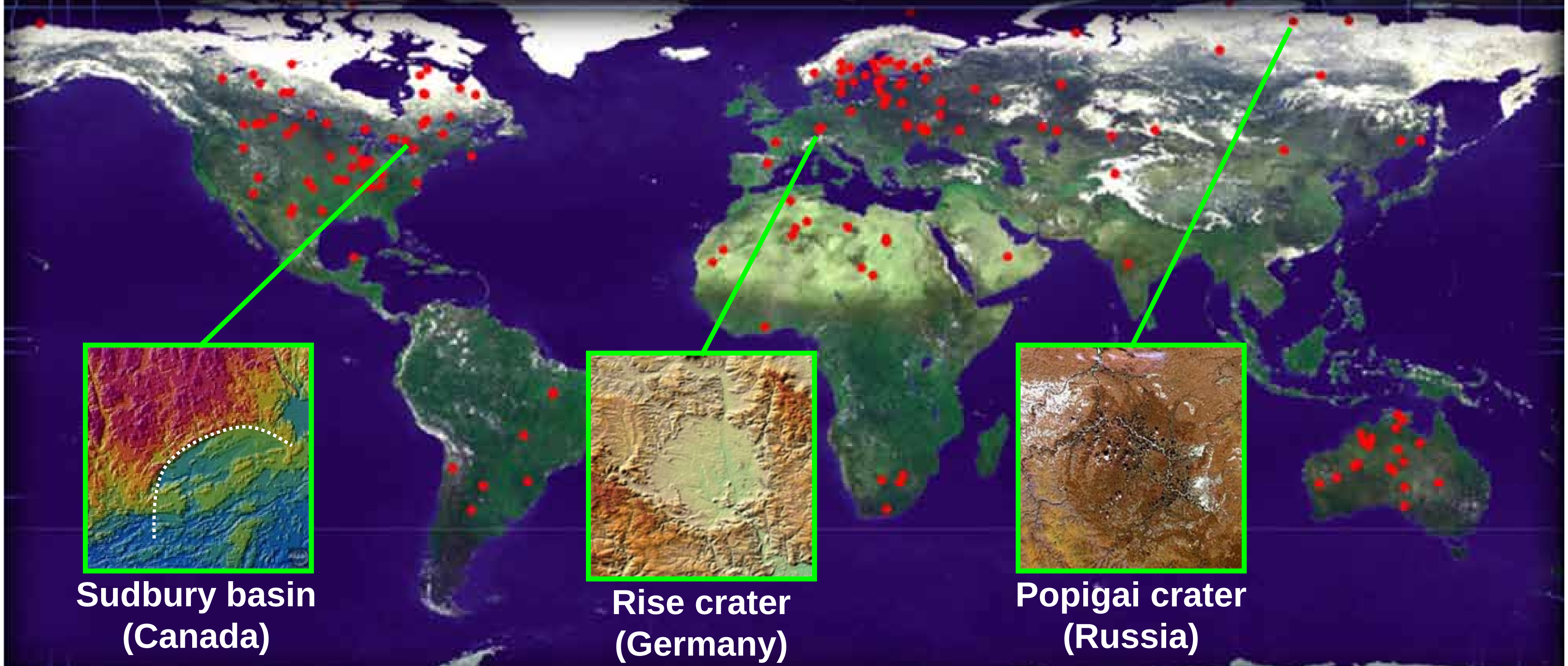
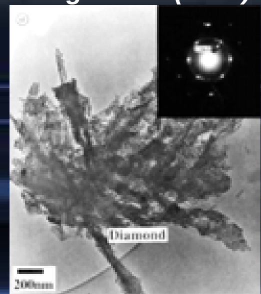
Diamonds from terrestrial impact craters



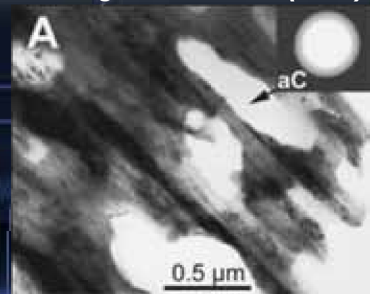
Impact diamond from Sudbury basin

Schmitt et al. (2005)

Hough et al. (1995)

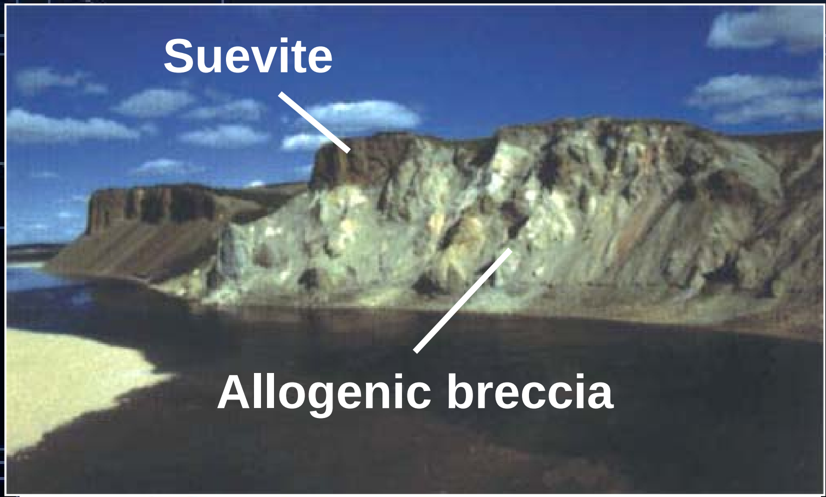


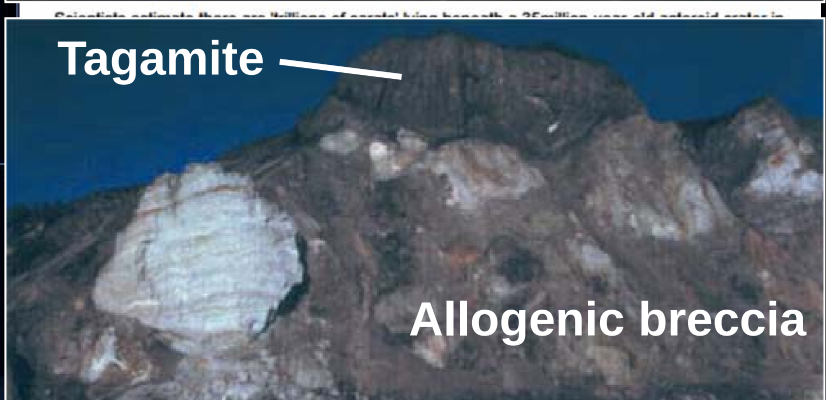
Langenhorst et al. (1999)

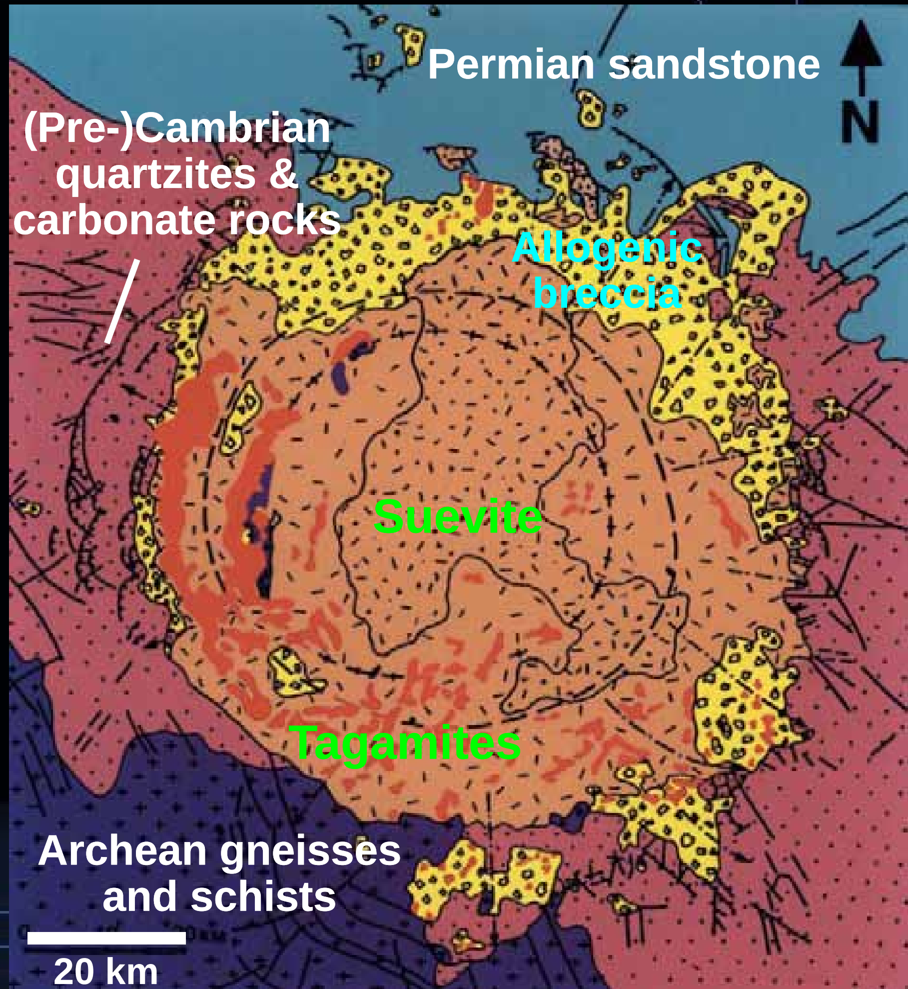


Impact diamonds from Rise crater

Popigai crater located in the north central Siberia



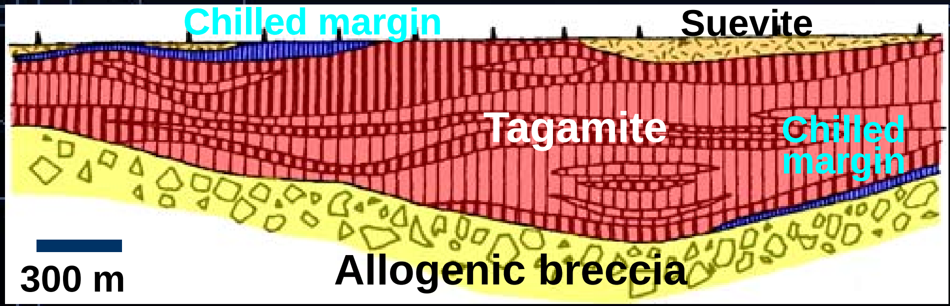


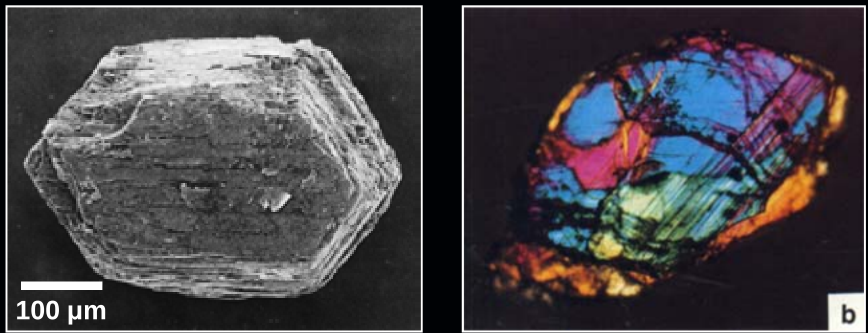


Geological map of the Popigai impact structure

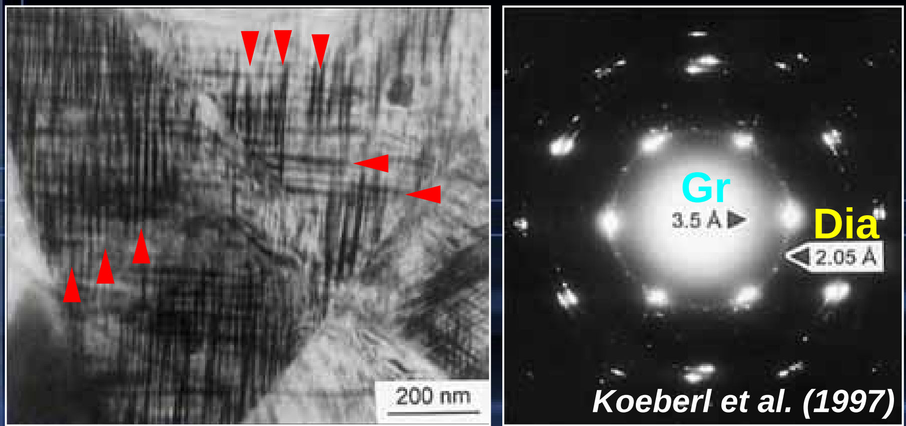
(Deutsch et al., 2000, modified after Masaitis (1998)

Impact diamonds from Popigai crater





Tabular diamond crystal showing strong birefringence
(Masaitis, 1997)



TEM image and electron diffraction of impact diamond

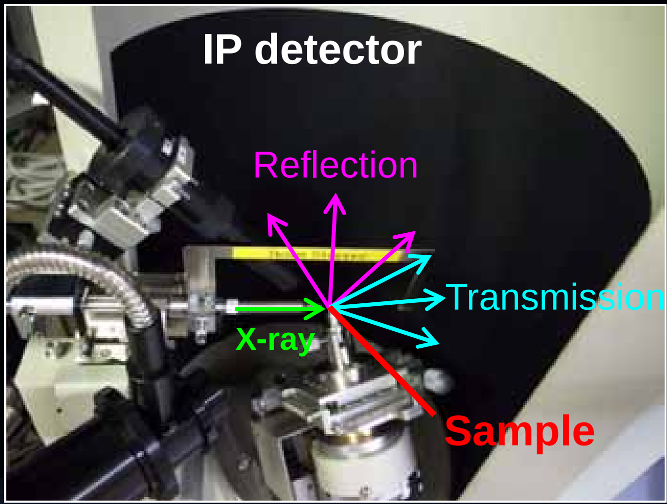
- Found in tagamit & suevite
- Mostly show tabular shapes
  → single crystal graphite origin?
- Show strong birefringence
  → due to internal strains?
- Associated with Lonsdaleite ± Graphite
- Details of microtexture and crystallographic features are still unknown.

Purpose of this study

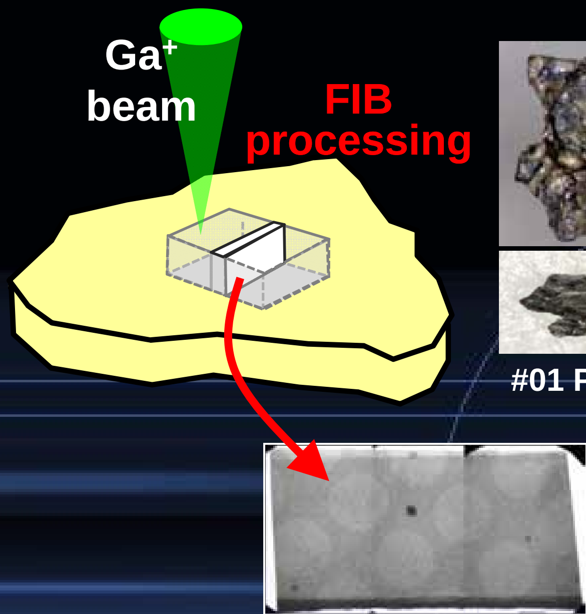
To investigate the microtexture and crystallographic nature of Popigai impact diamonds and understand the formation mechanism.

Analytical methods

XRD: Rigaku RAPID IV
(Mo-*Kα*, λ = 0.71073 Å)
Beam size: ϕ100 μm
① in reflection geometry
② in transmission geometry



10 impact diamond samples from Popigai crater



#01 Popigai diamond

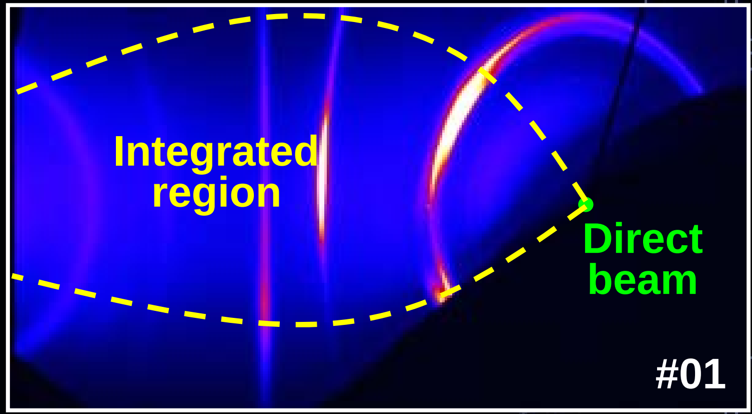
Cross-section foils (10 × 7 × 0.1 μm)

Raman: Renishaw RS-SYS 1000
Ar+ laser (λ = 514.5 nm)

FIB: JEOL, JEM-9310FIB

TEM: JEOL, JEM-2010 (200 kV)

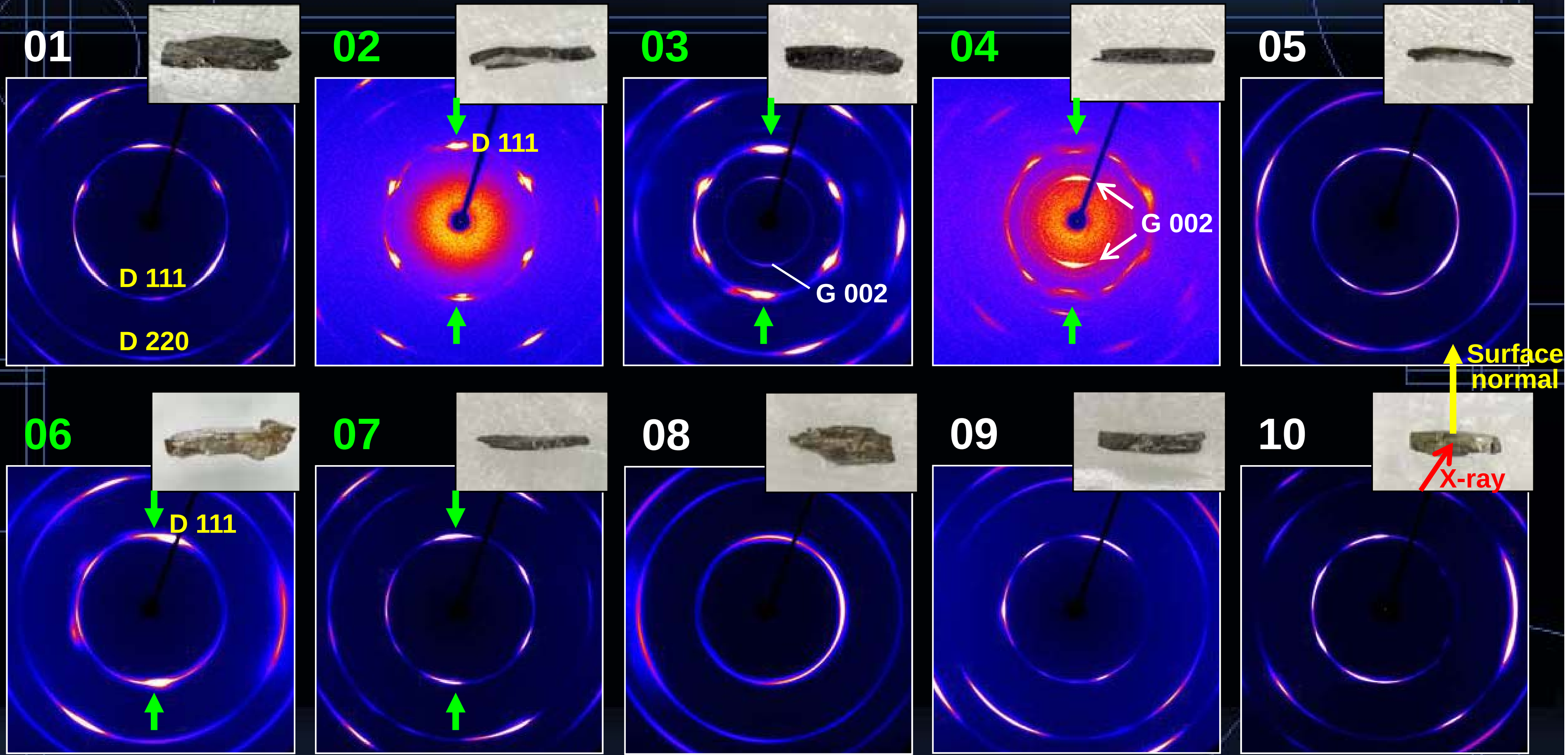
XRD analysis of Popigai impact diamonds



2D pattern in reflection geometry

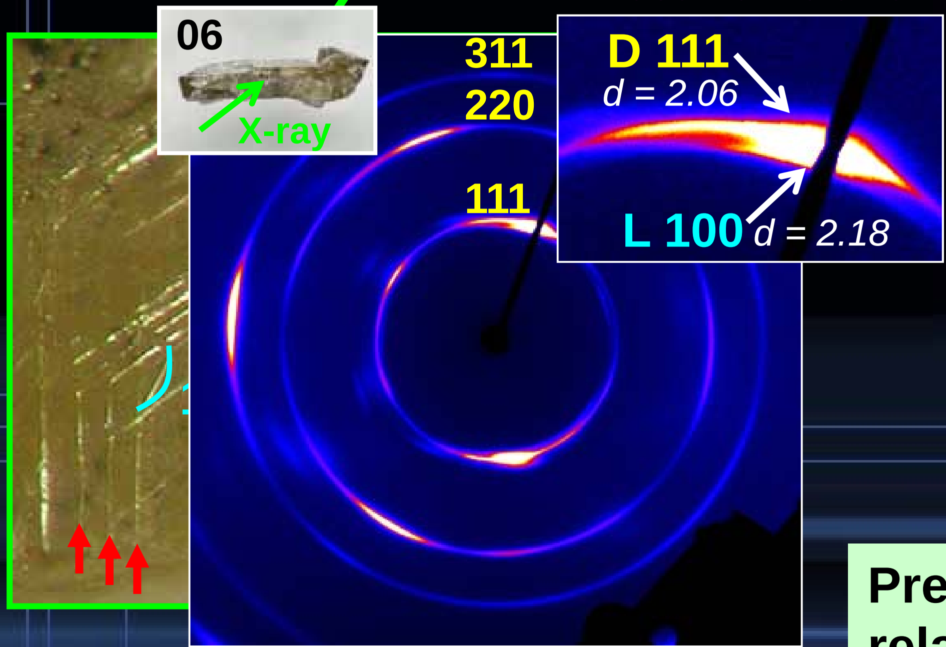
- ✓ Transparent samples consist of **diamond + lonsdaleite** (smaller).
- ✓ Opaque samples consist mainly of **D + L** and but also contain **graphite**.

2D XRD patterns (transmisssion) of Popigai diamonds

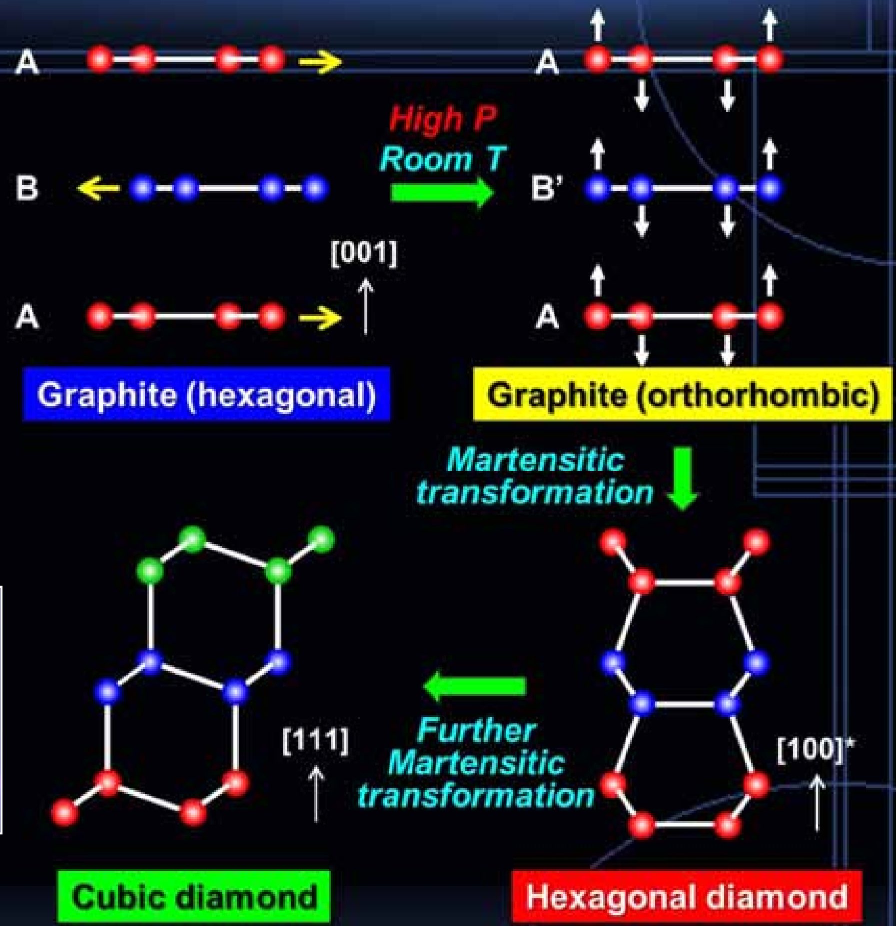


- ✓ **All samples show various degrees of preferred orientation (LPO).**
- ✓ **Some samples show strong [111] LPO along the sample surface normal in which lonsdaleite [100]* & graphite [002] are coaxial.**

2D XRD patterns (transmission) of Popigai diamonds



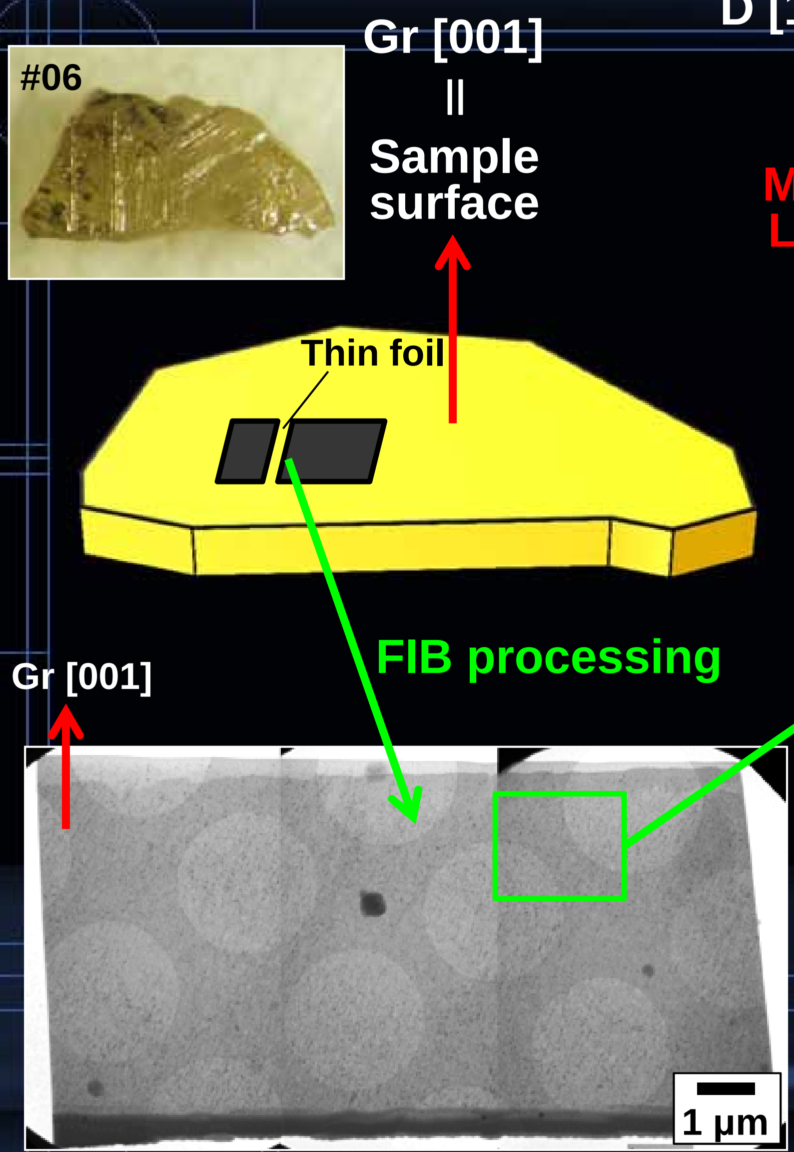
2D XRD pattern of #06 sample



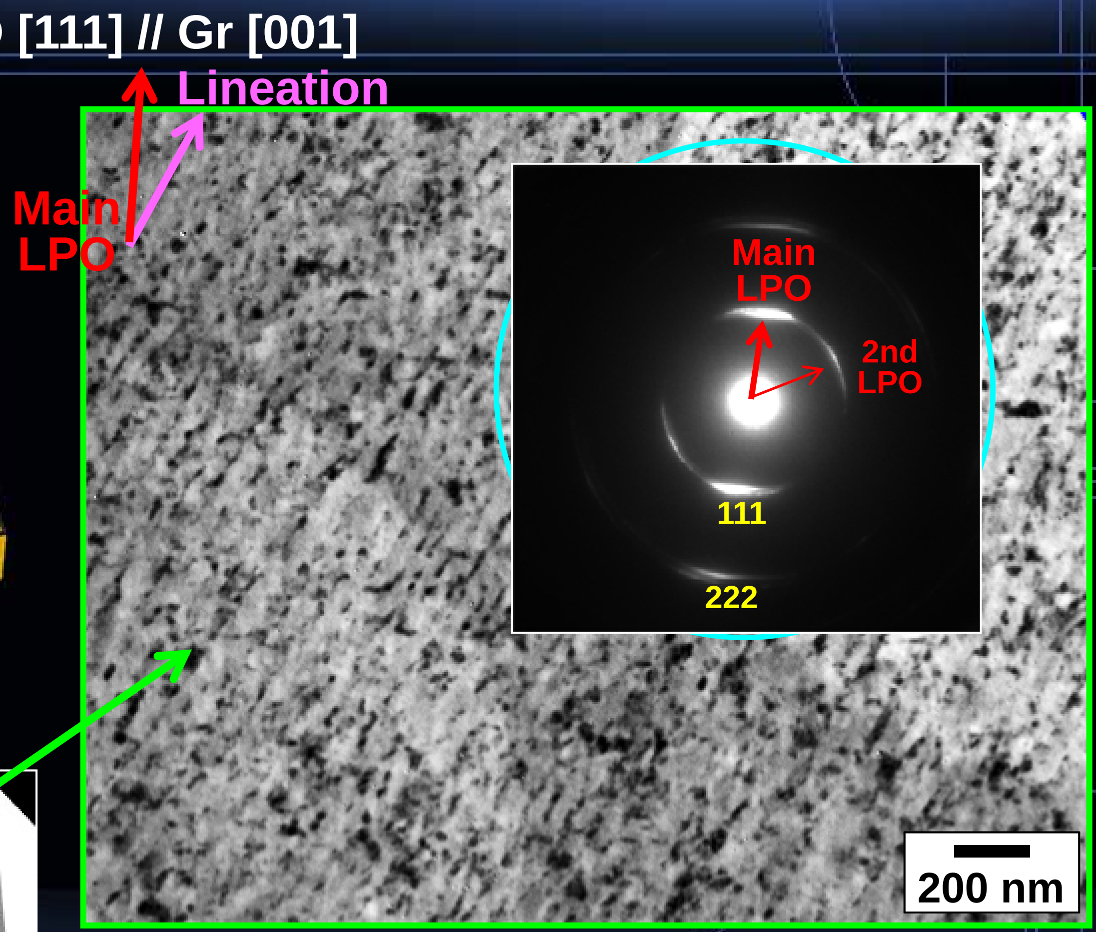
Martensitic phase transformation of graphite → lonsdaleite → diamond

Preferred orientation and coaxial relations suggest martensitic formation

TEM observation on cross-section foils from #06

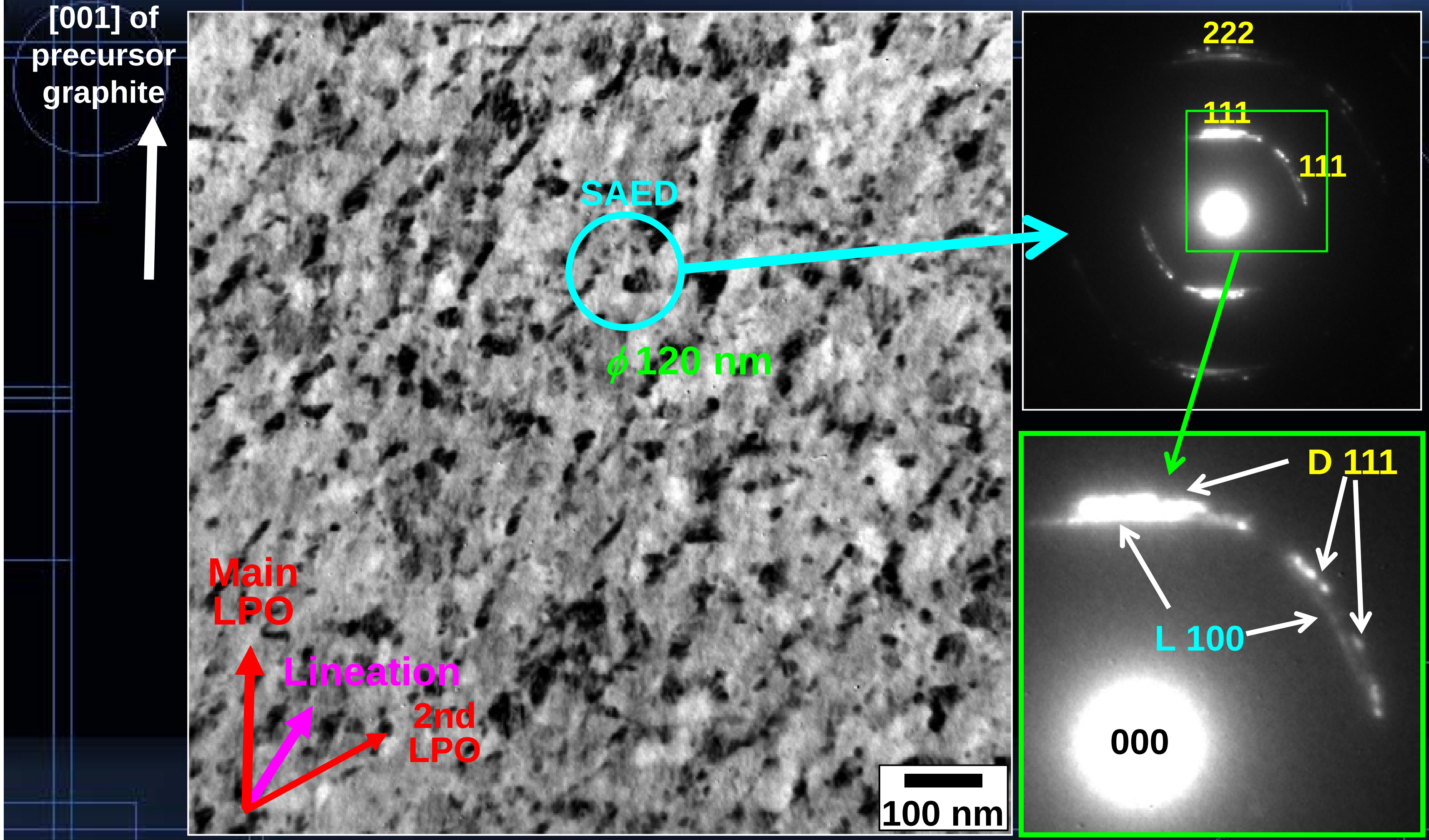


FIB Cross-section foil (100 nm thick)



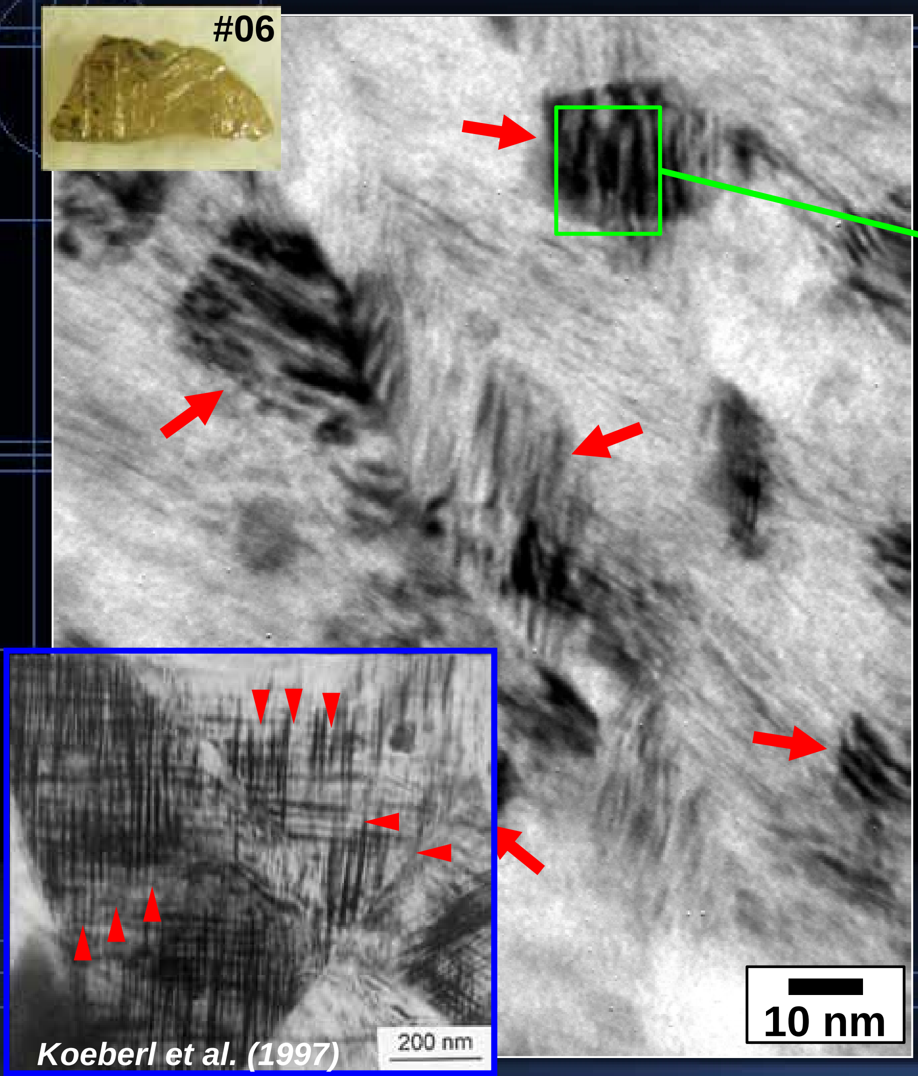
- ✓ Shows **two LPO patterns**, one of which corresponds to **sample surface normal**.
- ✓ LPO directions do not correspond to **lineation** created by aligned crystals.

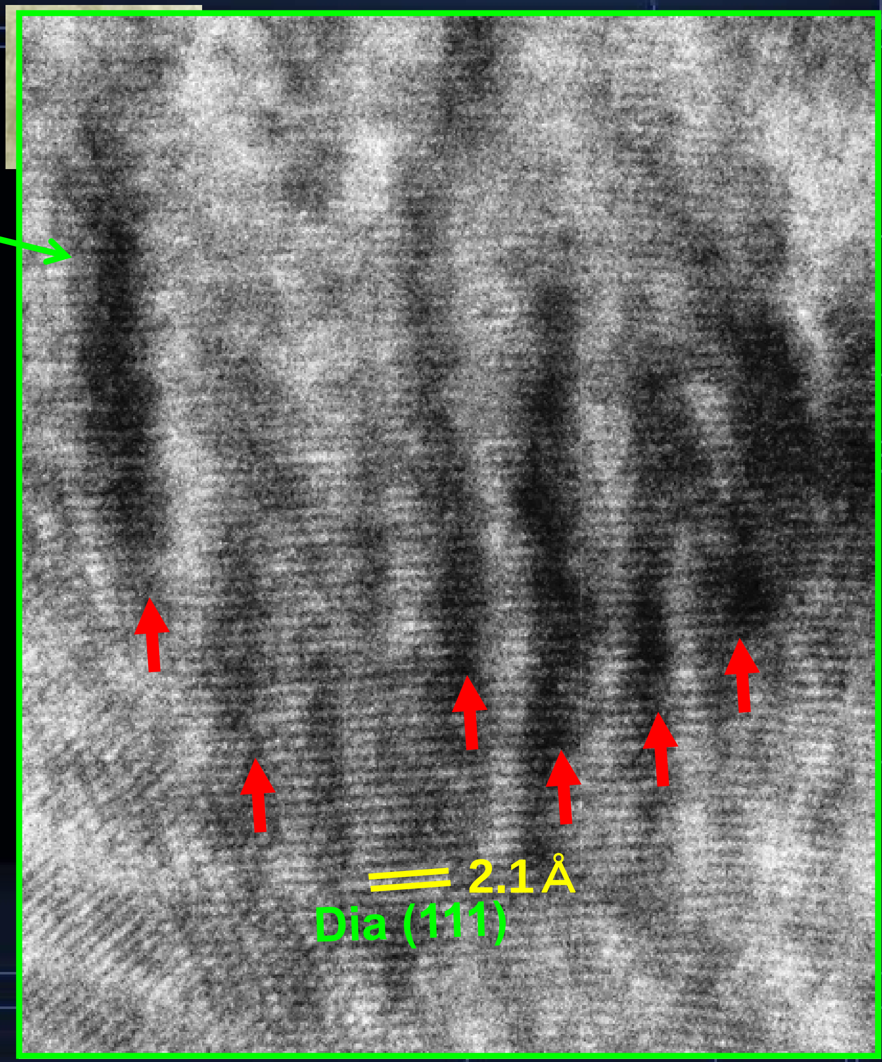
Microtexture of Popigai impact diamond (#06)



✓ **Diamond [111] // lonsdaleite [100]* coaxial relation is observed in the both LPO directions, implying that the transformation is not a simple martensitic process in a single crystal framework.**

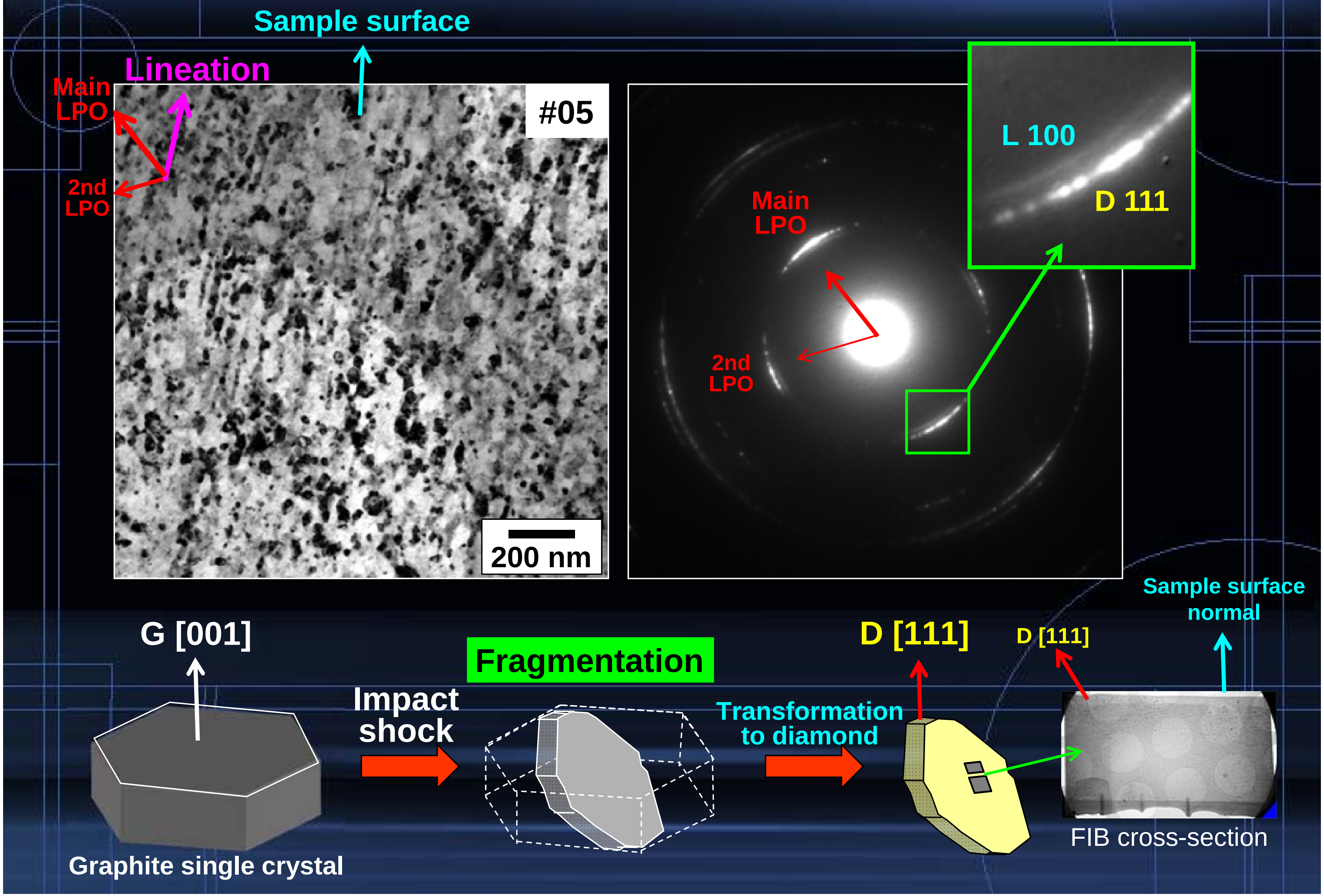
Crystallite (grain) size of the constituent grains



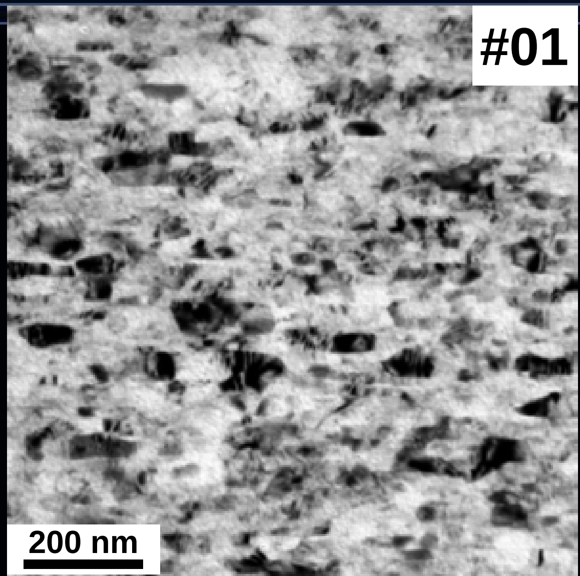


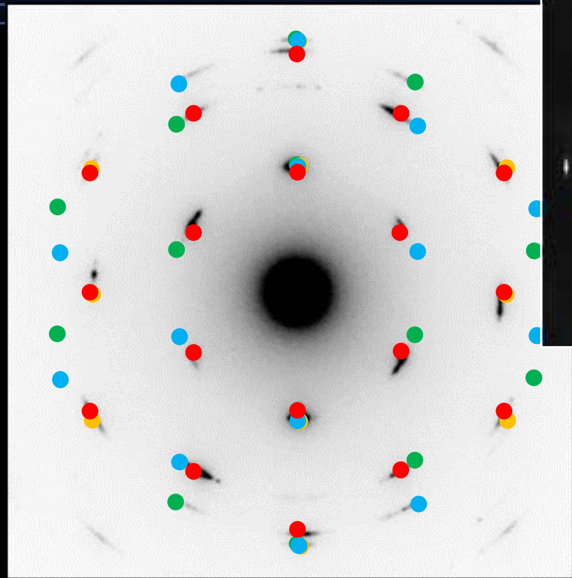
✓ **Individual grains are 5-30 nm size and show interference fringes, which probably derived from nano-kinks of diamond (111) lattice.**

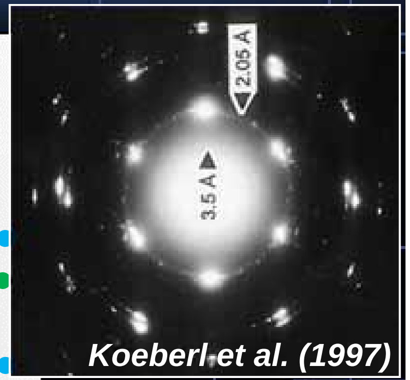
Fragmentation of the initial graphite source



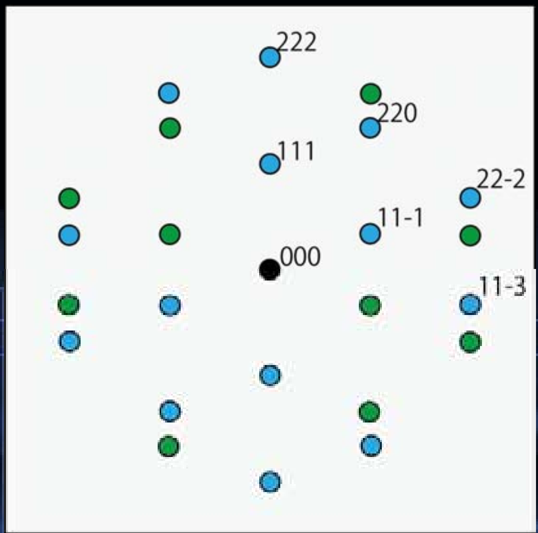
Single-crystal like pattern in some Popigai diamonds



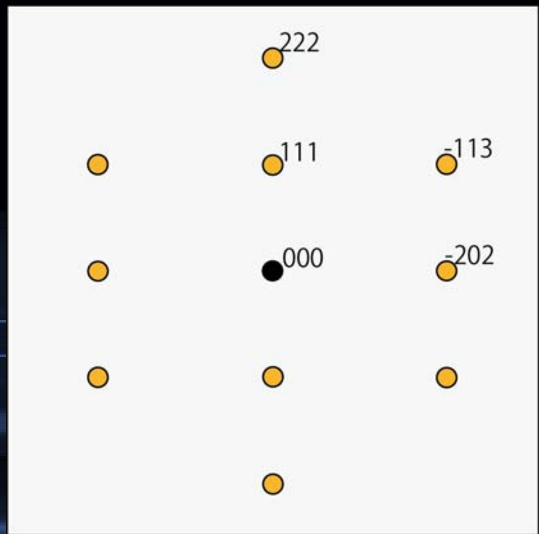




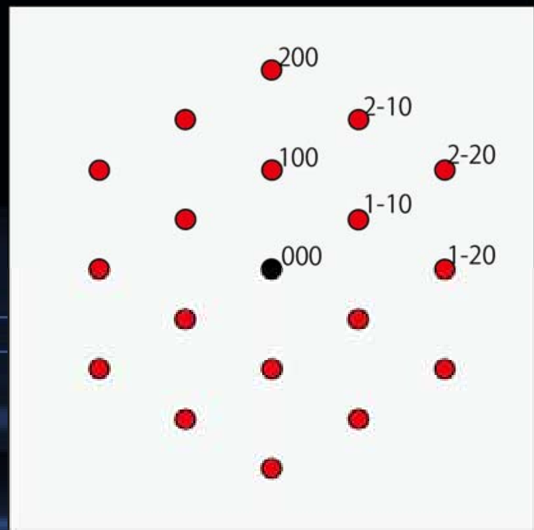
Koeberl et al. (1997)



D [110] projection（twinned）
D [110] projection

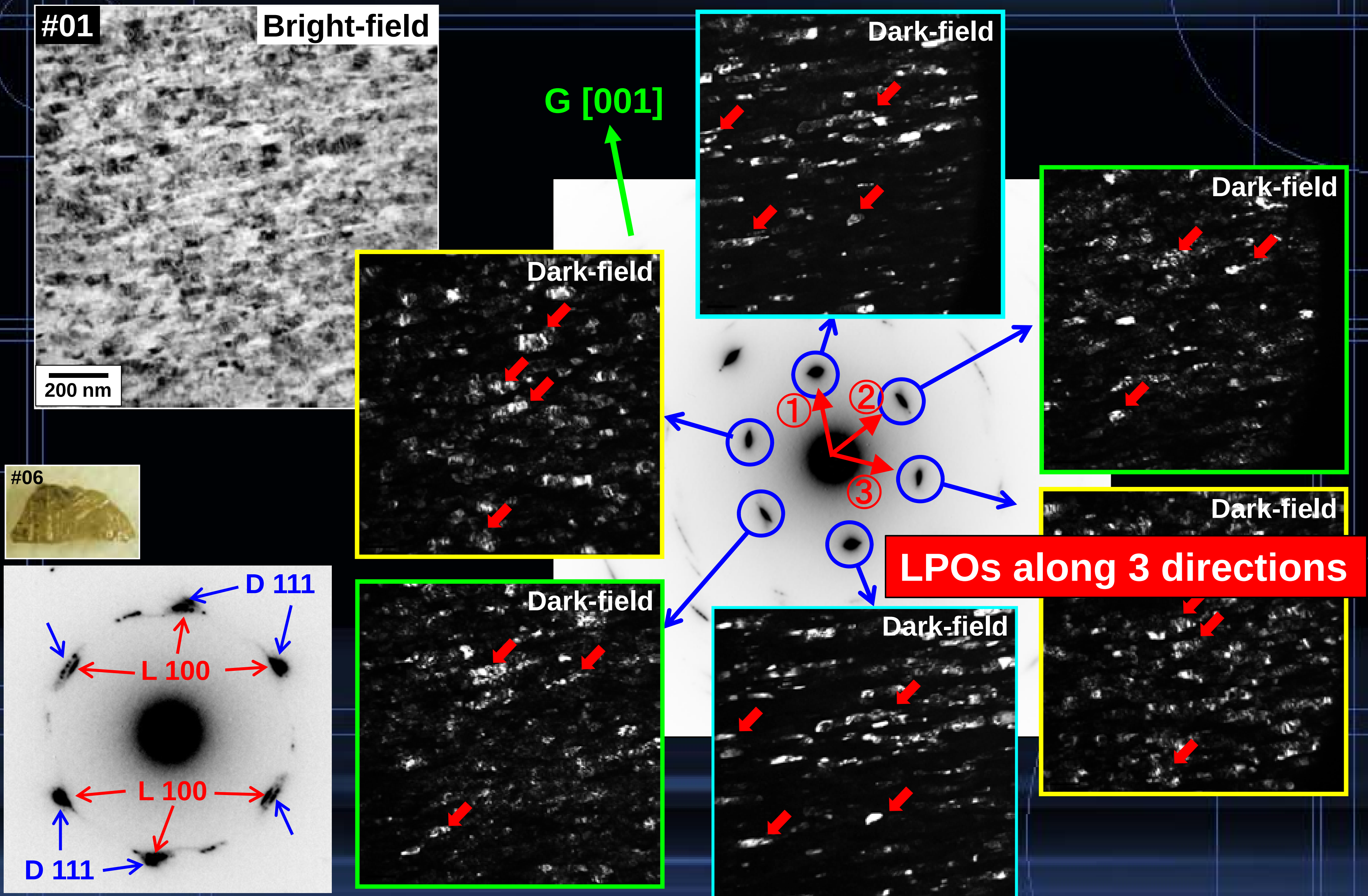


D [112] projection

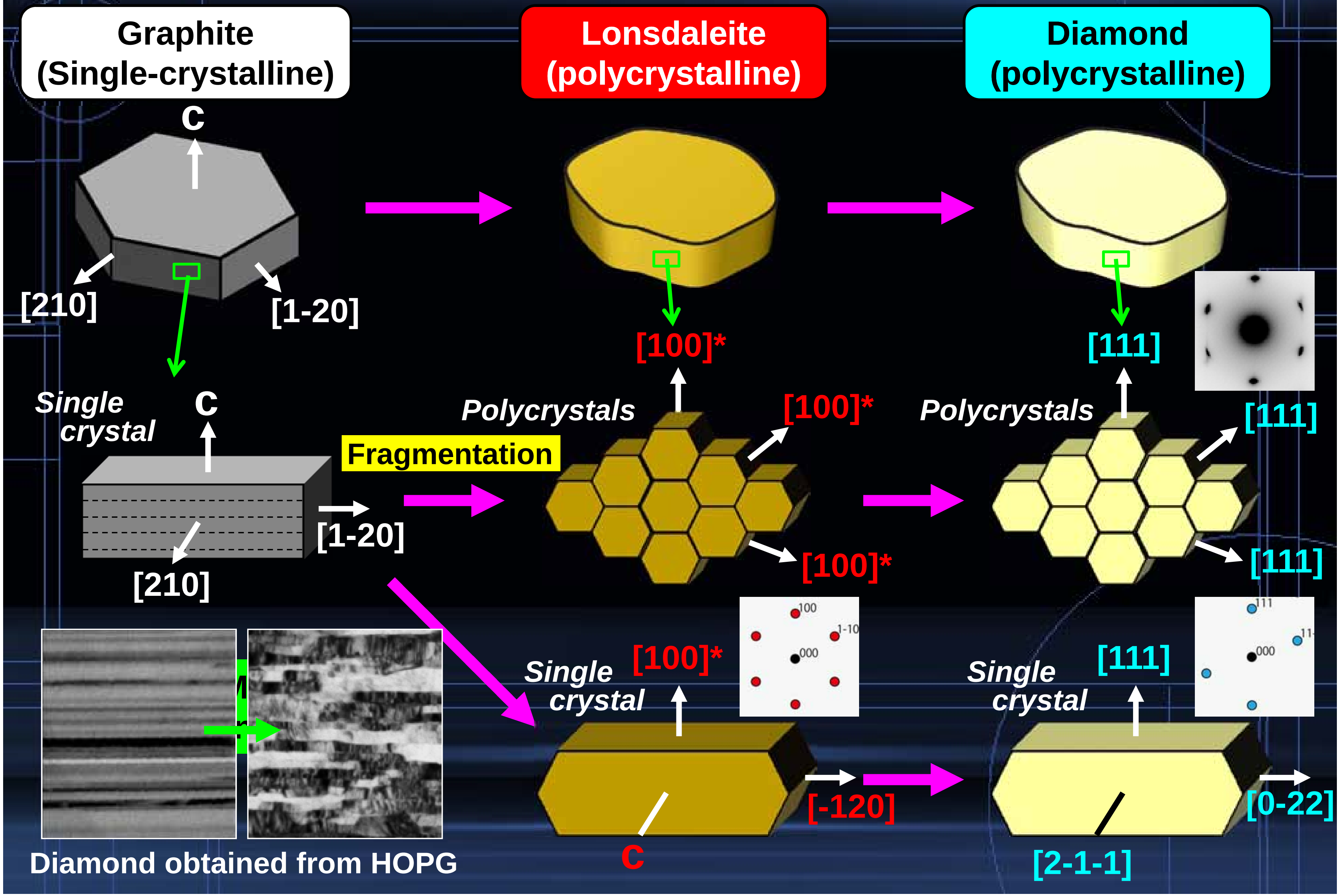


L [001] projection

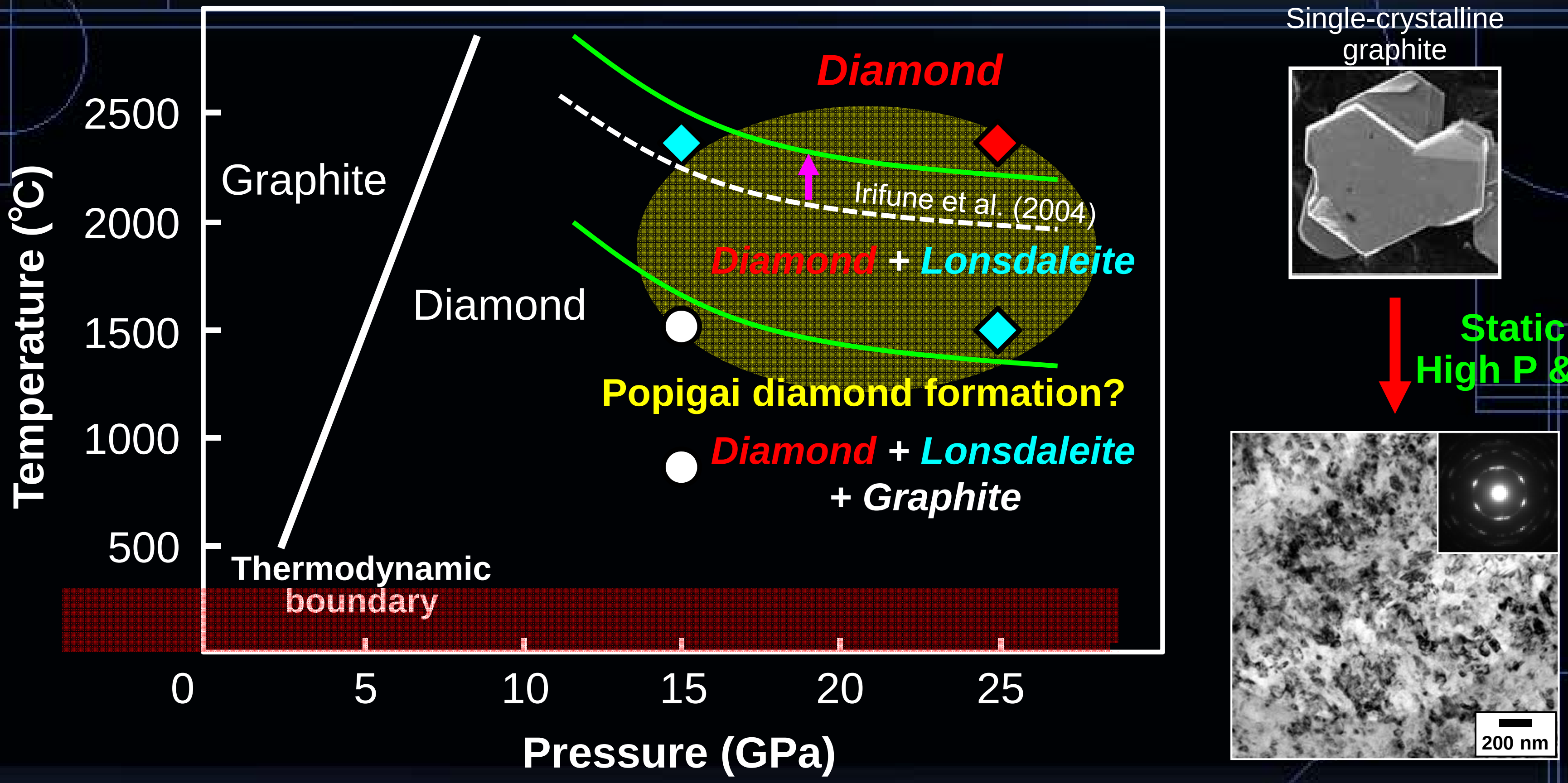
Origin of single-crystal like pattern in Popigai diamonds



Crystallization mechanism of Popigai impact diamonds



P-T conditions for the Popigai diamond formation



- ✓ The P-T condition required for diamond formation from single-crystalline graphite is >15-20 GPa and >1500℃, according to static high P-T exp.
- ✓ The estimated shock pressure, 35-50 GPa (Masaitis, 1998) for the Popigai diamond formation is likely overestimated.

Summary

- Impact diamonds from the Popigai crater consist mostly of nanocrystalline diamond (5-30 nm size) and of smaller amounts of lonsdaleite ± graphite.

- The three carbon phases are basically arranged in a coaxial relation, suggesting that the martensitic process is responsible for the formation mechanism.

- Many samples show distinct lattice preferred orientations, which are created through martensitic transformation of single crystalline graphite involving its local fragmentation into single-crystal domains of lonsdaleite-diamond.

- Microtexture of Popigai diamonds is well comparable to synthetic NPD having ultra-high hardness, and therefore they could be a promising source for industrial application.

- The previously suggested impact pressure (35-50 GPa) for Popigai diamond formation is likely overestimated. The revised shock P-T might be 15-20 GPa and 1500-2500℃.