

Jaws of *Platynereis dumerilii*: Biologically 3D printed miniature structures with hardness properties similar to those of crystalline metals

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Jaws of *Platynereis dumerilii*

- *Platynereis dumerilii* has emerged as a highly accessible model system for *Polychaeta* research
- highly successful group of invertebrate worms with a broad geographic distribution
- live in harsh pelagic coastal conditions
- abundance of *scolecodonts* in the Ordovician (490-440 million years ago)
- Biological 3D printing system
- *P. dumerilii* jaws are made up of secreted proteins enriched with glycine and histidine connected by metal and halogen ions (Figs. 1 and 6)

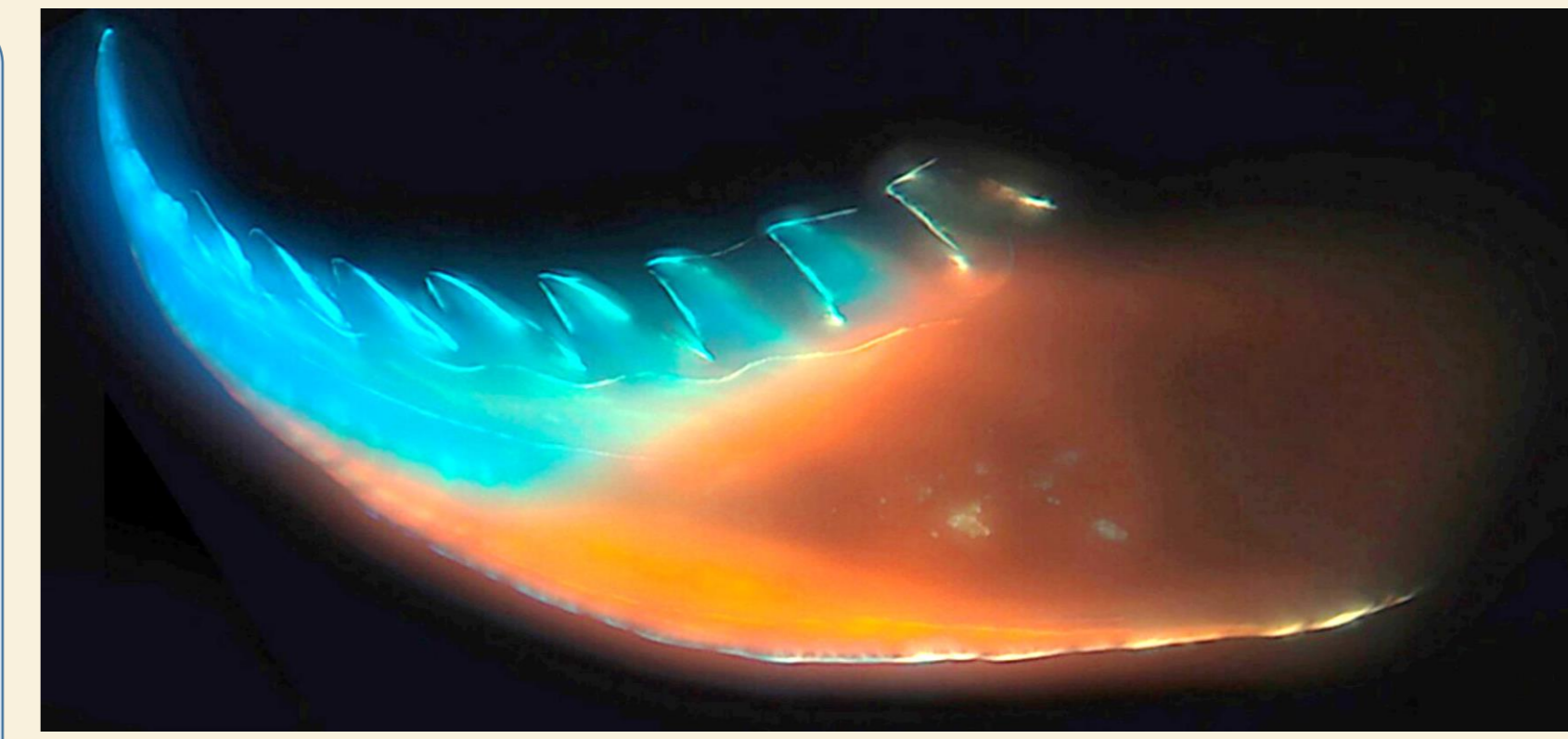


Figure 1: Light microscope image from *Platynereis dumerilii* jaw

Nanoindentation

- RMS roughness of 15 nm
- 156 indents
- 100 μN load control
- evaluation according to Oliver and Pharr (1992) *JMR*

$$E_r = \frac{\sqrt{\pi} S}{2\sqrt{A_c}}$$

$$H = \frac{F_{max}}{A_c}$$



Methods

Microcomputed tomography

- resolution of 1.2 μm
- identification of correct orientation from jaw (Fig. 2)

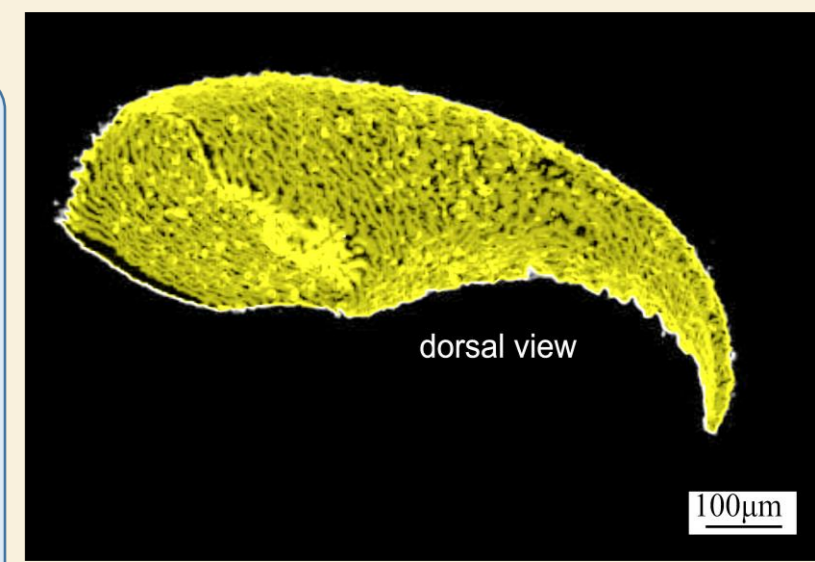
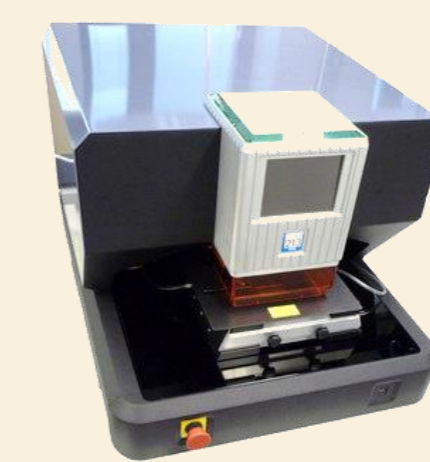


Figure 2: 3D rendered image from *P. dumerilii* jaw

Laser Ablation Induced Coupled Plasma Mass Spectrometer

- quantification of the spatial concentration distributions of halogen and metal ions in the *Platynereis dumerilii* jaw
- resolution of 10 μm (laser spot size)



Chemical analysis

- concentrations distributions of halogen and metal ions (Fig. 3)
- Br⁻, Cu⁻, Fe⁻, I⁻, Zn⁻
- matrix-matched standards

$$WF_i = \beta_i I_i^s$$

WF_imass fraction of ions
 β_islope factors
 I_i^sintensities (cps)

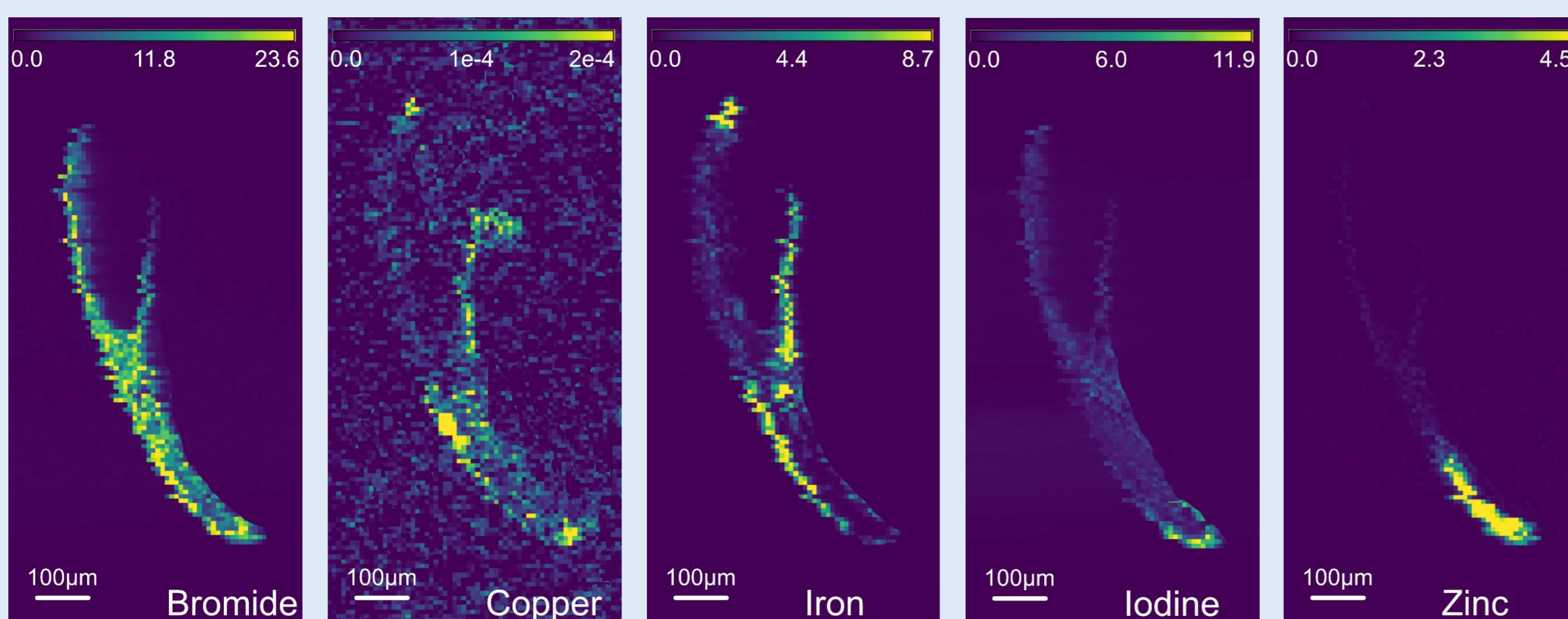


Figure 3: Ion concentration distribution in *Platynereis dumerilii* jaw

Size effect

- Nix and Gao (1998) *JMPS* derived the following relation between tested hardness and the contact indentation depths h_c :
- $$H^2 = H_0^2 \left(1 + \frac{h^*}{h_c} \right)$$
- Nix-Gao size effect is known for crystalline metals and it can be seen for *Polychaetae* jaws (Fig. 5)
 - macro-molecule **Pladu JP-1** with dislocation lines (Fig. 6)

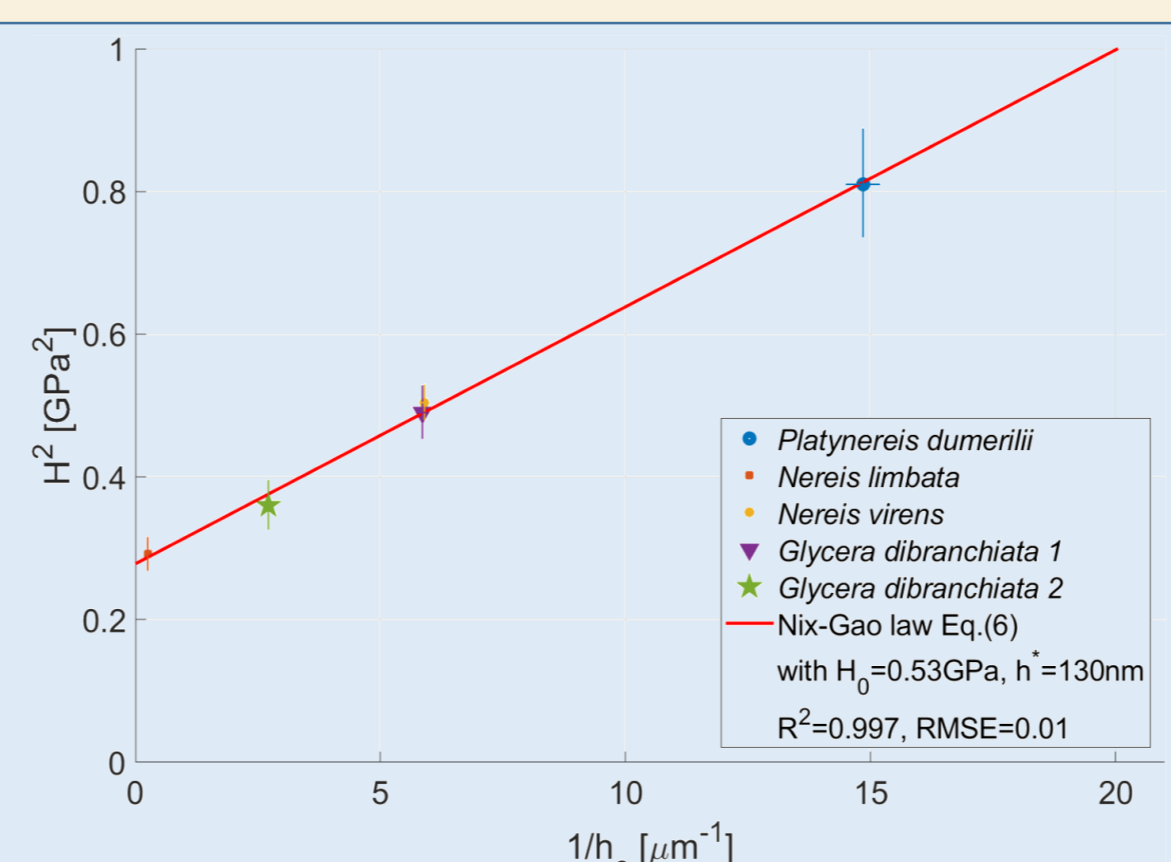


Figure 5: Graphical representation of size effect

Nanoindentation

- hardness and elasticity values in the jaw's tip region, exceeding those in the center region, can be traced back to more metal and halogen ions built into the structural protein matrix (Fig. 4)

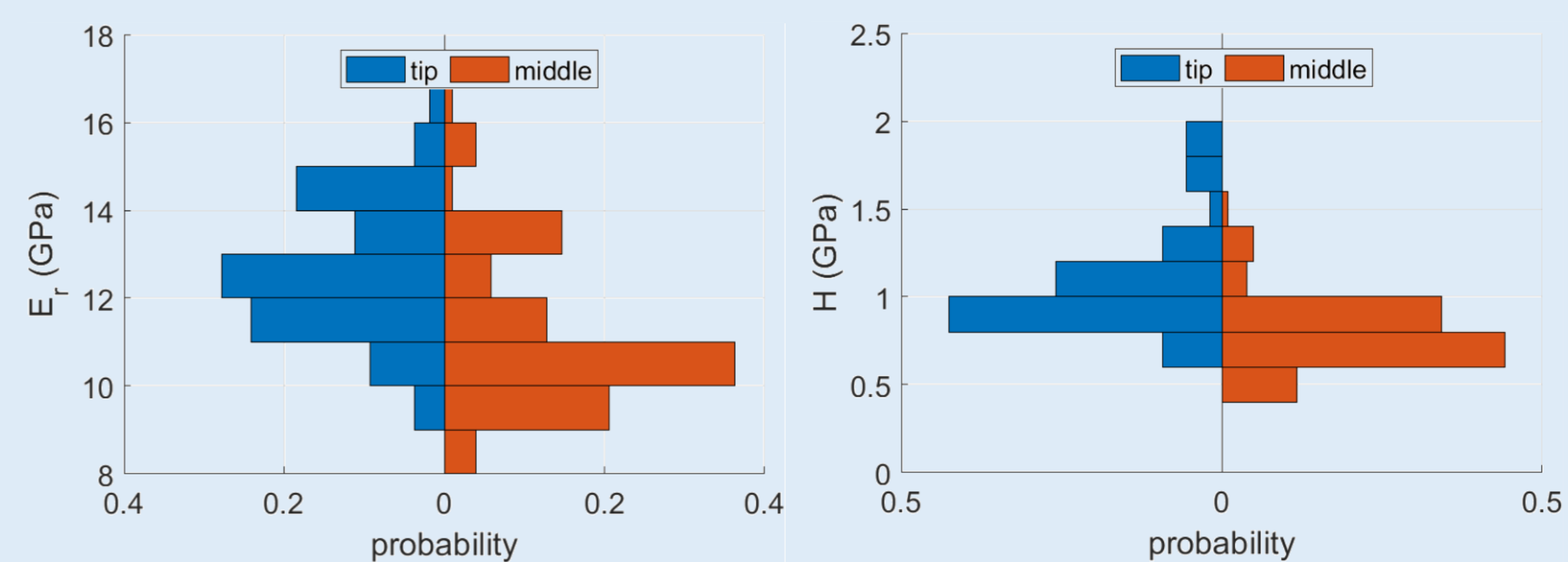


Figure 4: Tip- and middle-related histograms of elasticity and hardness values

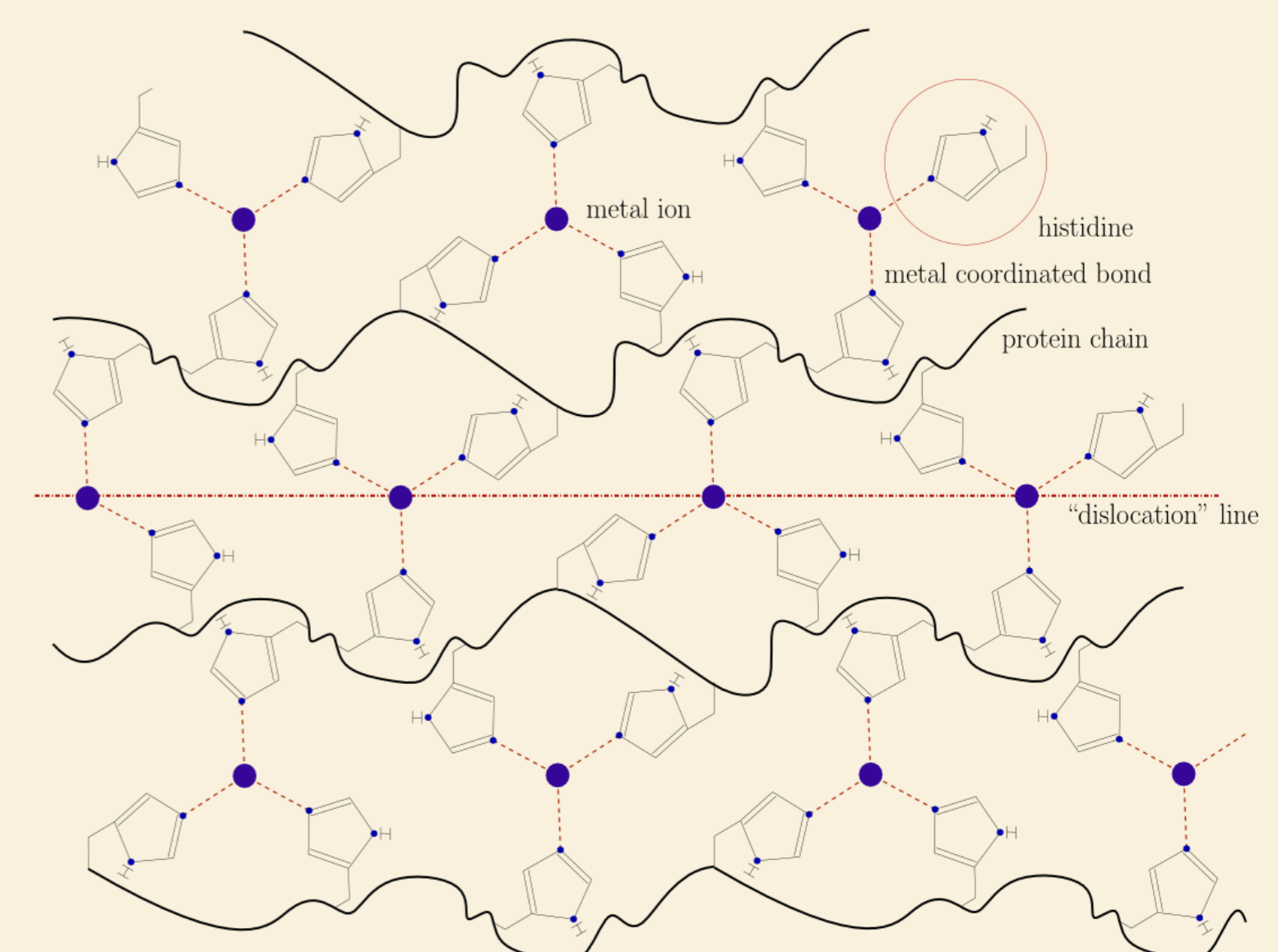


Figure 6: Histidine enriched proteins with metal coordinated bonds

Conclusions

- strength of the tested material is governed by the amount of dislocations in a 3D domain
- such a metal-like biogenic material is a major source for bio-inspiration

Acknowledgements

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