Nano-mechanics of coal

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Introduction

Coal is characterised by its complex composition, heterogeneity and anisotropy, which in turn results in significant scale dependent mechanical properties and behavior. Coal micromechanical properties are important for understanding coal fines generation and corresponding water drawdown practices, fracture propagation in coal matrixes, and borehole stability amongst other things.

Existing studies have primarily focused on gaining mechanical properties at a centimetre to a sub-meter scale. While important, few nanoscale mechanical properties studies have been conducted.

In this project, the Hysitron triboindenter was used to measure coal nanomechanical properties, including reduced modules, elastic modulus and hardness for both the loading and unloading paths. The qualitative relationship between nanomechanical properties and coal types was accessed. With the help of a confocal optical microscope and scanning electron microscopy (SEM), quantitative analysis of the influence of different macerals on micromechanical properties was also conducted.

Methodology

Samples from two different coal basins were tested. Each had two specimens, with the testing surface parallel and vertical to the bedding plane respectively. The surface of each coal sample was carefully polished and grinded to ensure the accuracy of surface flatness and smoothness. The method included using load-control mode from 0 to 10 mN, holding for 5 seconds, and then unloading linearly with a loading/unloading rate of 0.5 mN/s. 121 indents on a 11×11 square grid with a 50 μm interval were conducted. The reduced modulus (Er) and Hardness (H) were calculated from the load-displacement (P-h) curves using the *Oliver-Pharr* method. The Young's modulus of each point of each sample can be calculated using the follow formula:

$$E = \frac{E_i E_r \left(1-\mu^2\right)}{E_i - E_r\left(1-\mu_i^2\right)}$$

where E_i is Young's modulus of the indenter (1,140 GPa), μ_i is Poisson's ratio of the indenter (0.07). E_r is *the* reduced modulus. E is Young's modulus of the specimen, and μ is Poisson's ratio of the specimen. We used μ=0.3 in this case. Figure 1 shows the typical nanoindentation image and load-depth curves.

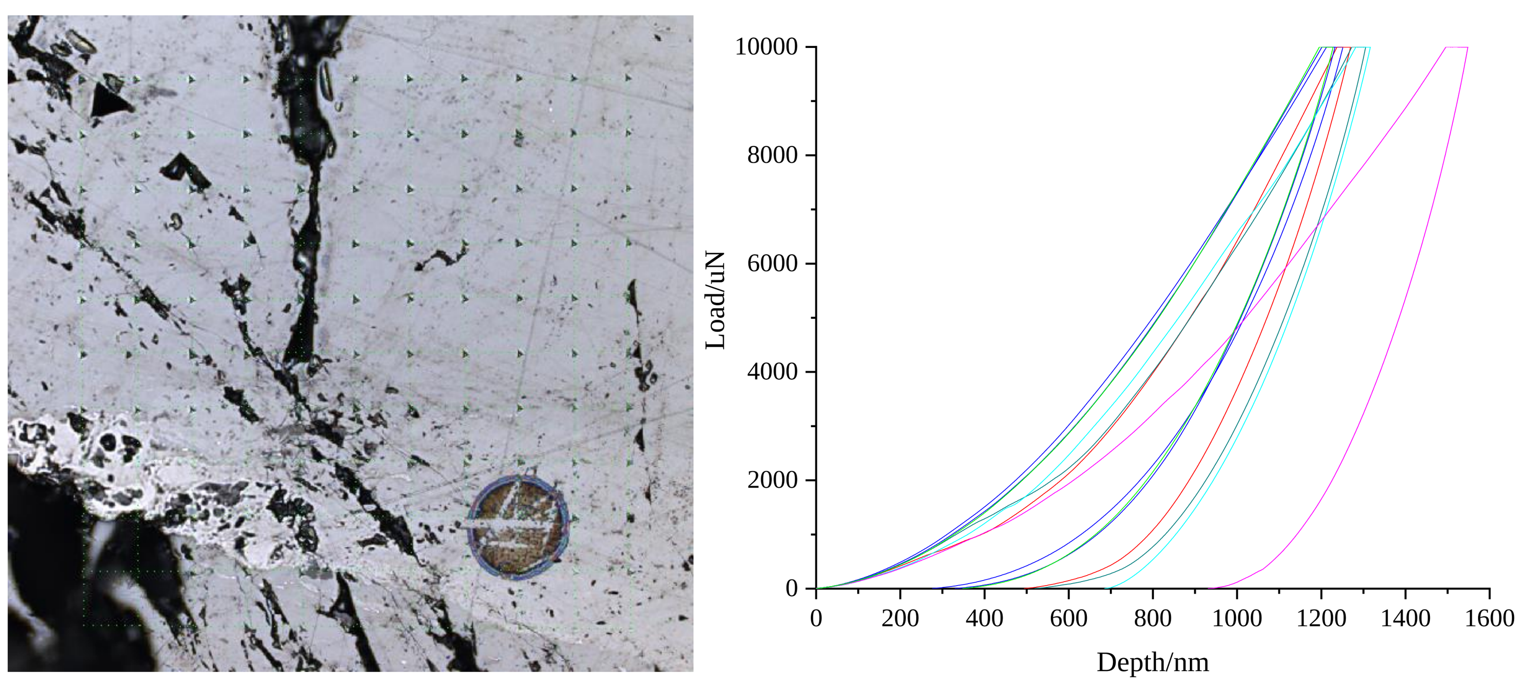

Figure 1: *An indentation image (left) and load-depth curve*

Results & analysis

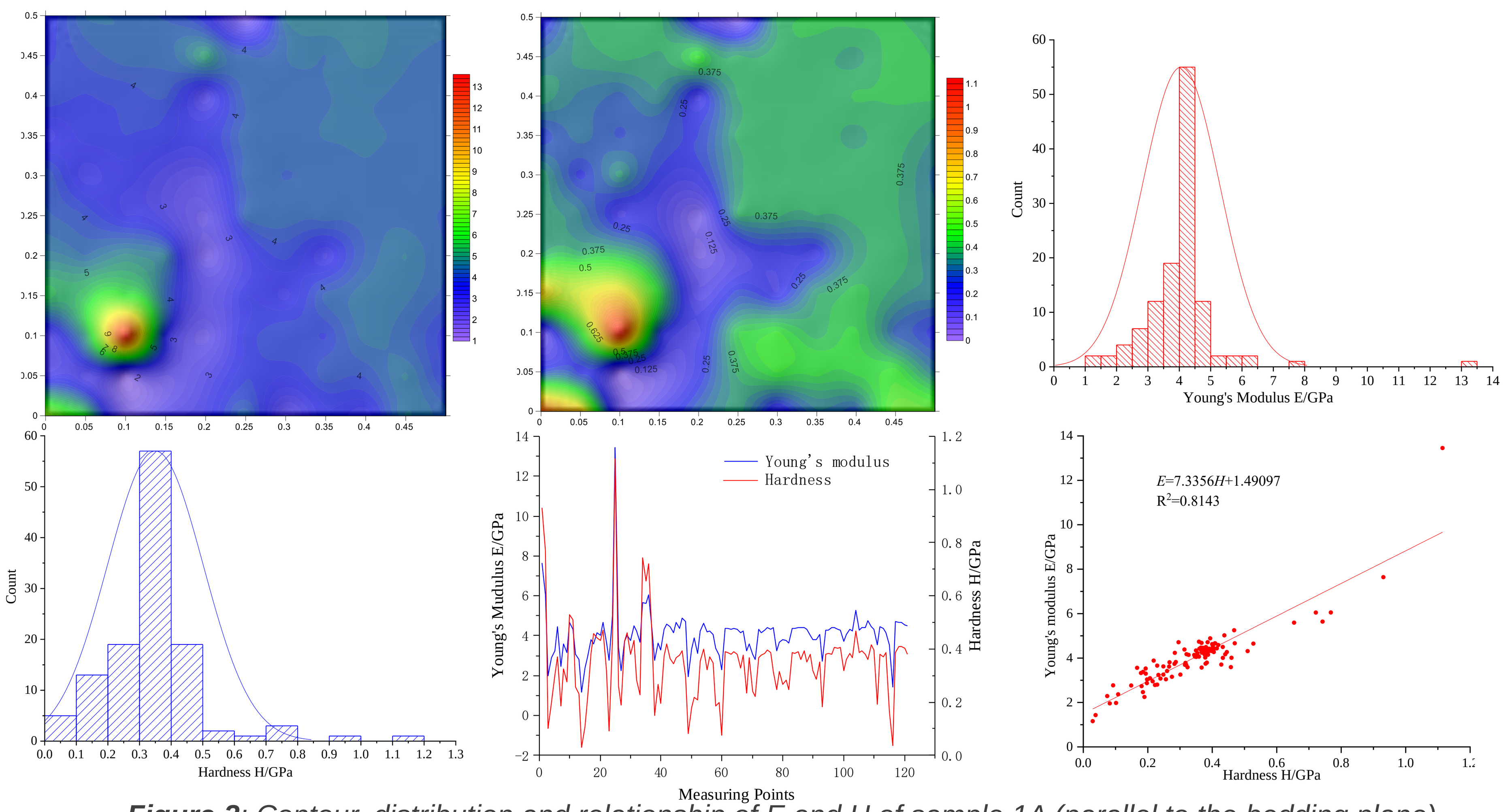

Figure 2*: Contour, distribution and relationship of E and H of sample 1A (parallel to the bedding plane)*

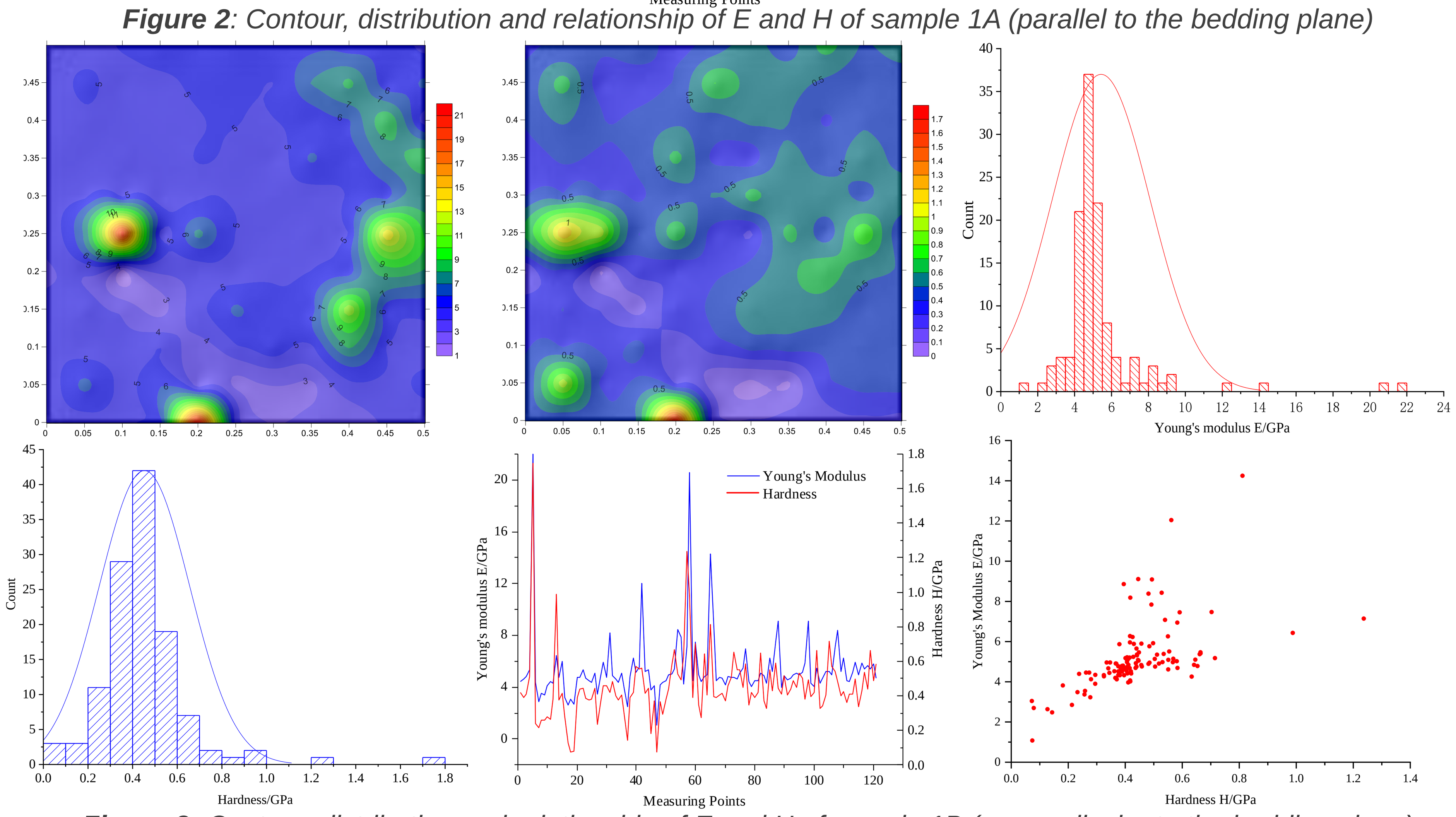

Figure 3: *Contour, distribution and relationship of E and H of sample 1B (perpendicular to the bedding plane)*

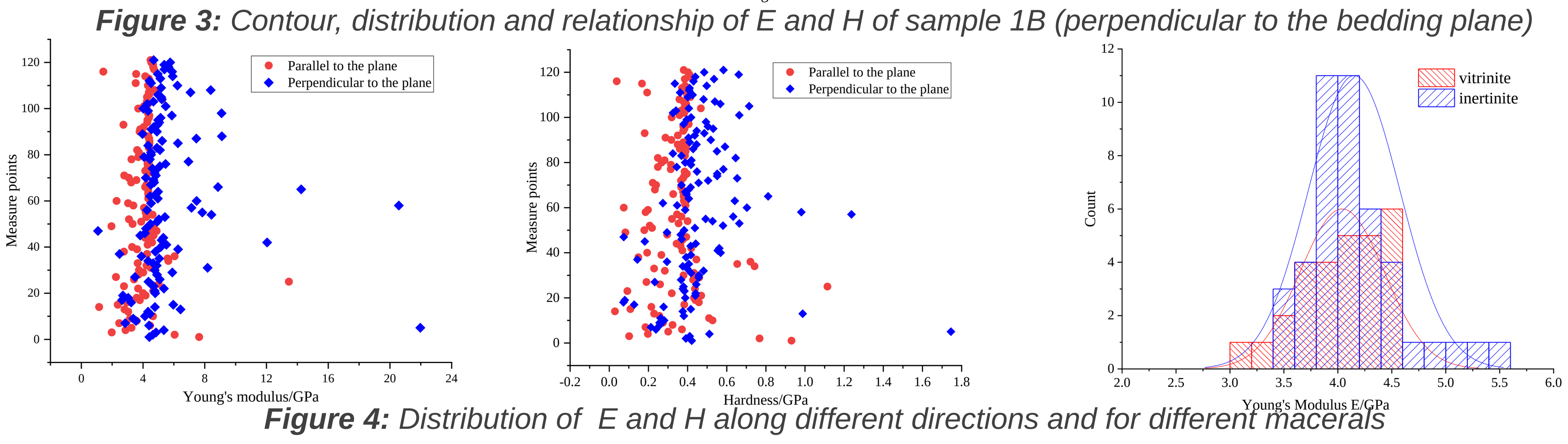

Figure 4: *Distribution of E and H along different directions and for different macerals*

The nanomechanical properties follow a certain distribution feature: the Young's modulus parallel to bedding plane direction are mainly 3-5 GPa, while in the orthogonal direction, the values are 4-6 Gpa (Figures 2, 3 and 4).

A positive relationship exists between Young's modulus and hardness in areas with the same macerals. The differences among macerals are not significant. Overall, inertinite is slightly higher than vitrinite.

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