Dear Editor,

We thank you for your assessment of our manuscript and the thorough your suggestions concerning our manuscript. Those comments are very valuable for improving our manuscript. The responses to the reviewer's comments are indicated below, and specific modifications are marked in blue in the text.

Sincerely yours,

Jianfeng Wang, on behalf of the authors

Editor and Reviewer comments:

Reviewer #1: This manuscript is quite substantial in content and provides relevant analysis from a novel perspective. It focuses on the microscale mechanical properties of the marine shale of the WF-LMX Formation and how these mechanical properties are related to sedimentary conditions. Overall, the manuscript is well organized, the expression of the results is clear enough, and the key points are highlighted. I propose to accept it with some modifications.

1. Line 251. Why do you use 7×7 grid indentations? What is your basis for that or do you have any references?

Response: We used 7×7 grid indentations based on our previous study (Wang et al., 2022). This study demonstrated a representative elementary area (REA) of shale at the microscale, being of no less than 300 μm*300 μm. The resulting areas under the 7×7 grid indentations of this study is approximately 450 μm × 450 μm, which is much larger than the REA of shale proposed by Liu et al. (2018). This ensures an unbiased statistical characterization. We have added the reference to the revised manuscript. Line 252.

2. Line 250-258. Does your shale exhibit a laminated texture? If the shale is of the laminar type, the method used to determine its bulk mechanical properties may not be appropriate. This is because some laminae within it can be several centimeters thick.

Response: Thank you for your insightful comment. You are correct. If the shale is laminar and the laminae are relatively thick, then the method used to determine its bulk mechanical properties may be incorrect. However, we did not find any obvious laminar structure in our shales. Unlike continental shale, our marine shale comes in the form of blocks, so a laminated texture is uncommon. We have included an explanation of this in the revised manuscript (Lines 255-256).

3. The indents in Fig.3 are not clear. Please mark them on the figure.

Response: We have marked the indent with yellow circles in the Fig. 3. Please find it in the revised manuscript.

4. Figure 4. EDS only gives elemental distributions. How exactly was mineralogy determined, knowing that many minerals can have identical Si/O distributions?

Response: EDS can determine elemental distributions. However, we can identify the mineral composition of shale using these distributions. As we know, the shale matrix includes quartz, feldspar, carbonate, pyrite, and so on. As Fig. 4f shows, the quartz particle contains only Si and O elements. The particle is large and has a smooth surface. If the particle contains other elements, then it may be a different mineral. Therefore, based on the elemental distribution and morphology, we can conclude that the particle is quartz.

5. Figure 5 displays the load-displacement curves on fracture areas. Do you use these data for statistical mechanical analysis? If not, please provide an explanation.

Response: For the indents in areas with cracks, the ultimate load that can be loaded generally cannot reach the set peak load, and the pop-in phenomenon is usually present in the load-displacement curve. Therefore, data obtained from these curves are not used for statistical analysis. We have included an explanation of this phenomenon in the revised manuscript (Lines 341-342).

6. Line 406-410. Since this is the results section, do not include any analysis or discussion; just present the obtained results directly.

Response: We have removed these sentences.

7. Table 2 is not of much significance in the main text and can therefore be placed in the Supplementary Files.

Response: We have moved this table to the Supplementary File (Table S4).

8. Line 517, Please provide references. Actually, it would be better to include data on trace elements in section 5.1.4. Please provide more literature to support the explanations in this part.

Response:
(1) Thank you for your suggestion. We have added the reference (Line 515-516).
(2) Thank you for your insightful suggestion. It is better to include trace elements in order to more comprehensively reveal the sedimentary paleoenvironment of shale. Unfortunately, we haven't conducted experiments on this topic. Given this limitation, we have removed the discussion of ancient paleosalinity of seawater during shale deposition from the text because it requires data on trace elements. For the redox conditions of seawater, we have added more references to support the explanations (Wang et al., 2024; Wei et al., 2021) (Line 516).

9. Line 574. It is well known that the fracture toughness of shale increases with increasing clay content. However, in your study, fracture toughness is positively related to hardness and Young's modulus. Can you explain why?

Response: Thank you for this question. In fact, the microfracture toughness measured by nanoindentation is negatively correlated with clay mineral content. This has also been reported in previous articles (Gupta et al., 2020). The previous positive correlation between Young's modulus and fracture toughness indirectly confirmed this conclusion as well (Gupta et al., 2020; Liu et al., 2016; Wang et al., 2022). We believe the difference between macro- and microfracture toughness may be related to sample volume. During nanoindentation test, the indenter primarily affects local mineral particles, such as clay minerals or quartz. Clay minerals usually have low hardness and are prone to plastic deformation. Areas rich in clay are prone to microcrack propagation, which results in a reduction in local fracture toughness. At the macro scale, shale is a heterogeneous composite material. Clay minerals may inhibit macrocrack propagation through energy dissipation mechanisms such as plastic deformation and particle slip. The ductility of materials reinforced with high clay content requires more energy to fracture, showing that macro toughness is improved.

10. Lines 635-638. Traditional uniaxial/triaxial compression tests can also predict mechanical parameters for both the X1 and X3 planes. However, it is important to emphasize the advantages offered by nanoindentation techniques.

Response: Thanks for your valuable comment. We have modified it. That is "Compared with Young's modulus from conventional logging, we can not only obtain the Young's modulus of shale via drill cuttings, but also predict its brittleness in the X1 and X3 planes (Figure 7)." Lines 636-638.

Reviewer #2: The paper analyzed the mineral composition, sedimentary environment, and micro mechanical characteristics of the shale in the Wufeng and Longmaxi formations. Proving the potential of using nanoindentation to effectively evaluate shale brittleness. Provided a continuous and accurate mechanical parameter interpretation profile, which helps determine favorable intervals for hydraulic fracturing in shale gas development design. In principle, I think the manuscript with minor revision could be suitable for the publication in this journal. The following major concerns may be useful for the manuscript improvement.

(1) For "WF-LMX formation", "WF-LMX Formation" and "WF-LMX Formations" in the abstract, it is recommended to express them uniformly and correctly.

Response: Thank you for this comment. We have unified them into the WF-LMX Formation, and we have also checked the full manuscript for consistency.

（2）The map of China shown in Figure 1 is incomplete. It is suggested to be modified.

Response: Thank you for this comment. We have modified Figure 1. Please check the revised version in the manuscript.

（3）When using the Chemical Alteration Index (CIA) in the text, have the potassium mineralization of shale and the recycling of ancient shale been considered?

Response: We apologize for not clearly explaining the conditions for applying the Chemical Alteration Index (CIA).

(1) Regarding the potassium mineralization of shale, the weathering line of the sample is generally parallel to the A-CN boundary (Figure 9), indicating that potassium has not been significantly leached during weathering and may have been only weakly affected by potassium metasomatism. Additionally, we cross-validated the weathering conditions using the Plagioclase Index of Alteration (PIA).

(2) For the recycling of ancient shale, We have added the explanation. Cox et al. (1995) proposed the Index of Component Variation (ICV), which is calculated as the molar ratio of (Fe_2O_3+ K_2O + Na_2O + CaO* + MgO +MnO+TiO2) to Al_2O_3. According to Cullers and Podkovyrov (2000), an ICV greater than 1 in fine-grained clastic rocks suggests low clay content and originally deposition in a tectonically active area. Conversely, an ICV less than 1 indicates high clay content resulting from chemical weathering or redeposition. In this study, the ICV values of the samples (1.18-1.46, see Table S2) exceed 1, which confirms the first deposition without redeposition and can reflect the weathering degree and paleoclimate of the source area. We added the influence of these two conditions in the revised manuscript (Lines 470-476 and 487-489).

References

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