大尺度構造對裂縫網絡連通性的影響：深入了解阿根廷紐肯盆地瓦卡穆埃爾塔非常規油氣儲層

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摘要

了解岩體中的天然裂隙網絡非常重要，因為它們對力學行為和流體動力學有重大影響。離散裂隙網絡 (Discrete Fracture Network, DFN) 模型提供了一個實用的框架來表示這些網絡並評估它們作為流體遷移路徑的作用。它們還可以研究裂隙與斷層、線性構造和裂隙走廊等大規模地質特徵之間的關係，所有這些都會影響裂隙網絡的連通性。最後一個特徵對於確定低滲透頁岩油藏中受控岩石體積的幾何形狀和預測井間干擾問題至關重要。在本研究中，使用一個資料集開發了 2D DFN 模型，該資料集將裂隙的現地測量結果與透過無人機 (Unmanned Aerial Vehicle, UAV) 調查產生的正射影像的解釋相結合。 Mallín de los Caballos 場址是瓦卡穆埃爾塔地層露頭內的 Los Catutos 所在地，被選為自然原型。此碳酸鹽為主的部分提供了良好的露頭，可以進行詳細的調查。建構的模型進行橫向連通性分析，發現背景系統連通性較差。然而，當引入更大規模的 ENE-WSW 走向的構造時，連通性和由此產生的滲透率各向異性會大幅增加，從而改變空間分佈和局部流體流動潛力。在儲層尺度上，這些構造對應於紐肯盆地三維地震資料中發現的近垂直走滑斷層，但它們的完整表徵受到地震分辨率的限制。這項部分提出了對 Tordillo 層的露頭上部發現的這些結構線進行改進的參數化。這些發現強調了整合各種規模的地質資料以全面了解瓦卡穆埃爾塔層等非常規儲層中流體流動行為的重要性。

關鍵字： 天然裂隙、裂隙走廊、離散裂隙網絡、裂隙連通性、紐肯盆地。

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Impact of large-scale structures on fracture network connectivity: Insights into the Vaca Muerta unconventional play, Neuquén basin, Argentina

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ABSTRACT

Understanding natural fracture networks in rock masses is crucial due to their significant impact on mechanical behavior and fluid flow dynamics. Discrete Fracture Network (DFN) models provide a robust framework for representing these networks and assessing their role as pathways for fluid migration. They also allow the study of the relationship between fracturing and large-scale geological features such as faults, lineaments, and fracture corridors, all of which influence fracture-network connectivity. This last feature is critical for defining the geometry of the stimulated rock volume in low-permeability shale oil reservoirs and predicting well interference problems. In this study, 2D DFN models were developed using a dataset that integrates field measurements of fractures with interpretations derived from a georeferenced orthomosaic generated through an Unmanned Aerial Vehicle (UAV) survey. The Mallín de los Caballos site, where the Los Catutos Member within the Vaca Muerta Formation outcrops, was selected as the natural prototype. This carbonate-dominated member provides notable exposures, enabling a detailed survey. Lateral connectivity analyses of the constructed models reveal a poorly connected background system. However, when larger-scale ENE-WSW-oriented structures are introduced, connectivity and resulting anisotropy of permeability increase substantially, transforming the spatial distribution and local fluid flow potential. At the reservoir scale, these structures correspond to subvertical strike-slip faults identified in 3D seismic data of the Neuquén Embayment, though their full characterization is limited by seismic resolution. This work proposes improved parametrization of these structural lineaments identified in the outcropping upper section of the Tordillo Formation. These findings highlight the importance of integrating geological data of various scales to comprehensively understand the behavior of fluid flow in unconventional reservoirs such as the Vaca Muerta Formation.