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Stress anisotropy analysis and its effect on unconventional resource development in Montney play, Kakwa, Canada

Heewon Tak *, Jaewon Choi, Sohyun Jo, Sukyeon Hwang

Korea National Oil Corporation, Republic of Korea

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ABSTRACT

Stress anisotropy analysis is important for estimating both stress regime and fracture geometry for the efficient development of unconventional resources. Despite being within the same play, different areas can have different stress regimes, which can affect drilling decisions. The Montney play is located in Canada between British Columbia and Alberta. In British Columbia it is known for its ductile shale and high horizontal stress anisotropy because of the Rocky Mountains; however, in Alberta, it has different geological characteristics with some studies finding weak horizontal stress anisotropy. Therefore, we studied the horizontal stress anisotropy using full azimuth seismic and well data in the Kakwa area in order to establish a drilling plan. Minimal horizontal anisotropy was discovered within the area and the direction of maximum horizontal anisotropy corresponded with the regional scale (i.e., NE–SW). The induced fractures were assumed to have a normal stress regime because of the large depth (>3000 m). Additionally, because of the very high brittleness (Young's modulus > 9) and relatively weak horizontal stress anisotropy, the fracture geometry in the Kakwa area was estimated as complex or complex planar, as opposed to simply planar.

1. Introduction

Hydraulic fracturing is widely used to develop unconventional resources such as shale and tight gas for efficient use of this technique, it is important to determine the stress state in the target area, as it can affect the regimes and geometries of hydraulically induced fractures.

As can be seen in Fig. 1, the type of deformation varies with the relative magnitudes of the three principal stresses: maximum horizontal stress (S_{Hmax}), minimum horizontal stress (S_{hmin}), and vertical stress (S_v). Horizontal fractures occur in the case of a reverse regime; therefore, such a situation would be undesirable for horizontal drilling and fracturing. Furthermore, stress anisotropy and rock brittleness also affect fracture geometry (Fig. 2). Fracturing in shale that is ductile or that has high stress anisotropy will often result in bi-wing fractures with little to no complexity. Conversely, fracturing in shale that is brittle or has low stress anisotropy can create a complex system of fractures. Depending on the brittleness and stress anisotropy, well completion focuses on either "fracture intensity," "reservoir diversion," or "stress-induced complexity" (McNeil et al., 2012). If such stress-state information is known, efficient fracturing and production plans such as well spacing and fracturing-stage spacing can be established.

Stress magnitudes can be measured or estimated using a variety of methods, e.g., the mini-frac test, the leak-off test, the overcoring method, or by calculation from density logs. However, reliable estimation of the S_{Hmax} magnitude remains particularly difficult because the numerous assumptions made impose high uncertainties (Reiter et al., 2014). Consequently, only the directions of maximum stress or stress anisotropy have previously been estimated using oriented caliper logs, seismic data, formation microimager (FMI), and microseismic data. The purpose of this study is to quantify the degree and direction of anisotropy in the Kakwa field of the Montney play in Canada. Such data were derived from analyses of seismic data and then compared with well data and the regional stress map. The advantage of using seismic data is that we can analyze different properties using the wide-range azimuth of seismic data, unlike core data and image logs. Additionally, we attempt to improve reliability by comparing the different scaled results.

2. Geological background

The Montney Formation of Triassic strata in the Western Canada Sedimentary Basin (WCSB) occurs in four main physiographic provinces: The Rocky Mountains, the Rocky Mountain foothills, the interior plains of northeastern British Columbia (BC) and northwestern Alberta (AB) (Gibson and Barclay, 1989), and the interior plains of southern Saskatchewan and Manitoba. The Montney Fm. isopach shows a lens-shaped basin thinning to the east and north because of erosion and non-deposition. The maximum thickness of the Montney Fm. is approximately 350 m. The formation also displays a local thinning trend to the west and south, probably because of slower rates of sedimentation. In addition, the eastern subcrop edge of the Montney Fm. comprises shallow-water

* Corresponding author.
E-mail addresses: heewon.tak@knoc.co.kr (H. Tak), jaewon.choi@knoc.co.kr (J. Choi), sohyun.jo@knoc.co.kr (S. Jo), sukyeon.hwang@knoc.co.kr (S. Hwang).

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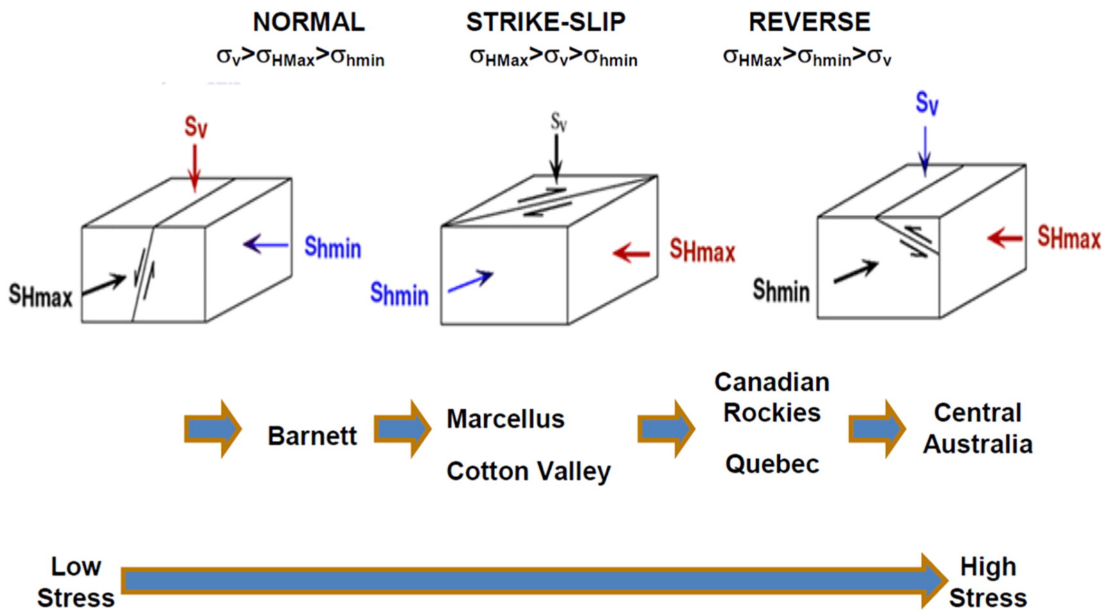

Fig. 1. Normal, strike-slip, and reverse stress regimes, defined by the relative magnitudes of the three principal stresses: σ_{HMax}, σ_{hmin}, and σ_v (Davey, 2012).

marine interbedded sandstone and shale, which is interpreted as being either of deltaic (Miall, 1976) or inner-shelf origin (Gibson and Barclay, 1989). The shallow-water eastern facies thicken and grade to the west into a deeper-water succession of siltstones and shales belonging to middle shelf, outer shelf, and shelf-slope environments. The depositional environment of the Kakwa field is between an inner shelf and outer-shelf transition zone, located relatively near to the eastern subcrop edge rather than the depocenter in central BC. The dominant lithology of the Montney Fm. near the depocenter is shale with interbedded argillaceous siltstone, and near the shoreline (landside, Alberta), it is argillaceous siltstone interbedded shale (Lower Montney) and interbedded very-fine- to fine-grained sandstone (Upper Montney) (Davies et al., 1997; Rokosh et al., 2012). The top depth of the Kakwa Montney Fm. is about 3000–3500 m, its thickness is about 200–250 m, and the total organic carbon (TOC) is 0–1.5 wt.%. The Kakwa Montney Fm. has lower TOC and coarser grained lithology than the depocenter and is highly cemented by dolomite and quartz. Thus, its geomechanical properties are much harder and more brittle than the BC Montney Fm. (Davies et al., 1997; Rokosh et al., 2012).

3. Stress anisotropy analysis

3.1. Previous stress anisotropy research in Montney play

Heidbach et al. (2008) released a world stress map in 2008, and Reiter et al. (2014) updated and revised the stress map of Canada by adding new stress orientation data to the existing data set. Fig. 3 shows the updated stress map of Alberta. The stress orientations are approximately perpendicular to the Rocky Mountain orogenic belt, varying by only a few degrees. The Canadian Rockies are known to have high stress (Fig. 1), and the Montney Fm. is considered ductile shale, which has bi-wing fractures (right-hand part of Fig. 1) (McNeil et al., 2012). Based on this information, we can presume that high horizontal stress anisotropy exists in southwestern Alberta, including the

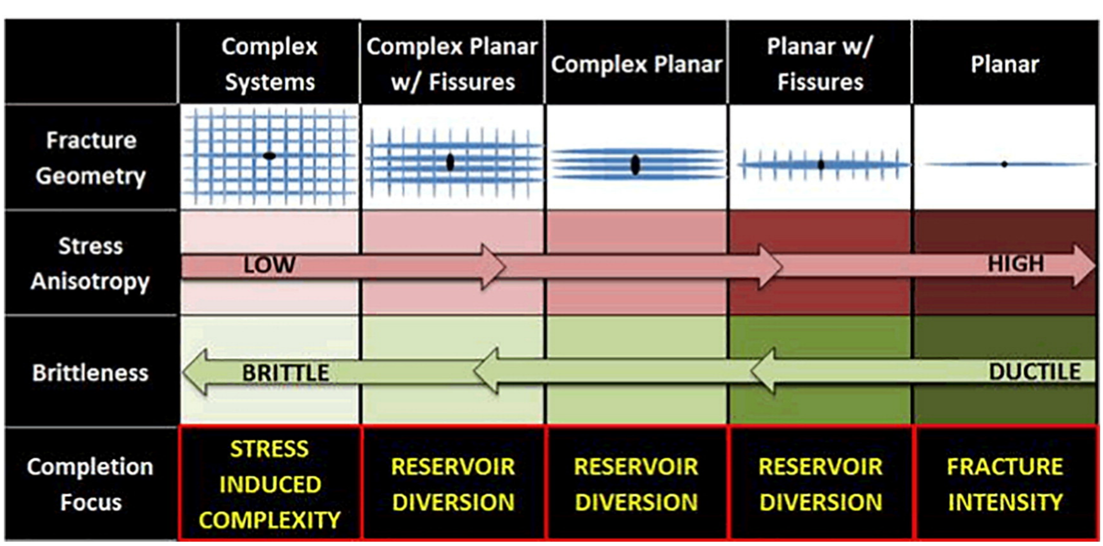

Fig. 2. Overview of completion strategy based on brittleness (McNeil et al., 2012).