

Hydrogen Sulphide within the Triassic Doig Formation, Northeastern British Columbia and Northwestern Alberta (Parts of NTS 083, 084, 093, 094)

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Introduction

The Lower to Middle Triassic Doig Formation of the Western Canada Sedimentary Basin (WCSB) extends continuously across northeastern British Columbia (BC) and northwestern Alberta. With the industry shifting the focus of development to unconventional reservoirs, the Doig Formation has been recognized as an important resource of gas and natural-gas liquids (Schenk et al., 2019). The Gas Technology Institute (Faraj et al., 2002) estimated the total gas-in-place in the Doig Formation at 4 trillion m³ (140 tcf), whereas Walsh et al. (2006) estimated the total gas-in-place as ranging between 1.1 and 5.7 trillion m³ (40–200 tcf). A more recent study by the U.S. Energy Information Administration (2015) estimated 2.8 trillion m³ (100 tcf) of gas-inplace for the Doig phosphate zone alone. The presence of hydrogen sulphide (H₂S) associated with hydrocarbons poses a problem due to potential corrosion of downhole and surface equipment; environmental, health and safety risks; and reduction of calorific and market value of the gas. Even in trace concentrations, larger than 4 ppm for pipeline transmission and larger than 10 ppm for personnel protection (Moore and Spitler, 2003), H₂S represents a risk for personal and facilities safety.

The amount of H_2S associated with the gas produced from the Doig Formation varies greatly across the basin, and the distribution of sour zones is very complex and challenging to predict. Hydrogen sulphide in petroleum systems may be generated through various chemical-reaction pathways and from multiple sources of sulphur, such as organosulfur compounds associated with the kerogen and hydrocarbons, metal sulphide minerals and dissolved sulphates in connate or injected water (Marriott et al., 2016). At shallow depths, where temperatures are lower than 80 °C, microbial activity can result in reservoir souring by sulphate-reducing bacteria (Shen and Buick, 2004; Amrani, 2014), so long as enough sulphate is supplied. Sulphate is provided through dissolved ions in connate water, introduction of well-stimulation fluid or mineral-fluid interactions. At higher temperatures, thermal sulphate-reduction reactions occur at the expense of reservoir hydrocarbons (Worden et al., 2000; Marriott et al., 2007), producing H₂S, CH₄ and CO₂, part of which is precipitated as carbonate minerals (Worden et al., 2000; Kelemen et al., 2008; King et al., 2014). Thermal sulphate reduction is initiated and catalyzed by reduced or low-oxidation-state sulphur and, owing to its slow reaction kinetics, is highly dependent on temperature. In shales, souring is commonly attributed to microbial activity due to surface-water injection during stimulation (Marriott et al., 2016); an extra layer of complexity is added to understanding the distribution of H₂S in the Doig, due to thermal sulphate reduction from the evaporitic sections of the overlying Charlie Lake and Halfway formations or the underlying Devonian section possibly generating H₂S in the Doig. Shale wells may produce H2S-free initially, with delayed souring (Weiland and Hatcher, 2012) due to sulphate production through the introduction of oxygenated waters and bacteria that colonize the reservoir and begin feeding on mineral or completion-additive sulphate. Reducing the uncertainty related to the production of sour gas from the Doig Formation involves mapping the distribution of H₂S, as well as understanding the source of the sulphur and the processes of H₂S generation.

Methods

Approximately 700 gas analyses of a public database of drill-stem tests and production tests from over 300 wells distributed throughout the entire extension of the Doig Formation subcrop in BC and Alberta were used to map the lateral distribution of H_2S (Figure 1). The data was screened to remove analyses showing drilling-mud contamination or consisting mostly of air by reviewing analysis remarks. Where multiple analyses existed for the same well, an arithmetic average was used. Additional analyses were removed due to inconsistent alkane profiles or regional disagreement, creating mapping artifacts such as bull's eyes and butterfly wings. Data was interpolated using ordinary kriging with a spherical-type experimental semivariogram and smoothed by two iterations of minimum-curvature interpolation.

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Figure 1. Distribution of H_2S from the Doig Formation based on gas samples and main faults that influence Triassic strata (after Berger et al., 2008) against a shaded-relief backdrop map, in northeastern British Columbia and adjacent area.



Preliminary Results

A total of 122 wells, representing 40% of the wells with available gas analyses, have had sour gas identified in either a drill-stem test or production test sample. The H₂S concentrations vary widely from 33 ppm to 28 000 ppm (28%), with 9% of the wells with sour gas containing 100 ppm or less and 10% of the wells containing 4000 ppm or more. The two areas with the highest concentrations of H₂S are the areas northwest of Fort St. John in BC and the area straddling the provincial border with Alberta, between Dawson Creek and Grande Prairie (Figure 1). These results confirm that there is a strong overlap between sour-gas analyses from both the Montney and the Doig formations, which had been previously noticed by Chalmers et al. (2020). These regions also largely overlap with the extent of the Charlie Lake Formation anhydrite mapped by Edwards et al. (1994), which suggests that sour gas within both the Montney and the Doig may be at least partly derived from migration of sulphate from overlying Triassic strata through fault and fracture pathways or through the contact of permeable strata created by the Coplin or sub-Manville unconformity, in addition to possible deeper Devonian sources.

Future Work

The H₂S distribution map generated by this study contributes to the mitigation of safety and health hazards and risks posed by drilling and hydrocarbon production in sour-gas zones. Additional work required to confirm the origin of the H₂S and generate predictive models includes isotopic analyses of the sulphur in the H₂S produced from the Doig and of oxygen and sulphur from Charlie Lake Formation anhydrite samples, as well as sulphur isotopes from anhydrite, pyrite and kerogen organosulfur compounds from the Doig Formation. Mapping of structures that could have potentially served as migration conduits of sulphate from the anhydrite-rich overlying Triassic strata to the Doig Formation would also be extremely valuable in explaining the origin of the sulphate; however, the lack of a public seismic database and the difficulty in accessing proprietary data pose a significant challenge to further research into this topic.

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