Tools to Get the Most Information from Shale Cores: An Example from the Lorraine and Utica Shales of Quebec*

Marianne Molgat[1] and Jean-Yves Chatellier[1]

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[1]Talisman Energy, suite 2000, 888, 3rd St SW Calgary (mmolgat@talisman-energy.com)

Abstract

Several hundreds of meters of cores were recently cut through the Ordovician Lorraine and Utica shales in the Saint-Lawrence Lowlands of Quebec. One of the exploration objectives was to identify horizontal targets with the highest potential for gas production within an approximate 300-m-thick Utica Shale succession. Another objective was to find a tool, other than logs, that could help distinguish the Flat Creek, Dolgeville, and Indian Castle formations within the Utica Group, as rock cuttings within this thick carbonate-rich succession appear to be undecipherable. A final objective was to understand lateral facies variations and determine the relative importance and distribution of natural fractures within the Utica Shale in the Saint-Lawrence Lowlands. Thus, several macroscopic and microscopic features in Utica and Lorraine cores are presented illustrating the significance of going beyond core descriptions and core analysis by applying methods and using tools that can truly enhance our understanding of mud-size sedimentary deposits.

Introduction

The Saint-Lawrence Lowlands is an approximate 50-km narrow sedimentary basin that lies mainly on the south shore of the Saint-Lawrence River between Quebec City and Montreal. The Lowlands are bounded to the north by Proterozoic Shield rocks and to the south by the Appalachian Mountains (Figure 1). The sedimentary fill consists of Cambro-Ordovician strata that are unconformably overlain by glacial deposits. In the area of interest, the Ordovician shales are several thousand meters thick, and historical gas shows within the shale succession have been frequently recorded.

The Saint-Lawrence Lowlands sedimentary basin has had a long and complex tectonic history that includes several episodes of compression, extension, and strike-slip events. The initial Cambrian rifting event created a basin underlain by several large normal fault blocks. During the closing of the Iapetus Ocean in Middle to Late Ordovician, these fault blocks were reactivated syn-depositionally due to the lithostatic loading in front of the Appalachians during the Taconian Orogeny (Konstantinovskaya et al., 2009). One of these faults is an important subsurface feature in the Saint-Lawrence Lowlands, termed the Yamaska Fault. It was reactivated as a reverse fault during Taconian time, and it delimits a 20-600m Utica (Corridor 1) from a 1500-2300m Utica (Corridor 2) (Figures 1 and 2). The basin is also characterized by numerous Cretaceous alkaline intrusions, known as the Monteregians, from which multiple bed-parallel sills extend several 10's of kilometres through the Utica and Lorraine formations, adding a localized element of complexity to the unconventional gas play.

The Utica Group was deposited during the drowning of the Trenton-Black River carbonate platform at the onset of the Taconian Orogeny. Carbonate sedimentation was succeeded by the deposition of the Lorraine Shale sourced from newly formed mountains. The contact between the Utica and the Lorraine shales is generally deemed to be conformable, although geochemical, stratigraphic, and structural evidence suggests that locally, it is not.

Sedimentology and Stratigraphy

There is little well control in many parts of the Saint-Lawrence Lowlands. Much of the historical oil and gas exploration activities was focused on conventional targets, such as fractured carbonate reservoirs in the fold-thrust belt, or shallow sandstone or carbonate targets.

Within Corridor 2, regional mapping using limited well control suggests that there is no significant variation in Utica thickness. Furthermore, there is very little lateral facies variation along strike and dip directions; this was expected, given the depositional setting is a drowned carbonate platform. As such, markers are regionally extensive and readily identifiable on gamma-ray logs, although not easily observed in core. The Utica is an interstratified argillaceous lime mudstone, generally composed of 60-70% calcite, 15% quartz, and 15-25% clay. Core desorption data shows that that the Indian Castle Formation within the Utica has the highest gas content.

XRF was run on a centimeter increment on the Saint-Edouard No.1 core in an attempt to determine if there is distinguishable elemental compositions within the cored interval. Box plots were created, and the resulting graph shows large packages of similar composition as well as sharp transitions, suggesting a temporary change in material sourcing or basin conditions (Figure 3). A similar exercise was conducted on crushed cuttings and on <60 microns size cuttings collected at the wellsite. Results suggest that a quick-turnaround XRF analysis can be used to rapidly identify stratal packages while drilling horizontally, ensuring best possible borehole placement within a stratal package selected for its mechanical rock properties as to best initiate hydraulic fracturing. The main target, from both geochemical and geomechanical aspects, is the informal "Lower Dolgeville" formation.

Although not readily apparent in core, the Lorraine shale differs greatly from the Utica. It has a mineralogical composition characterized by 50% clay minerals, (mainly illite with minor chlorite), 35% quartz and feldspar, and minor calcite or dolomite (Thériault, 2008). The Lorraine shale is generally leaner in TOC and natural gas content, making it a less interesting target for natural gas exploration.

Total organic carbon (from Rock-Eval) was also analyzed from core, and results corroborate with regional TOC studies (Thériault, 2008). The Utica is fairly lean in TOC, ranging from 1 to 3%. Much of the kerogen has already been converted to dry gas, essentially rendering the Utica a free gas play with some minor contributions from adsorbed gas. Based on vitrinite reflectance-equivalent work, maximum burial in Corridor 2 predates tectonic transport, and the succession is interpreted to have been uplifted by 5.6 to 7.5 km (Héroux and Bertrand, 1990). Great burial depths are also supported by the fact that clay minerals are dominated by illite with some minor chlorite. With depth, water sensitive clays are converted to more stable ones such as illite.

Regional TOC mapping also provides insight into the nature of the contact between the Utica and the Lorraine. In some parts of the basin, TOC values gradually increase towards this contact, then gradually decrease, suggesting this contact is conformable and possibly represents a maximum flooding surface. However, in other parts of the basin, there is a sharp drop in TOC at the Utica-Lorraine contact, suggesting an unconformable contact (Figure 4). Commonly, the Indian Castle Formation is absent due to either non-deposition, erosion, or faulting. Additionally, a hardground was identified in core near the Utica-Lorraine interface, further suggesting that locally, the contact is unconformable (Figure 5).

Structural Elements

Several other unconformable contacts can be observed in the Utica, some of which are structural in origin. Two Utica cores were cut in the Saint-Edouard well. The first core was cut in an imbricate with the Utica being thrusted over the Lorraine. It is characterized by numerous calcite-filled fractures and core-width folds and displacement features. These features are also observed at much larger scales with FMI logs in the overlying Lorraine Shale. Locally, the contact between the Flat Creek and the Dolgeville formations and between the Dolgeville Formation and the Lorraine Shale appears to be a horizontal portion of a thrust fault. Steeply dipping fractures are interpreted from FMI logs, and the coring operations were difficult with some unrecovered bottom core sections at the Flat Creek - Dolgeville interval. However, where wells are farther away from the deformation belt, natural fracture density appears to be insignificant and bedding is generally flat. Preliminary results suggest that the presence of natural fractures likely enhances initial productivity of a well, although it is unclear if their presence plays a role in ultimate gas recoveries.

Cores Displayed

Core 1: Talisman Saint-Edouard No. 1

In 2009, this vertical well was drilled through the Ordovician section to a depth of 2584 meters. A Utica imbricate was cored and the underlying Lorraine (footwall) from 1181 to 1934.8 meters. The para-authochtonous Utica was also cored from 1950 to 2031.2 meters. Both zones were fracture-stimulated, and it was reported that the well tested an average gas rate of 6 MMcf/day. Selected portions from both of these core runs were presented.

Core 2: Talisman Energy Saint-David No. 1

This well was drilled in 2008 across Ordovician strata to a depth of 1995 meters and reached TD in the Beekmantown Formation, below the Trenton-Black River platform carbonates. A total of 186.3 meters of Utica was cored, including the Indian Castle, Dolgeville, and Flat Creek formations from 1542 to 1728.3 meters. This well was fracture-stimulated in 2008 and reported to have an average gas rates of >400 mcf/d. Selected portions representative of each of these formations were presented.

Acknowledgments

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Thériault, R., 2008, Base de données (minéralogie/géochimie), Basses-Terres du Saint-Laurent: Ministère des Ressources naturelles et le la Faune du Québec.

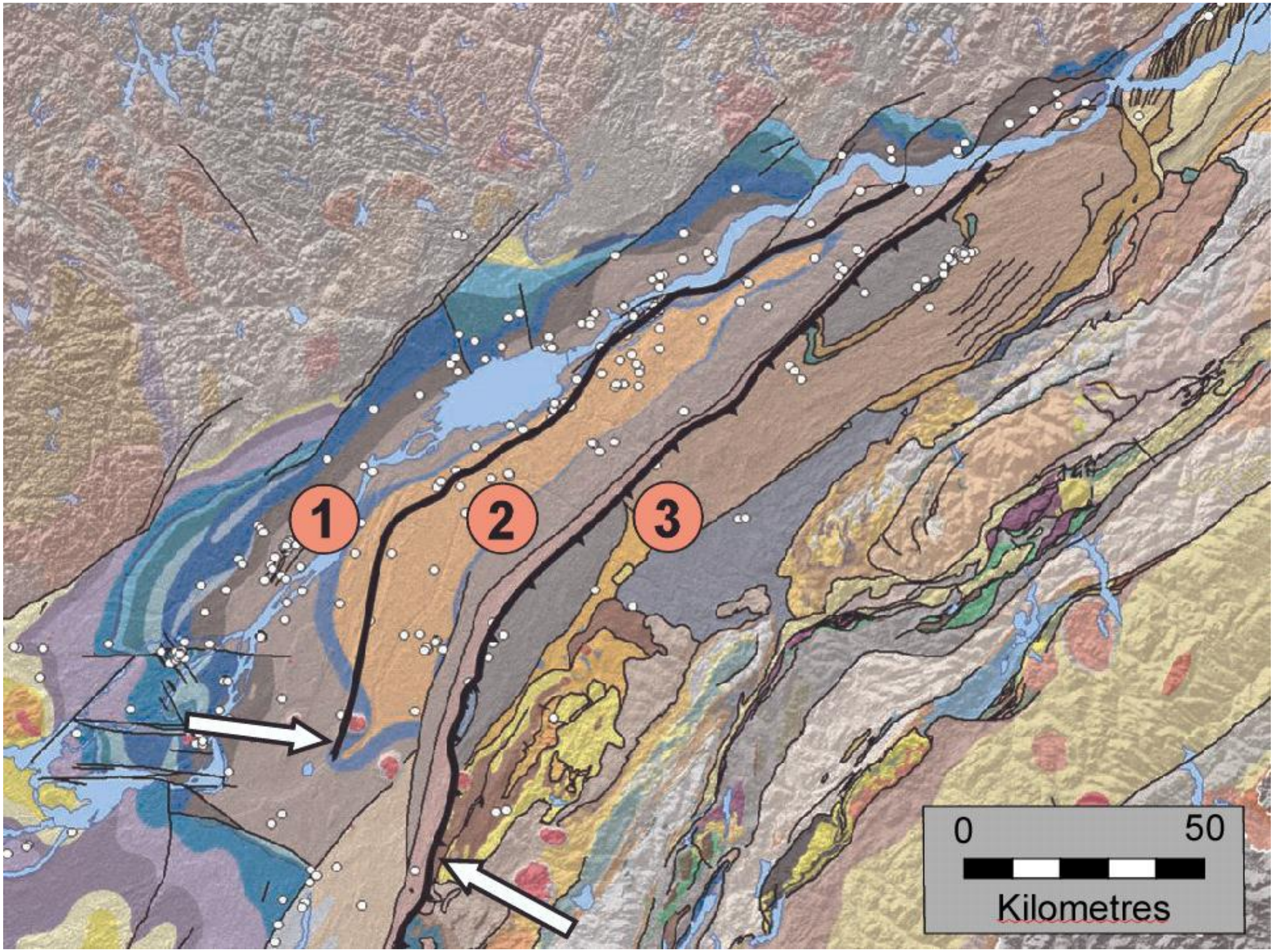

Figure 1. Geological map of the Saint-Lawrence Lowlands. The Utica crops out on the north side of the Saint-Lawrence River and lies about 1500-2500m south of the Yamaska Fault (top left arrow). Corridor 3 is the thrusted domain. White dots represent wells with geochemistry data. (Modified from Thériault 2008.)

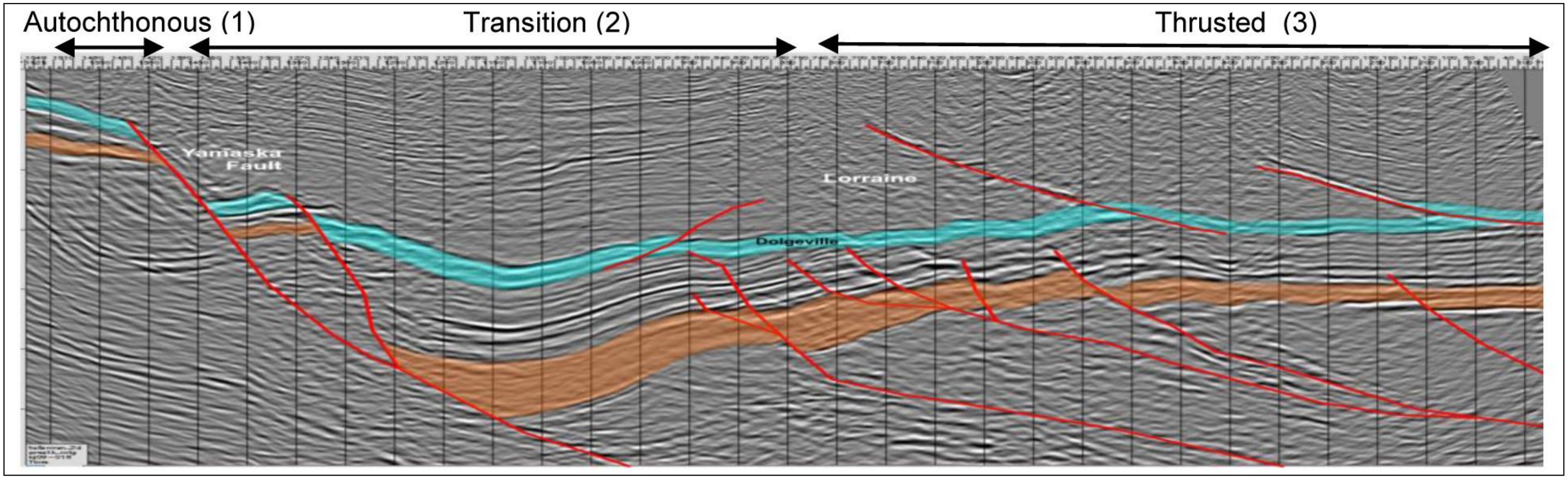

Figure 2. Seismic dip section showing various basement blocks reactivated syn-depositionally at Utica time. Here, the Yamaska fault exhibits approximately 600 meters of displacement.

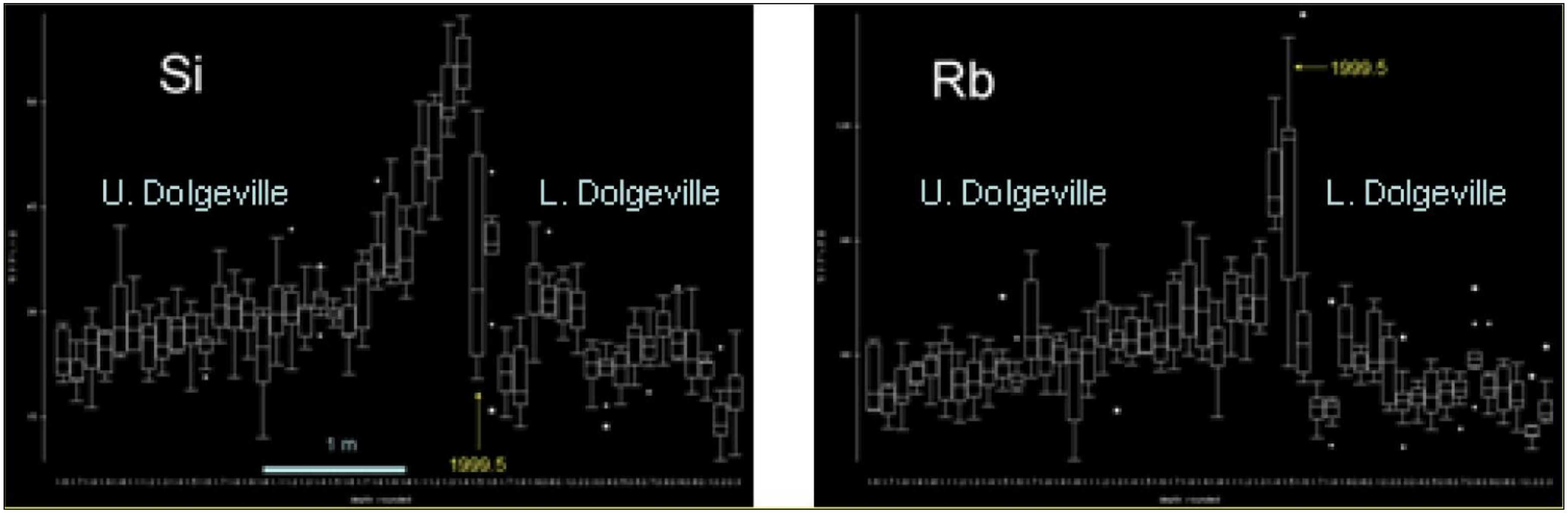

Figure 3. XRF data plotted in box plots, showing clear elemental ratio changes between the upper Dolgeville and Lower Dolgeville; this would otherwise be difficult to distinguish core or cuttings (only two elements shown).

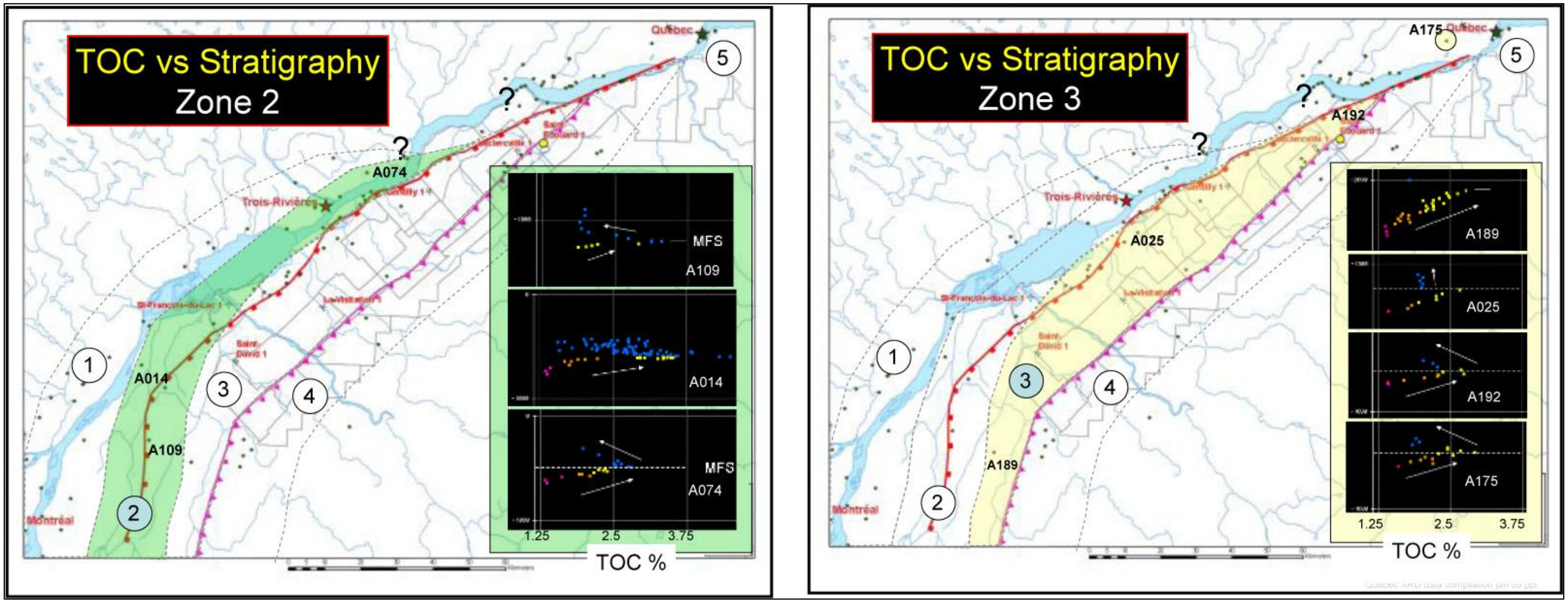

Figure 4. TOC data in the Saint-Lawrence basin shows a general increase then decrease in TOC in Zone 2, suggesting this contact is conformable and possibly represents a maximum flooding surface. Zone 3 shows a sharp drop in TOC at the Utica-Lorraine contact, suggesting an unconformable contact.

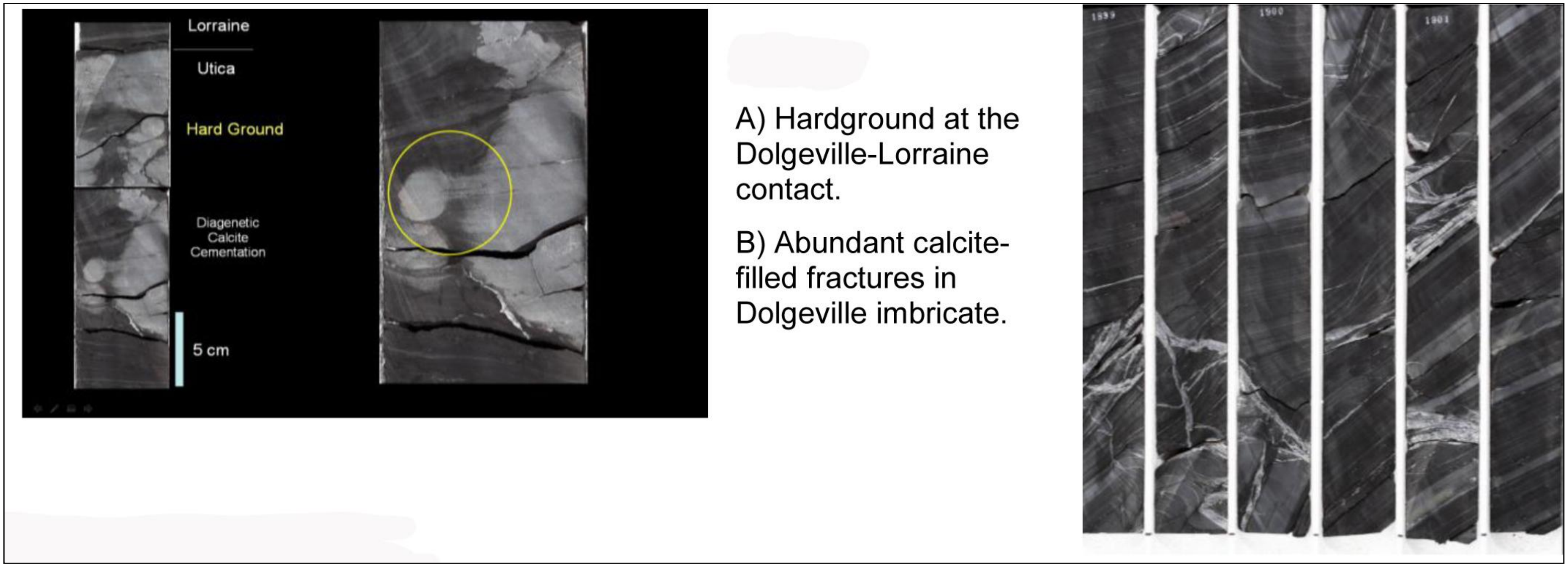

Figure 5. Left: Hardground at the Dolgeville-Lorraine contact. Right: Abundant calcite-filled fractures in Dolgeville imbricate.