Lithofacies Analysis and Depositional Scenarios for the Rock Creek Member and "Niton B" Sandstone of the Fernie Formation in West-Central Alberta*

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Abstract

The Fernie Formation in the subsurface of west-central Alberta was deposited as a mixed carbonate-siliciclastic wedge upon a west-facing homoclinal ramp. Deposition spans a period of ~50 Ma and includes Hettangian through Kimmeridgian stages of the Jurassic System. Within the Fernie Formation, the Rock Creek Member and "Niton B" sandstone are hydrocarbon-bearing units with complex lithostratigraphic relationships, and their depositional environments are the subjects of much debate. Based on forty cores, this study examines strata within the Poker Chip Shale, Rock Creek Member, "Niton B" sandstone, and the "Upper Fernie" shale through detailed lithofacies analysis, petrographical examination and geophysical well log correlation. Palynological studies in published reports from around the study area, and regional correlations to units with ammonites, indicate that a significant unconformity separates the lithologically distinctive "Niton B" sandstone (Upper Jurassic) from older units of the Rock Creek Member (lower Middle Jurassic) in the Niton Field. This means that it is a distinct younger unit of the Fernie Formation, now known informally as the "Niton B" sandstone, which is distinguished in part by the presence of a green mineral that is under study – the glauconite of previous reports.

Lithofacies within the Rock Creek Member include coquinas and 'wispy' flaser-bedded sandstones with couplets and bundles, wavy to lenticular beds that grade into mudstones with in situ bivalves, current-bedded, fully marine sandy, bioclastic limestones, and current- to planar-bedded sandstones with macroburrows diagnostic of the *Cruziana* and *Skolithos* ichnofacies. Lithofacies within the "Niton B" sandstone are less variable and include well bioturbated to churned sandstones and current-bedded sandstones. These lithofacies are arranged in characteristic vertical successions that are suggestive of shoreface and tidal depositional environments. A shallow/marginal marine interpretation for the Rock Creek Member and the "Niton B" sandstone is further supported by the observation of pedodiagenetic features such as illuviated clays and root structures. These and other features of early diagenetic alteration have not been previously reported in the literature for this interval.

Introduction

Since the discovery of economically significant oil and gas reserves in the western Canadian Sedimentary Basin (WCSB), the Jurassic and lowermost Cretaceous strata have been of interest to researchers in academia and industry. Much debate has focused on geological and sedimentological models that describe the western North American continental margin at the verge of its transformation by the Columbian Orogeny. The Jurassic period in the WCSB of Alberta is represented mainly by the Fernie Formation. Within the Fernie Formation, the “Niton B” sandstone and Rock Creek Member have attracted the most attention. These sandstones and the similar quartzose sandstones of the Ellerslie/Gething just above the pre-Cretaceous unconformity are hosts to significant gas and light oil reserves, but they are difficult to discriminate even with high quality geophysical logs. Most workers infer an “outer” shelf to shoreface to coastal plain origin of Middle Jurassic to lowermost Lower Cretaceous strata, but alternative interpretations include a deep-water origin for the Rock Creek Member. When considering that the geological evidence provided in these units would support such contrasting interpretations, it illustrates the need for detailed sedimentological studies of this interval. In this study, we examine strata from the upper Poker Chip Shale (Aalenian) to the “Upper Fernie” shale (Oxfordian/Kimmeridgian) of the Fernie Formation in west-central Alberta. Detailed sedimentological, ichnological and petrographical analyses confirm a shallow to marginal marine and shoreface to coastal plain depositional settings for the “Niton B” sandstone and the Rock Creek Member. In addition, a clear record of tidal-influenced sedimentation allows for discriminating the depositional setting of the Rock Creek Member into various subtidal to supratidal realms. For the first time, we demonstrate that strata in this interval have been modified by near-surface pedodiagenetic processes. The lithofacies succession in the study area attests to the complexity of the Jurassic depositional systems with high spatial and temporal variability.

Geological Setting

In the study area in west-central Alberta (Figure 1), the Fernie Formation includes the Nordegg Member, Poker Chip Shale, Rock Creek Member, “Niton B” sandstone, and “Upper Fernie” shale. Deposition of these units represents a time-span of approximately 50 Ma, from the Hettangian through Kimmeridgian stages of the Jurassic System (Figure 2). Deposits in the Rock Creek Member indicate deposition on a shallow marine shelf influenced by storm and tidal currents (Marion, 1982, 1984). Alternatively, a deep-water submarine-channel origin for the Rock Creek Member has been proposed based on a dominance of upper flow regime horizontal bedding and antidune stratification in conjunction with stressed marine ichnofacies, thickness variations, vertical and lateral facies changes, the channelized character, and the lack of indicators of subaerial exposure (Meloche, 2010). The “Upper Fernie” shale records a short-lived marine incursion prior to the fluvial infill of the “pre-Cretaceous” valley system by sandstones and shales of the Ellerslie Member. Previous studies have indicated that the producing sandstones of the Jurassic are comprised of two lithostratigraphic intervals, the Rock Creek Member below and the “Niton B” sandstone above (Losert 1990, Putnam and Moore, 1993). A shale-dominated unit that lies disconformably above the sandstones in most places is commonly assigned to the “Upper Fernie” shale. In other places, overlying strata have been assigned to the Lower Cretaceous Gething/Ellerslie (Basal Quartz) members. These are composed of cross-bedded, coarse- to fine-grained, quartzose and cherty sandstones and fine- to medium-grained quartzose sandstones interbedded to interlaminated rhythmically with organic-rich shales.

Methods

The study area is located about 150 km west of Edmonton and encompasses approximately 3,000 km^2 (Figure 2). Between townships 52 to 56 and ranges 11W5 to 16W5, more than 3,000 wells have been drilled, and 2015 of these wells have intersected the Rock Creek Member. Forty cores have been selected to perform detailed sedimentological and petrological analyses. Eighteen wells have been cored from the lowermost "Upper Fernie" shale to the top of the Poker Chip Shale. Cores were selected based on completeness of the stratigraphic interval, lithological variability as inferred from geophysical well logs and biostratigraphic control. For all cores, the lithofacies are established based on objective criteria such as bedding, colour, composition, grain size, mineralogy, body and trace fossils, physical sedimentary structures and rock fabric. Indicator for diagenetic modifications like colour mottling, authigenic mineral accumulation, and cementation intensity have received special attention. More than forty thin sections have been analyzed using standard polarized light microscopy. Established lithofacies are correlated across the study area using conventional geophysical well log correlation techniques.

Results

Based on objective lithological criteria, the "Niton B" sandstone and Rock Creek Member in the study area have been subdivided into seven lithofacies:

- calcareous bivalve sandstone to bivalve limestone (coquina) with minor amounts of mud rip-up clasts (LF 1);
- current-bedded, variably bioturbated fine- to medium-grained sandstone to shaly sandstone including horizontal bedding, dune and ripple-scale 3D cross bedding, compound cross bedding, and low-angle inclined stratification (LF 2);
- interlaminated, occasionally calcareous, shale and wavy to lenticular siltstone to sandstone with shrinkage cracks, mud curls, and cryptalgal lamination (LF 3);
- fine grained, dune and ripple-scale cross bedded, quartzose sandstone with mud flasers or 'wisps', wave ripples, climbing ripple stratification, and platy mud rip-up clasts (LF 4);
- interbedded, wavy to lenticular to thickly laminated, very fine-grained sandstone to siltstone and shales with climbing ripple stratification, mud rip-up's, and rhythmic bedding (couplets and bundles) (LF 5);
- coarsening-up or fining-up, cross-bedded to churned sandstone and interbedded, dark grey to black shale (LF 6);
- dm-thick intervals of current bedded, diverse-biota limestones (including brachiopods, bivalves, and echinoderms) with minor admixtures of quartzose sandstone, bedding includes horizontal bedding, dune and ripple-scale cross-bedding, compound cross-bedding and low-angle inclined stratification (LF 7);

The Rock Creek Member exhibits a succession of dm- to m-thick packages for lithofacies LF 4, separated by LF 1, LF 3, LF 5, and LF 7. Some variability allows for the alternation of LF 3, LF 4, and LF 5. Overall, the succession shallows upwards with LF 3 and LF 5 more frequently present. The overlying "Niton B" sandstone is commonly characterized by a several metres thick sandstone package of LF 2. Although in places it is lithologically identical with the Rock Creek sandstones below, it is (in every core examined) distinct in two important aspects: the abundance of a green mineral phase, described previously as glauconite; and a lack of interbedding with any of the other lithofacies.

Correlation with palynological data in Losert (1990) and Kramers and Dolby (1993) indicate that both sandstones are separated by a disconformity involving a six Ma hiatus. Informally named the “Niton B” sandstone, this “glauconitic” sandstone has yielded marine palynomorphs of Oxfordian age, in contrast to Aalenian to Bajocian ages for the sandstones of the Rock Creek Member below (Losert, 1990; Kramers and Dolby, 1993; Poulton et al., 1994). The top of the Jurassic sandstone package is unconformable and is usually readily visible in core and geophysical logs because of a higher concentration of “glauconite” and intense cementation by iron sulphides and/or siderite. The uppermost sandstone typically has a several dm-thick interval of LF 2 containing abundant current bedding (3D dune-scale), and a lack of bioturbation.

Facies-diagnostic sedimentological features in the Rock Creek Member include abundant flaser and lenticular bedding, wave and climbing ripples, “couplet and bundle-like” rhythmic bedding and mud rip-up clasts. These features are typical of sedimentation influenced by tidal currents. Lithofacies LF 3, LF 4, and LF 5 are interpreted as the sub- to intertidal sand flat, the intertidal mixed flat and the inter- to supratidal mud flat of a tidal flat system. Interbedded siliciclastic bivalve coquinas (LF 1) and Inclined Heterolithic Stratification (IHS)-bedded intervals represent tidal creeks that have dissected the intertidal portion of the sand flat. The bioclastic limestones of LF 7 are related to larger, subtidal channels or the seaward portion of a tidal inlet. In combination with sporadic current bedding and low-angle inclined stratification, a middle to lower shoreface origin is inferred for LF 2 that occurs in both the Rock Creek Member and the “Niton B” sandstone. Occasionally present shale-rich and intensely bioturbated intervals of LF 6 at the base of the Rock Creek Member and the “Niton B” sandstone are consistent with deposition in the offshore transition.

Apart from mud curls and mud cracks (LF 3) in the Rock Creek Member, features attributed to vadose diagenetic conditions have also been observed in the “Niton B” sandstone. These features include: A) illuviation of clay minerals and clay-sized particles (Figure 3); B) downward tapering/bifurcating plant/root material; C) crystallaria around framework grains; and D) birefringent, circumgranular clays around framework grains. All of the aforementioned supports the idea of frequent and extended subaerial exposure for these units.

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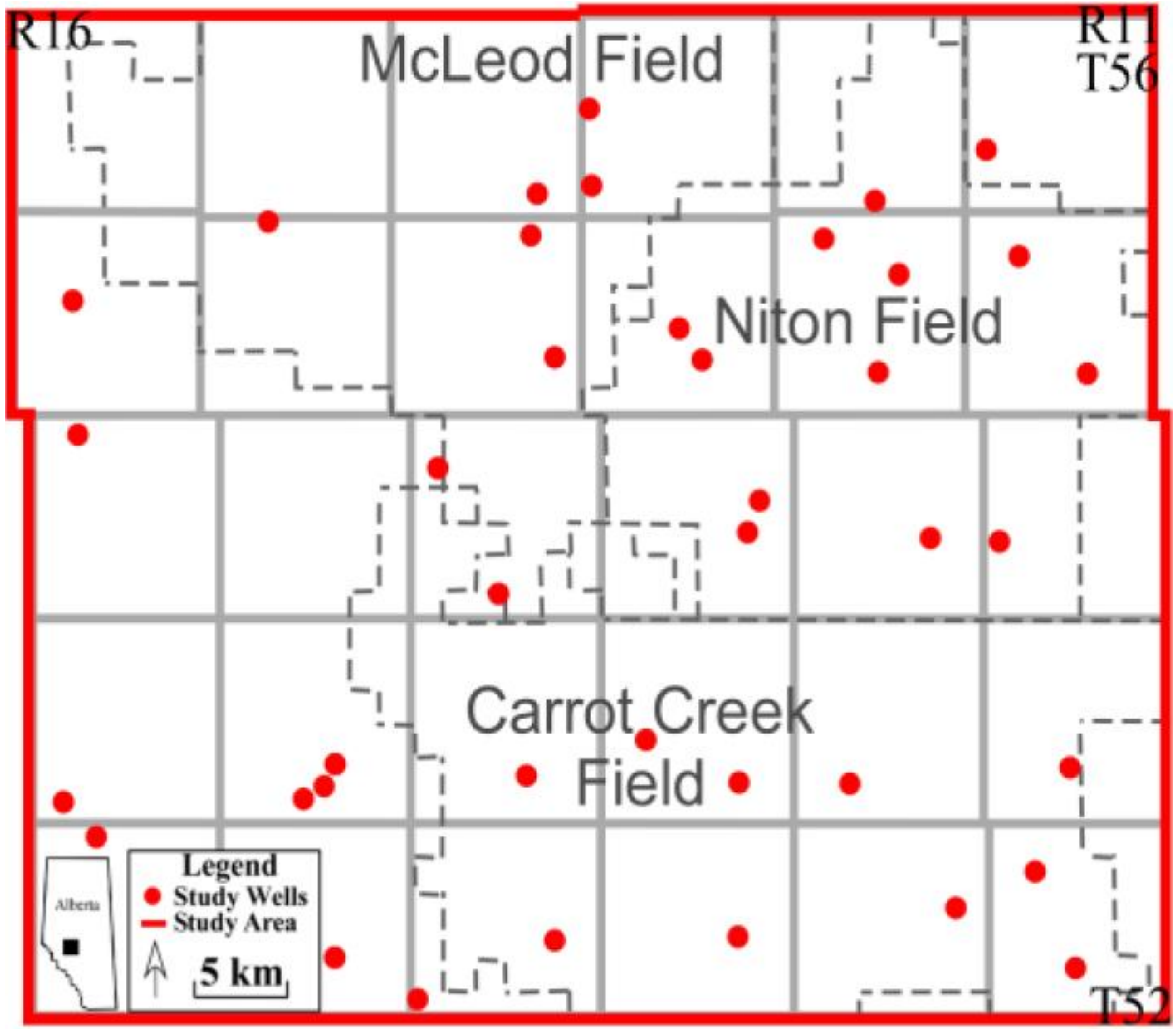

Figure 1. Outline of study area west-central Alberta. Red dots indicate cores examined for this study.

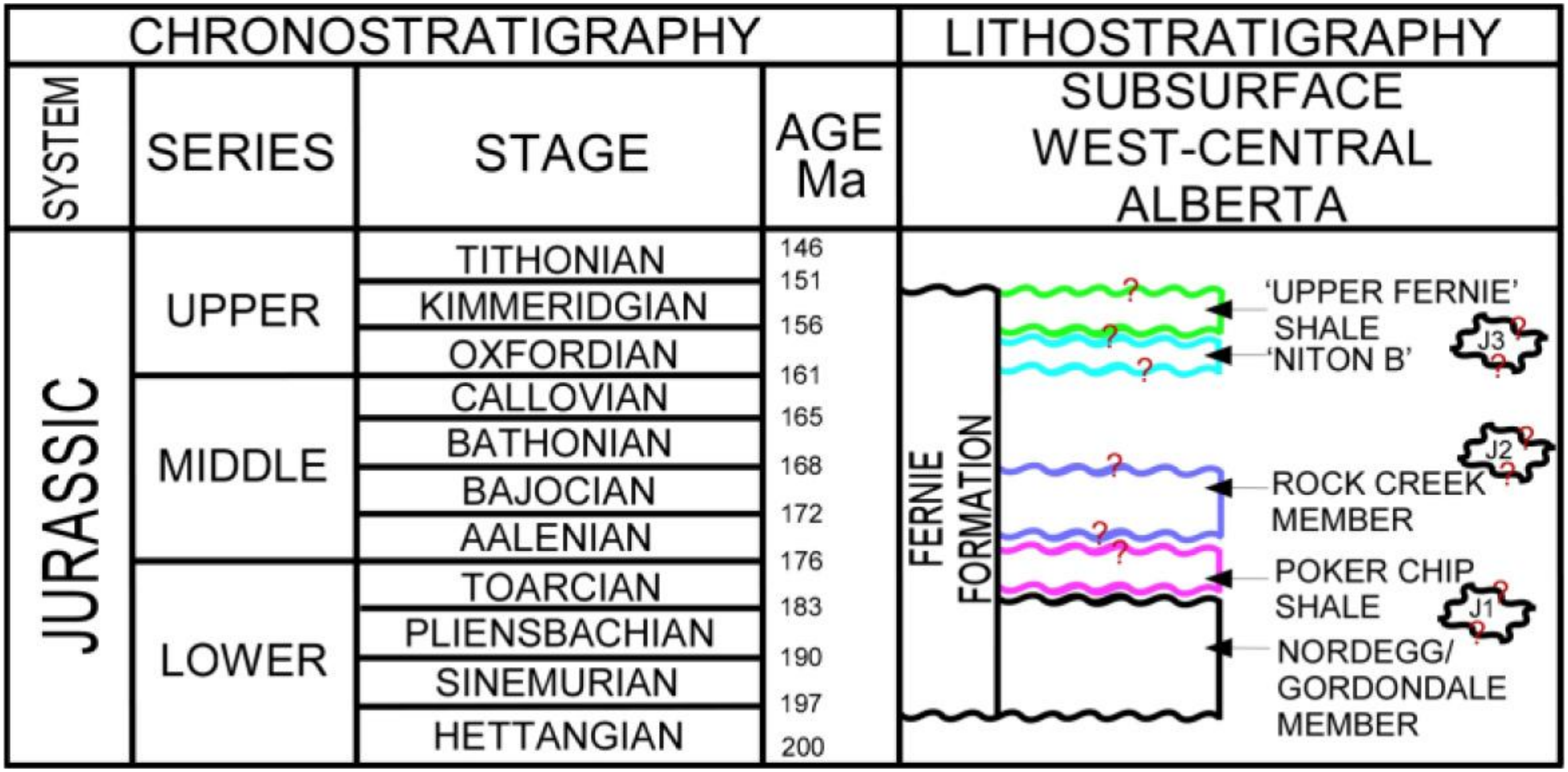

Figure 2. Summary of chrono- and lithostratigraphic relationships of Jurassic strata in west-central Alberta. Stages are not to scale and dating ranges (Ma) have been approximated with the International Commission on Stratigraphy (2009) chart. The "Niton B" sandstone may include strata as old as latest Callovian (Dolby, in Poulton et al., 1990). Compiled from Asgar-Deen et al., 2004; Hall, 2006; Losert, 1990; Poulton et al., 1994.

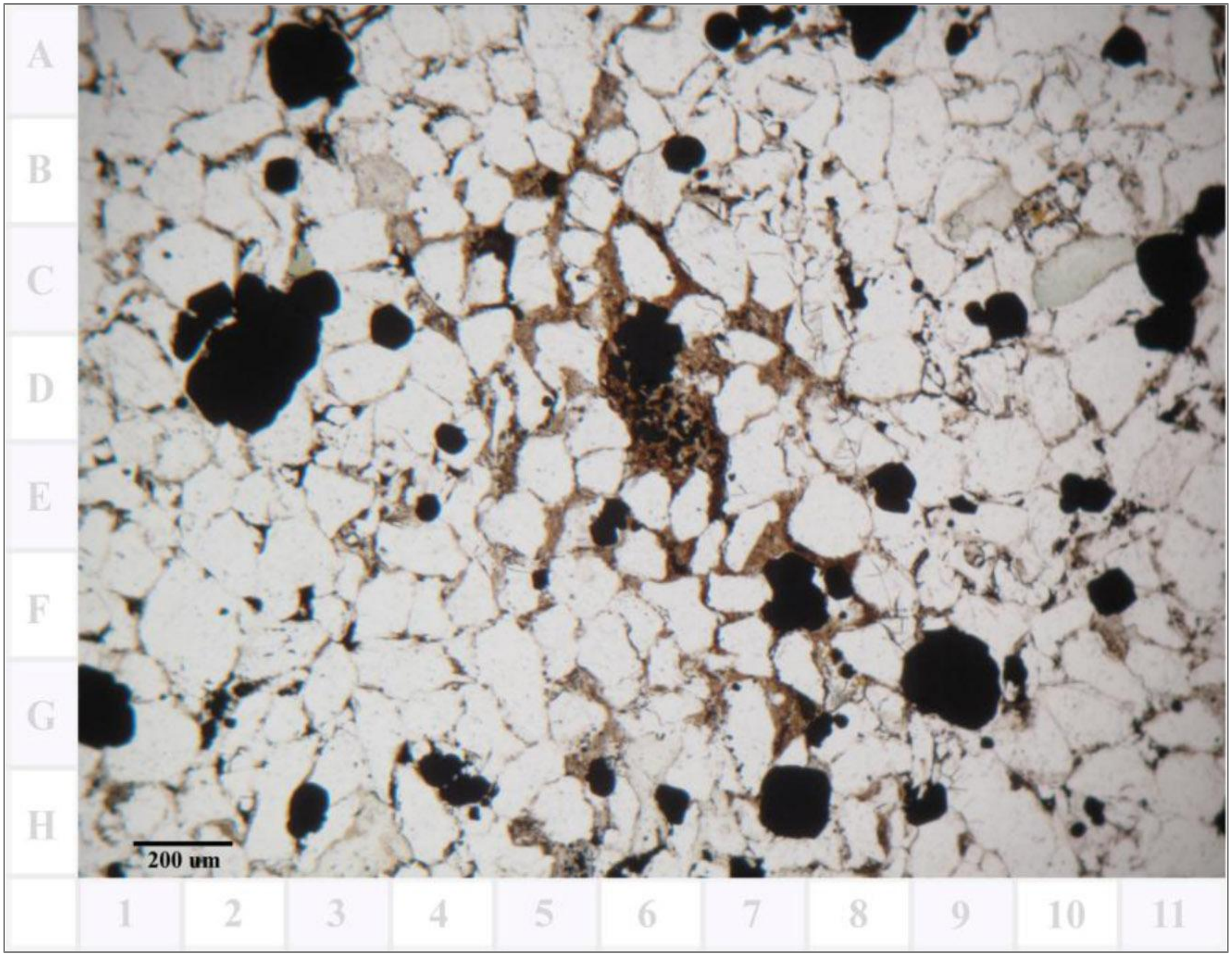

Figure 3. Clay minerals (brown) distributed in pores that outline an elongated subvertical zone of illuviation. Framework quartz grains are well cemented by syntaxial megaquartz overgrowths. Dark masses are Iron Sulphides. Lithofacies 2, “Niton B” sandstone (Sample TS2-4, 5x, PPL, well 16-4-53-15W5, at 2,363.75 m).