geoconvention
Calgary • Canada • May 12-14 2025

Sedimentologic properties and depositional environment of Late Jurassic succession of the western shelf of the Williston Basin: the Vanguard Group of Southwestern Saskatchewan

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Introduction

The Vanguard Group is a Late Jurassic sedimentary succession which accumulated in the northern shelf of the Williston Basin. The basin is an oval-shaped intracratonic depression, with a depocenter in North Dakota. It forms the southern portion of the Western Canada Sedimentary Basin and adjacent to the Alberta sub-basin (Fig. 1). The Williston Basin was intermittently connected to the Alberta sub-basin and the two regions were separated by Sweetgrass Arc (Salad Hersi and Bot. 2017a). Alternating connection and disconnection between the Williston and Alberta basins affected the depositional continuity across the arc (Kent and Christopher, 1994). The study area is located in southwestern Saskatchewan (Fig. 1) and its Jurassic succession includes red sandstone beds of Upper Watrous Formation, clastic-carbonate-evaporite strata of the Gravelbourg and Shaunavon formations and Middle Jurassic (late Bathonian) to Late Jurassic (Oxfordian) siliciclastic rocks of the Vanguard Group (Christopher 1974; Kent 1994). The Jurassic strata subcrop in southern Saskatchewan (Fig. 1) and become thicker farther southward into the neighbouring states of USA. The Vanguard Group is dominated by siliciclastic strata and lies over Shaunavon Formation of Bathonian age with a conformable contact (Christopher, 1974; Saskatchewan Ministry of Economy, 2014). The group is unconformably overlain by Success S1 Formation of Kimmeridgian age (Fig. 2).

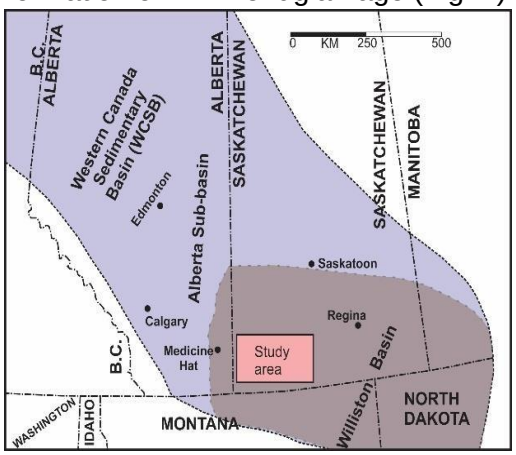

Fig. 1 The Williston Basin and its location within the Western Canada Sedimentary Basin. The study area occurs in the southwestern Saskatchewan Province.

The Vanguard Group of SW Saskatchewan consists of four formations that include Rierdon, Rush Lake, Roseray and Masefield (Fig. 2). The Rush Lake and Roseray formations are preserved in the western portion of the shelf and laterally merge to the Reirdon Fm. The latter consists of locally sandy, calcareous shale which accumulated in the deeper part of the basin. The Rush Lake Fm. appears to form as a westward-extending tongue of the Reirdon Fm. and occurs conformably under the Roseray Formation (Fig. 2). The Masefield Formation is shale which is preserved in both southwestern and southeastern regions of the province and caps the Reirdon and Roseray formations (Fig. 2)

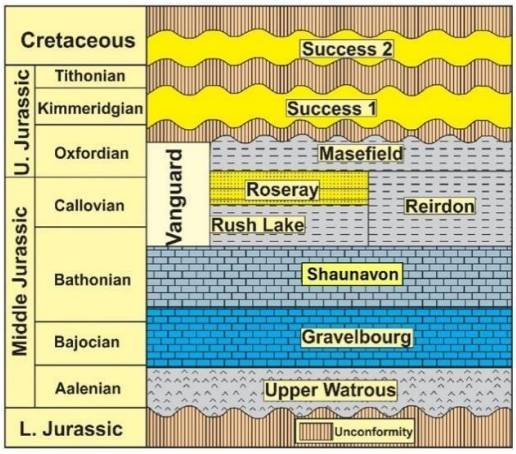

Fig. 2 Stratigraphic column of the Jurassic System of the study area. The Vanguard Group lies over the Shaunavon Formation conformably and overlain by the Success 1 Formation with unconformable contact. Redrawn from SK Stratigraphic Chart, SK Ministry of Economy (2014).

The Vanguard Group thins westward to the Alberta-Saskatchewan border. In this western region, younger Cretaceous Manville Group onlaps older late Paleozoic strata with a prominent erosional unconformity (sub-Mesozoic unconformity). This erosional unconformity is associated with deep cuts that penetrate the Jurassic strata reaching the upper part of the Shaunavon Fm. (Christopher, 1974). The formations of the Vanguard Group define a stratigraphic pattern influenced by tectonic uplifting of the Sweetgrass Arc and different events of sea level changes (Bot and Salad Hersi, 2015; Salad Hersi and Bot, 2017a, 2017b). The sandstone-dominated Roseray Formation consists of oil-producing sandstone. Besides the unit's economic interest, its porous lithologies are also deemed to be useful for subsurface Carbon Capture and Storage (CCS).

The objectives of this work are to identify the lithologic properties of the group and their depositional environments. The cores (11 wells) and wireline logs (30 wells) were analyzed (Table 1), and core samples were petrographically studied (Fig.3). Wells studied at this stage of the project does not include the Reirdon Formation. Thus, the sedimentologic properties and depositional setting of the Rush Lake, Roseray and Masefield formations are considered in this preliminary work.

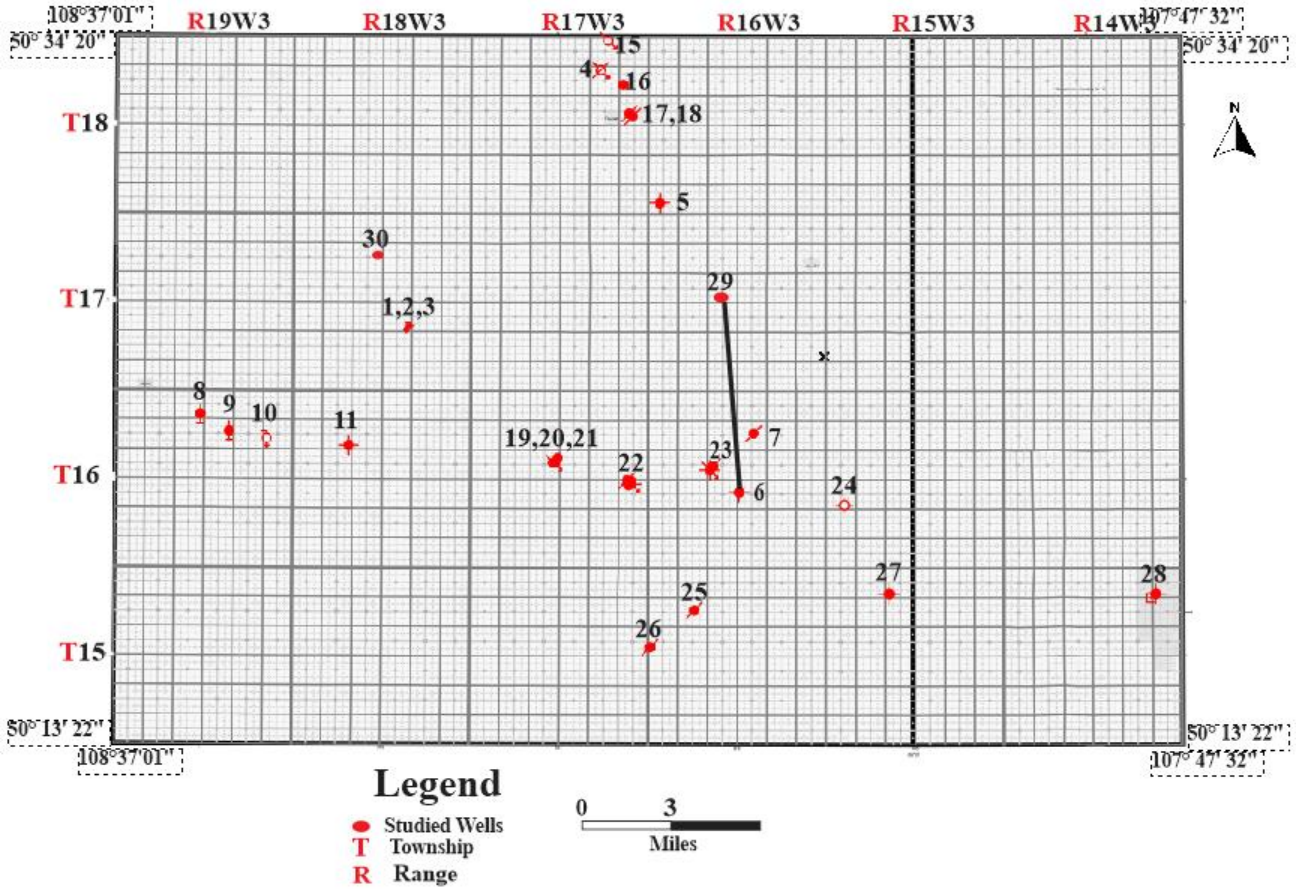

Fig. 3. Distribution of studied wells in the study area within the west of meridian 3.

Lithofacies attributes

The studied sections of the Vanguard Group allow recognition of 5 lithofacies units. Lithofacies 1 consists of two subfacies (Fig. 4A) defined by light green, locally sandy, bioturbated (*Planolites*) mudrock (F1a) and yellowish mudrock (F1b). The latter occurs at the top of the Rush Lake Fm. and its upper contact defines the contact between Rush Lake and Roseray formations (Fig. 4A). It is likely possible that the yellow color of F1b is due to weathering and exposure of the Rush Lake Fm. before deposition of the Roseray Fm. Facies 2 consists of light grey to brownish grey, medium- to coarse-

grained sandstone which varies from kaolinitic quartz arenite to quatzwacke (Fig. 4A). Facies 3 consists of oil-stained to unstained quartz arenite (Fig. 4A, 4B). The facies is highly porous and the dominant quartz grains of F3 are moderately sorted and subrounded to subangular (Fig. 4C). The sedimentary structures in F3 include thinly to thickly beds, crossbedding, flaser bedding, laminations and bioturbations. The latter includes *Ophiomorpha* and *Planolites*. Lithofacies 3 forms the bulk lithology of the Roseray Formation. Lithofacies 4 is defined as whitish kaolinite clay with subordinate planar to distorted fine sandstone layers (Fig. 4D). This facies is interbedded with facies 2 and facies 3 of the Roseray Formation. Lithofacies 5 is dominated by medium grey, horizontally burrowed shales with subordinate sandstone lenses. The latter defines lenticular bedding. This facies occurs in the Masefield Formation.

Table 1 summarizes all 30 wells, including those with both wireline logs and cores, and those with only wireline logs. See Fig. 3 for the locations of the wells.

Section	Well-ID	Cores	Wireline-logs
1	121/01-15-017-18W3	✓	✓
2	141/01-15-017-18W3	✓	✓
3	142/01-15-017-18W3	✓	✓
4	101/14-26-018-17W3	✓	✓
5	101/06-06-018-16W3	✓	✓
6	121/12-15-016-16W3	✓	✓
7	121/10-27-016-16W3	✓	✓
8	141/01-33-016-19W3		✓
9	101/09-27-016-19W3		✓
10	101/05-25-016-19W3		✓
11	101/01-29-016-19W3		✓
12	141/09-21-016-17W3		✓
13	121/09-21-016-17W3		✓
14	122/09-21-016-17W3		✓
15	101/15-35-018-17W3	✓	✓
16	101/05-25-018-17W3	✓	✓
17	111/06-24-018-17W3		✓
18	131/06-24-018-17W3		✓
19	121/09-21-016-17W3		✓
20	122/09-21-016-17W3		✓
21	141/09-21-016-17W3		✓
22	121/14-13-016-17W3		✓
23	121/05-21-016-16W3		✓
24	101/02-18-016-15W3		✓
25	121/10-29-015-16W3		✓
26	121/05-19-015-16W3		✓
27	101/04-33-015-15W3		✓
28	191/04-36-015-14W3		✓
29	122/03-21-017-16W3	✓	✓
30	141/09-28-017-18W3	✓	✓

Fig. 4 (left) A) Core photo showing the contact between Rush Lake and Roseray formations along with the various lithofacies (F1a, F1b, F2 and F3-s) present in the core. F3-s – facies 3 oil-stained, B) contact between Roseray and Maisfield formations. F3-c = clean (unstained) f3. F5 = shales of the Masefield Fm. Well 142/1-15-17-18W3. C) Thin section photomicrograph of the quartz arenite facies (F3). D) Inerbeds of F2, F3 (oil-stained) and F4.

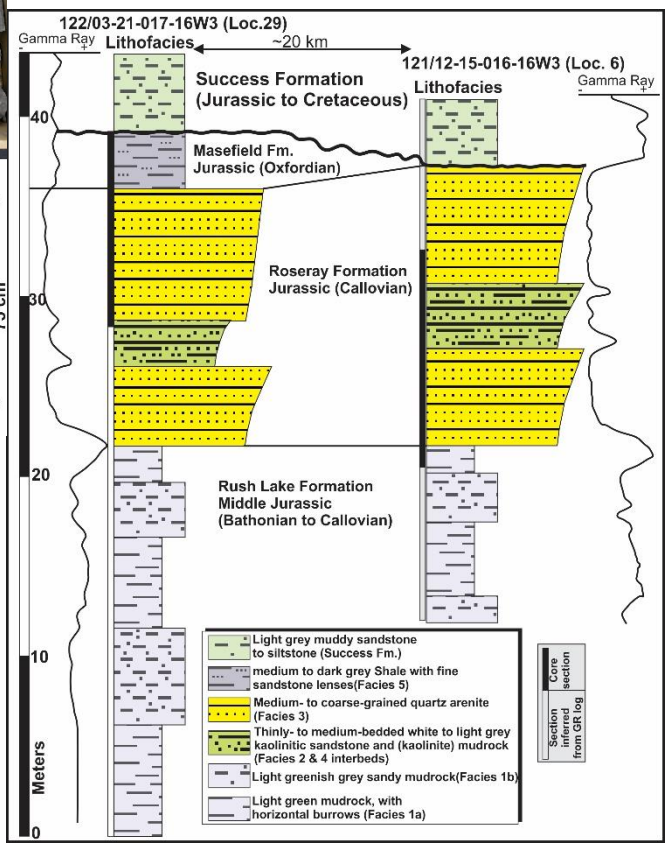

Fig. 5 (right) Lithologic correlation of the Rush Lake, Roseray and Maisfield formations from wells 122/03-21-017-16W3/00 and 121/12-15-016-16W3. Distribution of the five lithofacies of the three formations are shown. The lithologs are based on information combined from cores (black bars along the logs) and lithologies inferred from Gamma Ray logs (white bars). Note the erosional unconformity that reduces the Masefield Fm to 0 in Loc. 6.

Depositional Environment of the Formations of the Vanguard Group

The lithologic properties of the Rush Lake, Roseray and Masefield formations of the Vanguard Group in SW Saskatchewan and the stratigraphic relationships among these formations indicate significant environmental variations. The textural properties and horizontal burrows of the shales of the Rush Lake and Masefield are suggest deposition in a quiet environment of shallow subtidal setting. The Roseray Formation accumulated on the western shelf of the Williston Basin under medium to high energy shoreface setting. This is suggested by its coarse-grain texture, high energy bedforms (e.g., planar crossbedding, flaser bedding) and various degrees of bioturbations, mainly *Skolithos* and *Ophiomorpha* ichnofossils. Subordinate fine sand to silt lithofacies contain horizontal burrows (*Planolites*) suggesting localized quieter, sheltered (possibly between subaqueous dunes) depositional realm (MacEachern, et al. 2010. The stratigraphic arrangement of the Vanguard Group indicates a change from a high sea level (Rush Lake Fm.) which apparently became shallower as indicated by the possible weathered interval at the top of the Rush lake Fm. (Fig. 4A) through sea level drop (Roseray Fm.) to the return of sea level rise (Masefield Fm.).

Conclusion

The sedimentary structures and textures of the formations of the Vanguard Group suggest deposition in offshore (Rush Lake and Masefield formations) and shallow marine, medium to high energy shoreface (Roseray Fm.) depositional environments. The vertical stacking pattern of the group in the study area indicates relative sea level high during deposition of the Rush Lake Formation followed by a drop and deposition of the sandstones of the Roseray Formation. Subsequent sea level rise deposited the Masefield Fm and its accumulation a relatively deep shelf setting. Late Oxfordian relative sea level drop resulted in exposure of the shelf and development of post-Masefield unconformity. This erosional vacuity had wiped out the Masefield Formation (and possibly upper part of the Roseray Fm.) in different localities of the Williston Basin of southern Saskatchewan.

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