geoconvention
Virtual Event
September 21-23
2020
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Observations on Transgression, Regression and Sequence Stratigraphy in the McMurray Formation, Athabasca Oil Sands Area

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Summary

Most of the geological studies of the Lower Cretaceous McMurray Formation in the Athabasca Oil Sands Area have focused on Middle/Upper McMurray channel-belt deposits which contain the majority of the bitumen resource. These channel belts have eroded into the original pre-existing sediments which have not been adequately studied. This paper identifies and describes some examples of these 'pre-existing' sediments, especially from the northern, basinward limit of the Athabasca Area. The stratigraphy suggests a transgressive-regressive sequence resulting from a single 4th order cycle of sea level rise and fall. A regional Transgressive Surface at the top of the Lower McMurray and a Maximum Flooding Surface within the Middle McMurray are proposed. A transgressive sand commonly overlies the Lower-Middle McMurray contact. The Maximum Flooding Surface above this basal sand is overlain by northward prograding, upward-coarsening pro-delta and delta front deposits. With continued progradation, these were cannibalized by the advancing estuarine distributary channel system.

Observations and Conclusions

Across the entire Athabasca Oil Sands Area, there is a clear demarcation between the fluvial Lower Member of the McMurray Formation (Fig. 1) and the overlying estuarine Middle Member where the sediments contain abundant brackish water trace fossils. This contact always occurs at approximately 60 metres (varying from 50 to 70m) below the top of Wabiskaw C unit (T11 Marker) which is a marine datum across the entire Athabasca Area (Figure 1). The relatively flat, conformable, mappable contact between these two units is a Transgressive Surface signaling a sudden, regional shift in facies from fluvial to estuarine. Differentiation of the Lower from the Middle Member is generally straightforward when core is available but this important contact has not been recognized or mapped in many of the regional studies of the McMurray Formation (e.g., AEUB, 2003).

The approximate distribution of the Lower Member and the lower 10 metres of the Middle Member is shown in yellow in Figure 2. This represents the area of initial transgression of the Middle Member and the area where the lowermost Middle Member sediments are present.

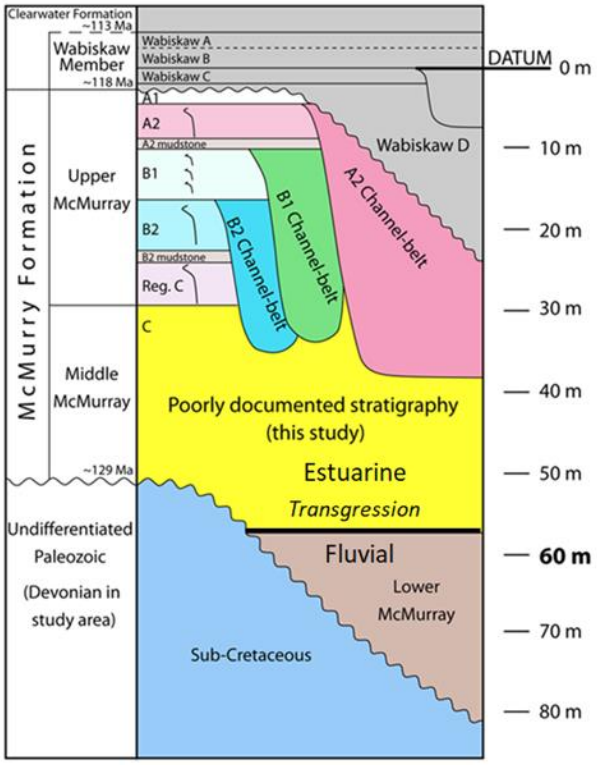

Figure 1.Stratigrahic framework of the McMurray Formation. Modified from Martin (2018) and AEUB (2003).

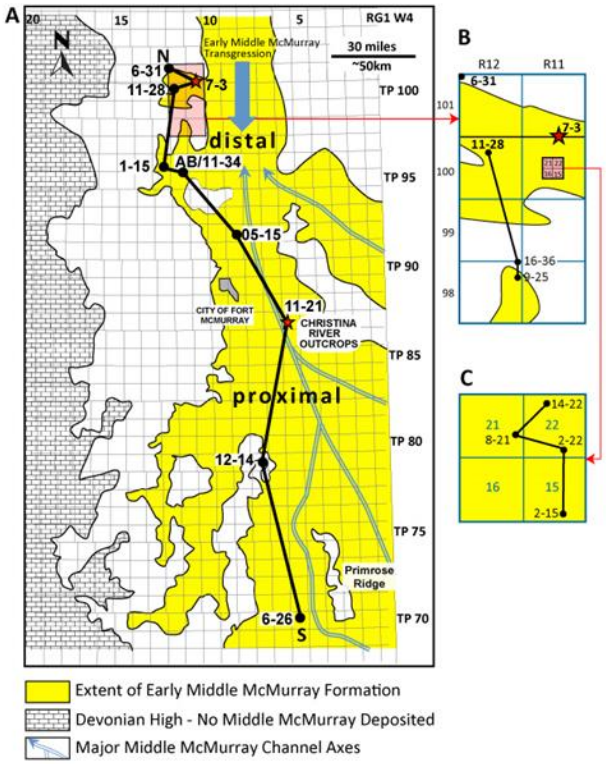

Figure 2.McMurray Formation paleogeographic map at the time of the initial Middle Member transgression (Top of Lower Member).

In the far north of the Athabasca Oil Sands Area (near 'N' of Fig 2A), the Middle McMurray is, in places, composed of upward-coarsening units, up to 20 metres or more in thickness, overlying clean sands of variable thickness at the base (Figures 3, 4 and 5; locations are shown on Figure 2A, B and C). Dip meter data confirm many of these upward-coarsening successions are single genetic units (Fig. 3), indicating deposition into water at least 20 metres deep. Abundant mud couplets in the upward-coarsening units (Fig. 3E) indicate a tidal influence. The upward-coarsening units are interpreted as tidally-influenced pro-delta and delta front sediments which prograded into relatively deep brackish water in Middle McMurray time, following the transgression. The basal Middle McMurray sands in Figures 3, 4 and 5 are interpreted as estuarine tidal sands deposited during the initial transgression. The overlying mudstone interval was deposited as water deepened and a Time of Maximum Flooding (TMF) occurred across the basin when transgression reached its maximum. The TMF is coloured dark green in Figures 4 and 5. A late McMurray channel has removed this pre-existing sequence in well 2-22 (Fig. 4).

In many other areas of Athabasca, a clean sand up to 10 metres thick at the base of the Middle McMurray grades up to mudstone which is overlain by upward-coarsening units, similar to these examples shown from north Athabasca. An example of this is seen in outcrop at the Christina River southeast of Fort McMurray (Figure 6). The thick bedded sands at the base of the Middle McMurray which are exposed in outcrop contain numerous tidal structures including bioturbated

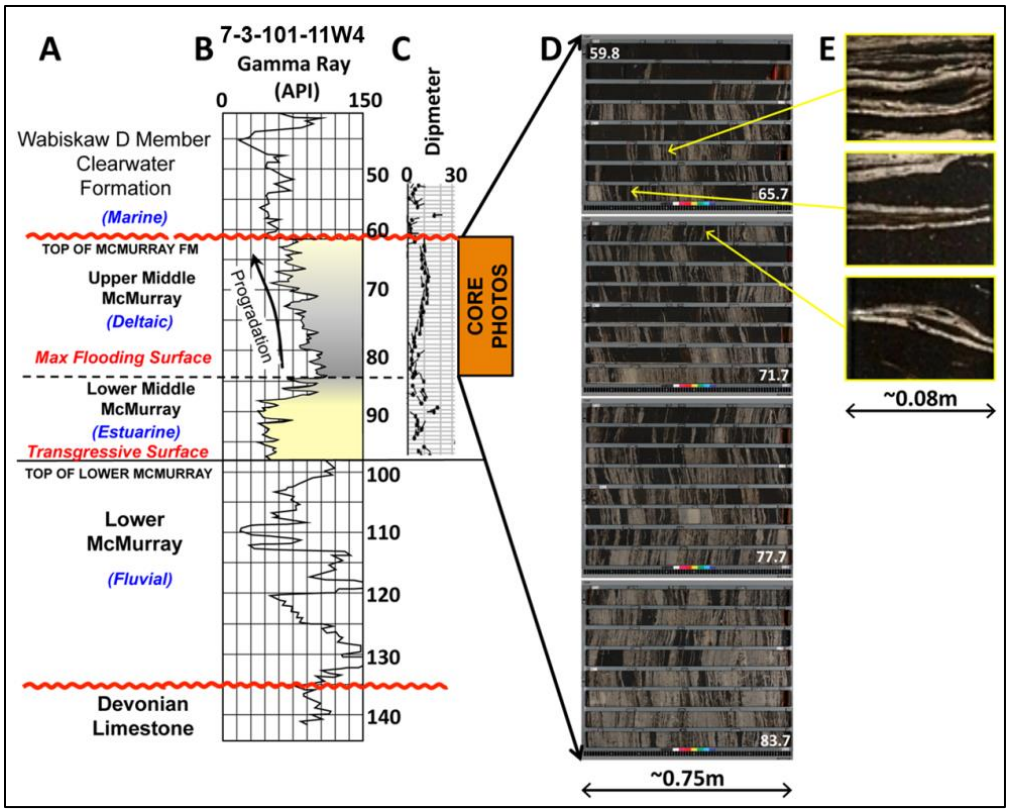

Figure 3. Well 7-3-101-11W4. See location in Fig. 2. A) Interpreted formation tops, stratigraphic units and surfaces; B) gamma ray log; C) Dipmeter tad pole data; D) Core image with depths; E) close-up images showing tidal mud couplets.

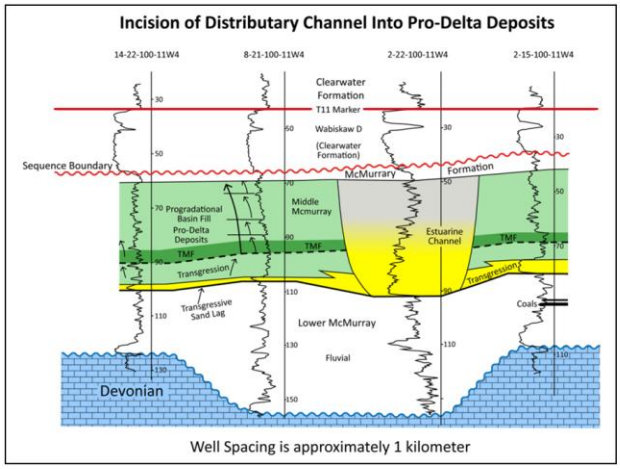

Figure 4. A cross-section of wells from north Athabasca. See location in Fig 2C.

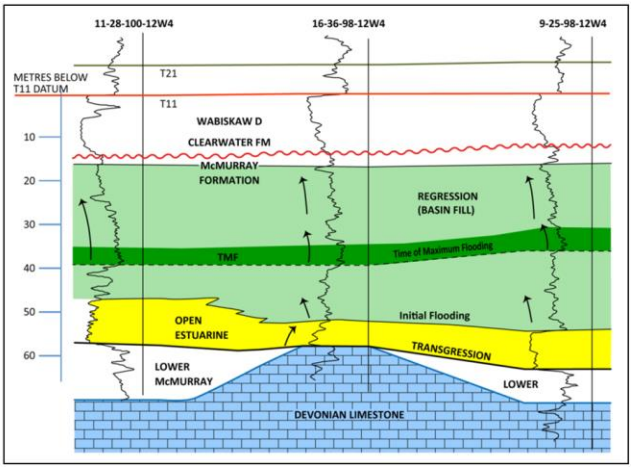

Figure 5. A cross-section of wells from north Athabasca . See location in Fig 2B.

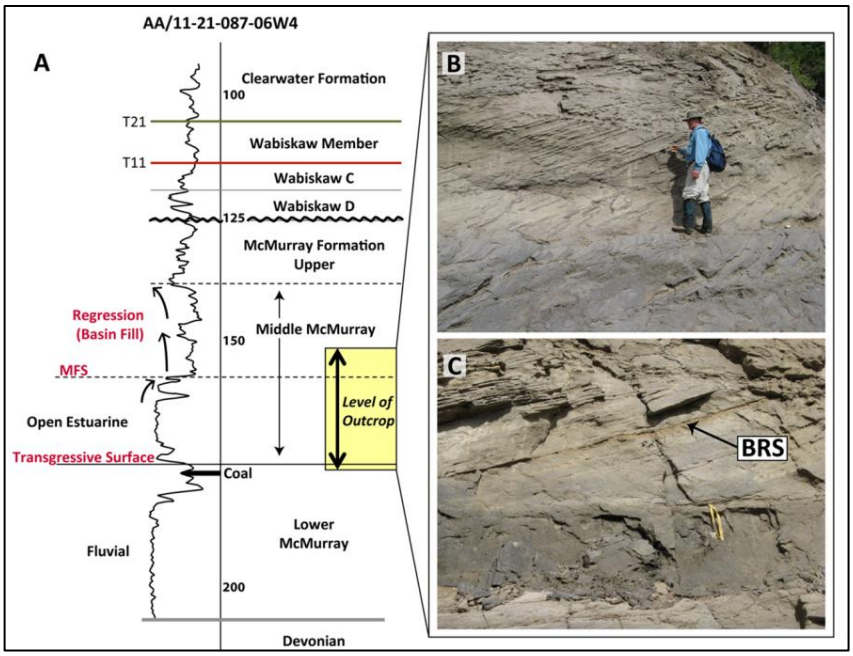

Figure 6. A) Well log of AA/11-21-087-06W4, located approximately 7.5 km from the Christina River outcrop (location in Fig. 7). B-C) Images of Christina River outcrop. Note up to 2m thick bedding and bioturbated reactivation surface (BRS).

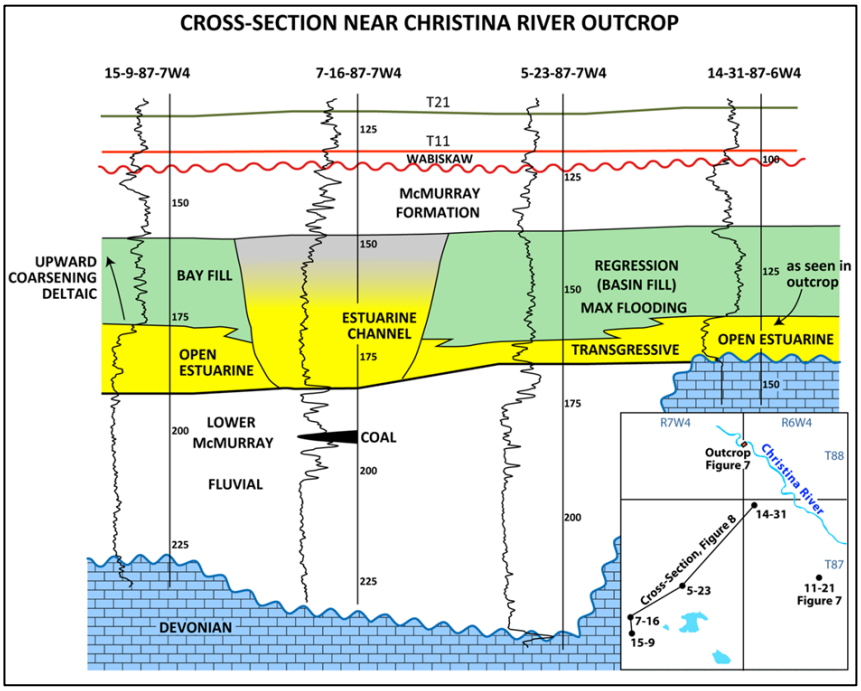

Figure 7. Cross-section in vicinity of Christina River outcrop of Figure 6. See regional location in Fig. 2.

reactivation surfaces, cross strata on dipping master bedding planes, herringbone cross-strata and ripples climbing up the foresets of cross-strata. These sands directly overlie coal-bearing, continental Lower McMurray sediments. Figure 7 shows a similar succession in wells near this outcrop, as well as a late McMurray channel deposit which replaces the original pre-existing sediments (7-16 well in Fig. 7).

Based on the outcrop evidence, the sands at the base of the Middle McMurray are interpreted as open-estuarine tidal sediments deposited during transgression. They are overlain by a mudstone-dominated interval which is interpreted as representing the Time of Maximum Flooding in the lower to middle part of the Middle Member. In places, this mudstone is upward-coarsening in character, representing deltaic progradation into the Middle McMurray basin.

The sequence of basal Middle McMurray transgressive sand grading up to mudstone and overlain by upward-coarsening deltaic units is present across the length of the Athabasca Oil Sands Area (Fig. 8). The sequence is interpreted as being the result of a single 4th order cycle of sea level change within the overall Aptian-Albian transgression (Fig. 9).

The continental deposits of the Lower Member represent the Lowstand Systems Tract and the beginning of the Transgressive Systems Tract. As the **rate** of sea level rise increased and reached its maximum during the transgression, a continental-sized drainage system flowing north was overpowered by sea level rise and an open estuarine environment was formed. Transgressive sands at the base of the Middle McMurray were deposited on top of the Lower Member floodplain surface. This brackish flooding due to transgression occurred as a rapid pulse that reached far south in a short period of time. As the water deepened, creating a large brackish bay, the mudstone representing the time of maximum flooding was deposited. As the **rate** of sea level rise decreased, sediment supply from the large fluvial system from the south became dominant, resulting in basin infilling and sediment progradation to the north. This event marked the beginning of the Highstand Systems Tract. The progradation is manifested by contemporaneous deposition of upward-coarsening deltaic deposits in distal areas and channel-belt deposits of advancing distributary meander belts in proximal parts. Progradation continued through the Middle McMurray until the 20 to 30 metre deep brackish bay basin was filled and the deltaic deposits were largely reworked by the advancing meandering distributary channel-belts.

In Upper Member time, deposition of brackish bay-fills and channel-belt deposits continued and laterally persistent upward-coarsening units are common, especially in the southern part of the deposit (Ranger and Pemberton, 1997; Baniak and Kingsmith, 2018). These Upper Member progradational deposits are thinner than Middle Member counterparts because of the slower sea level rise and low accommodation space. Within the main channel belt, the coarsening upward successions are frequently not preserved. At the end of McMurray Formation time, sea level fall brought an end to this 4th order sequence and the beginning of deposition of the Wabiskaw D Member of the Clearwater Formation above the sequence boundary.

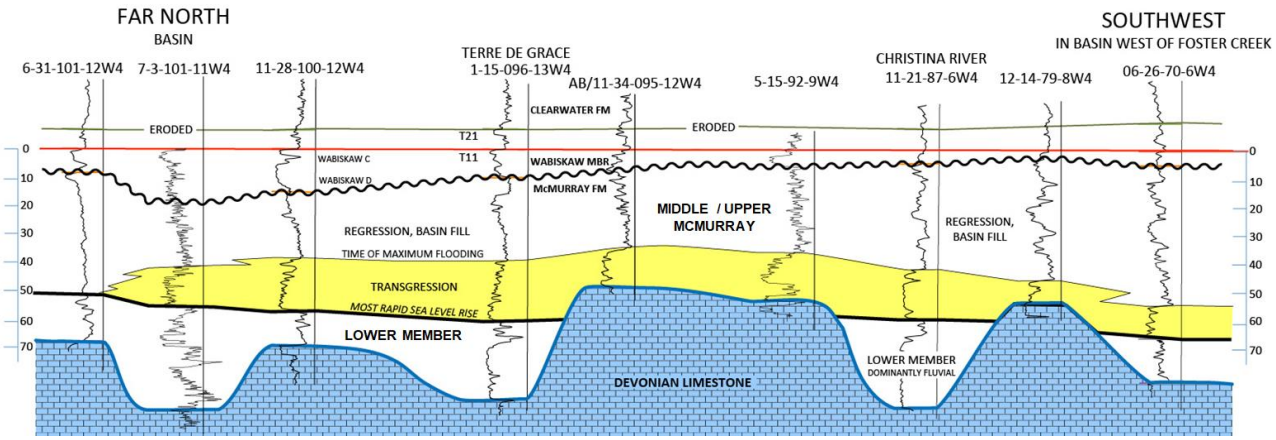

Figure 8. Regional north-south cross-section of the McMurray Formation. Well locations are shown on Figure 2.

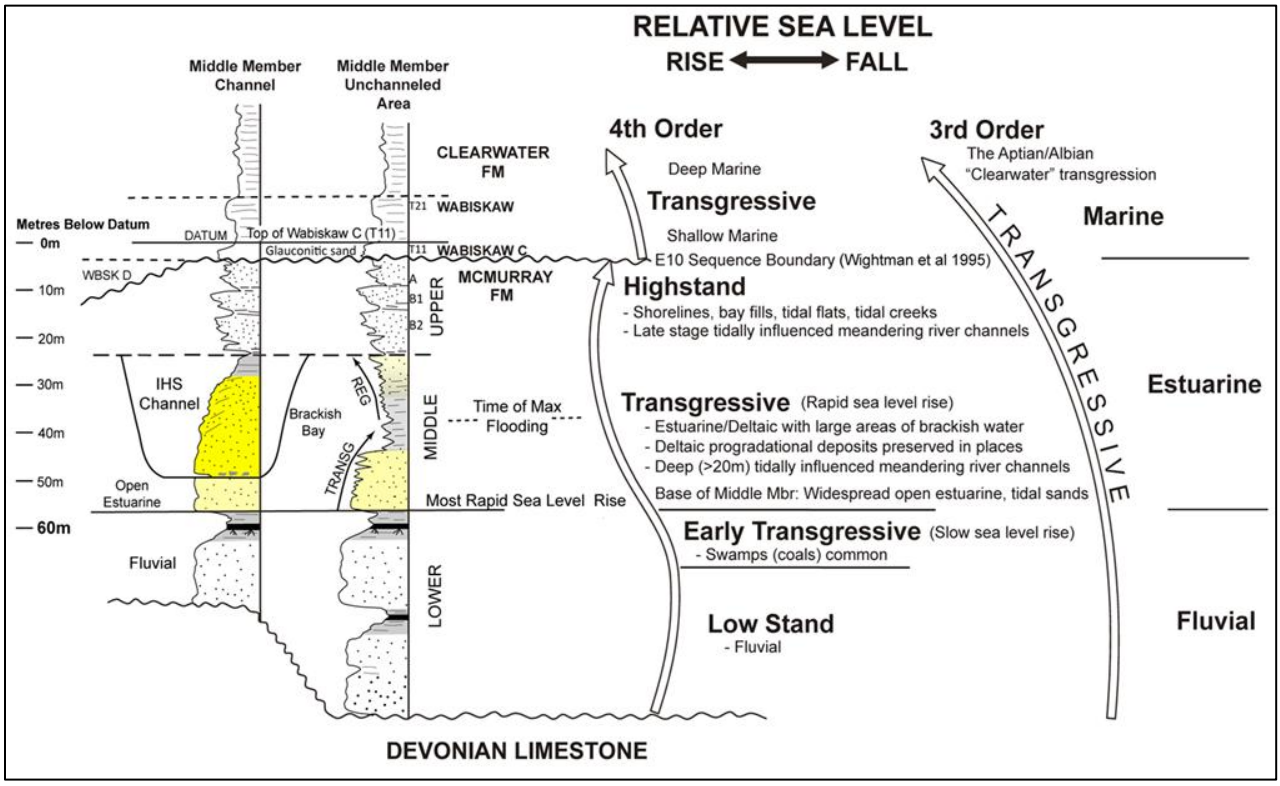

Figure 9. Conceptualized schematic stratigraphy and sequence stratigraphy of the McMurray Formation (modified after Flach and Hein, 2001)

We propose that the regional correlation of a Transgressive Surface (the top of the Lower Member) and a Maximum Flooding Surface (in the middle of the Middle Member) are possible, especially in the peripheral parts of the system. These surfaces can be correlated into the more central parts of the Main Valley, especially where reworking of the sediments was curtailed.

Final Comment

When the senior authors first studied the outcrops of the McMurray Formation, it seemed odd that the obviously tidal deposits at Christina River (Fig. 6) were south (landward) of typical outcrop exposures such as at the Steepbank River (Mossop and Flach, 1983; Jablonski and Dalrymple, 2016) where the sediments were deposited by fluvially-dominated meandering channels with brackish water indicators but little or no tidal influence. We thought that the sediments would become more tidal and then more marine as one moved seaward to the north. We now propose that the tidal sediments at Christina River are part of the early Middle Member transgression whereas the channel deposits of the Steepbank River (60 kilometres seaward) and elsewhere are part of the later fluvially-dominated regression which removed much of the 'pre-existing' Middle Member sediments in the Main McMurray Valley.

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