Estimation of Source-To-Sink Mass Balance by a Fulcrum Approach Using Channel Paleohydrologic Parameters of the Cretaceous Dunvegan Formation, Canada*

Wen Lin¹ and Janok P. Bhattacharya¹

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¹SGES, McMaster University, Hamilton, Ontario, Canada (linw33@mcmaster.ca)

Abstract

Trunk rivers transport the bulk of the sediment in a source-to-sink (S2S) system, and total mass passing through any cross section (i.e., fulcrum) of a trunk river over geologic time should allow matching of source area sediment delivery budgets, to the downstream sediment volumes deposited in the basin. We analyze the paleohydrology of ancient trunk channels and linked downstream deltaic strata of Allomember E of the Cretaceous Dunvegan Formation in the Western Canadian Sedimentary Basin to test the total mass balance fulcrum approach. Bankfull channel depth and width, grain size, paleoslope, velocity, and discharge are derived from outcrop, core, and well logs. Some parameter estimates use multiple methods providing a range of values and serving as a cross check of independent methods. Annual flood frequency and paleodischarge estimates, associated with long-term geologic time estimates, are derived from chronostratigraphic analysis and allow cumulative sediment discharge calculation. Isopach maps are used to estimate sink area sediment volumes. The results indicate that the trunk river of Allomember E was 10-20m deep and 150-250m wide, carried fine to medium-grained (average 180 microns) sand and flowed over a low-gradient paleoslope of 10^-5. Annual total sediment discharge is estimated to range from 2.6×10^6 to 8.4×10^6 m^3. Within 70,000 to 100,000 years, the river is estimated to have transported 1.83 ×10^11 m^3 – 8.39 ×10^11 m^3 of sediment into the basin. This is consistent with the 1.1×10^11 m^3 of sediment documented in the sink area. However, the upper range estimate of sediment delivered into the sink is up to 8 times the measured sediment volumes, which, if accurate, suggests significant sediment escape. This supports the hypothesis that in Dunvegan time, mud was widely dispersed southward, along the Alberta Foreland Basin by geostrophic currents associated with storm processes and counterclockwise oceanic gyres in the Cretaceous Seaway.

References Cited


Bhattacharya, J.P., P. Copeland, T.E. Lawton, and J. Holbrook, 2016, Estimation of source area, river paleo-discharge, paleoslope, and


**Methodology**

The total sediment volume produced from the catchment should match the volume accumulated in downstream sinks in an ideally closed Source-To-Sink (S2S) system. The total mass passing through any cross section over a given time should match both the sediment delivered from the catchment and the sediment volume passing forward to the sink. The cross section in the sediment routing system acts as a ‘fulcrum’. The largest-scale incised trunk rivers and serve as key fulcrum points. The fulcrum approach requires calculating the instantaneous paleodischarge in trunk rivers and serve as key fulcrum points.

**Figure 3. Paleogeographic map of valleys and lowstand deltas in the Upper Cretaceous Dunvegan Formation, Alberta Foreland Basin, Canada using a combination of outcrop and subsurface data.**

**Results**

The total sediment volume produced from the catchment should match the volume accumulated in downstream sinks in an ideally closed Source-To-Sink (S2S) system. The total mass passing through any cross section over a given time should match both the sediment delivered from the catchment and the sediment volume passing forward to the sink. The cross section in the sediment routing system acts as a ‘fulcrum’. The largest-scale incised trunk rivers and serve as key fulcrum points. The fulcrum approach requires calculating the instantaneous paleodischarge in trunk rivers and serve as key fulcrum points.

**Introduction**

The annual sediment delivery to the delta can be estimated using the following equation:

\[ Q_{mas} = Q_{tsb} \times \frac{7.3}{25\%} \]

**Figure 1. Paleogeographic map of valleys and lowstand deltas in the Upper Cretaceous Dunvegan Formation, Alberta Foreland Basin, Canada using a combination of outcrop and subsurface data.**

**Figure 2. Cumulative Sediment Load.**

**Figure 3. paleogeographic map of valleys and lowstand deltas in the Upper Cretaceous Dunvegan Formation, Alberta Foreland Basin, Canada using a combination of outcrop and subsurface data.**

**Figure 4.** The map well portrayed the lobate feature of river-dominated deltaic deposition.

**Figure 5.** The map is used for volumetric assessment of sediment accumulation down-dip to the fulcrum point. 3.5 x 10^11 m^3 of total sediment volume of Allomember E was deposited in Parasequence E1. Dash lines were extended from original contours based upon the depositional configuration and progradational characteristics of Allomember E. The map also allows sandy sediment volume calculation of the Dunvegan delta deposit.

**Figure 6.** The map is used for volumetric assessment of sediment accumulation down-dip to the fulcrum point. 3.5 x 10^11 m^3 of total sediment volume of Allomember E was deposited in Parasequence E1. Dash lines were extended from original contours based upon the depositional configuration and progradational characteristics of Allomember E. The map also allows sandy sediment volume calculation of the Dunvegan delta deposit.

**Figure 7.** The map is used for volumetric assessment of sediment accumulation down-dip to the fulcrum point. 3.5 x 10^11 m^3 of total sediment volume of Allomember E was deposited in Parasequence E1. Dash lines were extended from original contours based upon the depositional configuration and progradational characteristics of Allomember E. The map also allows sandy sediment volume calculation of the Dunvegan delta deposit.
Discussion

The upper range estimate of sediment delivered from the source is 3 times the measured sediment volume in the sink area, which if accurate, would suggest significant sediment escape (Bhattacharya et al., 2016). This supports the hypothesis that in Dunvegan time, mud was widely dispersed southward along the Alberta Foreland Basin by geostrophic currents associated with storm processes and counterclockwise oceanic gyres (see Plint et al., 2009).

Errors and Uncertainties

The fulcrum approach involves a number of uncertainties, including field measurements, numerical assessments used to estimate paleohydrologic parameters, paleomorphodynamics derived from stratigraphic records, applicability of empirical equations, chronologic estimates, and modern analogue data selection. The integration of these variables constrain the accuracy of sediment volume estimation to at worst, one order of magnitude (see discussion in Holbrook and Wanans, 2014; Hajek and Wolinski, 2012; Bhattacharya et al., 2016).

The most sensitive error is related to annual discharge estimate, and can show an error of an order of magnitude.

Paleodischarge of the ancient trunk river was estimated to be in the range of 1.5 – 3.5 x 10^3 m^3/s and this is in agreement with the discharge of the Rhine River (approximately 3.5 x 10^3 m^3/s), which represents a likely modern analogue for the Dunvegan trunk river as is also suggested by Davidson and North (2009).

The bedload in the trunk river of Allomember E is about 3% of the total sediment load, suggesting low shear stress due to the low gradient. This may also indicate that a significant amount of sandy sediments were transported as suspended load.

The correlations between estimated drainage basin area and sediment load and sediment yield suggests that the Dunvegan E1 trunk fluvial system may be categorized as a moderate-sized mountain river drainage system (Milliman and Syvitski, 1992).

### References


