

PS A Biomarker Review of the Palaeoecosystem and Palaeodepositional Environment of the Bakken Shales of Saskatchewan*

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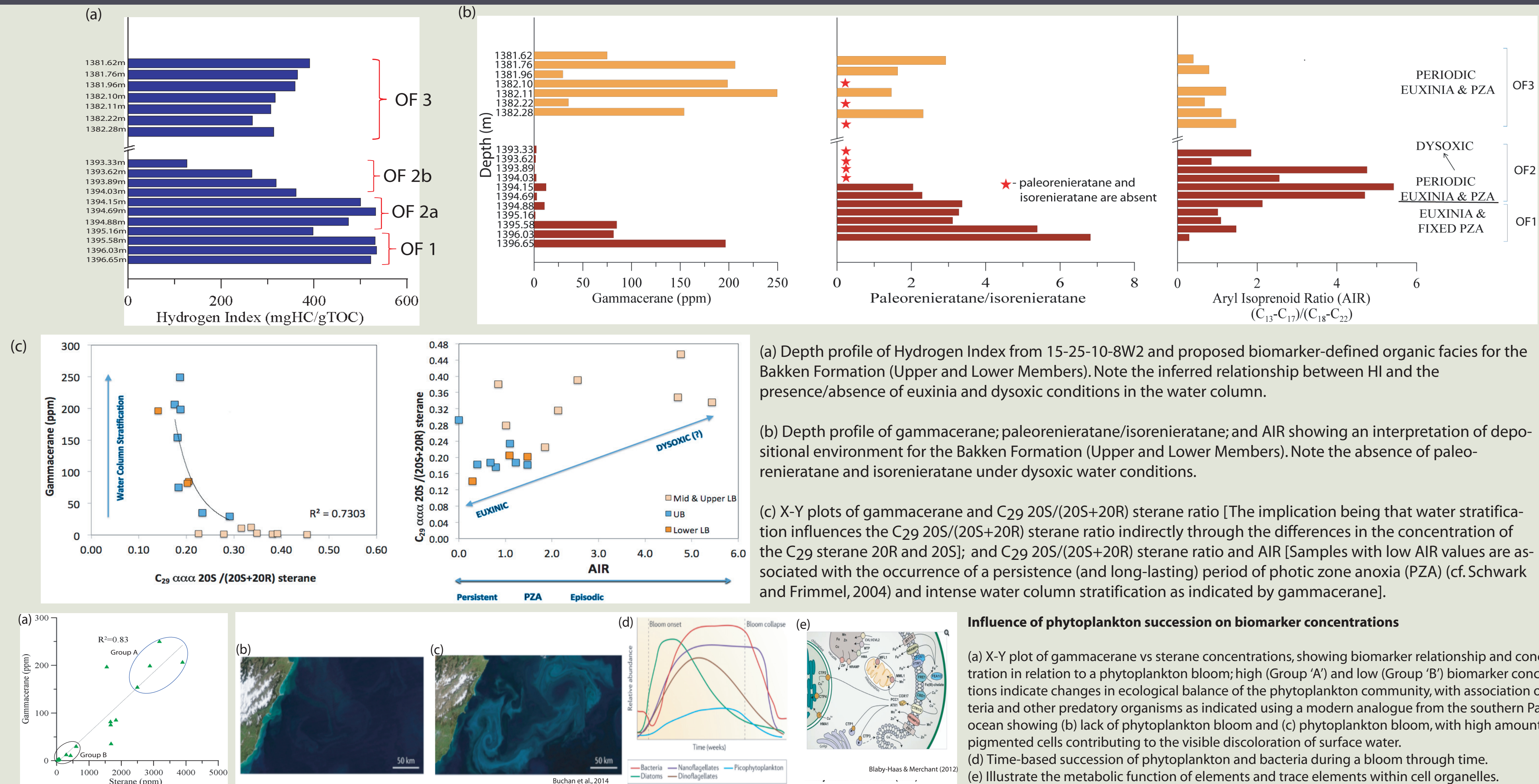
Abstract

This study presents a detailed source characterization in relation to depositional condition during the deposition of the Bakken shales, using a biomarker approach. The geochemical characteristics for the Bakken shales is investigated using core samples to conduct a depth biomarker profile, examining the organic matter input and depositional markers within the Bakken shales in the northern part of the Williston Basin. The Bakken shales are reported to consist mainly of Type II kerogen, with some distinct molecular ‘fingerprints’ associated with their organic inputs and depositional environment. These molecular discriminants distinguish the Bakken shales from other sources within the Williston Basin and employed as a means to trace Bakken oils, identify migration pathways and also to define petroleum systems. Results from this study suggest a significant variation in concentration of steranes, hopanes and gammacerane within a single borehole and when compared spatially. The geochemical trend is such that it can be correlated when compared for several boreholes across Saskatchewan. The results reveal the presence of more than a single source facies within the Lower Bakken shales. The top section of the Lower Bakken shale imply a dysoxic condition, hosting a number of phytoplankton communities including algae and cyanobacteria while the other half through the base of the Lower Bakken suggests the presence of water column stratification, associated with photic zone euxinia, the presence of green sulphur bacteria and ciliates. This is evident from the high concentrations of gammacerane, presence of aryl isoprenoids and isorenieratane. Similar variations were noted for the Upper Bakken shale, although these variations were irregular. Based on these analyses, a generalized characteristic is inapplicable to correlate the Bakken shale. The Type II kerogen within the Upper and Lower Bakken shales are maceral assemblages consisting of a number of biological entities and not a single organic matter Type, as defined by bulk pyrolysis parameters. This study identified a number of molecular fingerprints, associated with multiple source facies within the Bakken shale. This study not only provide an understanding of heterogeneity in hydrocarbon potential for the Bakken shales but also documents a number of characteristics useful for oil to source correlation studies as well as defining an accurate petroleum system.

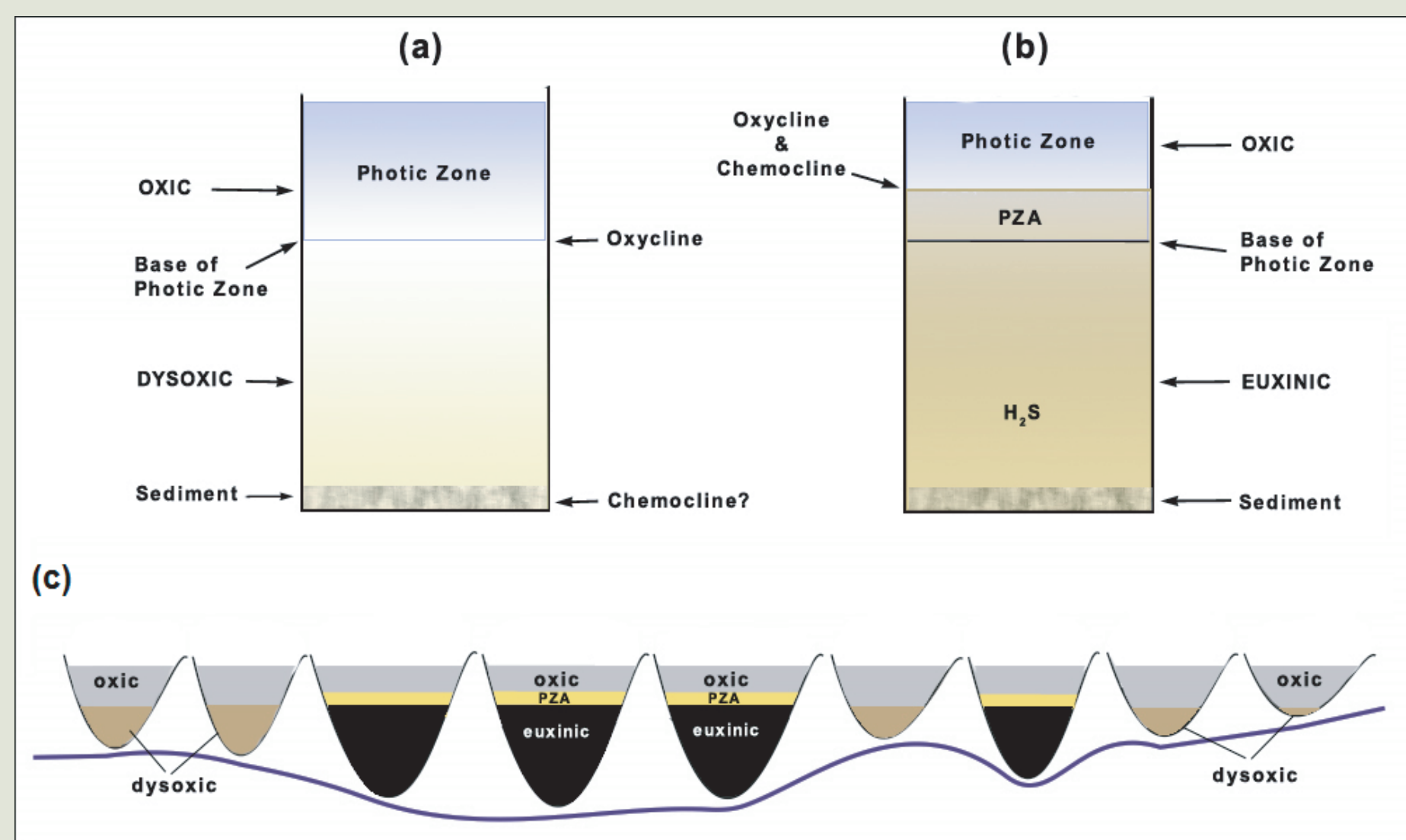


A biomarker review of the palaeoecosystem and palaeodepositional environment of the Bakken shales of Saskatchewan (Part II)

A biomarker interpretation of depositional environment within the Upper and Lower Bakken Formation shale



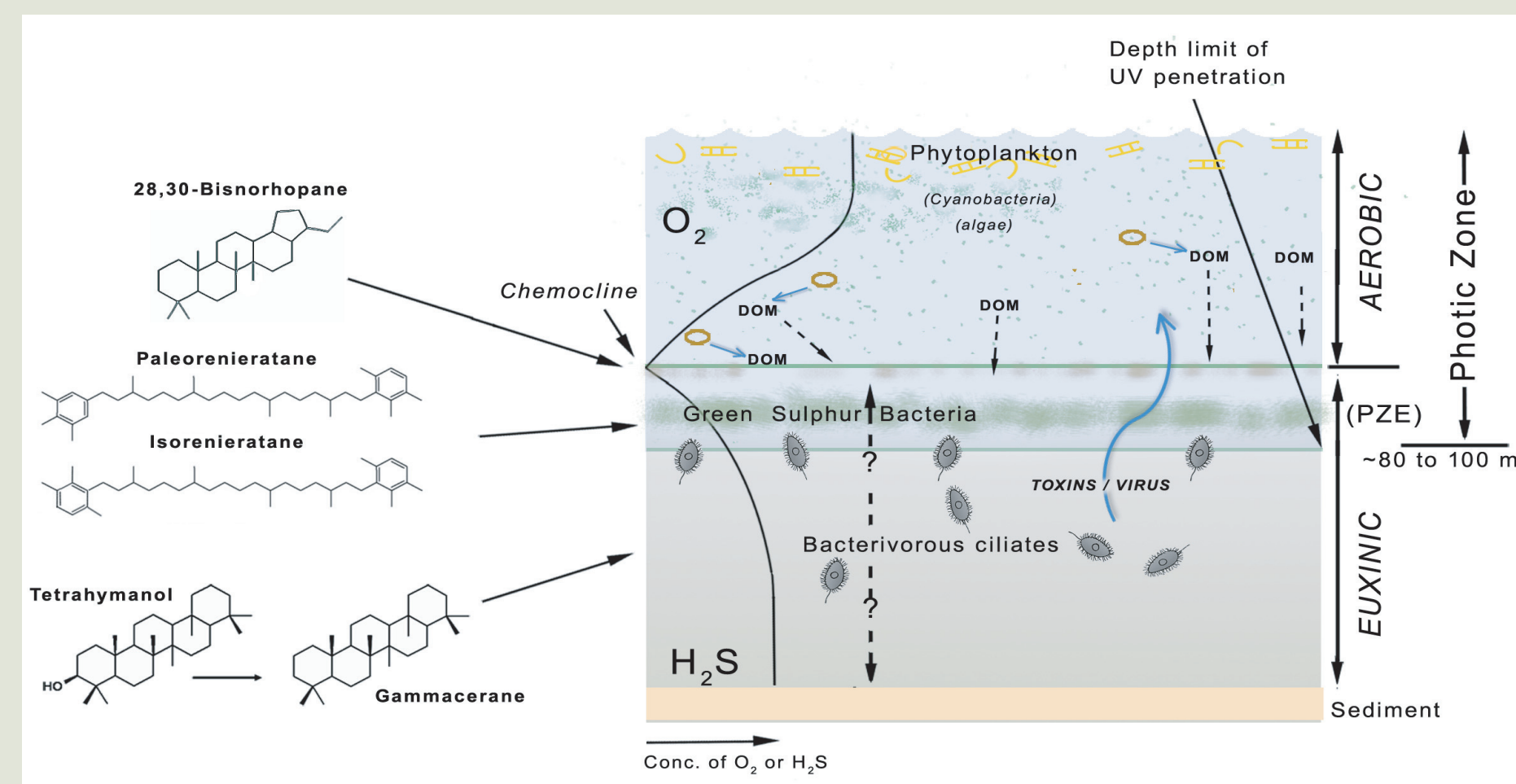
Schematic of depositional environment



Proposed palaeo-depositional model for the Upper and Lower Bakken Member

- (a) Palaeo-water conditions showing the absence of euxinia and the absence of PZA with the chemocline located within the sediment
- (b) Palaeo-water conditions with highly stratified water under euxinic conditions, with the presence of a PZA and the chemocline within the PZA
- (c) A schematic showing variations in palaeo-water depth that influences the redox conditions during deposition, which in turn impacts the OM characteristics within the Bakken shale in SK

Palaeo-ecological relationship based on biomarker associations



Schematic of palaeo-water and palaeo-ecology (relationship between phytoplankton-GSB-bacterivorous ciliates) based on the occurrence and distribution of key biomarker compounds

CONCLUSIONS

- The Upper and Lower Bakken Members exhibit variations (depth/spatial) in source characteristics.
- Differences in source characteristics reflect variation in organic input and redox conditions within the palaeo- water column during deposition.
- Three biomarker-defined organic facies are proposed using key biomarker associations.
- Inferences from biomarker associations and trace element abundance indicates the presence of a dynamic depositional environment, ranging from dysoxic to euxinic with the absence/presence of PZA.
- A biomarker-defined palaeo-ecological association of organisms is presented for the Bakken Fm (U & L Members).

A biomarker review of the palaeoecosystem and palaeodepositional environment of the Bakken shales of Saskatchewan (Part I)

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Research goals and objectives

The overall research goal is to integrate organic and inorganic geochemistry to provide an understanding of the depositional environment and palaeoecology within the Upper and Lower Bakken Formation shale.

The specific objectives include:

- Examine the spatial and temporal variation in geochemical characteristics within the Upper and Lower Bakken
- Examine the occurrence and distribution of biomarkers within a high resolution depth profile through the Upper and Lower Bakken
- Examine the occurrence and distribution of key trace element within the Upper and Lower Bakken
- Provide a palaeodepositional environment model that explains the variation in source potential within the Upper and Lower Bakken

Research Methodology

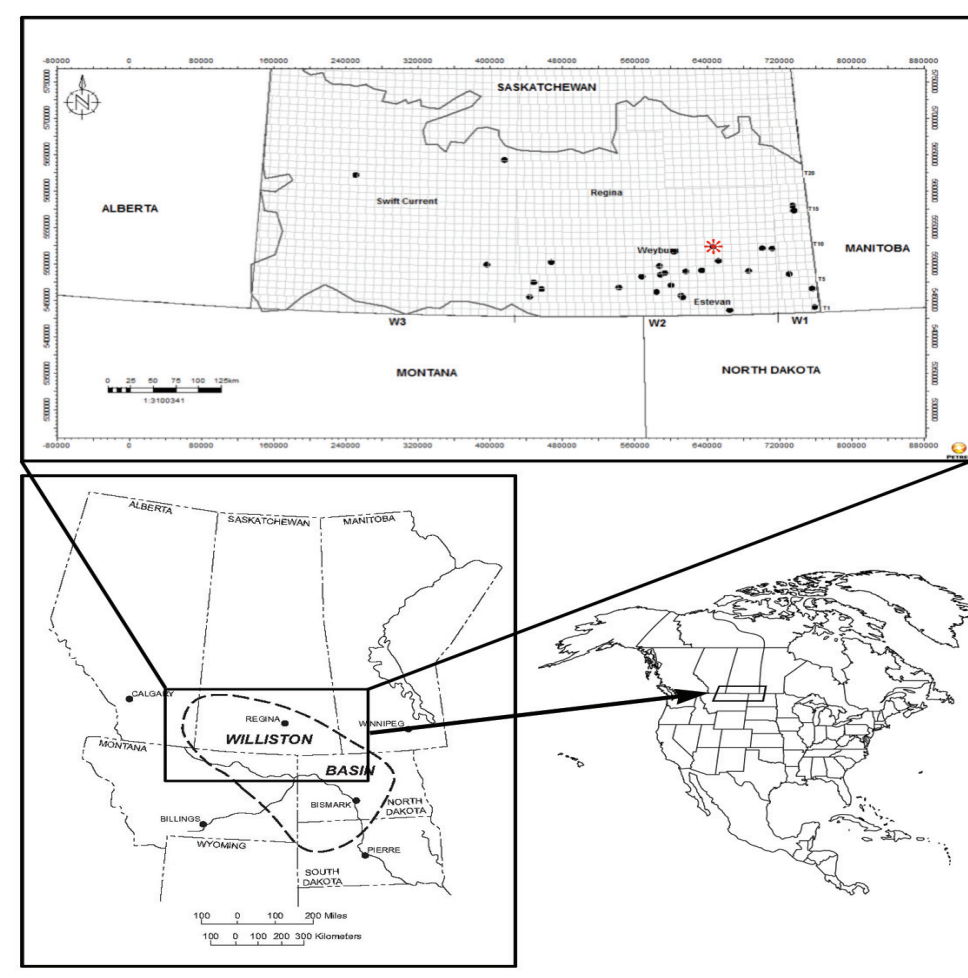
32 boreholes were sampled for analyses (base upon core recovery)
All analyses are conducted on samples from core
Core samples cleaned and weathered surfaces removed

Source rock screening and TOC analysis: Rock-Eval VI pyrolysis
Source rock extraction: Soxhlet and Soxtec (DCM:MeOH; 93:7 v/v)
Liquid column fractionation: pet ether-saturate; pet ether and DCM (50:50 v/v)-aromatic; and DCM and MeOH (50:50 v/v)-NSO fraction

Gas chromatography (GC) and gas chromatography-mass spectrometry (GC-MS) analyses on saturate and aromatic: Varian 3800 GC split/splitless injector linked to a varian 1200L Triple quadrupole MSD and HP 6890 split/splitless injector linked to HP 5973 MSD. Internal standard was added to the saturate fraction for quantitation

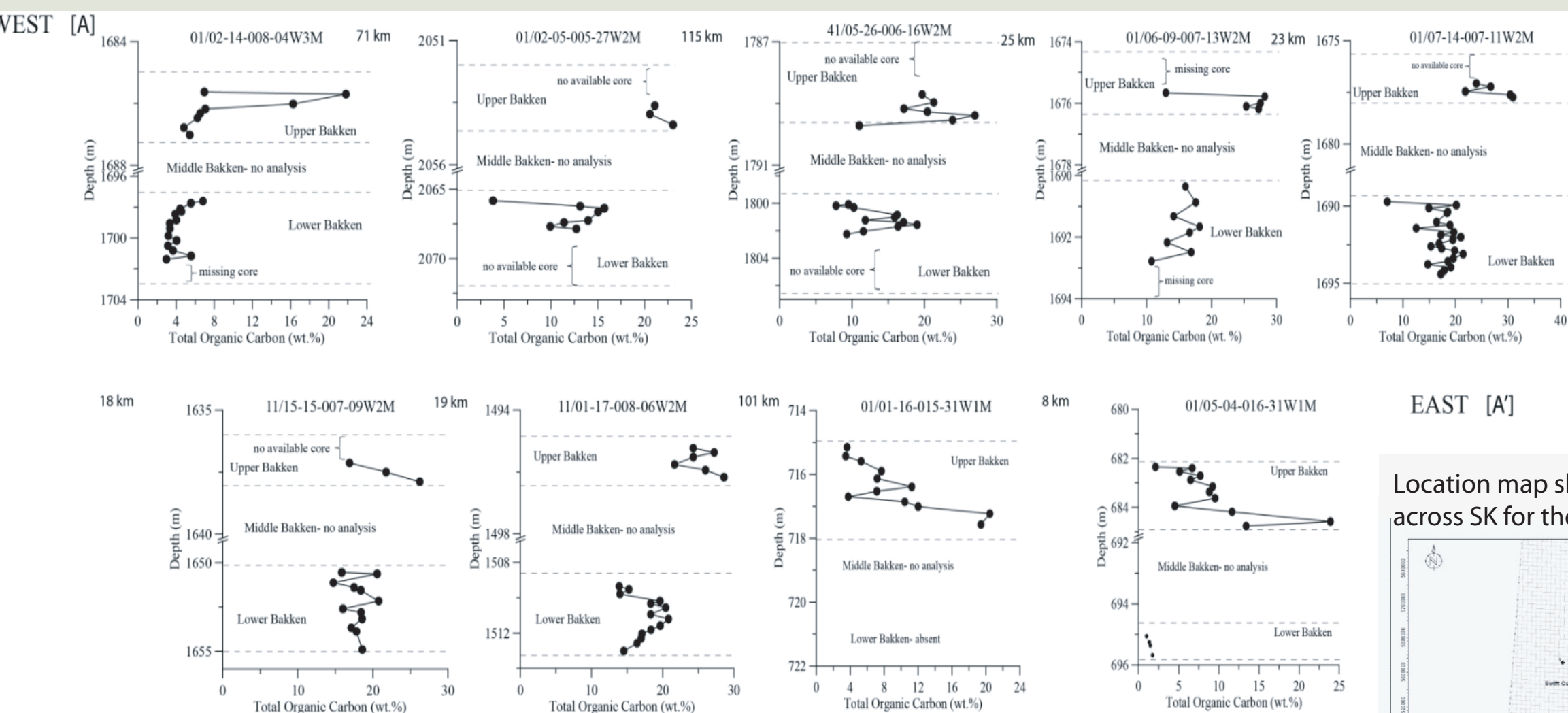
Inorganic geochemistry was obtained using ICP, XRF, NAA and atomic absorption analyses (courtesy Karma, 1991)

Study area map and borehole location

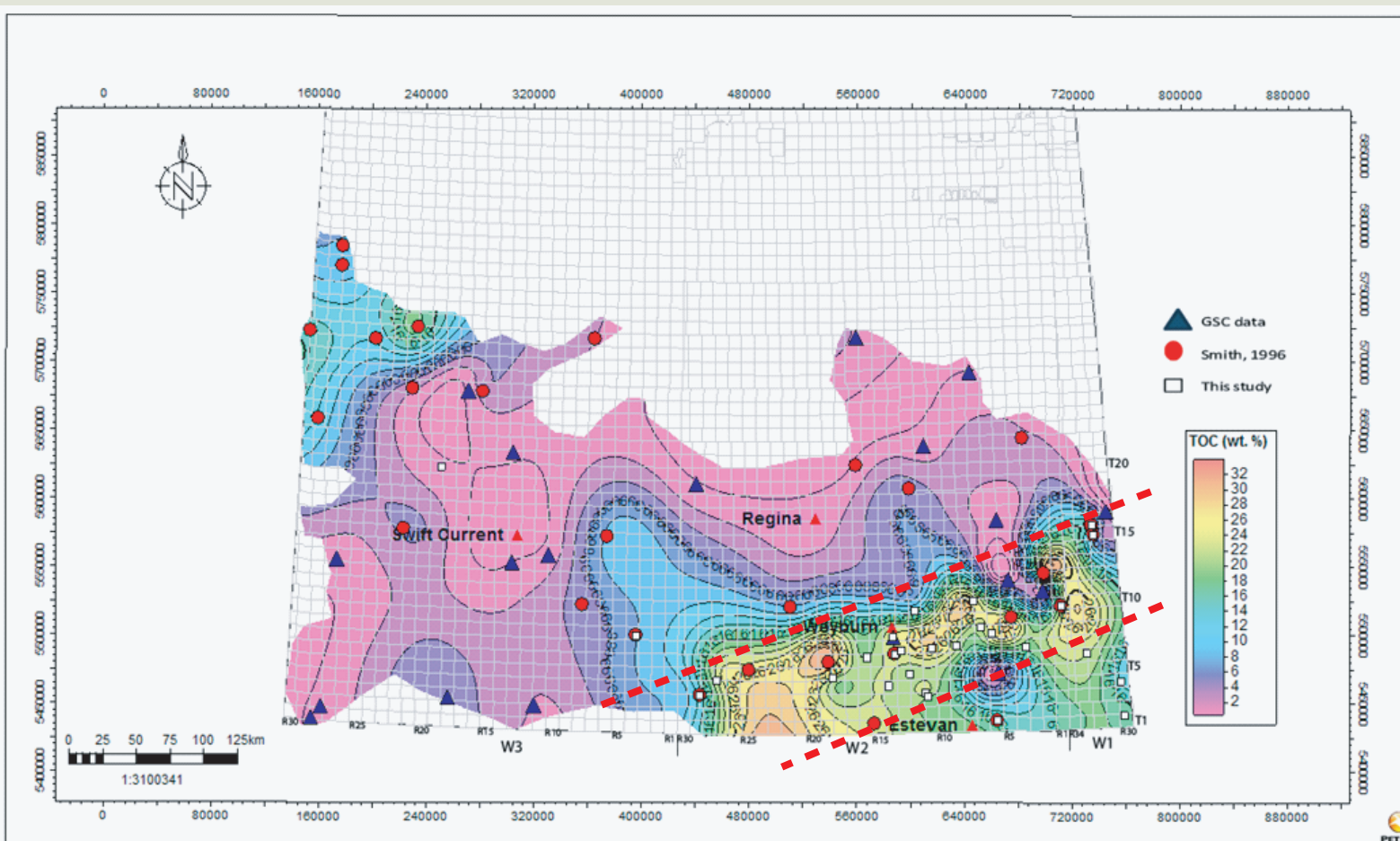


Spatial/temporal variation in TOC within the Upper and Lower Bakken Members

Spatial and temporal variation in TOC within the Upper and Lower Bakken Members across southern Saskatchewan. Note the variation with depth for a single borehole and the depth-wise difference in TOC values in each of the nine exemplified boreholes. The highest TOC consistently occurs in the Upper Bakken Member

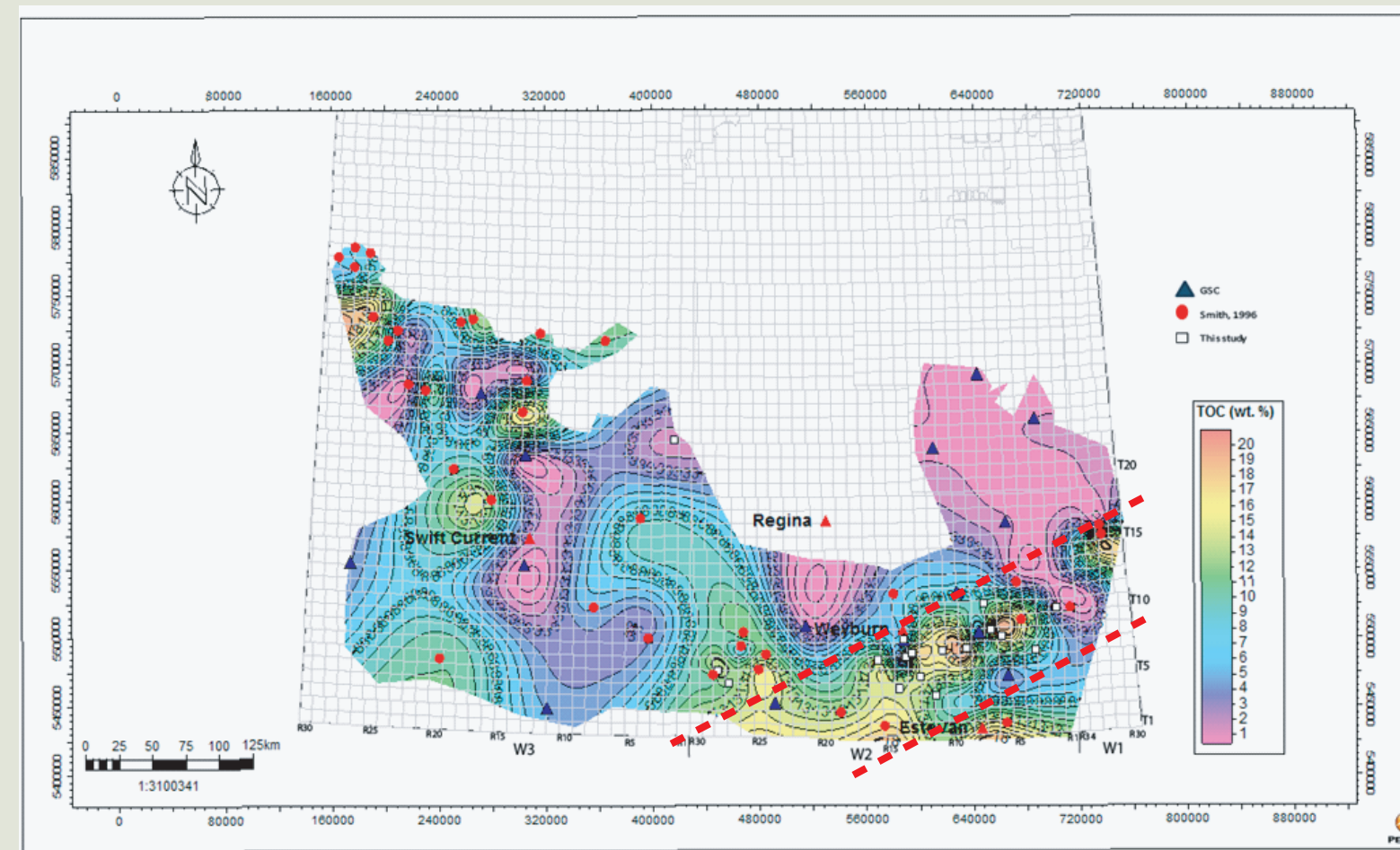


Spatial variation in TOC within the Upper and Lower Bakken Member



Average TOC distribution for the Upper Bakken Member

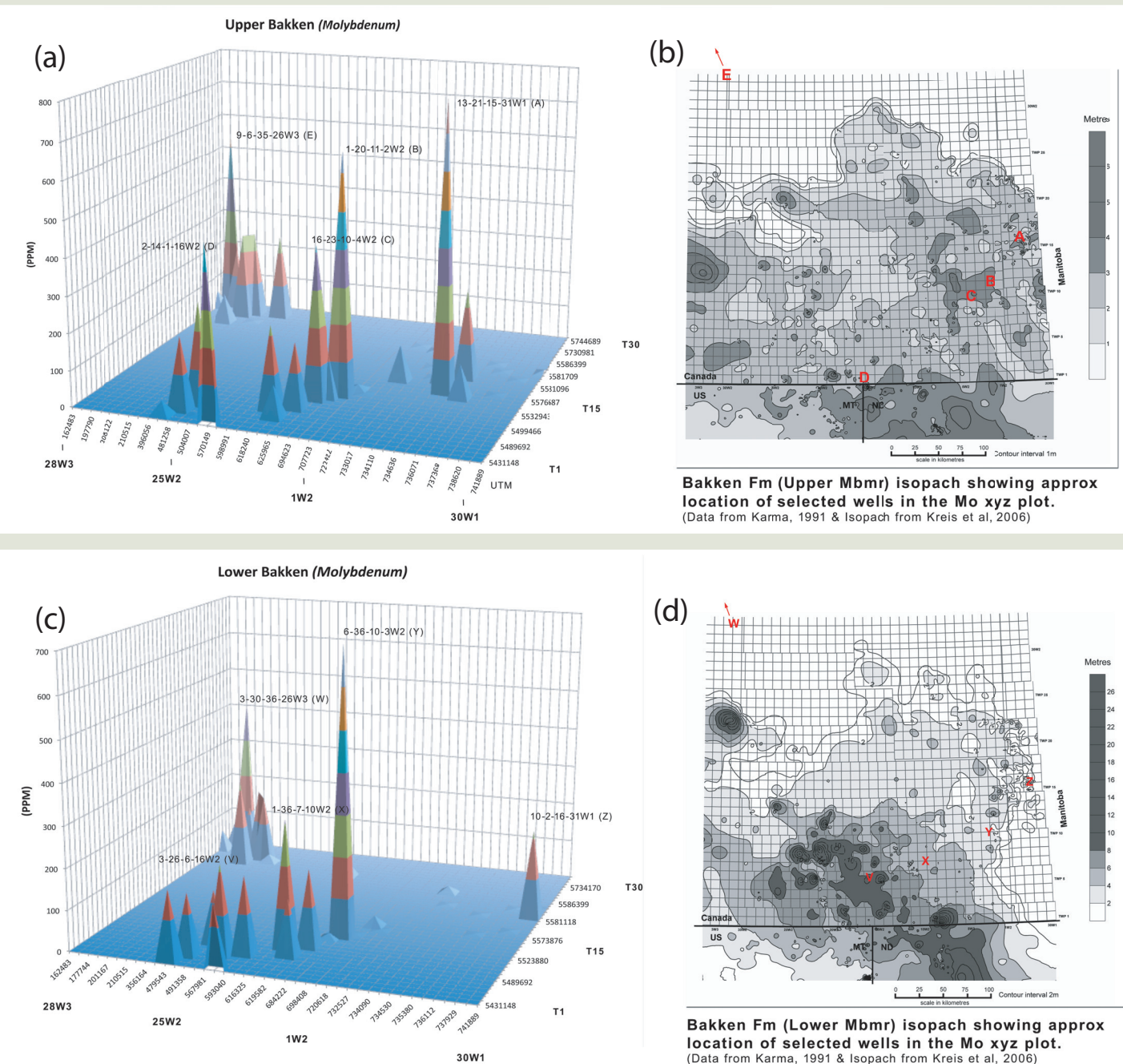
Note: Plotted values represent the average values for each borehole and do not indicate the variance in data. Also note the existence of 'pockets' of high TOC, that are within areas bounded by the dash lines that approximately follow the Torquay-Rocanville trend. Highest values of TOC occur at R1, T13; R5-R12, T7-T10; R19, T6. High TOC between R20 to R25 are software artifacts due to paucity of data in those areas. Supplemental data from Smith (1996) and the GSC



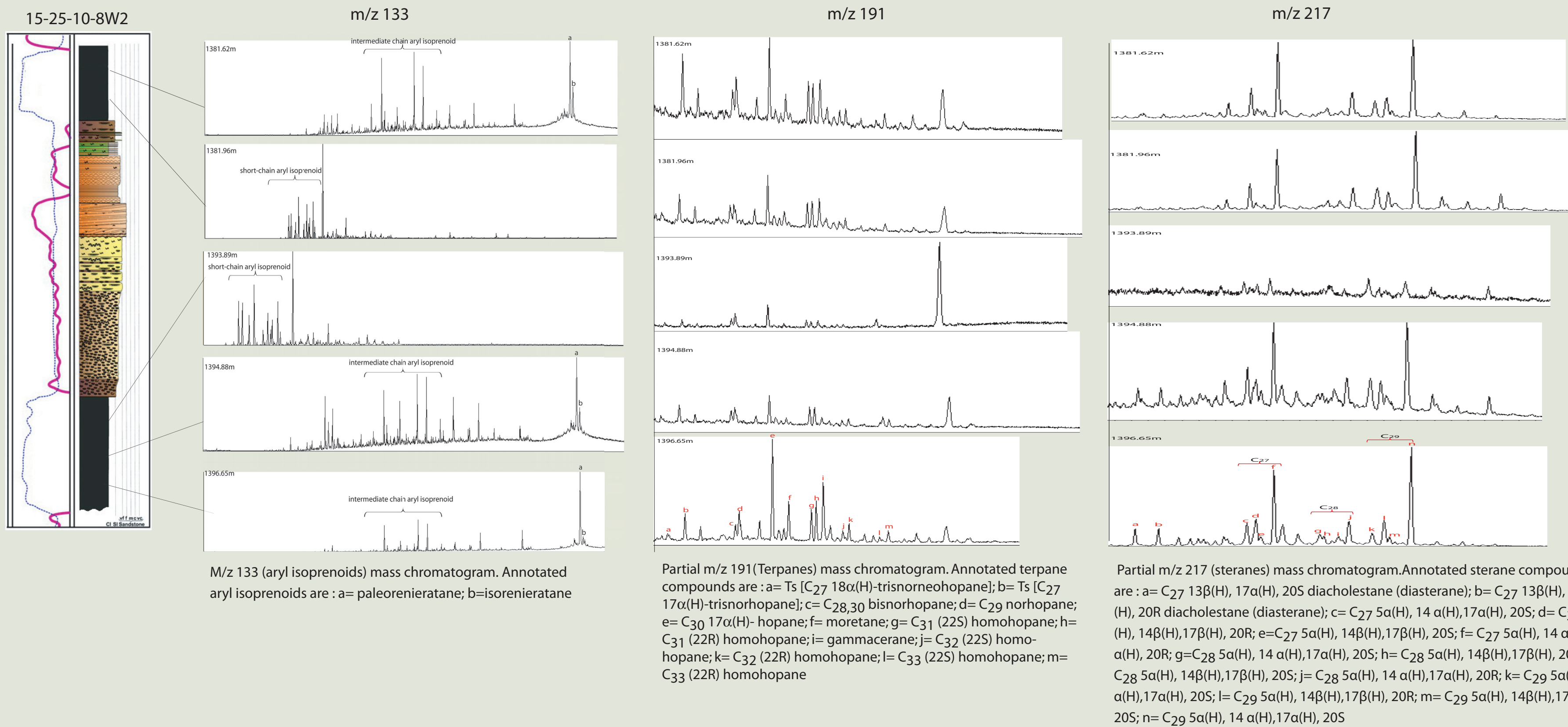
Average TOC distribution for the Lower Bakken Member

Note: Plotted values represent the average values for each borehole and do not indicate the variance in data. Also note the existence of 'pockets' of high TOC, that are within areas bounded by the dash lines that approximately follow the Torquay-Rocanville trend. Highest values of TOC occur at R6, T8 & T9; R10, T7. High TOC between R20 to R25 are software artifacts due to paucity of data in those areas.

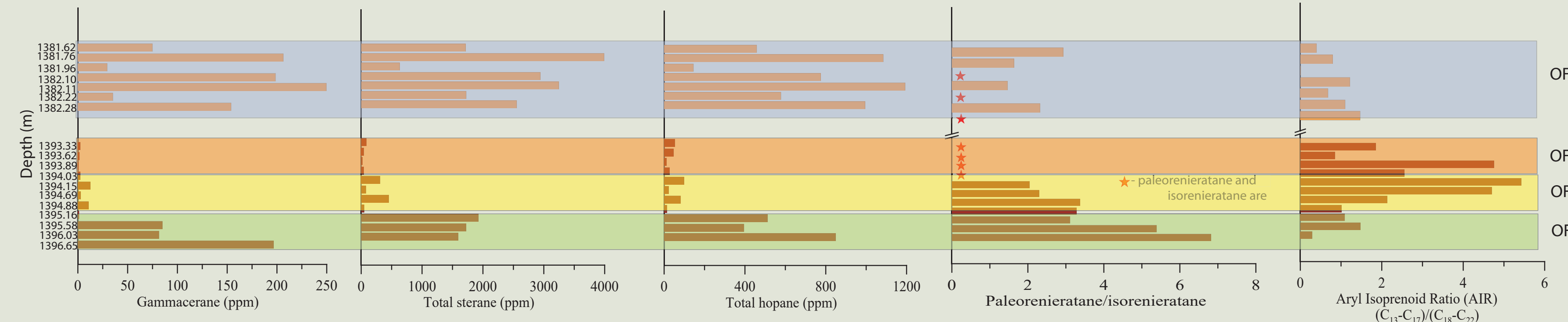
Trace element analysis for the Upper and Lower Bakken Members



Variation in biomarkers (mass chromatogram) within the Upper and Lower Bakken Members

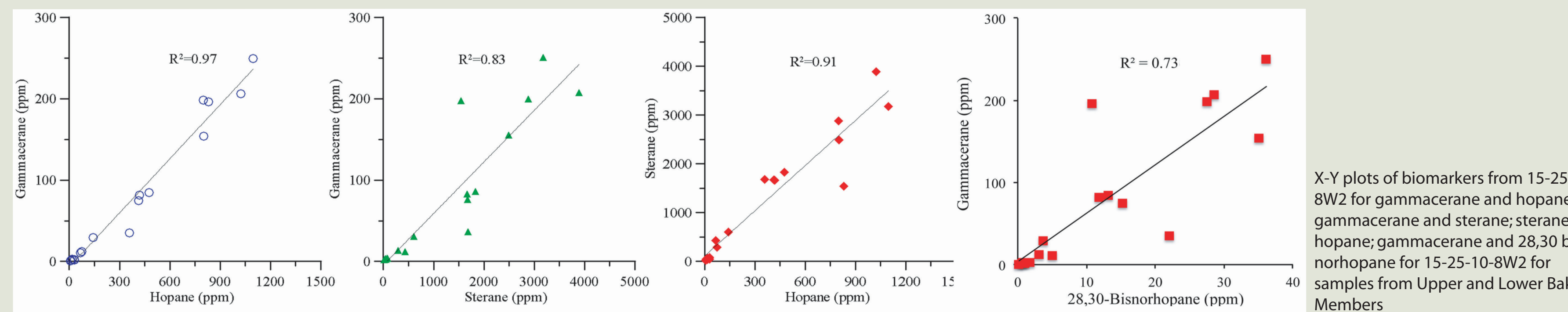


Biomarker depth profile within the Upper and Lower Bakken Members



Depth profile for gammacerane, sterane, hopane, paleorenieratane to isorenieratane and AIR; showing variation in biomarkers and biomarker ratios with depth and proposed biomarker-defined organic facies within the Upper and Lower Bakken Members

Statistical relationship between selected biomarkers from 15-25-10-W2 within the Upper and Lower Bakken Members



X-Y plots of biomarkers from 15-25-10-W2 for gammacerane and hopane; gammacerane and sterane; sterane and hopane; gammacerane and 28,30-bisnorhopane for 15-25-10-W2 for samples from Upper and Lower Bakken Members