[PS]Stratigraphy and Depositional Dynamics of the Haynesville-Bossier Sequence: Inferences from Whole-Rock Elemental Data*

Michael C. Dix[1], David Spain[2], Colin Walling[2], Jennifer Sano[3], Nicolo Casarta[4], and Allison Richardson[5]

Search and Discovery Article #10298 (2011)
Posted February 15, 2011

*Adapted from poster presentation at AAPG Convention, New Orleans, Louisiana, April 11-14, 2010

[1]Elemental Applications Consultants, Houston, TX (Michael.Dix@weatherford.com)
[2]BP America Inc., Houston, TX
[3]Chemostrat Inc., Houston, TX
[4]Halliburton - Sperry Drilling, Houston, TX
[5]Earth & Environmental Sciences, University of Kentucky, Lexington, KY

Abstract

The organic-rich mudstone facies of the late Jurassic Haynesville Formation were deposited under arid climatic conditions in a restricted instrashelf basin on the evolving Gulf Coast passive margin. A high-resolution (< 2 feet sampling) whole-rock elemental geochemical study was performed on cored wells from across the basin in order to: 1) establish a chemostratigraphic zonation that could be integrated with conventional data, 2) assess depositional conditions effective in concentrating organic matter, and 3) assess provenance of siliciclastic input versus carbonate input.

The Haynesville "Shale" can be broadly divided into three correlative chemostratigraphic packages, termed here lower, middle and upper Haynesville. The lower and middle Haynesville consist of silty mudstone facies with TOC values up to 5%, but are differentiated by their concentrations of V, Ni, U, S, As, and Mo. Higher concentrations of these elements in the lower Haynesville indicate bottom waters during deposition were both dysoxic and oxic, with periods of true anoxia and euxinia. The upper Haynesville is more calcareous, with two to three carbonate-rich cycles represented, and relatively low trace metal content. In the middle and upper Haynesville, higher TOC values sometimes correspond to peaks in carbonate cycles, and sometimes to clastic maxima. Mechanisms of organic-matter enrichment appear to have varied over time in the Haynesville, representing a complex interplay of carbonate productivity, clastic input, variable burial rates, and variable bottom water anoxia and euxinia.

A distinctive transition zone to the lower Bossier occurs above the upper Haynesville chemostratigraphic package, and is characterized by the presence of two to three widespread dolomitic beds. TOC and redox-sensitive trace metals generally drop to “average shale” levels above this zone, and a subtle but distinctive shift in immobile trace element composition indicates a slightly different provenance.

Stratigraphy and Depositional Dynamics of the Haynesville-Bossier Sequence: Inferences from Whole-Rock Elemental Data

Michael C. Dix[1], David Spain[2], Colin Walling[2], Jennifer Sano[3], Nicolo Casarta[4], and Allison Richardson[5]

[1] Chemostrat International Ltd. 5850 San Felipe, Suite 500 Houston, Texas 77057, USA

[2] BP Americas Production Company 200 WestLake Park Boulevard Houston, Texas 77079, USA

[3] Chemostrat Inc. 5850 San Felipe, Suite 500 Houston, Texas 77057, USA

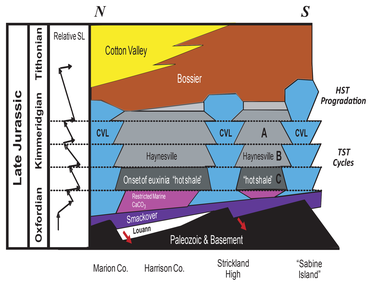
[4] Halliburton Sperry Drilling 3000 North Sam Houston Parkway East Houston, Texas 77032, USA

[5] Department of Earth & Environmental Sciences University of Kentucky Lexington, Kentucky 40506, USA

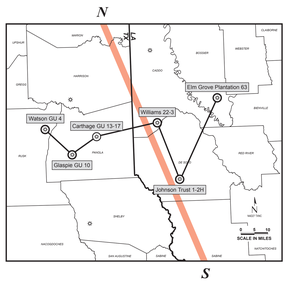
Introduction

The shaley facies of the late Jurassic (Kimmeridgian) Haynesville Formation in northeast Texas and northwest Louisiana is the target of one of the most active shale gas plays in the world. The shale contains an appreciable amount of carbonate throughout the section, enough that some intervals contain true marls, and TOC values typically range from 2-6 wt%.

The Haynesville Shale was deposited in an extensive intrashelf basin on the young passive margin of the U.S. Gulf Coast during a period of arid climatic conditions. Antecedent topography on the shelf, resulting from both basement faulting and salt movement, appears to have controlled the initial water depths in the basin. This established regions of seabottom that were restricted to varying degrees in their water mass exchange with the open ocean, and recurrently experienced dysoxic or anoxic conditions.



Schematic N-S cross section of Haynesville Shale depositional system in the Texas and Louisiana play area. Units labelled A, B, and C ("hot shale") constitute the shaley, organic-rich facies of the Haynesville Formation.

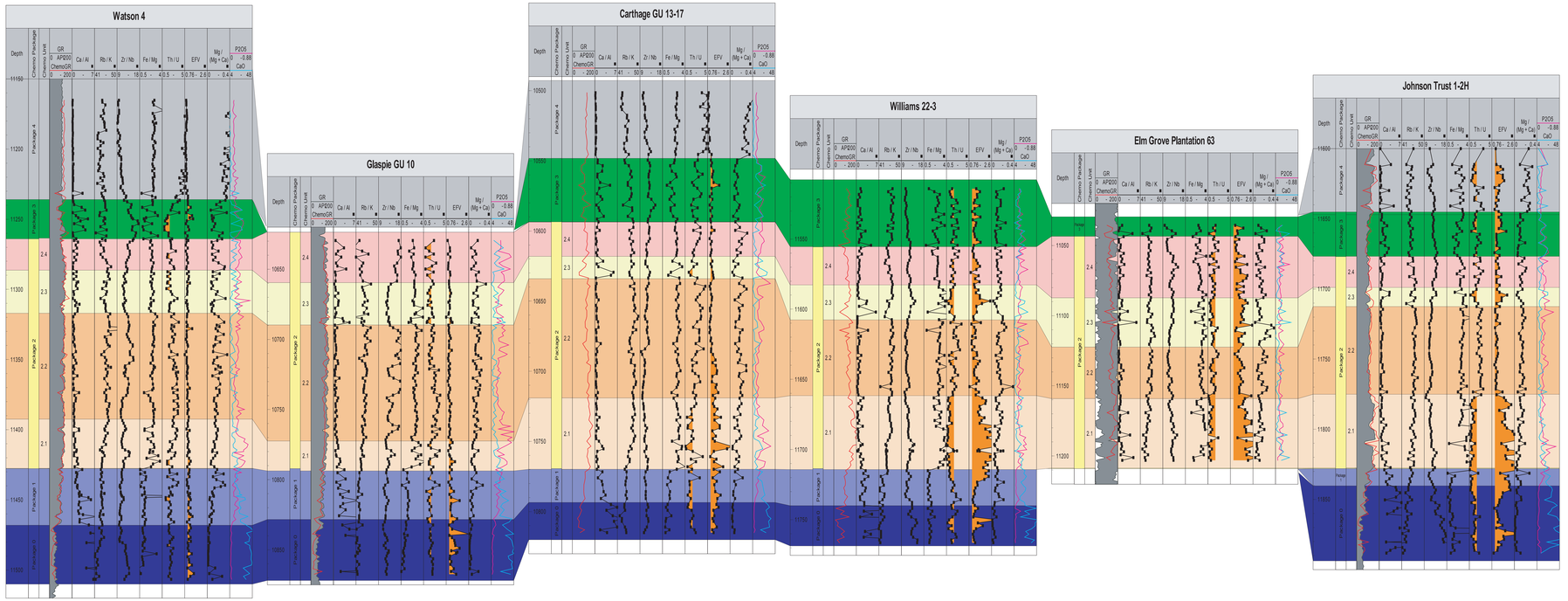


County map of main Haynesville Shale play area in northeast Texas and northwest Louisiana, with line of section for depositional system shown. All 10 located wells are included in the study. The six highlighted wells are show in the correlation panel at right.

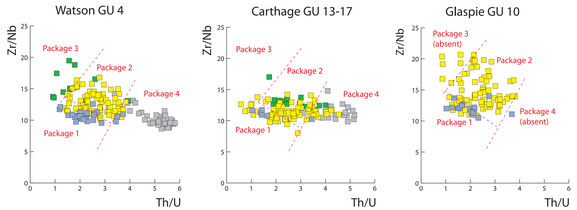
As part of an integrated program to characterize the Haynesville Shale, a high-resolution whole-rock elemental study was conducted on 1450 core samples from 10 wells across the play area. The average spacing for core samples ranged from 1.7 to 2.5 feet. In most wells, the top of the underlying "Haynesville Limestone" and the base of the overlying Bossier Shale were sampled also. Data was acquired for 53 elements using a combination of inductively-coupled plasma (ICP) and x-ray fluorescence (XRF) analytical technologies. The goals of the study were:

- Construct a chemostratigraphic zonation for the Haynesville shale, and identify key elements and elemental ratios for differentiating packages and units in the sequence;
- Correlate the 10 study wells based on the zonation, and identify areas where the correlation is of higher or lower resolution;
- Use elemental proxies for anoxia and euxinia to assess the paleoenvironmental conditions, and their change over time in the sequence;
- Use immobile elements to assess sediment influx and provenance changes in the sequence;
- Establish relationships between elemental composition, mineralogy, and TOC content in light of supporting petrologic data.

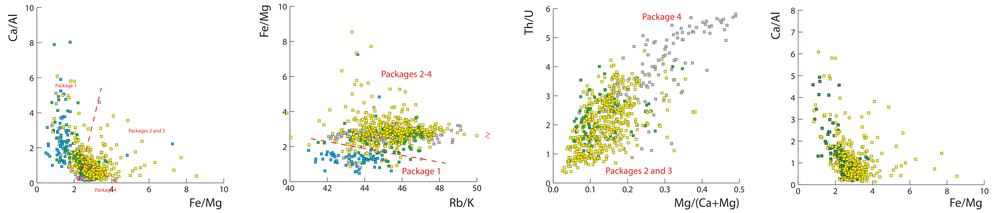
Chemostratigraphic Zonation & Correlation



Zr/Nb vs. Th/U Plots to Differentiate Packages for Selected Wells
Chemostratigraphic Packages 1-4

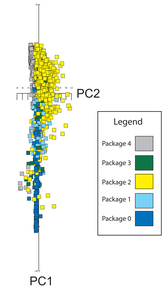


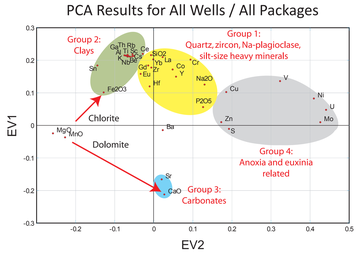
Selected Elemental Ratio Plots Showing Degree of Overlap in Chemostratigraphic Packages 1-4
Includes Haynesville Shale and Lower Bossier Shale

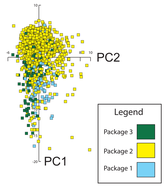


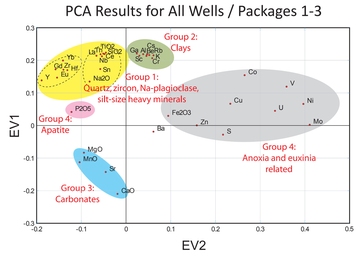
Elemental Affinities

Elemental data can contribute to a better understanding of the Haynesville Shale when the relationships between elements are understood. It is also essential to relate the elements to the minerals that control their abundance, and to the processes that produce and modify the mineralogy. Principal components analysis (PCA) is a valuable tool that can help elucidate the various relationships. Shown below are results of PCA analysis on all or part of the Haynesville-Bossier elemental data set. The influence of dysoxic, anoxic, and sulfidic conditions can be readily inferred from the relative positions of V, Ni, Mo, U, S, Zn and Cu.



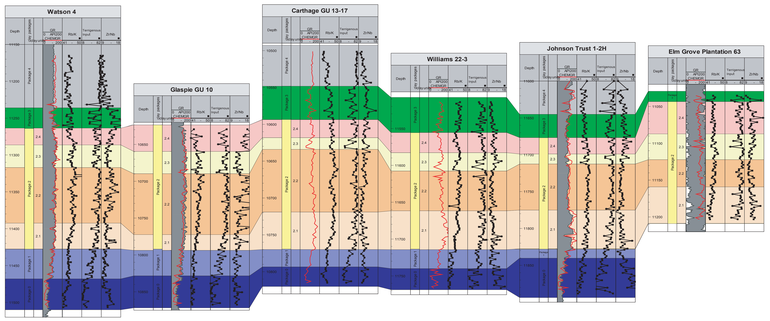






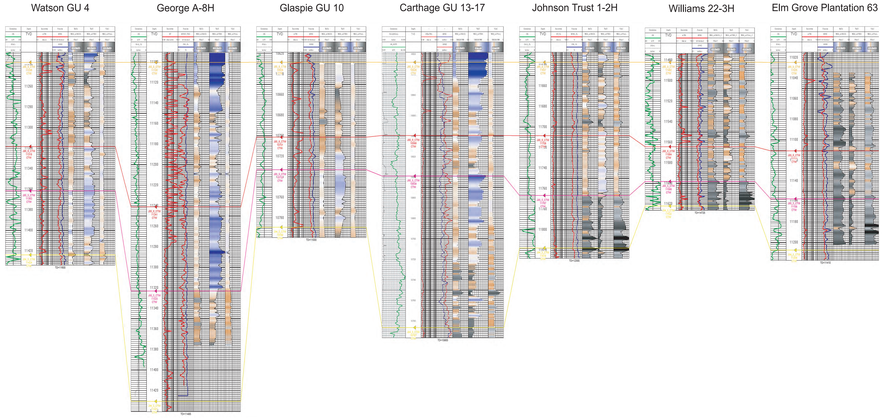
Terrigeneous Input

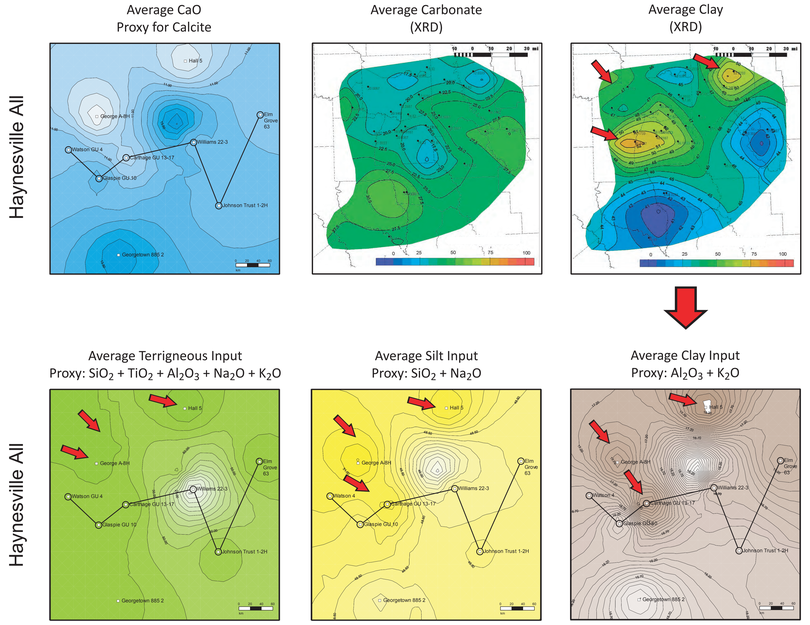
The Zr/Nb ratio appears to be a proxy for cycles of relatively silty detritus entering the Haynesville basin from the west and northwest, even though the total terrigeneous influx ($SiO_2 + TiO_2 + Al_2O_3 + Na_2O + K_2O$) shows only a slow graudual increase during deposition of Packages 1-3. The cycles are more numerous and better developed in the western study wells, and are difficult to recognize in the easternmost study wells.



Paleoenvironmental Indicators

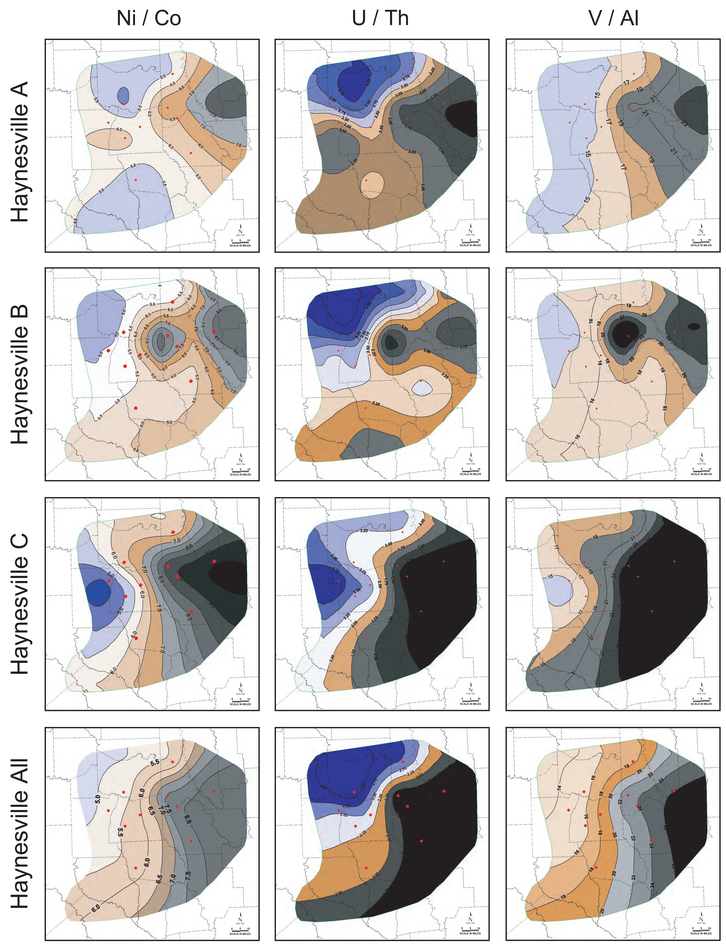
Estimated Distribution of Anoxia Across Haynesville Play Area Based on Integrated Elemental Proxies





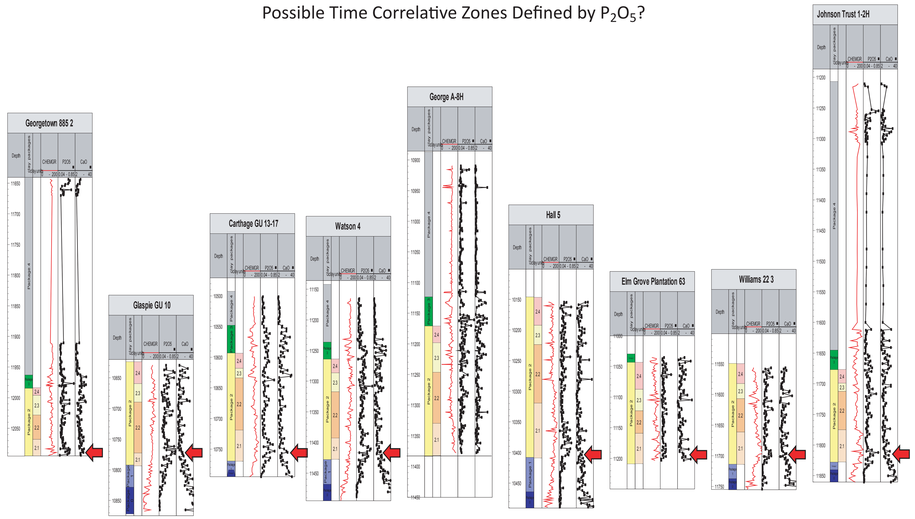
It is well established that U and most transition metals (primarily V and Ni, but also Co, Cu, and Zn) show elevated concentrations in organic-rich shales. The enrichments are due to the redox behavior of these elements in the dysoxic to anoxic bottom-water and pore-fluid conditions that usually accompany organic matter accumulation and preservation. Mo is often elevated as well, mostly incorporated into sulfide phases and sulphurized organic matter, and its occurrence is related to euxinic as well as anoxic conditions.

In order to estimate areal and vertical distribution of anoxic and euxinic conditions in the Haynesville shale, elemental ratios employed by previous workers investigating ancient black shales and modern anoxic sediments were applied to the studied core samples. The maps below show time slice averages for three key ratios. The cross-section at left shows the vertical distribution of the weighted and summed ratios. It is clear fom these indicators that persistent anoxia was better developed in the eastern part of the study area throughout Haynesville time.

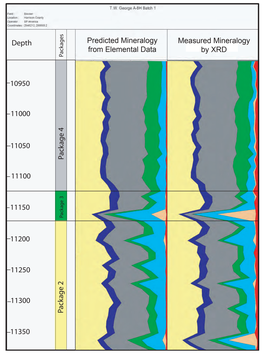


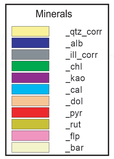
Paleoenvironmental Indicators

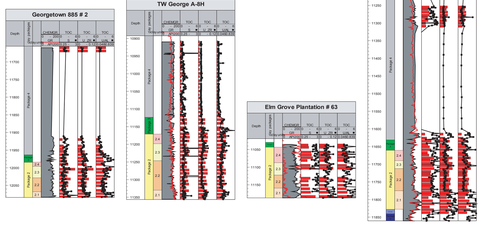
Possible Time Correlative Zones Defined by P_2O_5?

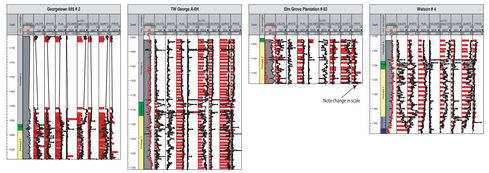


Mineralogy & TOC

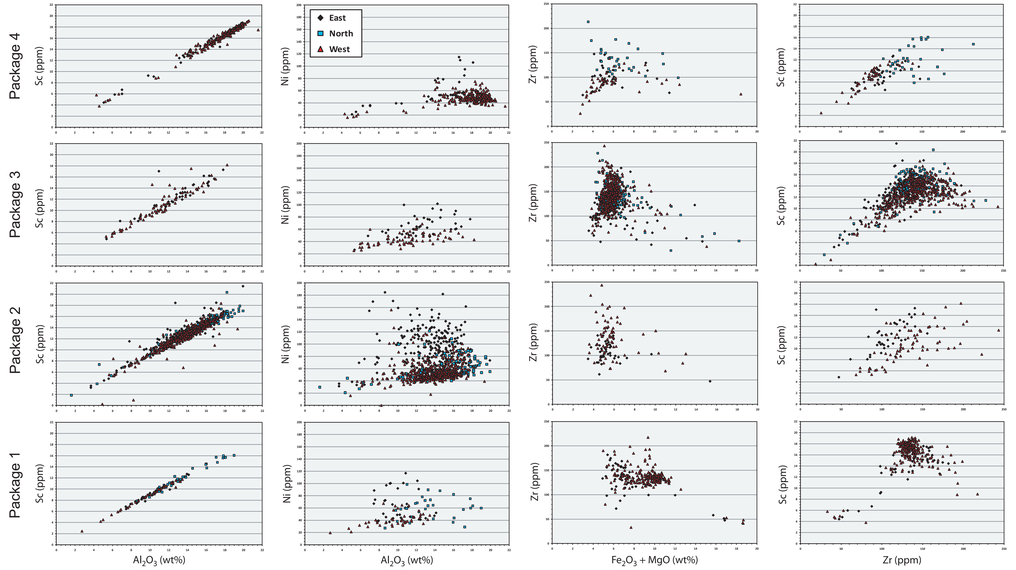






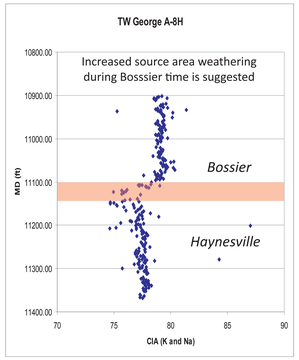


Provenance



Sc is insensitive to redox conditions

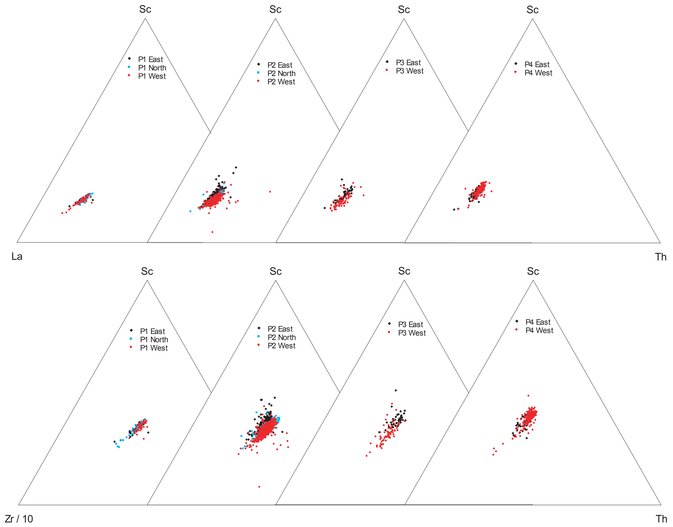
Ni is greatly enriched due to redox conditions



The Chemical Index of Alteration (CIA) is applied to shales, with caution, to assess the degree of weathering the sediment may have experienced in the source area or during transport. It is defined as:

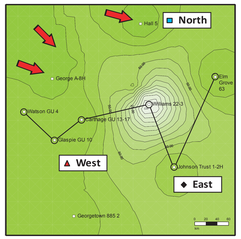
$$CIA = \frac{100 \times Al_2O_3}{Al_2O_3 + CaO + Na_2O + K_2O}$$

Because the Haynesville-Bossier sequence contains high CaO from carbonate, CaO was not used in the CIA assessment. Higher values of CIA indicate greater degrees of weathering.



Average Terrigneous Input

Proxy: $SiO_2 + TiO_2 + Al_2O_3 + Na_2O + K_2O$



Conclusions

- A chemostratigraphic zonation can be recognized in the Haynesville-Bossier sequence, with a resolution of tens of feet;
- Gradational changes typify the zonation, so it is difficult to clearly separate units in binary and ternary diagrams;
- Discriminant Function Analysis (DFA) correctly classifies 85% of the study samples based on the zonation constructed;
- The zonation becomes slightly less defined from west to east across the study area;
- The Zr/Nb ratio is interpreted to be a proxy for relatively silty incursions from the western and northwestern shelf area;
- Commonly-used elemental proxies for anoxia and euxinia are in good agreement on the vertical and areal extent of those conditions during Haynesville-Bossier time;
- Immobile elements can be used to detect subtle but definite changes in sediment provenance both vertically in the section and areally across the play area;
- Haynesville and Bossier mineralogy can be reasonably modeled using theoretical parceling logic, with decision points based on actual mineralogy measured by XRD;
- TOC cannot be consistently predicted by any one proxy in the Haynesville Shale, and is complexly related to both clastic and carbonate content.

Acknowledgments

The authors wold like to thank BP America Production Company for allowing us to show these results. We would also like to thank Mercer Brugler (Core Labs) and Ron Martino (Weatherford Labs) for hospitality and assistance while sampling several of the cores used in this study.