Well-Site Chemostratigraphy as an Aid to Drilling Decisions

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Abstract

Chemostratigraphy (or chemical stratigraphy) is a technique used to correlate sedimentary successions based on subtle changes in concentrations of key major, trace, and rare earth elements. Recent technological advances now enable determination of selected major and trace element concentrations from cuttings at a well site within minutes of the sample's arriving at the surface. Comparison of the data obtained while drilling to information from previously drilled offset wells increases confidence in stratigraphic location of the bit. The study wells presented here are from the Dutch Sector of the North Sea in a Chalk Play where landing a casing point within the basal few metres of the Tertiary is key to successful well completion. This study demonstrates how to track a borehole with respect to a chemostratigraphic framework. Once a stratigraphic geochemical characterisation is defined, it becomes possible to track a borehole while drilling subsequent wells. This particular study involves characterization of the Tertiary overburden succession in one well and correlations to it.

Chemostratigraphy also allows a real-time correlation framework to be constantly updated. More importantly, from a drilling perspective in this play, key geochemical changes may be identified within the Tertiary shales immediately overlying the Chalk. These geochemical changes provide a means to accurately pick the key 9 5/8-in. casing point in the Chalk Play.

Introduction

The technique of chemostratigraphy is based on the recognition of subtle variations in the whole rock elemental composition of sedimentary rocks. These variations are used to subdivide and correlate sedimentary sequences. The technique has the potential to establish distinctive geochemical 'fingerprints' for formations, packages of sedimentary rocks within formations, and, in some cases, for individual beds.

The primary controls on geochemical variability of siliciclastic rocks are changes in gross lithology (i.e. sandstone, siltstone, claystone). However, such gross changes are not of prime importance to chemostratigraphy. Rather, subtle elemental changes in apparently homogenous sequences are of prime importance. These subtle changes are controlled by variations in source rock composition, by the mixing of clastic material derived from different source areas during transport, and also by post depositional processes. These variables are the keys to creating a useful chemostratigraphy. Well-site chemostratigraphy in particular enables determination of subtle changes in selected major and trace element concentrations while drilling and thereby provides enhanced correlation to offset wells. Well-site chemostratigraphy (the LaserStrat^{TM} service) revolves around a portable Laser Induced Breakdown Spectrometry (LIBS) instrument and a proprietary sample preparation technique that allows data for up to 15 elements to be determined within minutes of a cuttings sample's arriving at the shale shaker.

A well-site chemostratigraphic study from the Dutch Sector of the North Sea obtained geochemical data in four wells from Pliocene through to base Eocene, and, later, the Cretaceous

Chalk reservoir. Well-site data were used in two ways. Firstly, data were collected through the entire study interval while drilling the first well. These data then acted as a template to supply a real-time chemostratigraphic type section while drilling equivalent sequences in subsequent wells. Secondly — and of prime importance — geochemical data were used to accurately pick a casing point several metres above the unconformity that separates the Tertiary shales from the Chalk. Because of the critical nature of accurately landing the casing, samples from a section extending 50m upwards from the Cretaceous/Tertiary unconformity in previously drilled wells were analysed in the laboratory prior to carrying out the well-site analyses. By identifying key geochemical features at and above the ideal casing point prior to carrying out well-site analysis, it was possible to accurately pick the casing point at well-site in all wells in the drilling program.

Correlation of Tertiary Successions

Silty claystone cuttings samples were analysed at well-site throughout the Eocene, Oligocene, Miocene, and Pliocene during the drilling of four wells. Samples were analysed, on average, every 20m through a sequence that is 700-800-metres thick, with sample spacing reduced to 5-10m as the base of the Tertiary was approached. Figure 1 displays selected geochemical profiles for the Tertiary study interval in one of the wells, together with a series of binary diagrams designed to differentiate the main stratigraphic units. Samples from each of the Eocene, Oligocene, Miocene, and Pliocene portions of the wells can be geochemically differentiated from one another. Samples from the Pliocene are readily differentiated from those from the underlying Miocene by the position in which they plot on a Ti/Al vs. Ca/Mg binary diagram. Samples from the Pliocene have high values of Ti/Al and low values of Ca/Mg when compared to the Miocene samples.

The Miocene samples fall into two fields on a Ca/Mg vs. Ti/Al binary diagram, a cluster that contains samples from the lower Miocene (unit C5, Figure 1) and a cluster that contains samples from the upper Miocene (C4). When additional data from subsequent wells were considered, this two-fold division of the Miocene is seen to be a stratigraphically significant feature (Figure 2).

Oligocene samples are characterised by low Ca/Mg and low Ti/Al values, resulting in the samples forming a distinctive cluster on the Ti/Al vs. Ca/Mg binary diagram (Figure 1).

The Oligocene/Eocene contact is very clearly defined on geochemical profiles by a marked downhole drop in values of Fe/Ca and Ti/K and a sharp increase in the Al/(Ca + Mg + K + Na) ratio. Values of Al/(Ca + M + K + Na) remain high throughout the Eocene, clearly allowing its differentiation from the younger sequences. The Eocene is further divided into three subunits, based on changes in Ca/Mg, Fe/Ti and Ti/Al (Figure 1). All of thee subunits can be recognized in offset wells.

Once the template displayed in Figure 1 has been created from the first well drilled, it is possible to track the TD of subsequent nearby wells while drilling. Tracking is accomplished by comparing geochemical data obtained from cuttings samples at well-site with the template created from the first well. The successful correlation of Tertiary sequences in four wells is displayed in Figure 2. As data from new wells are added to the framework and sample numbers increase, the proposed correlation is refined and becomes more robust.

The correlation displayed on Figure 2 relies primarily on major element data obtained by a LIBS instrument at well-site. As such, caution is required when trying to carry out either detailed or regional correlation. The elements used on Figures 1 and 2 can be mobilised by diagenesis, and variations in their concentrations probably relate to changes in types of carbonate and clay minerals within the silty claystones. Both carbonate precipitation and clay transformations can be affected or largely controlled by diagenesis, which would tend to obscure the primary provenance signature of the sediments. In order to fully test a correlation such as the one in Figure 2 and to obtain a robust, field-wide, or a detailed reservoir-scale correlation, a suite of less mobile trace elements and rare earth elements (REE) is required. However, on a gross scale, the correlation proposed on Figure 2 was supported over this four well study by biostratigraphic and wire line interpretations.

Identification of "Base Tertiary Casing Point"

Identification of the casing point immediately above the Cretaceous/Tertiary unconformity is key to successfully completing wells in this play. Due to the importance of this casing point, samples from the base Tertiary in four previously drilled wells were analysed in the laboratory prior to collecting data at well-site. The silty claystones immediately above the Cretaceous/Tertiary boundary (2-5m) showed enrichments in Si, Ca and Zr but depletions in Ti and Al. These variations are distinctive and repeated in all four control wells. The geological explanation for these elemental variations is the presence of a silty claystone deposited as a gently winnowed lag draped over the Cretaceous/Tertiary unconformable surface. The enrichments in Ca and Si reflect reworked Chalk and cherts respectively. Zr enrichments are controlled by the heavy mineral zircon. Zircon concentration is typical of a winnowed lag deposit. Al and Ti decrease in response to removal of clay minerals and micas decrease in response to winnowing. Despite these clear geochemical indicators, the cuttings samples from the basal Tertiary are not readily differentiated from those of the overlying Tertiary sequences when viewed under a binocular microscope.

When dealing with historical wells from which only stored cuttings are available, sample spacing is often insufficient to completely characterise relatively thin horizons. Therefore, the thin basal "lag" was only represented by one or two samples from offset wells. However, at well-site where spot samples can be caught and analysed with greater frequency, thinner units can often be better characterised. Therefore, the confidence with which relatively thin horizons can be identified increases as each well in a program is drilled and thoughtfully sampled.

In addition to geochemical recognition of the casing point, it also became apparent as new wells were drilled that the changing downhole geochemistry could be used to track the distance to critical well bore features. On Figure 3, for example, a distinctive marker — where Ti/Al reaches local maximum and Ca/Al values display a sharp downhole decrease — identifies a point that is 120-150m above a tuffite horizon. The tuffite horizon is a key feature to be identified when drilling these wells. It marks the point where controlled drilling begins in order to ensure that a correct casing point is picked. Below the Ti/Al marker, there is a second distinctive feature, 20-30m above the tuffite, where K values increase. The tuffite itself is geochemically identified by its high Ti values (Figure 3).