Chemostratigraphy of Oligo-Miocene sequences in Cook Inlet Alaska as based from core samples from the following wells:

- ConocoPhillips Alaska Inc North Cook Inlet Unit A0-2 (4,445.5' – 5,014.5')
- XTO Energy Inc (Shell Oil Co.) Middle Ground Shoal A13-01 (4,150.0' – 8,533.3')
- XTO Energy Inc (Shell Oil Co.) Middle Ground Shoal A33-11 (8,612.5' – 9,392.0')
- XTO Energy Inc (Shell Oil Co.) Middle Ground Shoal C31-26 (8,455.0' – 9,068.0')
- ARCO Alaska Inc. Swanson River Unit 34-10 the Swanson River Unit No 1 discovery well (4,720.37' – 12,276' and
- Standard Oil Company of California Deep Creek Unit No. 1 (1000.0'-13773')

ALASKA DEPARTMENT OF NATURAL RESOURCES

Received December 2007

Alaska Geologic Materials Center Data Report No. 356 Total 35 Pages in report (excluding data)

CHEMOSTRAT

REPORT Ci278

Chemostratigraphy of Oligo-Miocene sequences in the Cook Inlet, Alaska

prepared for

Department of Natural Resources,
Alaskan State Geological Survey

by

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September 2007

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EXECUTIVE SUMMARY

This report presents the results and conclusions of a chemostratigraphic pilot study undertaken on the Oligo-Miocene-aged sediments from the Cook Inlet, Alaska. All of the samples analysed are core chips taken from 6 wells in the North Cook Inlet Unit (NCIU), the Middle Ground Shoals Field (MGS), the Swanson River Unit (SRU) and the Deep Creek Unit (DCU).

The Cook Inlet is a prolific gas-prone hydrocarbon basin. However, stratigraphic complexity within the basin has resulted in no single stable reference stratigraphic framework being erected. Stable reference stratigraphic frameworks are the starting blocks of exploration in any hydrocarbon basin and are commonly based on lithostratigraphic principals. However, in the Cook Inlet, several, often apparently conflicting, lithostratigraphic schemes have been proposed. This study has been commissioned by Meg Kremer of the Division of Natural Resources, Alaskan State Geological Survey in order to test whether chemostratigraphy is a technique that has the potential to define a stable reference stratigraphic framework that would be independent of previously defined lithostratigraphic schemes. Therefore, the primary aim of the current study is to determine to what extent the technique of chemostratigraphy has the potential to characterise the Oligo-Miocene sequences of the Cook Inlet. In order to achieve this aim, 147 core samples have been analysed geochemically.

The inorganic geochemical data used in this study have been acquired using inductively coupled plasma optical emission spectrometry (ICP-OES) and inductively coupled plasma mass spectrometry resulting in data for 50 elements.

PRINCIPAL CONCLUSIONS

1) The pilot study report herein strongly suggests that by using whole rock inorganic geochemical data it should be possible to erect a stable reference chemostratigraphic framework for the Oligo-Miocene sequences in the Cook Inlet.

2) In SRU 34-10, the well with the largest dataset and greatest stratigraphic range, there are marked variations in the whole rock geochemistry that allow definition of 5 chemostratigraphic packages. Broadly, these packages appear to be equivalent to lithostratigraphic units:

   P1 = Jurassic,

   P2 = Hemlock Formation,

   P3 and P4 = Tyonek Formation and

   P5 = Beluga Formation

3) The changes in sandstone chemistry that allow the Hemlock, Tyonek and Beluga formations to be differentiated in SRU 34-10 are interpreted to occur in response to a variety of parameters. It is tentatively suggested that marked changes in sediment provenance occurred, resulting in variation in heavy mineral and feldspar content of the sandstones. It is also apparent from changes in the whole rock geochemistry that changes in clay mineralogy occur within the Oligo-Miocene sediments. Although changes in clay mineralogy may be related to diagenesis, experience also suggests that the changes between the Hemlock Formation and the overlying formations may be related to either variations in provenance and / or changes in syn-depositional weathering. If some of the changes in clay mineralogy modeled from the whole rock geochemistry can be demonstrated to be related to variations in syn-depositional weathering intensity, they could be regionally correlative.

4) By using the changes in whole rock geochemistry observed in SRU 34-10 as a template against which data from other wells can be compared, it is possible to assign the study intervals in others wells to a chemostratigraphic package and therefore tentatively to a lithostratigraphic unit.

5) Because changes in the chemistry are controlled by multiple factors and they appear consistent within the study wells, it is highly probable that a regional chemostratigraphic zonation scheme is readily achievable. Furthermore, since whole rock geochemical data are fully quantitative and in no way subjective, they are ideally suited to definition of stable stratigraphic reference frameworks.

RECOMMENDATIONS

a) Cuttings from the study wells reported herein should be analysed. Specifically, analysis of a suite of cuttings samples from the type well, SRU 34-10, to supplement and infill between the core samples is strongly recommended. This approach would not only provide a complete stratigraphic succession, but would also allow the quality of data obtained from cuttings samples to be assessed.

b) Cuttings (or core if available) should be analysed from additional wells. The current well distribution covers a wide geographic area with large distances between many of the wells from individual units / fields. It is recommended that multiple wells from each unit / field be analysed and wells from units / fields not yet incorporated in the study should also be analysed.

c) Both sandstones and claystones should be analysed if possible, although studies on the Cosmopolitan Unit suggests the sandstone lithologies are better preserved in cuttings samples from Oligo-Miocene sequences in the Cook Inlet.,

d) It is strongly recommended that a subset of samples be analysed mineralogically, ideally using a combination of XRD, petrography and heavy mineral analyses. This would add to the confidence of the geochemistry and mineralogy interpretations made herein.

INTRODUCTION

Presented herein are the results and conclusions of a chemostratigraphic pilot study undertaken on Oligo-Miocene-aged sequences as penetrated by 6 wells (**Table 1**). The wells incorporated into the study are from the North Cook Inlet Unit (NCIU), the Middle Ground Shoals Field (MGS), the Swanson River Unit (SRU) and the Deep Creek Unit (DCU). These units / fields are spread from the northern parts of the Cook Inlet (NCUI) through to the southern part of the inlet (DCU) (**Figure 1**).

The primary aim of this pilot study is to determine to what extent chemostratigraphy can be used in the Cook Inlet to provide a stable reference stratigraphic framework. Due to the primary goal, this phase of the study has incorporated core samples only, in order that chemostratigraphic "fingerprints" can be established for key Oligo-Miocene intervals within the Cook Inlet. In most study wells, the cored intervals cover a relatively short stratigraphic interval. The only well with a wide stratigraphic coverage is SRU 34-10 and this well is used as a "type section" against which other wells are compared.

The client supplied lithostratigraphic schemes for all wells, including schemes proposed by different workers that, in most of the wells, are not consistent. Since the primary aim of this study is to provide a stable reference stratigraphic scheme for the Oligo-Miocene of the Cook Inlet, the lithostratigraphic schemes have largely been ignored. However, to provide a cross reference between the litho- and chemo-stratigraphy, the samples in SRU 34-10 have been assigned to lithostratigraphic units, largely relying on the Alaskan Geological Survey (AGS) lithostratigraphic scheme.

Table 1. Sample summary

Unit/Field	Well	Claystones	Sandstones
North Cook Inlet Unit (NCIU)	NCIU A-02	4	15
Middle Ground Shoals Field (MGS)	MGS A13-01	10	13
	MGS A33-11	0	4
	MGS C31-26	0	4
Swanson River Unit (SRU)	SRU-34-10	19	56
Deep Creek Unit (DCU)	DCU-1	17	5
Total		**50**	**97**

CHEMOSTRATIGRAPHIC CHARACTERISATION

INTRODUCTION

Chemostratigraphy *sensu stricto* is a stratigraphic method that subdivides based on variations in whole rock inorganic geochemistry. Therefore, a chemostratigraphic zonation based, for example on changes in Ca values is as equally valid as a zonation based on changes in Zr and Hf concentrations. However, the significance of the two hypothetical zonation schemes is likely to be very different. The scheme based on changes in Ca values is probably reflecting subtle differences in diagenetic history and or lithology, whereas the immobile, provenance related elements Zr and Hf are likely to provide a correlation scheme based on changes in sediment provenance through time. Understanding the mineralogical and therefore geological significance of a chemostratigraphic zonation becomes vitally important when attempting to geographically extend a zonation scheme in order to build a chemostratigraphic correlation framework.

Chemostratigraphy, as with any stratigraphic technique, requires a hierarchical approach. Therefore, when erecting a basin-wide chemostratigraphic scheme, “Packages” are normally regarded as 1st order chemostratigraphic divisions and “geochemical units” as 2nd order divisions. Packages are likely to be regionally extensive in nature, whereas units will provide a more detailed correlation between closely spaced wells and therefore allow sediment architecture to be determined. As a study progresses to multi-wells, the geochemical boundaries will remain constant, but the hierarchy may change, typical of any evolving stratigraphic approach. In this study, where the chemostratigraphy is being linked to lithostratigraphy, the packages are likely to be equivalent to formations, with units approximating to members.

METHODOLOGY

The sample preparation methods (alkali fusion) and data acquisition using ICP-OES and ICP-MS are those described by Jarvis & Jarvis (1995). Data QC and drift correction is carried out in–house using samples prepared in triplicate and 5 standard reference materials (SRM). The ICP laboratory has achieved ISO 9001 certification.

Following data acquisition, the interpretative methodology used to define chemostratigraphic zonation schemes and correlation frameworks is an entirely pragmatic one. Data are obtained for a large number of elements (49 in the case of this study), only a limited number of which are normally used to define a framework. The elements used are specific to a study area and will be dependent on lithology, facies, provenance etc. Initially, all elements are considered and it is commonly found that some display no systematic changes within a specific study, others show a lot of noise in the dataset and others still display systematic changes with time. It is this latter set of elements that form the initial dataset used for zonation. Within this initial group of elements, some will display a close linear relationship with one another (e.g. Zr and Hf), allowing the element array to be further reduced. At this point, the remaining elements are considered to be the key chemostratigraphic elements. Key element ratios are then devised from the key chemostratigraphic elements that emphasise subtle changes in single elements. The resultant ratios are the key element ratios that are used to define a chemostratigraphic zonation scheme and correlation framework. Generally as a study progresses, additional element ratios will be generated that provide additional resolution and confidence in the proposed characterisations / correlations. Provided datasets are sufficiently large multivariate statistical analyses are used to test the proposed correlation.

At this stage a correlation has been proposed independent of the mineralogy and geology. Therefore, the next step involved attempting to understand the likely mineralogical controls on the element distribution and element ratio values. Ideally, this phase of a study is carried out by directly comparing whole rock geochemical data and mineralogical data. The mineralogical data should ideally include petrography and heavy mineral analysis on the sandstone samples and XRD analysis on the claystone samples (see

Recommendations). In preliminary studies such as the one reported herein, where mineralogical data have not yet been acquired, it is possible to gain a basic understanding of the relationship between geochemistry and mineralogy using multivariate statistical analysis

CHEMOSTRATIGRAPHIC ZONATION

Chemostratigraphy can be applied equally well to sandstones, claystones and limestones. However, when considering a mixed lithological sequence, as is the case in this study, the sandstone data and claystone data initially need to be considered separately. If the data from both lithologies were considered together the geochemical variation between a claystone and sandstone would be far greater than any stratigraphic variations within a single lithology. Although the two datasets are considered separately, when a multi-well study is complete, an integrated chemostratigraphic correlation incorporating all data is produced.

SRU 34-10

SRU 34-10, from the Swanson River Unit, appears to have the greatest stratigraphic sequence of the wells sampled in this initial phase. Therefore, it is used as a template against which wells with shorter stratigraphic extent can be compared.

Figure 2 displays the chemostratigraphic zonation of SRU 34-10 defined using sandstone data. Additionally, the lithostratigraphic zonation of the Alaskan Geological Survey for this well is displayed. The sandstone samples fall into 4 geochemical packages (P2-P5), two of which (P2 and P4) are well defined by high sample numbers and two of which are defined by relatively smaller sample sets. Furthermore, an additional package (P1) at the base of the study interval is defined by claystone samples (**Figure 3**).

On **Figures 4-8** binary diagrams constructed from sandstone samples in SRU 34-10 are displayed and are compared against data from each of the other study wells.

Package 1

Package 1 appears to be part of the Jurassic succession that underlies the Cretaceous sediments of the main study interval. Four claystone samples, all reported from a depth range of 12276-85’ have been assigned to Package 1. Three of these samples have similar geochemistry to one another, this being taken as a typical Jurassic fingerprint.

The four claystones of Package 1 are lithologically different to those above, their generally higher Ca and Mg contents suggesting they are more calcareous. Furthermore, the claystones of Package 1 have far higher Na/Al values than those of the overlying formations (**Figure 3**).

Package 2

Package 2 appears to be part of Hemlock Formation and its chemistry is therefore taken to be typical of this lithostratigraphic unit. It is characterised by high Rb/Al and Ti/Nb values, and low Na/Al, Ga/Rb, K/Rb, Cr/K and K/Na values of the component sandstones (**Figure 2**).

Relatively few claystones samples have been analysed from P2, but those that have, appear to have higher Rb/Al values and lower Ti/Nb values than the overlying claystones (**Figure 2**).

The sandstones and claystones within Package 2 display subtle variations that allow the package to be tentatively subdivided into 3 geochemical units (2.1, 2.2 and 2.3). These units may prove correlative, but with the current dataset this cannot be tested.

Package 3

Package 3 is represented by only three sandstone samples, but these three samples do have values of Nb/(Cs/Al) that are higher than all others in the study (**Figure 2**). It may be that, when a larger dataset is available Package 3 becomes assimilated into a larger package as a unit (Package 4?).

Package 4

Package 4 appears to be part of the Tyonek Formation (Middle Ground Shoals Member) and its chemistry is therefore taken to be typical of this lithostratigraphic unit. The sandstones of Package 4 are clearly differentiated from those of Package 2 by their low

Rb/Al and Ti/Nb values, and high Na/Al, Ga/Rb, K/Rb, Cr/K and K/Na values. They are differentiated from those of Package 3 by their low Nb/(Cs/Al) values and from Package 5 by their high Na/Al values (**Figure 2**). Only one claystone sample was analysed from within Package 4.

There are three sandstone samples and five silty claystone samples in the interval 6400-8800’. These samples are all relatively isolated making it difficult to comment upon their likely stratigraphic significance.

Package 5

Package 5 appears to be part of the Beluga Formation. Although only two samples have been made available from this formation, the chemistry of those two samples appears to be consistent with other wells where the same formation is believed to have been sampled. The two sandstones of Package 5 are differentiated from those of Package 3 and Package 4 by their low Na/Al values and from P2 by their low Rb/Al and K/Al values (**Figure 2**).

In the section below, the binary diagrams constructed from the sandstone samples of well SRU 34-10 (**Figures 4 - 8**) are used as templates to allow a stratigraphic assignment to be made for samples from the other study wells.

WELL MGS C31-26

Four sandstone core samples have been analysed from well MGS 31-26 (**Figure 4**). No claystone samples have been analysed from this well. All samples analysed plot in association with samples from Package 2 (=Hemlock Fm) on all binary diagrams (**Figure 4**). The lowermost sample analysed (9068’) is reported as Hemlock Formation, the remainder being placed in the Middle Ground Shoals Member, part of the Tyonek Formation. With the current geochemical dataset, these samples should perhaps be reassigned to the Hemlock Formation, but a larger dataset from this well would be required to make this re-assignment with confidence.

WELL MGS A33-11

Four sandstone core samples have been analysed from well MGS A33-11 (**Figure 5**). No claystone samples have been analysed from this well. Two samples (9383’ and 9392’) plot in association with Package 2 (=Hemlock Fm) and two (8612.5’ and 8621.5’) in association with Package 4 (=Tyonek Fm) on the Na/Al vs. Rb/Al binary diagram, suggesting that the Hemlock / Tyonek boundary lies between 8621.5’ and 9383’. However, with only four samples, caution is required when making this interpretation.,

WELL MGS A13-01

A total of thirteen sandstone core samples and ten claystone core samples have been analysed from well MGS A13-01. The majority of the sandstone and claystone samples plot in association with Package 2 (=Hemlock Fm) (**Figures 3** and **6**). This interpretation appears to contradict the lithostratigraphic assignment that places the samples in the Middle Ground Shoal Member of the Tyonek Formation. Additional geochemical data from this well and other wells would be required to confidently suggest the best stratigraphic assignment of these samples.

WELL NCIU A-02

A total of fifteen sandstone core samples and four claystone core samples have been analysed from well NCIU A-02. The sandstone and claystone samples plot in association with Package 4 (=Tyonek Fm) on most graphical plots (**Figures 3** and **7**). However, on the Hf/Al vs. Cs/Al binary diagram (**Figure 7**), the sandstone samples from this well plot in a separate field to all others in the study intervals. This suggests that while they are geochemically broadly similar to the Tyonek Formation, they are also subtly different. The claystones of NCIU A-02 are geochemically different to others in the study interval due to their high Ca/Al values (**Figure 3**).

WELL DEEP CK1

A total of five sandstone core samples and seventeen claystone samples have been analysed from well Deep CK1. The sandstone samples all plot in association with Package 5 (= Beluga Fm) (**Figure 8**). Claystones between 1000 and 5517’ plot in association with Package 5 (=Beluga Fm), samples between 6990-9271’ plot in association with Package 4 (=Tyonek Fm) and the lowermost two samples plot in isolation, suggesting that they belong to a separate unit (CRCS ?) (**Figure 3**).

GEOCHEMISTRY AND MINERALOGY

As discussed above, understanding the likely controls on the key elements and element ratios is an import part of any chemostratigraphic study. In order to do this, mineralogical data, in the form of petrographic data, XRD data or heavy mineral data, are typically acquired from a subset samples that have been subjected to geochemical analysis. These data have not yet been acquired (see **Recommendations**), which is typical for a pilot study where the aim is to initially demonstrate changes in whole rock geochemistry through time. It has been recommended (see **Recommendations**) that as the project progresses a subset of mineralogical data be acquired so that the elemental data can be calibrated against the mineralogical data.

However, when no mineralogical data are available, broad generalisations can be made regarding the likely controlling factors using multivariate statistics, principally principal components analysis (PCA). PCA reduces the total variation in a dataset, which in this case are the element concentrations, to a smaller number of variables termed principal components (PC). PC1, PC2 and PC3 account for approximately 70% of the total variation in the entire geochemical dataset acquired for this study. The principal component score assigned to each sample is determined from the eigenvectors (EV). When eigenvector values are plotted against each other, the closer the variables (elements) plot to one another, the more closely associated they are to one another in the sedimentary rocks, thereby providing a means to determine the relationship between the elements and minerals (**Figure 9**). **Figure 9** shows that when the EV1 and EV2 values for the individual elements are plotted, several broad element associations can be recognised, as described below. However, overriding these groups the simplest of controls on whole rock geochemistry is displayed, namely quartz (=Si) and all other components. This is displayed by the fact that Si plots with negative EV1 scores and all other elements plot with +ve 1 scores. It is the variation beneath this initial level that allows an understanding of the geochemistry and mineralogy to be determined:

Group 1: this group of elements includes Si, the abundance of which provides a broad indication of quartz content in sandstones, which is mostly inversely related to the amount of clay. Other elements plotting in association with Si are assumed to be linked with silt – sand-sized grains, rather than to clay minerals or diagenetic features.

Group 2: this group includes K and Rb. These two elements are commonly associated with clay minerals (notably illite) and feldspars. In this study, the K and Rb have similar EV2 scores to Si, strongly implying that they are being controlled by detrital grains rather than diagenetic products. Normally, this would be interpreted to indicate a strong relationship between these elements and K-feldspar. However, the client has indicated that igneous and volcanic rock fragments are commonplace in the intervals being studied. So, the K and Rb concentrations may be influenced by lithic fragments as well as by K-feldspar.

Group 3: this group includes Ti, Cr, Hf, Ta, Th, U, Y, Zr and the REE's. Zr and Hf are two elements normally associated with the heavy mineral zircon. Consequently, the other Group 3 elements presumably have affinities with heavy minerals. The fact that the group displays a linear array with variable EV2 scores strongly suggests that there are changes in the relative proportions of heavy mineral species through time, i.e. ratios of these elements will probably relate to changes in sediment provenance.

Group 4: contains Al, Sc, Ga and V. Al is typically a proxy for the total clay content in a sandstone. More specifically, when Al is associated with Ga, as is the case here, it suggests that Al is strongly related to kaolinite contents.

Group 5: contains Fe, Mg, Mn, Na and Co. This group of elements are likely controlled by a mixture of minerals, but can be interpreted as a typical basic / intermediate igneous association. It may therefore be that these elements are related to basic igneous input, either in the form of minerals or lithic fragments. These elements also plot in proximity to Al, strongly suggesting they are likely to be in part related to clay minerals.

The most notable feature on EV2 vs. EV3 (**Figure 9**) is apparent separation of acidic and basic heavy minerals (e.g. Cr-Spinel (Cr) and Monazite (Th), further suggesting marked provenance changes could be modelled. It is also possible, of course, that the heavy minerals are components of acidic and basic igneous lithic fragments. Petrographic data and heavy mineral analyses would be required to test which of these alternatives is more probable.

Based on the discussions above and on experience of using whole rock geochemical data from a wide variety of settings, the following significance of the key element ratios used to characterise the sandstones can be tentatively suggested

Na/Al: Na has mixed affinities including plagioclase feldspar, intermediate / basic igneous lithic fragments and clay minerals. By normalising Na against Al, the influence of non-clay related components, i.e. plagioclase and intermediate / basic lithic fragments is emphasised.

Rb/Al: This ratio is most likely recording the amount of illite in a sandstone sample, although both mica and feldspar may also influence this ratio.

Ga/Rb: Both these elements to some extent are related to clay minerals, but Ga is a preferentially substituted into kaolinite, whereas as Rb is preferentially enriched in illite. Therefore, this ratio is recording the kaolinite : illite ratio. While this may be a diagenetic feature, it can also commonly indicate a change in palaeoclimate of the hinterland and / or changes in syn-depositional weathering, with kaolinite being a product of more intense weathering in a humid climate.

K/Rb: both K and Rb are influenced by clay minerals, notably illite, and K-feldspar. However, the K/Rb ratio is higher in K-feldspar than in illite, therefore, this ratio should emphasise the abundance of K-feldspar.

Cr/Th: Both elements appear to be associated with heavy minerals, but plot at different ends of the heavy mineral groupings on an EV2 vs EV3 plot, suggesting that they are controlled by different heavy minerals. Cr is often strongly influenced by Cr-spinels, and Th is often related to monazite. Thus the Cr/Th ratio may be recording a change in sediment provenance.

Cr/K: This ratio is designed to reflect the relative influence of basic igneous input (Cr-Spinel) and acidic igneous input (K).

K/Na: Both K and Na are controlled by a variety of Al-silicate minerals (e.g. plagioclase, clay minerals, mica), but the ratio of the two elements should be recording the proportion of plagioclase feldspar vs. K-feldspar.

Ti/Nb: Both these elements are associated with Ti-oxide heavy minerals and a marked excursion in the Ti/Nb ratio almost always reflects a change in sediment provenance, but the exact nature of that change cannot yet be determined in this study.

Nb/(Cs/Al): Nb is almost certainly related to Ti-oxide heavy minerals and Cs/Al is probably reflecting the amount of mica (?), making this ratio a proxy for Ti:oxide / mica.

The claystone dataset is currently only 50 samples, which is not sufficient to get meaningful results from PCA. Additionally, no mineralogical data have been acquired for the claystones, preventing an understanding of the mineralogical controls on this lithology impossible with the current dataset.

DISCUSSION

In SRU 34-10, the most marked geochemical changes are seen between the sandstones of the three lithostratigraphic units, namely the Hemlock, Tyonek and Beluga Formations. Each of these formations in SRU 34-10 has a distinctive geochemical fingerprint. The change in chemistry is most notable between the Hemlock and the Tyonek formations, with the chemistry suggesting that between these two units there is a major change in the sediment provenance and also a change in clay mineralogy, the latter possibly reflecting a change in the nature of the weathering.

The changes in chemistry seen in SRU 34-10 can be used as a template against which the relatively short core sections in other wells can be compared. Generally, the samples from the wells other than SRU 34-10 plot in similar fields to those defined from SRU 34-10, strongly suggesting that chemostratigraphy can fingerprint geochemical units and therefore supply a stable reference framework for the Oligo-Miocene sequences of the Cook Inlet.

Chemostratigraphy, based around fully quantitative elemental data is an ideal tool for the development of basinal stable stratigraphic frameworks. These frameworks are most commonly based upon lithostratigraphy, but this is not readily possible in the Oligo-Miocene of the Cook Inlet. This pilot study has demonstrated that chemostratigraphy is likely to provide a robust and stable framework, however a far larger dataset would be required.

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FIGURES

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Location of study areas

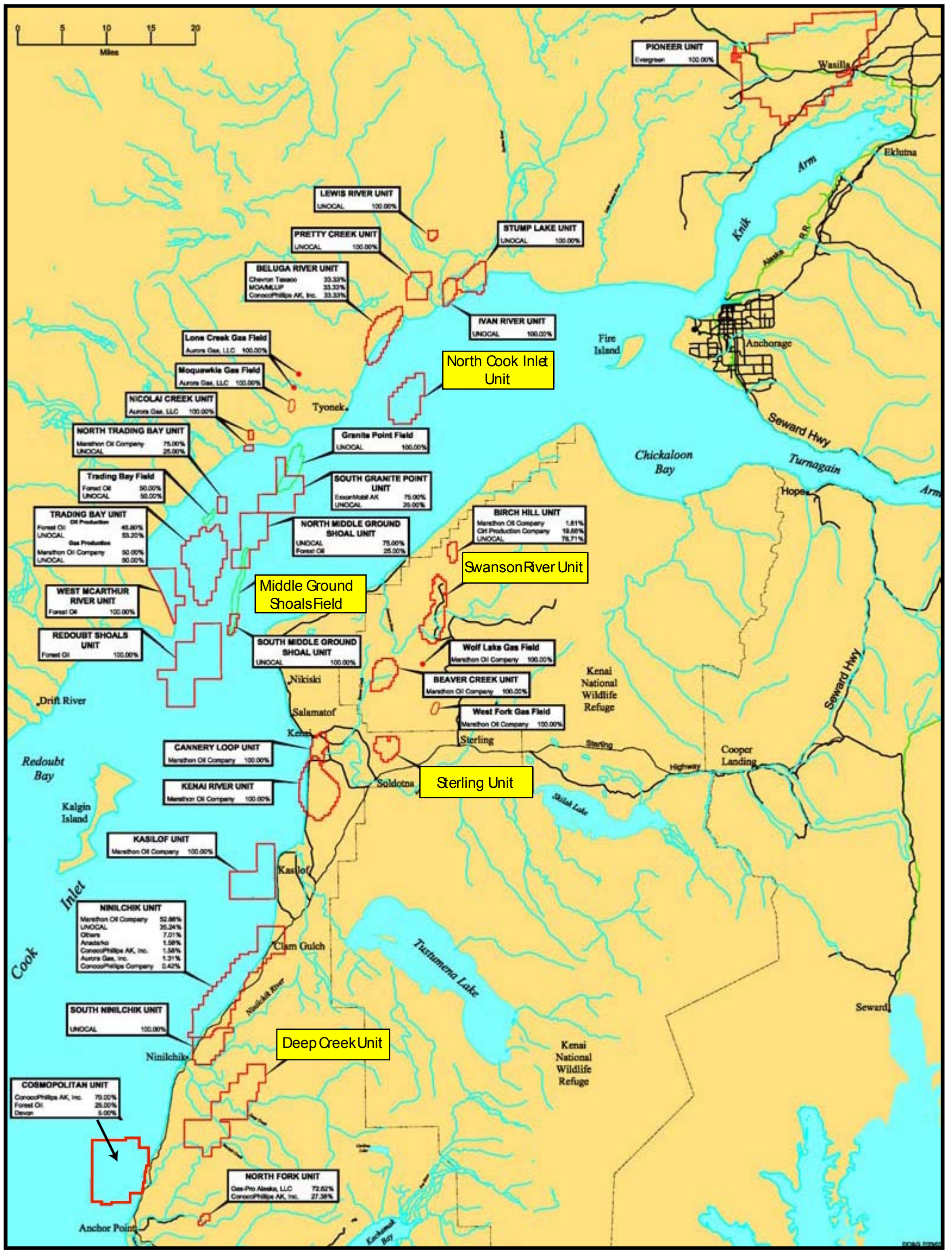

Figure 1. Location of units and fields included in the study (highlighted in yellow).

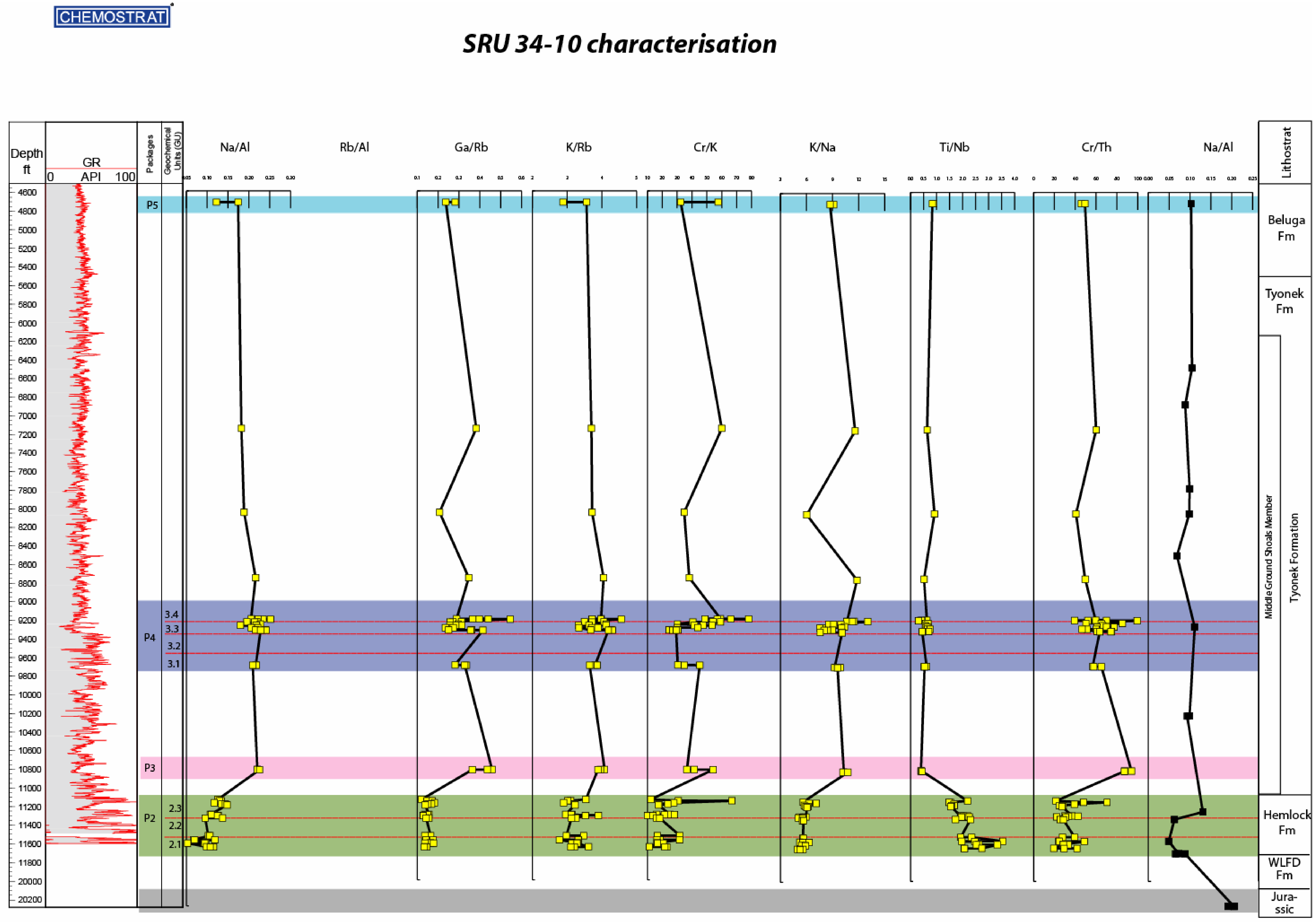

Figure 2. Chemostratigraphic characterisation of sandstones from SRU 34-10 using chemical logs constructed from core samples.

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Claystone Characterisation

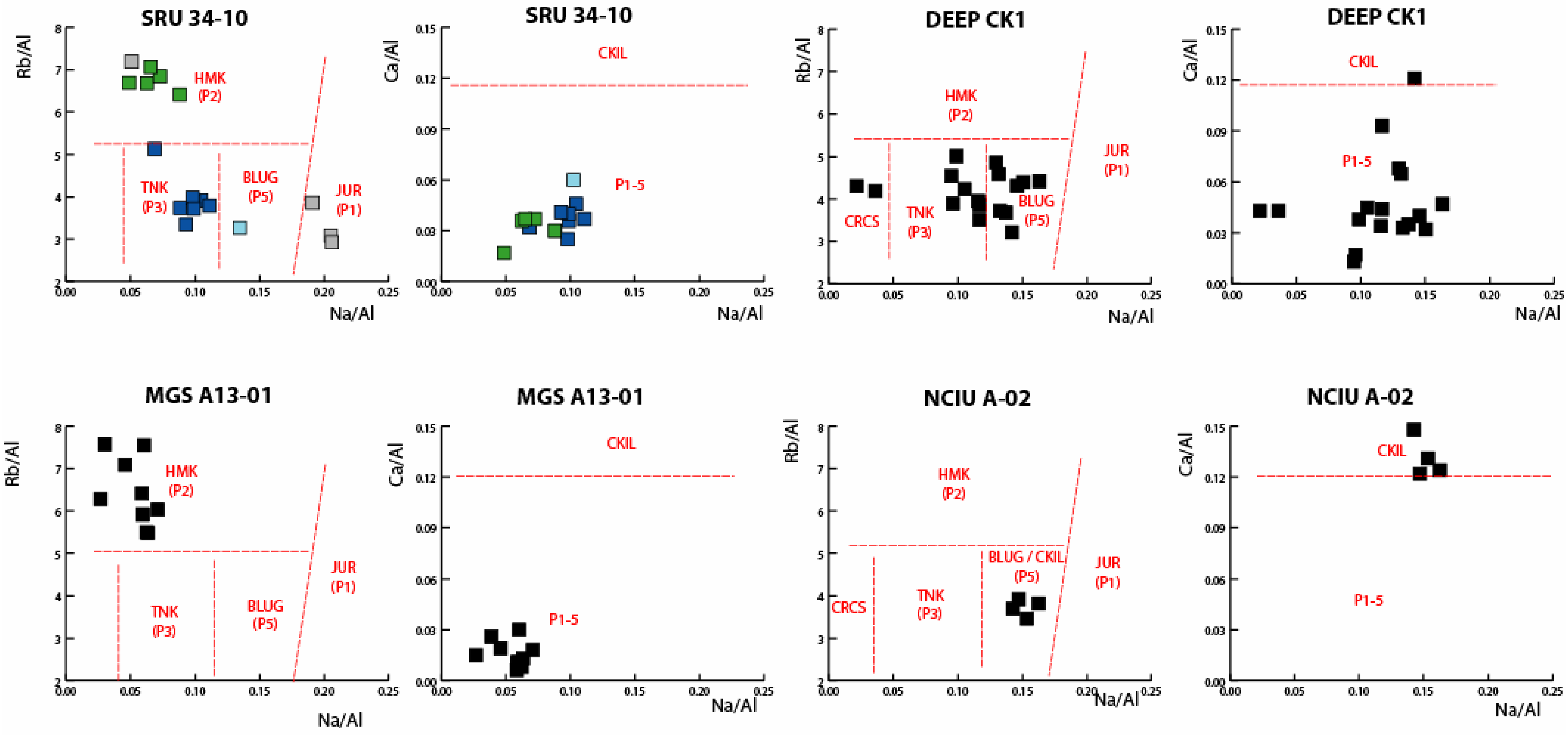

Figure 3. Chemostratigraphic characterisation of claystones from SRU 34-10, Deep CK1, MGS A13-01 and NCIU A-02 using binary diagrams constructed from core samples.

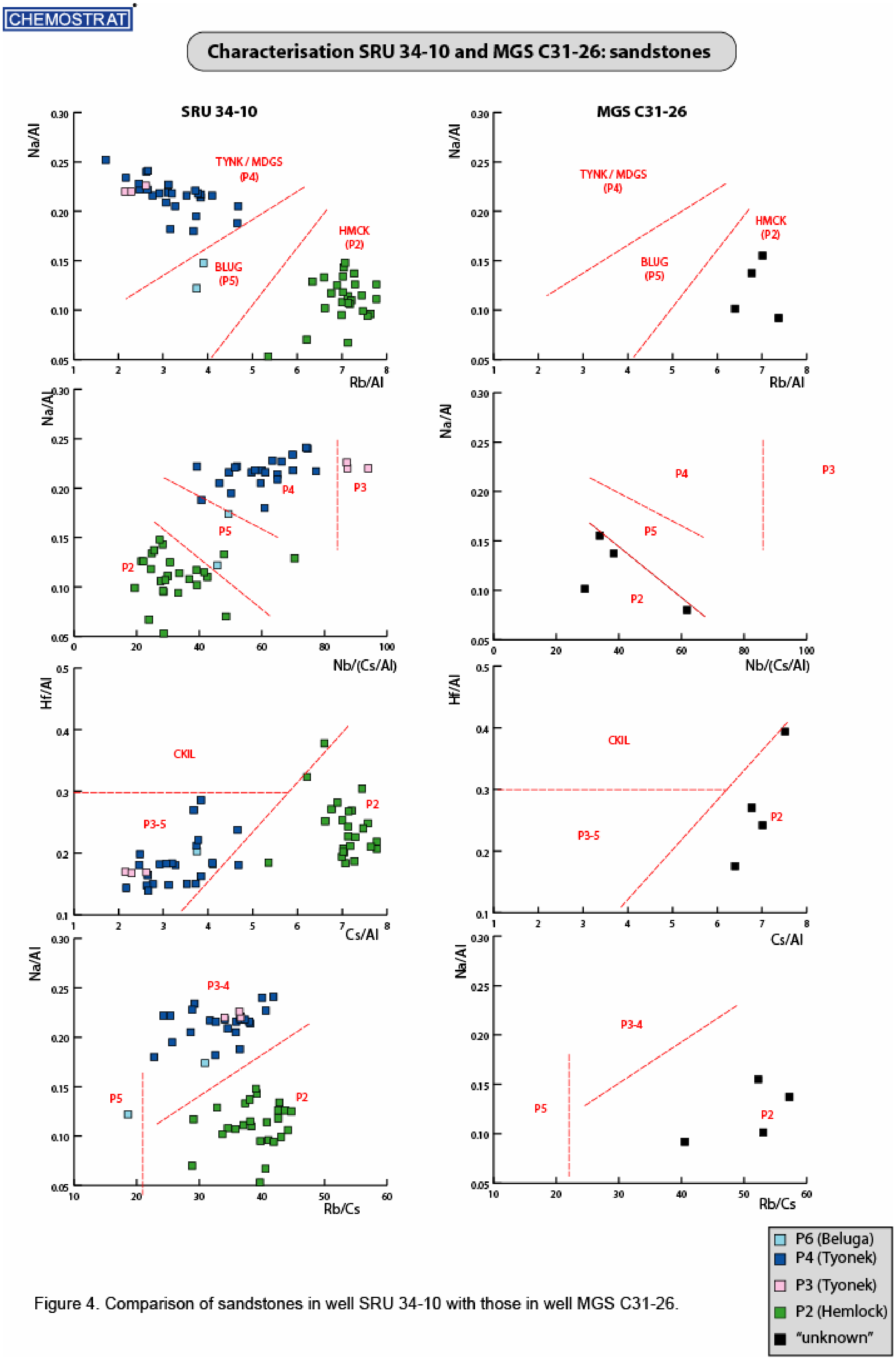

Figure 4. Comparison of sandstones in well SRU 34-10 with those in well MGS C31-26.

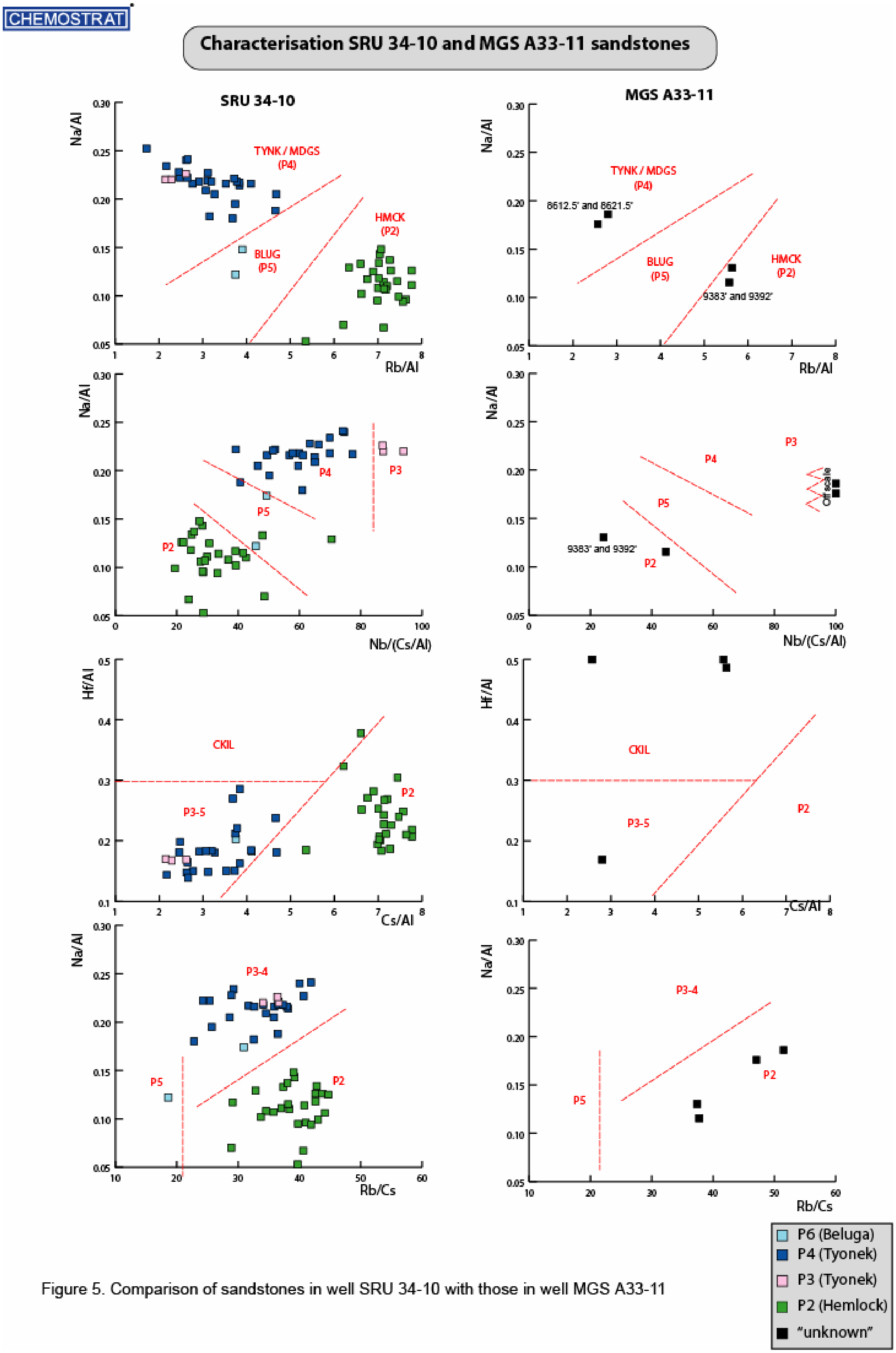

Figure 5. Comparison of sandstones in well SRU 34-10 with those in well MGS A33-11

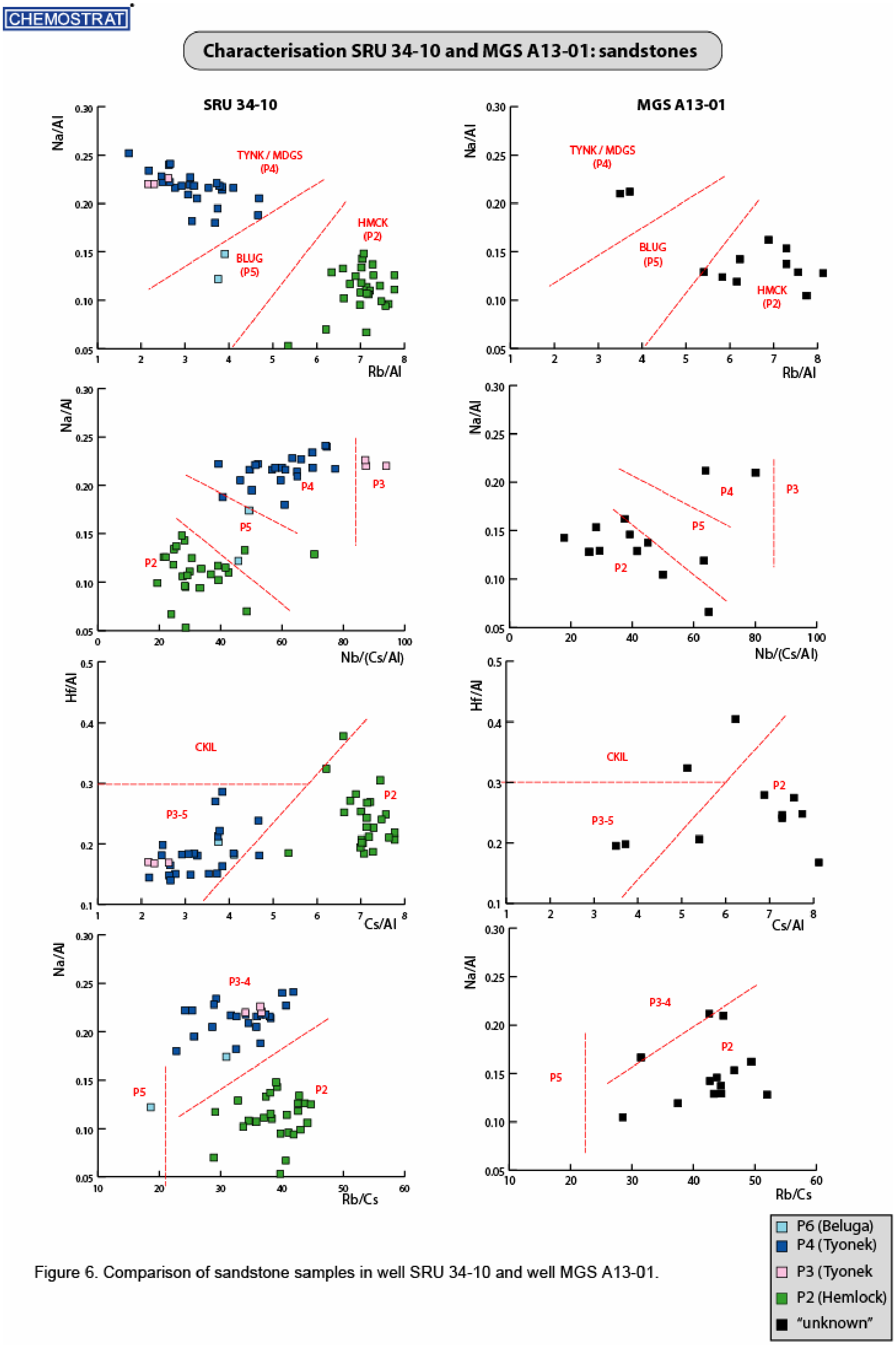

Figure 6. Comparison of sandstone samples in well SRU 34-10 and well MGS A13-01.

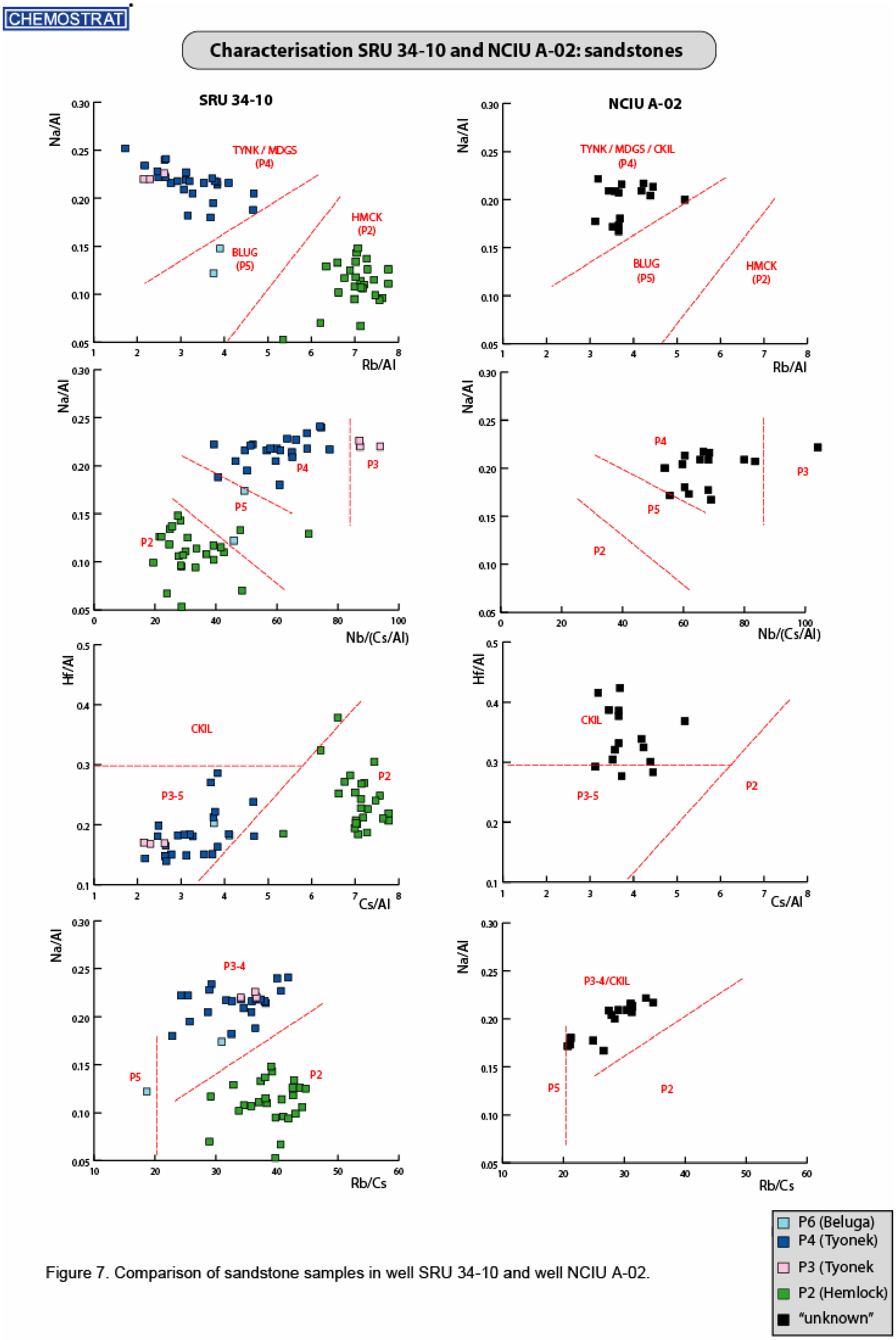

Figure 7. Comparison of sandstone samples in well SRU 34-10 and well NCIU A-02.

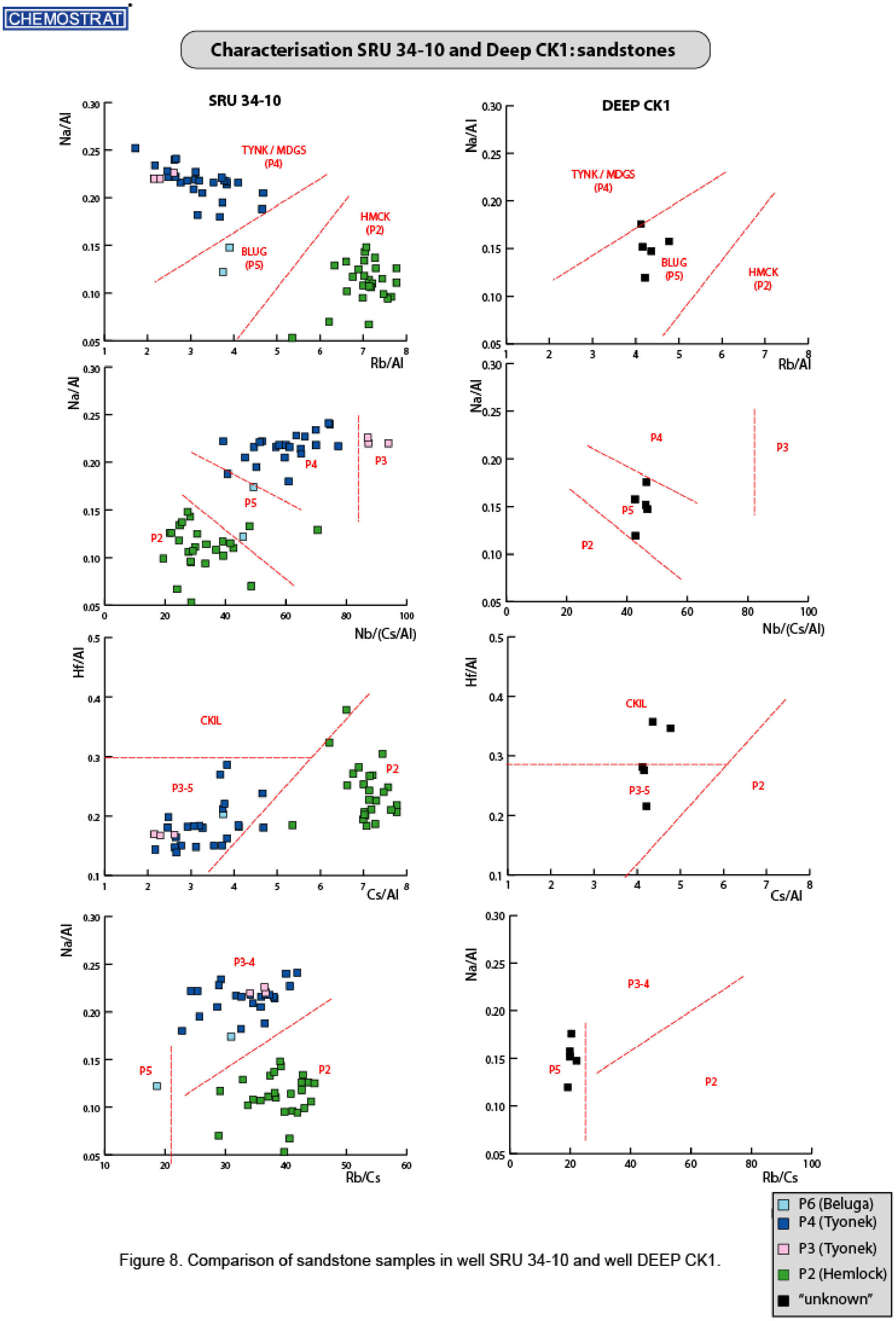

Figure 8. Comparison of sandstone samples in well SRU 34-10 and well DEEP CK1.

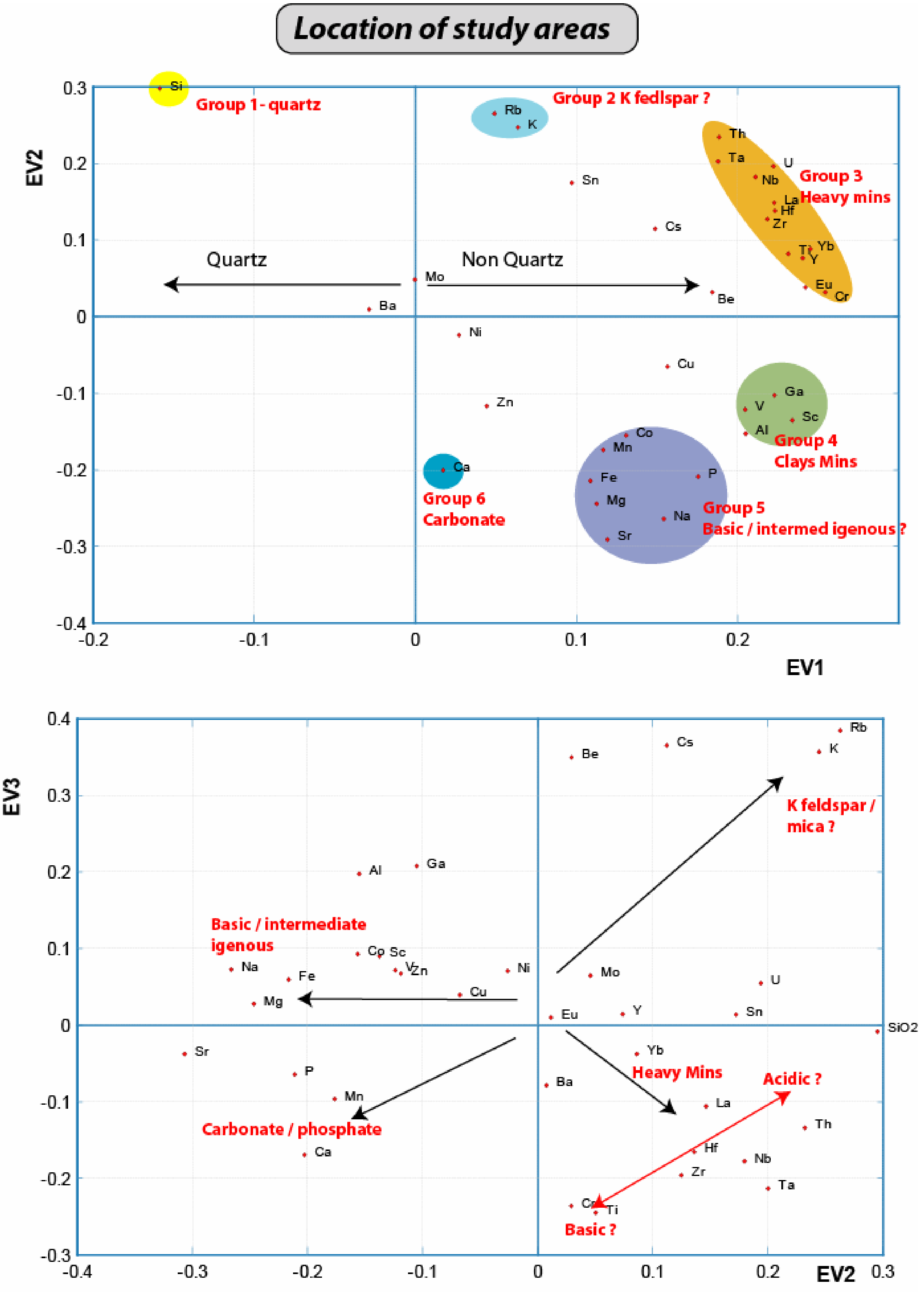

Figure 9. Summary of results of PCA undertaken on entire sandstone dataset.

APPENDIX 1

Table A1a. Elements and their chemical symbols

Symbol	Atomic Mass	Element	Symbol	Atomic Mass	Element
Si	28	Silica	Ti	48	Titanium
Al	27	Aluminium	Fe	56	Iron
Mg	24	Magnesium	Mn	55	Manganese
Ca	40	Calcium	Na	23	Sodium
K	39	Potassium	P	31	Phosphorus
Be	9	Beryllium	Ba	137	Barium
Co	59	Cobalt	Ce	140	Cerium
Cs	133	Caesium	Cr	52	Chromium
Dy	163	Dysprosium	Cu	64	Copper
Eu	152	Europium	Er	167	Erbium
Hf	179	Hafnium	Ga	70	Gallium
La	139	Lanthanum	Gd	157	Gadolinium
Nb	93	Niobium	Ho	165	Holmium
Ni	59	Nickel	Lu	175	Lutetium
Rb	86	Rubidium	Nd	144	Neodymium
Sm	150	Samarium	Pr	141	Praseodymium
Sr	88	Strontium	Sc	45	Scandium
Tl	204	Thallium	Sn	119	Tin
Th	232	Thorium	Ta	181	Tantalum
U	238	Uranium	Tb	159	Terbium
W	184	Tungsten	Tm	169	Thulium
Yb	173	Ytterbium	V	51	Vanadium
Zn	65	Zinc	Y	89	Yttrium
Zr	91	Zirconium	Pb	207	Lead
Bi	209	Bismuth	Mo	42	Molybdenum

APPENDIX 2

Geochemical Data (enclosed CD)