TERRASTATION OMNI CODE FOR PETROPHYSICAL LOG PROCESSING AND RHOMAA-UMAA LITHOLOGY DISCRIMINATION

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John F. Hopkins, Kansas Geological Survey

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INTRODUCTION

The purpose of this Open File Report is to document the Terrastation Omni code I have written for log processing. The Omni module has its own programming language and it is hoped that by archiving this code it will be of some use in the future. The code (Appendix I) consists several short routines for standard log manipulation and a rather long routine for a Rhomaa-Umaa lithology classification.

WELL LOGS

Resistivity

Resistivity logs measure the resistivity or conductivity of the formation and formation fluids. The major factors governing the resistivity reading are porosity and fluid content. Thus a tight unit will have a higher resistivity than a porous and permeable one. Likewise, a porous formation filled with hydrocarbons will have a higher resistivity than if the formation were filled with brine. Three resistivity logs are generally run together. Each log has different spacing of electrodes and different depth of investigation. The tool with the closest spacing has the shallowest range of investigation and in essence measures the resistivity of the flushed zone near the borehole. The medium and far spaced resistivity tools investigate the formation at intermediate and deep ranges. The intermediate spaced log measures the resistivity of the transition between the flushed zone and the unmolested formation. The deep resistivity tool has the farthest spacing between electrodes and more or less measures the resistivity of the *in situ* formation and formation fluids. The resistivity logs allow one to estimate fluid content, salinity, and qualitatively formation permeability.

Resistivity logs are also widely used for making stratigraphic correlations (Doveton, John H., 1994, Asquith, George with Charles Gibson, 1982).

Neutron

The neutron log provides a measure of porosity. The tool consists of a radioactive source which emits "fast" neutrons. The neutrons bombard the formation and are scattered back to a neutron counter in the tool. When the fast neutrons encounter hydrogen atoms they loose energy. In the subsurface the most common and "densest" source of hydrogen is water. So, the higher the number of slow neutrons detected, the higher the water content of the formation and therefore the higher the porosity of the interval. Minerals and lithologies containing bound water (i.e.: gypsum, chert, and shales) give a false or inflated porosity reading (Doveton, John H., 1994).

Density

The density log measures the density of the formation near the borehole and is used to derive porosity figures. The bulk density of the formation is obtained by bombarding the strata with gamma-rays from a radioactive source. These particles are scattered back to a detector in numbers proportional to the density of the formation. The denser the interval the greater the number of particles scattered back to the detector. Contributors to this are matrix density, the amount of pore space, and the fluid density. A porosity curve is derived from the density curve by assuming matrix (limestone or sandstone lithology) and a fluid density (usually that of water) (Doveton, John H., 1994, Asquith, George with Charles Gibson, 1982). The density derived porosity is simply the ratio of the instrument reading of bulk density to the assumed lithology density subtracted from unity, or:

$$\phi_b = \frac{\rho_{ma} - \rho_b}{}$$

ρ_{ma} -1

Photo-Electric Index

The photoelectric index (or Pe) gives an indication of mineralogy. The Pe tool is normally attached to the formation density log. The Pe log measures the absorption of low energy gamma rays by the formation in barns/electron. This value is a function of the aggregate atomic number (Z) of the elements in the formation. For any given element, the photoelectric index is:

$$Pe = (Z/10)^{3.6}$$

Since the Pe measurement is so closely tied to aggregate atomic number of the formation, the Pe tool is a good indicator of mineralogy (Doveton, John H., 1994).

CROSS-PLOTS

PHIav

By using two independent measurements of porosity it is possible to derive a better porosity estimate. There are many ways of doing this. For this project the method chosen was the arithmetic average:

$$\phi_{av.} = \frac{\phi den + \phi neut}{2}$$

This estimator gives an unbiased estimate of the true porosity which is very close to cross-plot porosities and one which is intuitively understood.

Rhomaa

Average porosity is only one of two composite log derived from the density and neutron logs for this project. The other composite log is Rhomaa, or apparent matrix

density. Calculation of Rhomaa mathematically separates the effects of lithology and porosity on the density log. The resulting figure is an approximation of matrix density, or Rhomaa. The formula

$$Rhomaa = (\rho_b - \phi_t)/(1-\phi_t)$$

is used in this study (Doveton, John H., 1994). Note that ϕ_t is the true porosity of the zone under consideration. In this study the average porosity $\phi_{av.}$ is used to estimate ϕ_t. Rhomaa is a useful lithology discriminator. Using this log alone, one can tell the difference between dolomite and quartz matrices. However, lithologies which lie between these two end members (i.e.: limestone, sandy dolomites, etc.) are indeterminate.

Umaa

The photoelectric factor log, or Pe, measures the absorption of low energy gamma rays by the formation and pore fluids. This measurement is a function of the aggregate atomic number of the formation and pore fluids, as such it is a good mineralogy indicator (Doveton, John H., 1994). From this logging tool and the average porosity composite log, another log curve is calculated: Umaa, or the apparent volumetric photoelectric absorption. Mathematically, this calculation removes the effect of porosity and pore fluids leaving the effect due to the lithology. In this study the following formula was used:

$$Umaa = (Pe*\rho_b - \phi_t)/(1-\phi_t)$$

Umaa is useful as a lithology discriminator with similar restrictions to Rhomaa. Umaa is pretty good at telling the difference between quartz and calcite, but lithologies which fall between these two end members are indeterminate.

Rwa

The last composite log in the list is R_{wa}, apparent resistivity of formation water. Although not a lithology discriminator, Rwa can provide valuable information on fluid type (Doveton, John H., 1994, Asquith, George with Charles Gibson, 1982). The formula used in this calculation is :

$$R_{wa} = R_t * \phi_t^2 \text{ or}$$

$$R_{wa} \approx R_{ild} * \phi_{av.}^2$$

An abnormally large Rwa reading may indicate the presence of hydrocarbons or deep invasion. In cases of deep invasion, pore fluid has been replaced by mud filtrate with a higher resistivity than the formation water.

Rhomaa-Umaa

One goal of petrophysical analysis is to determine lithology from downhole data. The basic idea is to use groups of logging tools whose composite responses to different lithologies can be partitioned to discriminate lithologies explicitly. A Rhomaa-Umaa classification was developed to discriminate between lithologies. This system divides Rhomaa-Umaa space into non-orthogonal regions in an attempt to classify mineralogy in a discrete fashion (Figure 1) and includes anhydrite as an end member. The outsides of the mineralogy polygons are enlarged to allow for instrument error. The width of this zone 0.02 gm/cc, which corresponds to ~5% of the difference in densities between quartz and dolomite. This lithology discriminator has eight classes: gas/halite, shale, quartz, calcite, anhydritic-calcite, dolomite, anhydritic-dolomite, and anhydrite. The classes are not designed to tell the difference between a sandy-dolomite and a dolomite. Rather, they are designed to relate the major mineralogic constituent. The numbering of the classes is arranged so that similar lithologic regions (calcite-quartz and calcite-anhydrite) have similar numbers. Problems still arise, however, in

mixed zones. For instance, a zone having mineralogy near the juncture of classes 3, 4, 5, and 6 will have, when transformed into a log curve, a complicated signature. This does not mean, necessarily, that the lithology of the zone is changing rapidly, more likely it is a zone made up of calcite and dolomite in nearly equal proportions with minor anhydrite.

Additional classes can be created by implementing of log curves with a lithology discriminator. Gamma-ray values help in distinguishing "hot" lithologies from "clean" lithologies. Adding Rwa classes can help to flag pay from non-pay zones. Likewise, porosity classes aid in reservoir characterization. Combining mineralogy description with additional parameters and transforming these results into pseudoseismic conveys a large amount of information in a cross-sectional graphical form.

THE LANGUAGE OF TERRASTATION OMNI

Omni is a Terrastation dependent programming language used to generate custom log processing routines within the Terrastation environment. Omni allows one to perform mathematical and logical operations on individual or multiple curves from one well (TerraSciences, 1993). The Terrastation manual (TerraSciences, 1993) gives a full treatment of the Omni language. Omni programs are written outside of the Terrastation environment in a text editor. All references to Terrastation or the Omni module and its programming language are from the Terrastation manual (TerraSciences, 1993) and my personal experience. Basically, an Omni program consists of three parts: defining channels, manipulating channels, and a stop command.

Channels are defined by how they are stored within Terrastation. They are assigned a number and a name either by the user or by the data loading utilities. If the channels have names that Terrastation recognize (such as GR for gamma ray), then the program will load the curve into a standard position (i.e.: 03GR). If Terrastation does

not recognize the channel name (CGR for corrected gamma ray), then the program will place the log in an open unnamed channel. Unfortunately, different well logging companies call the same curves by different names confusing geologists and computer software alike. Therefore it behooves the Terrastation user to know which curves are stored in what channels. In the Omni language existing curves are referred to by prefixing an X to the channel number (X03 would be the gamma ray curve). Output channels that will be created by the program are defined by prefixing an N to the desired channel (example: N123 for a normalized gamma ray). All input and output channels must be defined at the beginning of the program.

Constants, like data channels, must be defined at the beginning of the Omni program. Constants can be assigned a specific value (such as pi = 3.14...) or calculated values (handy in logical operations). Constants are labeled in a similar to data channels. They have a C followed by a number greater than 10 (constants 1-10 are used internally by Terrastation).

Once the variables or channels are defined, log manipulation code can follow. Terrastation has simple mathematical and logical capabilities. The mathematical abilities include addition, subtraction, multiplication, division, and some higher functions (base ten logarithm, exponential, square roots). These mathematical operators can be used on a single channel or among several channels. For instance, you can multiply a channel by a constant, or you can multiply two channels sample by sample.

The logical capabilities of Terrastation are limited to direct comparisons between two values. Nested comparisons, nested loops, and multiple comparisons are not allowed in the Omni language. As a result of this Omni code is often redundant and longer than it would be in other programming languages. Omni does, however, handle the input and output of the data smoothly. The Rhomaa-Umaa lithology discrimination code makes extensive use of direct comparisons.

Other Omni conventions are comments and function calls. Comments in Omni are denoted by an * at the beginning of the line. Some mathematical functions (such as base 10 logarithm or LOG) must be prefixed by an @. This tells the Omni compiler that a function rather than a variable follows. A full list of these is provided in the Terrastation manual.

APPENDIX I: Omni Code

```
* Terrastation Omni code for petrophysical log processing
*   VARIABLES
*
*    X04  = RHOB
*    X05  = PE
*    X07  = NPHI
*    X11   = ILD
*    X28   = PORZ
*   N110 = PHIT
*   N111 = Rhomaa
*   N112 = RWa
*   N113 = Umaa
*   N117 = LITH -- Rhomaa-Umaa
*   N120 = LOG(ild)
*   N121 = LOG(rwa)
*
*
```

```
* ---- Average porosity -----
N110 = (X07 + X28)/2
* ---- Rhomaa ----
N111 = (X04 - (X110/100))/(1-(X110/100))
*----- Apparent water resistivity: Rwa ----
N112 = X11*((X110/100)**2)
* ---- Umaa ----
N113 = ((X05*X04) - (X110/100))/(1-(X110/100))
* ---- Base ten logarithm of deep resistivity channel ----
N120 = @log(X11)

* ---- Rhomaa-Umaa lithology discrimination routine -----
* The output curve LITH has a range between 0 and 7.  The key for these values is
* shown below.
* 0 = GAS, 1 = SHALE, 2 = QUARTZ, 3 = CALCITE, 4 = CALCITE/ANHYDRITE
* 5 = DOLOMITE, 6 = DOLOMITE/ANHYDRITE, 7 = ANHYDRITE
*
*
N117 = 0
*
* The following constant block defines the boundaries for each mineralogic end
* member
* above.  Constants are used instead of direct comparisons because Omni only does
* direct comparisons between two numbers.  Omni can not perform calculations in a
* comparison.
```

```
C11 = 0.0078*X113+2.6027-0.02
C12 = 0.0504*X113+2.3994+0.02
C13 = (-0.0291)*X113+3.11
C14 = 0.0208*X113+2.54436
C15 = 0.0213*X113+2.6594+0.02
C16 = (-0.1339)*X113+2.1595
C17 = 0.0546*X113+2.1595
IF(X111<C11)
 N117=0
 GOTO STOP
ENDIF
*
IF(X111>C12)
 N117=1
 GOTO STOP
ENDIF
*
* TESTS IF DATA POINT IS IN THE Q-C-D OR C-D-A DOMAIN
*
IF(X111>C13)
 GOTO ANHYDRITE
ENDIF
*
* SUBSETS Q-C-D DOMAIN
*
```

```
IF(X113<9.23)
 GOTO QDOL
ENDIF
*
IF(X111<C14)
 N117 = 3
 GOTO STOP
ENDIF
N117=5
*
:QDOL
  IF(X111<2.74)
    N117=2
    GOTO STOP
  ENDIF
  N117=5
*
:ANHYDRITE
IF(X111>C15)
  N117=1
  GOTO STOP
ENDIF
*
IF(X111<2.85)
  GOTO CAAN
```

```
ENDIF
*
IF(X111>C16)
  N117=7
  GOTO STOP
ENDIF
*
 N117=6
 GOTO STOP
*
:CAAN
IF(X111<C17)
 N117=4
 GOTO STOP
ENDIF
*
 N117=6
 GOTO STOP
:STOP
```

BIBLIOGRAPHY

Asquith, George with Charles Gibson, 1982, Basic Well Log Analysis for Geologists: AAPG Methods in Exploration Series No. 3, pp. 216.

Doveton, John H., 1994, Geologic Log Interpretation: SEPM Short Course No. 29.

TerraSciences, 1993, TerraStation Manual, Version 5.4: TerraSciences Denver, Houston, and London.

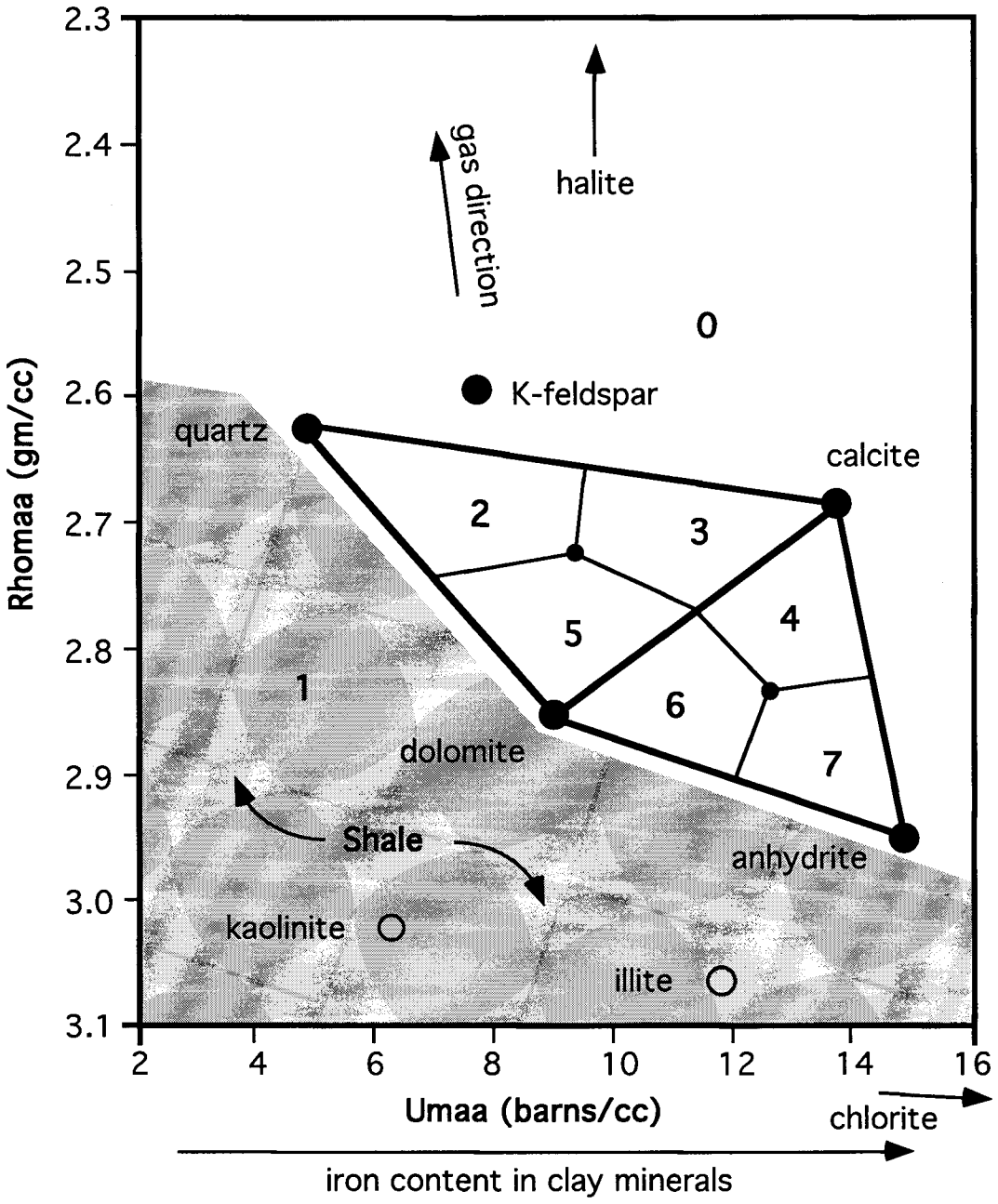

Figure 1: Rhomaa-Umaa classification chart. The large numbers correspond to the discrete classification zones in the Rhomaa-Umaa classification routine. 0 = gas, halite, or washout, 1 = shale, 2 = quartz, 3 = calcite, 4 = anhydritic limestone, 5 = dolomite, 6 = anhhydritic dolomite, and 7 = anhydrite. After Doveton, 1994.