A Self-Adaptive Optimization Solution to Petrophysical Properties Inversion from Well Logs

Yexin Liu*
Calgary, AB
yexinliu@gmail.com

Summary

During the well logging processing (inversion) and interpretation, it is important for us to select the fluid type, clay type and mineral components. Usually the clay and fluid types can be referred to field experience and other measurements, but the mineral components could be variable from borehole top to bottom (depth-variable). One component model maybe is appropriate for one geological section, but the other section may need to use another mineral component model. Also it is difficult for us to know the mineral components at the different sections!

Here we present a self-adaptive approach to add/remove the mineral components according to the rules pre-defined by users and the best mineral components will be selected automatically during the inversion. Also a multi-objective optimization mechanism has been used to inverse the porosity, volumes of clay and mineral components from well logs using the selected mineral components combined with both fluid and clay types.

During the inversion, according to field experience there are differing logging response equations available from the same well log tool, which can be selected interactively. For example, the water saturation can be calculated from dual-water model, and also be calculated from Archie or Indonesian equations. Also the inversion procedure is a section/zone-based mechanism to meet the petrophysical model depth-variable's needs. The method has demonstrated a reasonable and robust result after processing well logging dataset from both conventional sand-shale formation and complex carbonate formation.

Introduction

When you set up a petrophysical inversion model to calculate the volume of shale, volume of mineral, porosity and water saturation from well logs, you must pre-define your mineral model, such as fluid-clay-sand-shale model, fluid-clay-calcite-dolomite model, or others complex lithology models, and also you should know both clay and fluid types. Figure 1 shows a petrophysical inversion model.

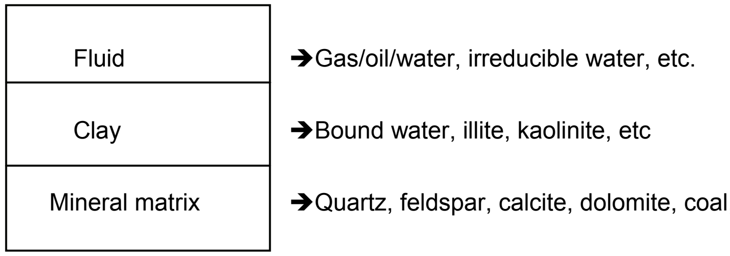

Figure 1 Petrophysical model for well logging inversion

Fluid is important to evaluate whether the reservoir is hydrocarbon accumulation or water. Usually we can calculate water saturation from resistivity tool to evaluate the reservoir. Clay has been used to describe the volume of the non-productive portions of a reservoir. There are several clay types such as illite, kaolinite,montmotillonite, etc. The wet clays are composed of dry clay and bound water. The wet clay volume can be easily calculated using a gamma ray tool. Rock mineral matrix could be sand-shale components or calcite-dolomite, or others. The volume of mineral matix can be calculated from some well logs tools.

It seems we can calculate the volume of clay from a gamma tool, water saturaton from resistivity tool and volume of mineral from density tool or neutron tool. However each response equation of the well logging tool is the function of fulid, clay and mineral components. So it is difficult to use only one tool to calculate one property, such as porosity or volume of clay. In fact well logging responses are the contributions of three parts: the clay, fluid and mineral. Also the contribution of each part will be depth-variable. So we need to adjust the components, such as remove a component or add a component while inversion.

Here we present a self-adaptive regulation mechanism to adjust the mineral components according to field experience rules pre-defined by users, and then a multi-objective optimization algorithm will be used to inverse all the volumes, including fluid, clay and mineral components using all available well logging measurements. Because of ill-posed issues during the inversion, the constrained conditions of properties and the weights of well logging measurements will be applied. The result sounds reasonable and robust.

Method

A well logging general response equation can be expressed:

f(logging) = fluid + clay + mineral matrix

The contributions of well logging response consist of three parts, fluid, clay and mineral matrix

If the logging tool is density, for example, the response equation can be rewritten:

$$den = \sum_{flushed\ zone} den_{fluid} * volume_{fluid} + \sum_{undisturbed\ zone} den_{fluid} * volume_{fluid} + \sum den_{clay} * volume_{clay} + \sum den_{matrix} * volume_{matrix}$$

If the tools measure only flushed zone, such as gamma ray tool, the fluid contributions of undisturbed zone should be removed. Otherwise, if the tool only measures the undisturbed zone, such as true resistivity tool, the fluid contributions of undisturbed zone will be removed.

Fluid types:

There are several fluid types which can be added to your model, such as gas, oil, and water

Clay types:

Wet clays are composed of illite, kaolinite, etc. Bound waters are removed from wet clays to obtain the dry clay volume.

Mineral components:

The field experience rules can be pre-defined to determine whether the mineral components should be removed or added to your petrophysical model during inversion. For example, coal component could exist when density is less than 1.9 kg/cm3. While inversion, the petrophysical model will add coal to your mineral components, otherwise, the coal will be removed from your mineral components automatically. Also some case-based experience could be integrated into the inversion procedure when add/remove the mineral component. For instance, If there are only sand-shale components at your areas, the calcite, dolomite, etc should not be selected.

Multi-objective optimization & Ill-posed problems:

The components to be selected from fluid, clay and mineral matrix will be the functions of well logging measurements. Each response equation of well logging measurement can construct one inversion objective. The porosity, water saturation, volume of clay and volume of mineral are the target properties of each function. If more well logs are available, we can combine the response equations to construct more objective functions. The multi-objective optimization solution can easily inverse the target properties. However, because the well logging is affected by borehole geometry, temperature and pressure, although the influence can be corrected before inversion, the ill-posed issues still are a big challenge for inversion.

Because of ill-posed issues, solutions might not be unique and/or might not depend continuously on the data. Hence their mathematical analysis is subtle. Usually when the logging reading is a minor change, the output will have no solution or the output is not robust. Here a multi-objective optimization solution is presented to solve the ill-posed issues. All well logging response equations can be normalized using their standard deviation to remove measurement unit affection and then the penalty factors will be applied to some objective functions when the target property cannot meet the constrained conditions, and also a small random variable with mean zero to add the response equation and target properties. The Broyden-Fletcher-Goldfarb-Shanno (BFSG) method is selected to optimize and inverse the property and it performs extremely well.

Examples

Figure 2 shows an example of the sand-shale components inversed by the method presented here. The 4th track is the volume of clay and mineral matrix. The volume of coal can be easily calculated using the experiece rules during invversion. The fluid types will be gas and water. A dual-water resistivity model will be applied to calculate the water saturation. Figure 3 is a complex carbonate model. The mineal components are composed of quartz, calcite, dolomite and coal. During inversion, the petrophysical model will adjust the mineral components according to pre-defined rules and well loggings. The above quartz zone and bottom calcite and dolomite zones are easily found. And also there is a possible low porosity limestone reservoir zone at the bottom. The quality control curve shows the porosity, volume of clay, water saturation and volume of mineral components are resonable.

Conclusions

We present a self-adaptive optimization solution to inverse petrophsical properties from well logs. The methods can handle different clay types, fluid types, and also can adjust the mineral components according the experiece rules provided by users and well loggings. The method has been successfully applied to both sand-shale formation and complex lithology formation, such as calcite/dolomite. Because a best mineral component model will be selected and well-posed solution during inversion, the inversion results show the the porosity, volume of clay, water saturation and volume of mineral are resonable and robust.

References

Schlumberger Well Evaluation Conference, 1997, China

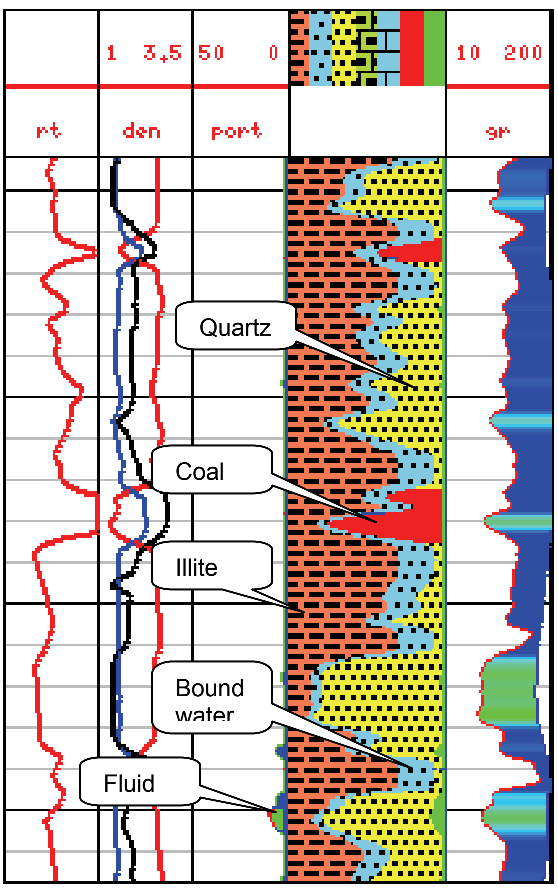

Figure 2: Sand-shale model inversion

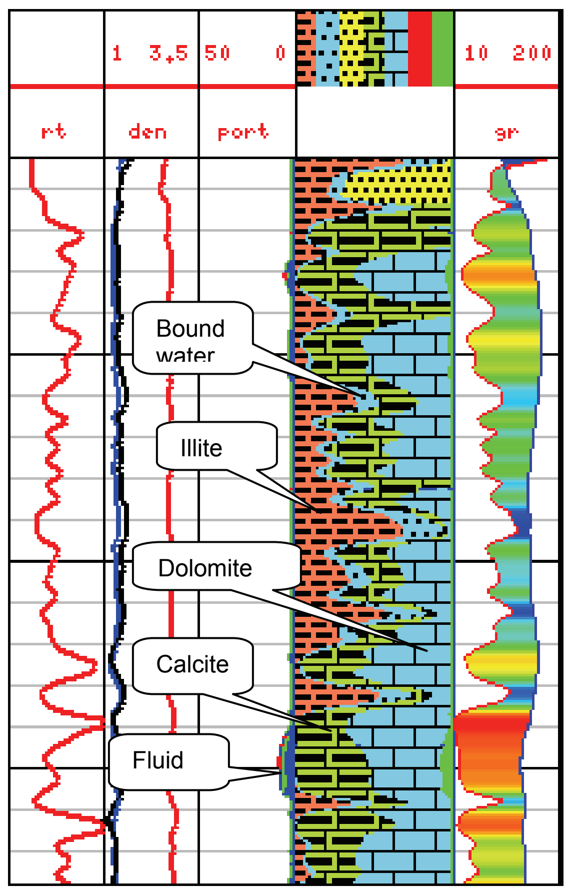

Figure 3: Complex carbonate model inversions