[PS]Generalized Method for the Estimation of TOC from GR and Rt*

Kenneth A. Heslop[1]

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[1]Oakrock Ltd., Irricana, AB, Canada (kenneth.heslop@logx.ca)

Abstract

Determination of TOC is critical to the evaluation of every shale resource. The ideal method for determining the TOC fraction within shale formations would utilize common well log data, and not require manual interpretation for each depositional layer. Methods which are dependent upon extensive laboratory testing are limited by the availability and integrity of the rock samples. Well log data will generally be available for the majority of wells being evaluated.

The well log methods commonly used to estimate TOC utilize resistivity and porosity logs. Porosity logs incorporate a lithology response in addition to porosity, plus the complication of borehole related errors. These methods require the user to manually interpret and calibrate for each depositional layer.

The two most common and reliable log curves are the Gamma Ray (GR) and Resistivity (Rt). Experience has shown there is an inverse relationship between these curves. The GR typically decreases in a clean matrix, whereas the Rt increases. In "non-source" shale (i.e., no TOC,) the GR increases while the Rt decreases. These two log curves tend to "hour-glass" when plotted using conventional scales. Reversing one of the scales causes the GR and Rt curves to track. The exception to these observations occurs where TOC is present. There the GR and Rt both increase.

A relationship was developed to model these log curves in the absence of TOC. In simple terms we can state that GR is a function of Rt. This relationship should hold true throughout the section, except in shale intervals where TOC is present. There GR should be greater than the function of Rt.

Recognizing the increase in GR and Rt to be related to TOC within the shale, it is possible to estimate the weight percent of TOC present. The TOC effect is the difference between the actual GR and Rt response and the GR and Rt relationship for non-source rocks. This method of estimating TOC avoids the tedium and potential errors of log overlay techniques, providing consistent results across the field, and even regionally.

Generalized Method for the Estimation of TOC from GR and Rt

Kenneth A. Heslop, Oakrock Ltd. – Petrophysical Consultant

- TOC data from geochemical analyses are ***expensive***, ***time consuming*** and ***subject to sampling bias.***
- Prediction of TOC from Wireline Logs provides ***rapid evaluation of organic content*** within a shale, producing a ***continuous record*** while ***eliminating sampling issues***.
- Shale HC potential observed on Logs as:
  - ***elevated resistivity (Rt)*** > Shale Rt,
  - ***lower RHOB*** relative to Shale Density,
  - a ***"hot" GR*** response > Shale GR,
  - ***increased DT*** relative to Shale DT,
  - ***increased NPHI*** relative to Shale Neutron.
- New method to ***predict TOC in Shales using GR & Rt Logs* was developed**. Both of these logs are commonly recorded, and are less sensitive to borehole washouts.
- GR vs Rt method presented here ***builds upon ΔlogR method, but uses GR*** in place of a porosity log. The Δlog gap between GR and Rt in a "Source" Shale is defined as the units of separation between the curves using the standardized scales.
- ***GR and Rt logs tend to "hour-glass".*** These responses appear to be independent of lithology or other changes within the Shales. ***Reversing and selecting appropriate values for the Rt scale*** provides a scenario where the GR and Rt log curves track, except in "Source" Shales.
- Assuming TOC within a "Source" Shale would act upon GR and Rt equally, a model was developed in which the ***deviation of each log curve from the "Non-Source" response was a function of TOC***.
- The gap between the curves was partially attributed to each curve.

$$\Delta GR + \Delta Rt = TOC \times [GR_{TOC} + \log_{10}(Rt_{TOC})]$$

- GR_{TOC} and Rt_{TOC} were determined using TOC lab data correlated to the GR vs Rt gap.

Looking Forward:

- Extend research of the GR vs Rt Method as additional log and lab data become available. In particular, test method over entire range of shale maturities, including Oil Shales.
- Expand method to include use of porosity logs where borehole effects are not an issue.

OAKROCK Ltd.

agent for: LOGX inc.

Box 92, Irricana, AB   T0M 1B0   (403) 935-4641
Kenneth Heslop <kenneth.heslop@logx.ca>

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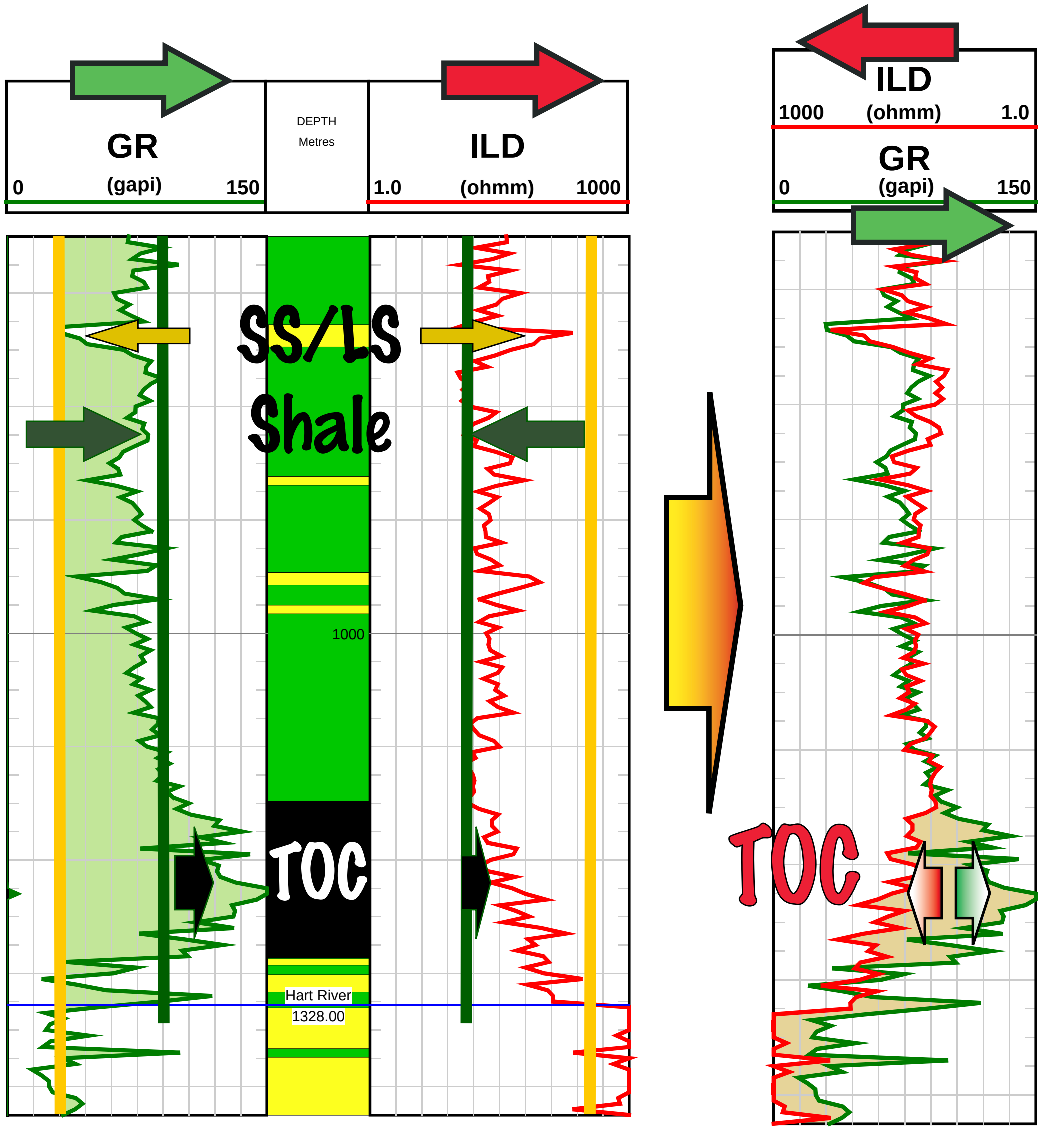

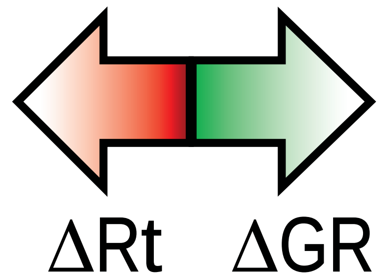

$$\Delta GR = TOC*GR_{TOC}$$

$$\Delta Rt = TOC*\log_{10}(Rt_{TOC})$$

OAKROCK Ltd.
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Box 92, Irricana, AB T0M 1B0 (403) 935-4641
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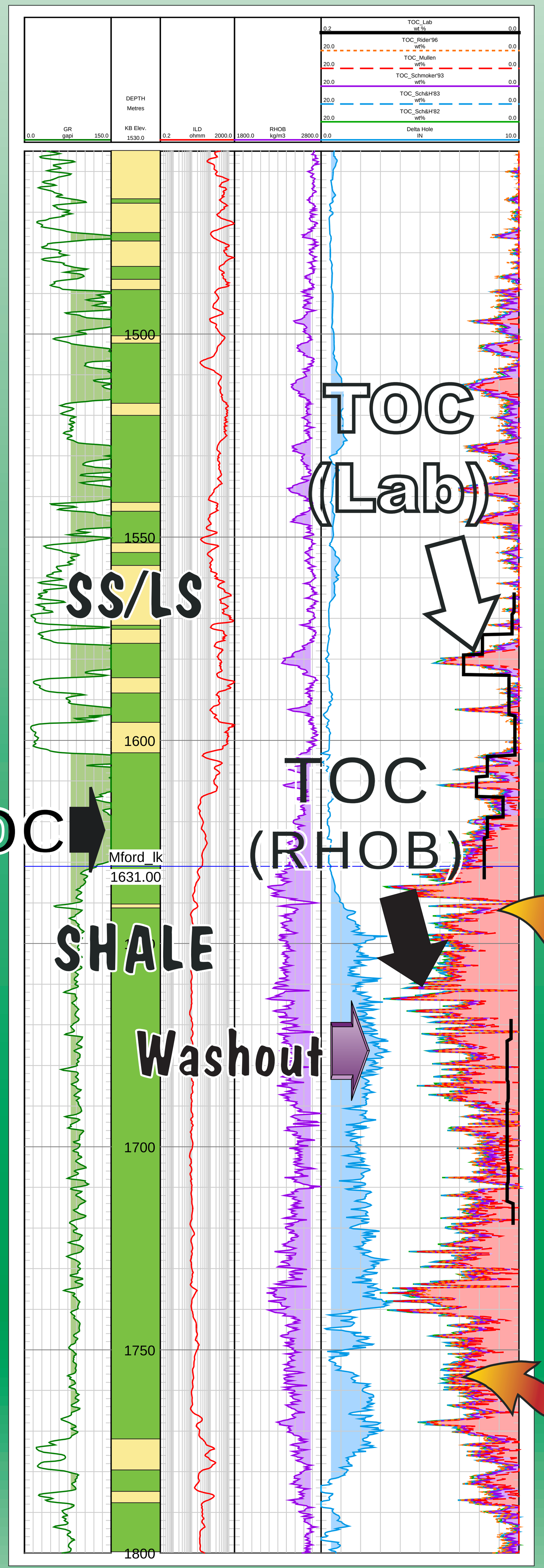
INTRODUCTION

- TOC data from *geochemical analyses are expensive, time consuming* and *subject to sampling bias.*
- Prediction of TOC from Wireline Logs provides *rapid evaluation of organic content* within a shale, producing a *continuous record* while *eliminating sampling issues*.
- Shale HC potential observed on Logs as:
  - a *"hot" GR* response > Shale GR,
  - *elevated resistivity (Rt)* > Shale Rt,
  - *increased DT* relative to Shale DT,
  - *lower RHOB* relative to Shale Density,
  - *increased NPHI* relative to Shale Neutron.
- Previous TOC from Wireline Log methods are generally defined as one of the following:
  - TOC from *RHOB* only,
  - TOC from *Rt & Porosity log* (ie. ΔlogR.)

  These methods are subject to borehole effects, highly dependent upon parameter selection, and therefore tend to be a "manual" process.
- New method to *predict TOC in Shales using GR & Rt Logs* was developed. Both of these wireline logs are commonly recorded, and are less sensitive to borehole washouts.

BACKGROUND

RHOB Methods



TOC from RHOB Equations

$$TOC = (A/\rho_{bs}) - B$$

A=156.956, B=58.272 Schmoker & Hester, 1982
A=154.497, B=57.261 Schmoker & Hester, 1983

$$TOC = A\times(\rho_{ns}/\rho_{bs}) - B$$

A=58.82, B=0.5882 Rider et al, 1991
A=55.82, B=55.82 Schmoker, 1993

$$TOC = A - B\times\rho_{bs}$$

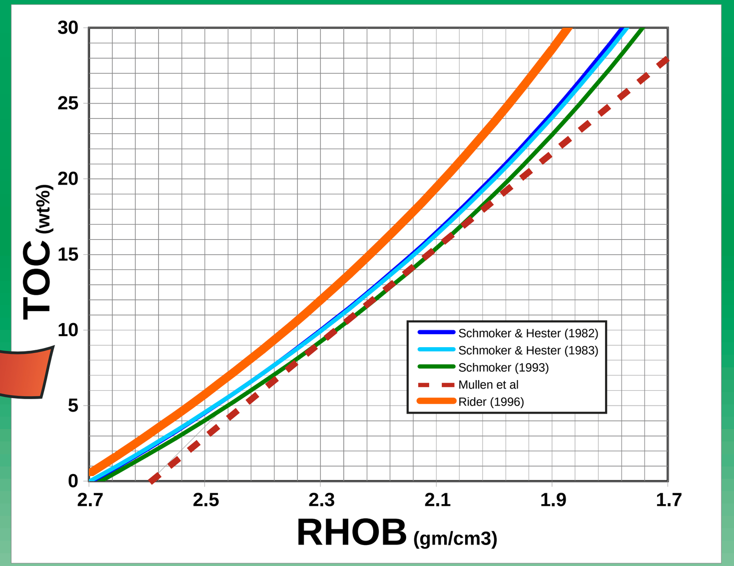
A=81.4, B=31.4 Mullen, Bray & Blauch

$$TOC = 100\times\left[\frac{(A\times\rho_{om}\times\phi_{om})}{((\rho_{om}\times\phi_{om})-\rho_{ma}\times(1-\phi_{om}-\phi_{fl}))}\right]$$

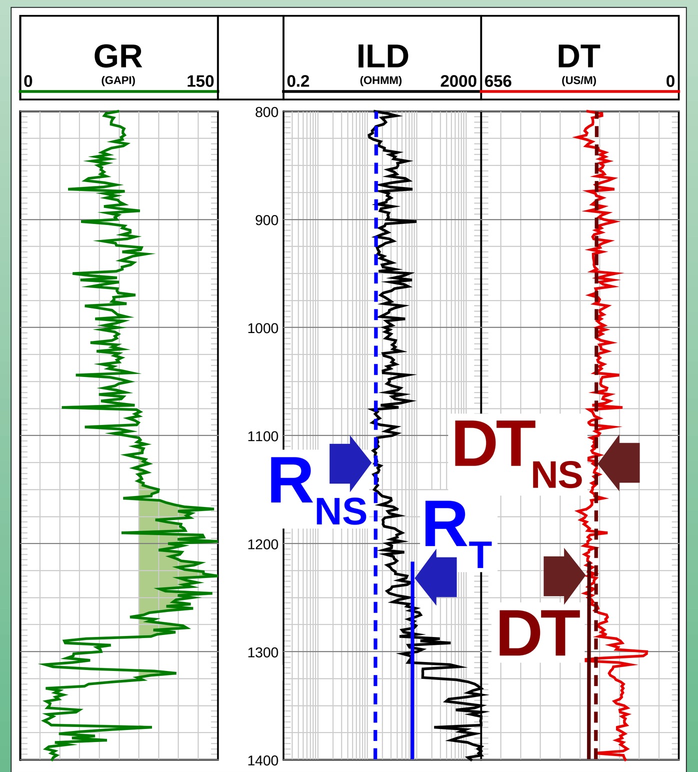
A=0.85 Rider et al, 1996

ρ_{bs} = Density of Black Shale
ρ_{ns} = Density of Non-Source Shale
ρ_{om} = Density of Organic Matter
ρ_{ma} = Density of Matrix
ϕ_{om} = Volume of Organic Matter
ϕ_{fl} = Volume of Fluids

TOC from RHOB susceptible to borehole washouts and lithology changes.

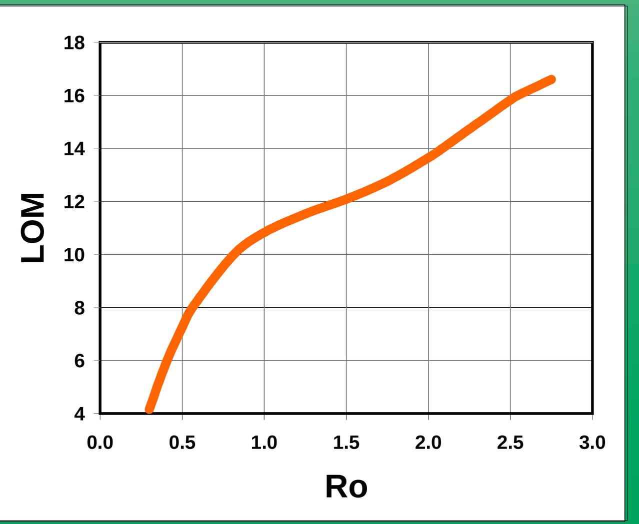


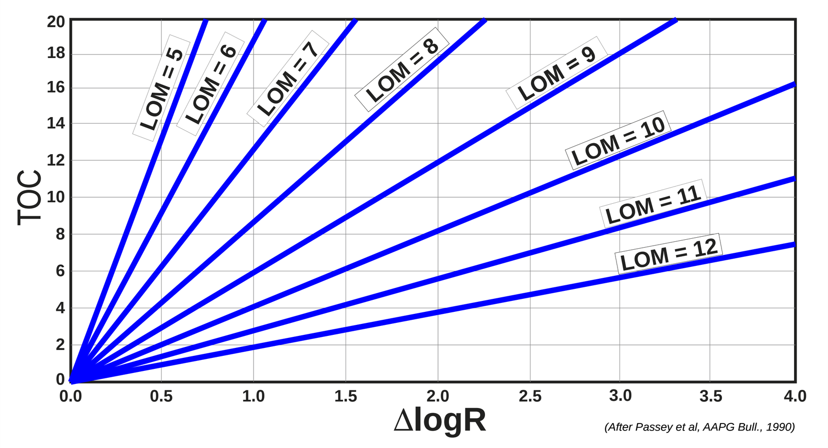
ΔlogR Method

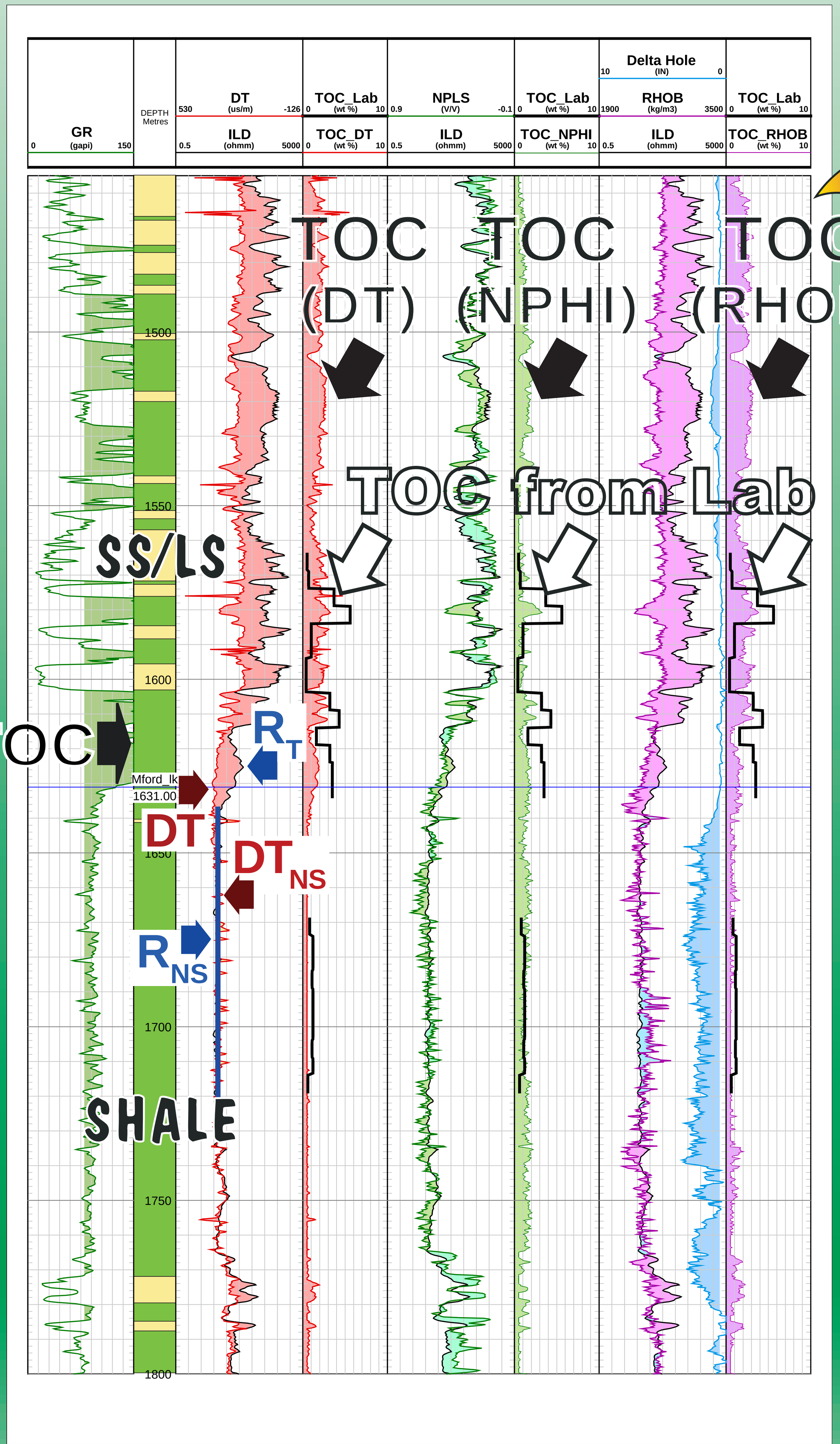


$$\Delta logR = \log_{10}(R_T/R_{NS}) + k(DT-DT_{NS})$$

where: k = 0.02 ft/us
k = 0.0061 m/us



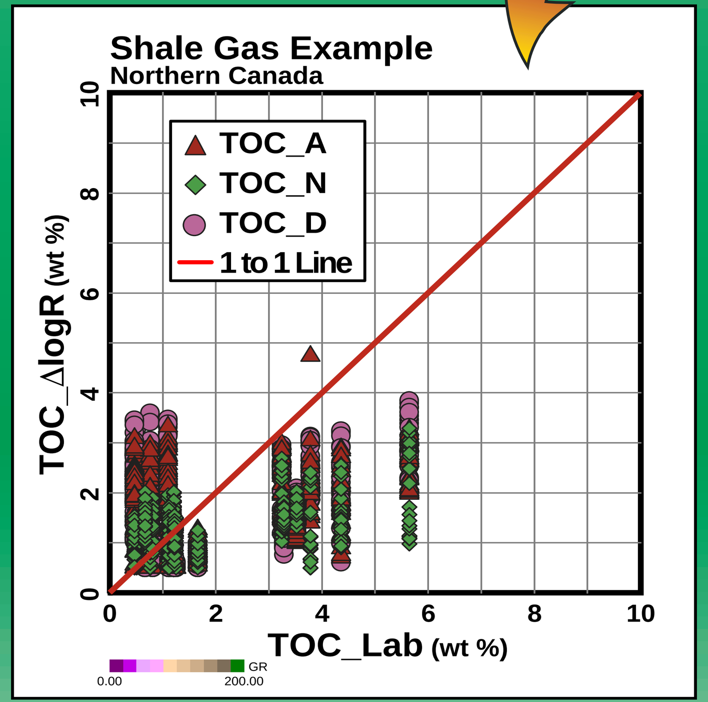




Porosity Log Scales used are inconsistent, therefore the ΔlogR contribution varies for each porosity log.
DT scale ~ 141%,
NPHI scale ~ 100%,
RHOB scale ~ 94%

ΔlogR results vary depending on "Non-Source" parameters selected for each "Source" shale interval.

TOC results from NPHI much lower than TOC results from DT or RHOB.



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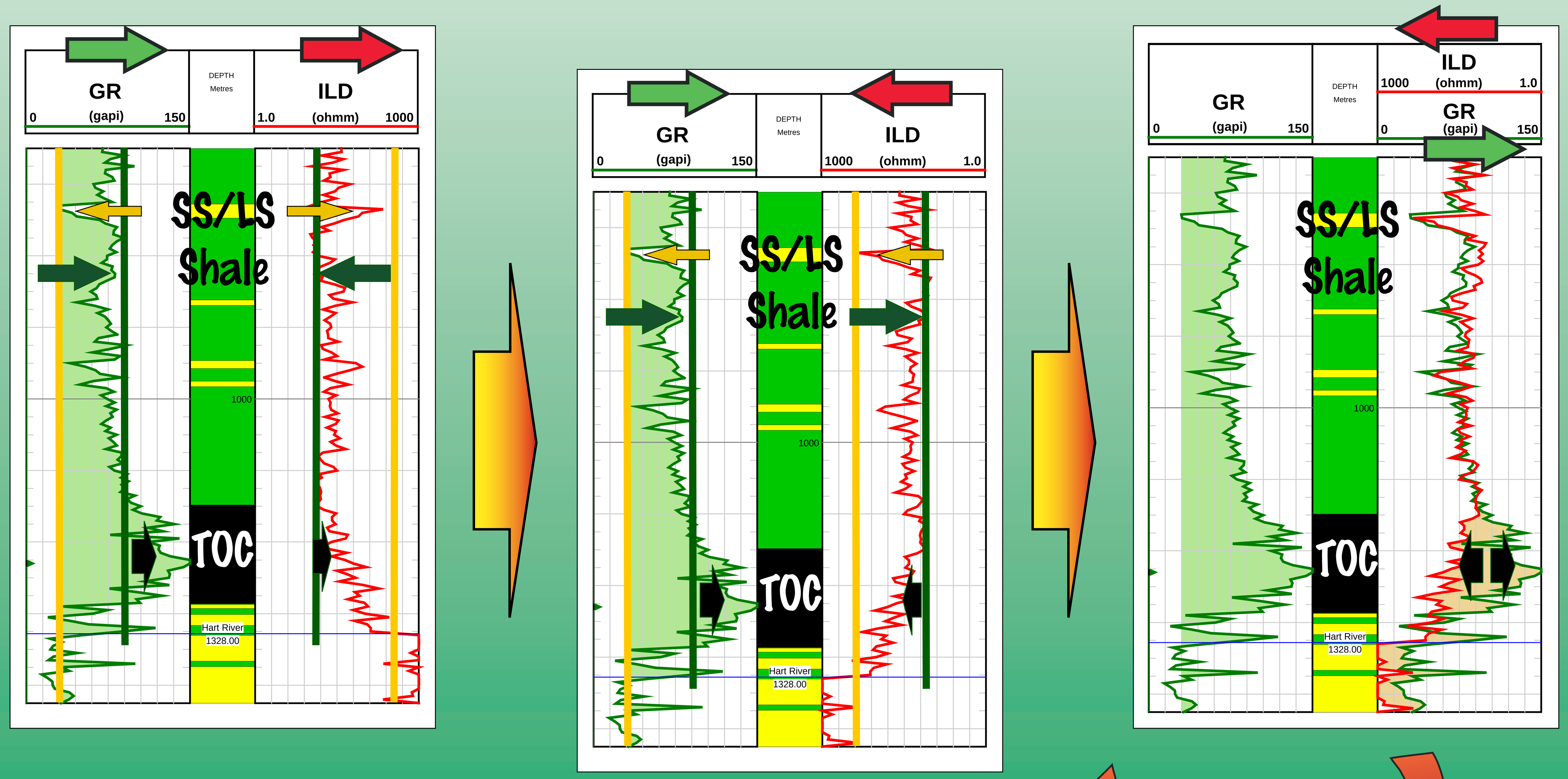
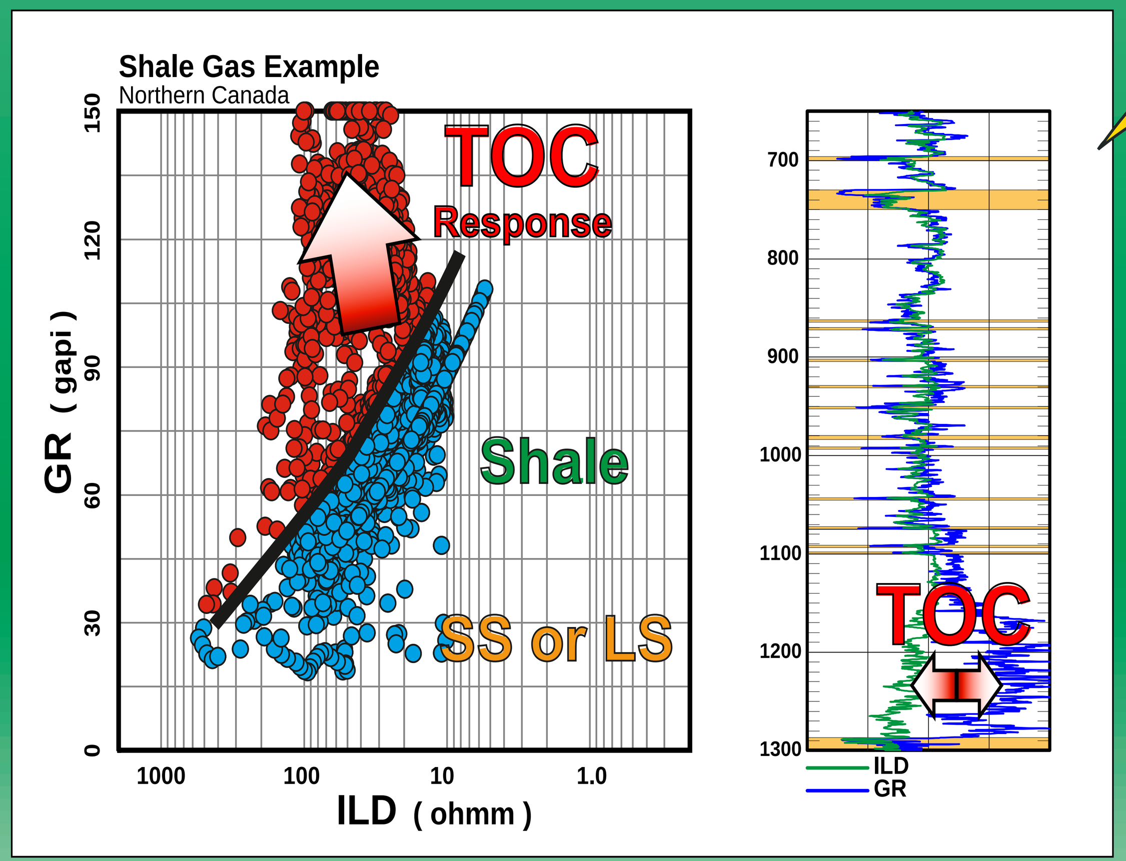
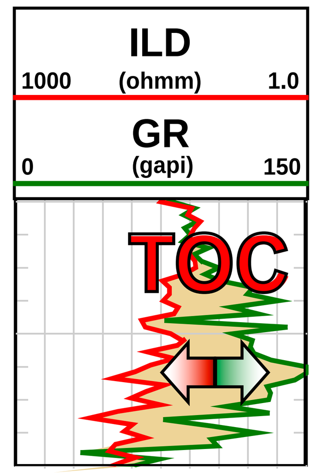
Simplified GR vs Rt Model





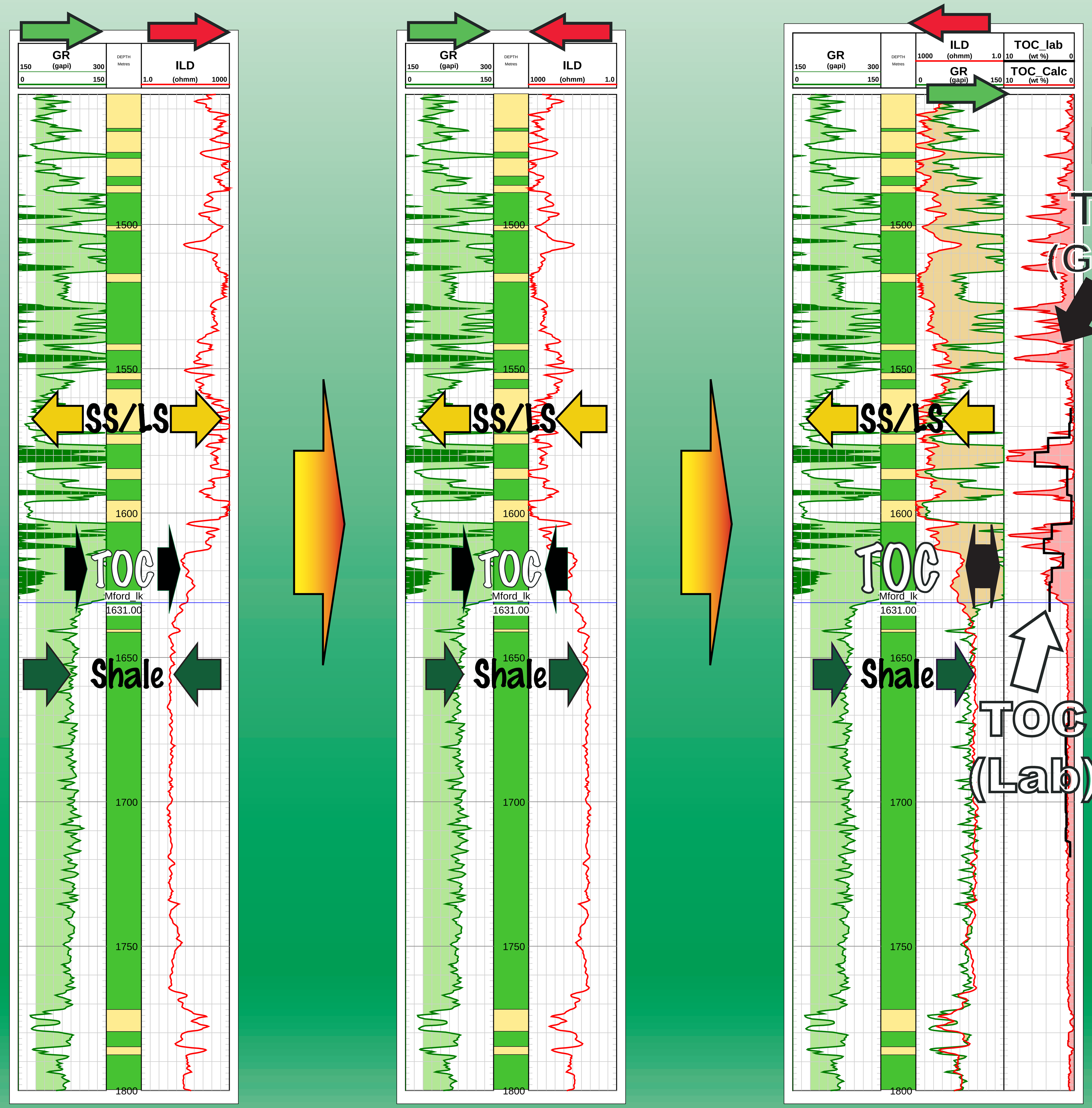


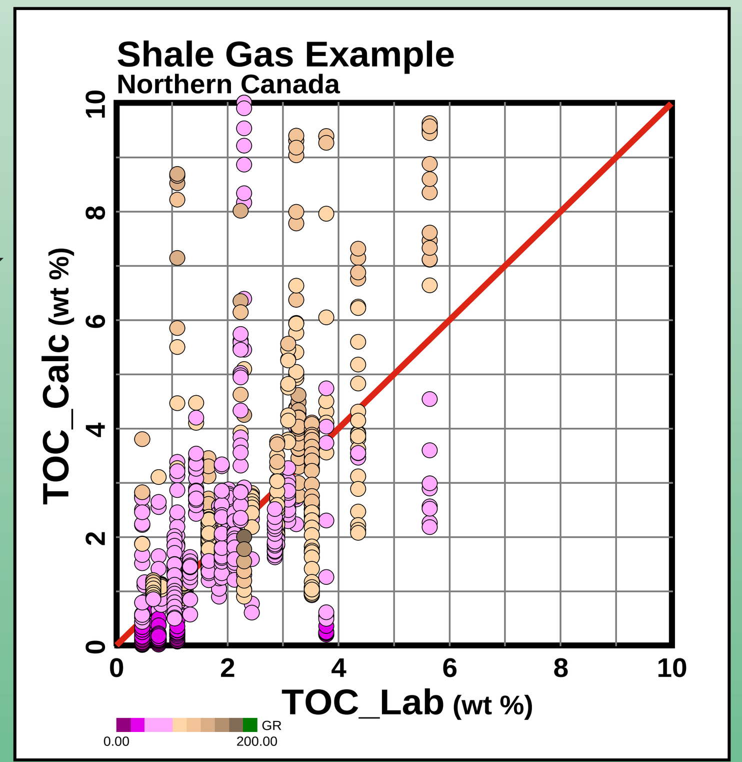
ΔRt ΔGR

$$\Delta GR = TOC*GR_{TOC}$$

$$\Delta Rt = TOC*\log_{10}(Rt_{TOC})$$

Application





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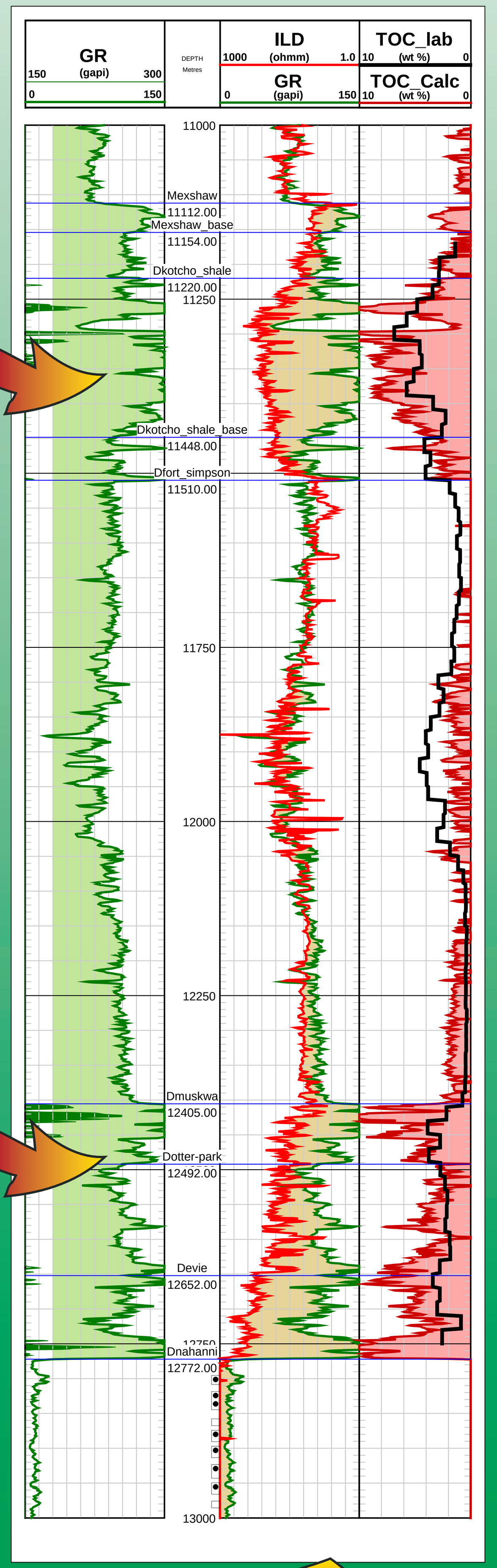
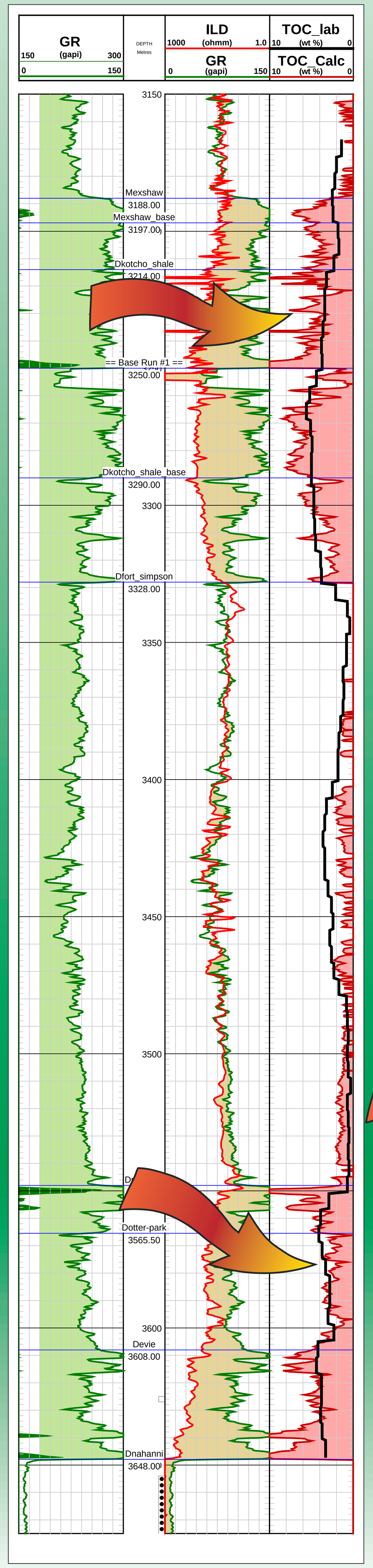
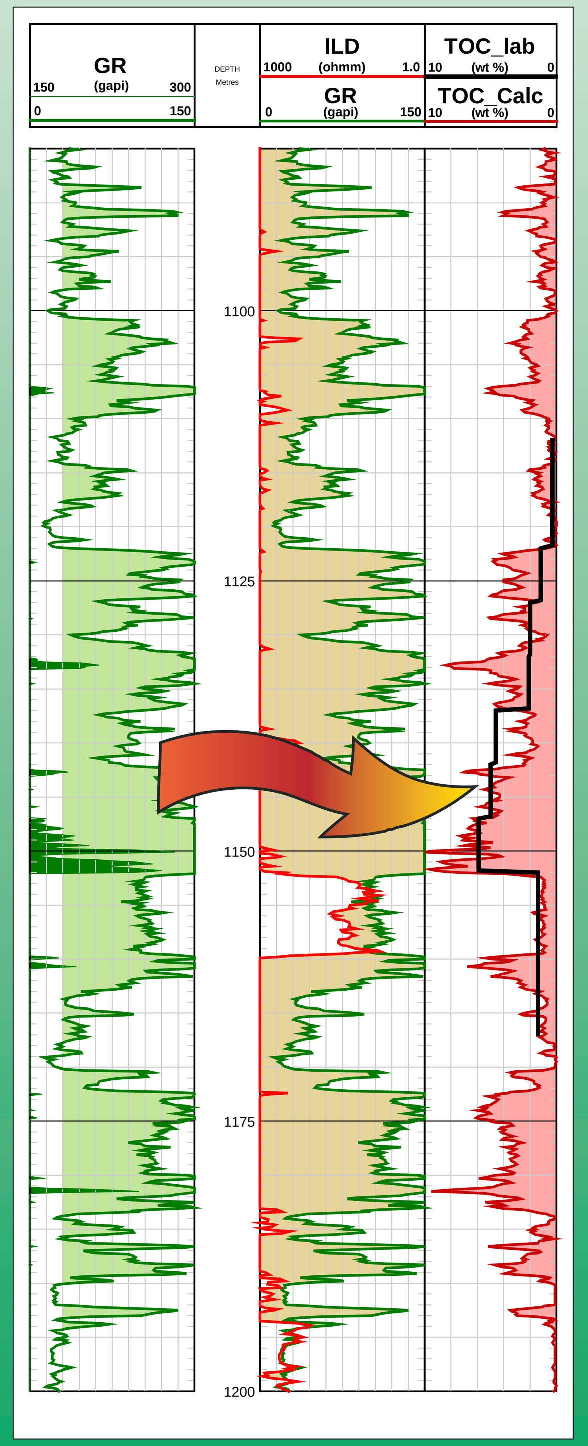
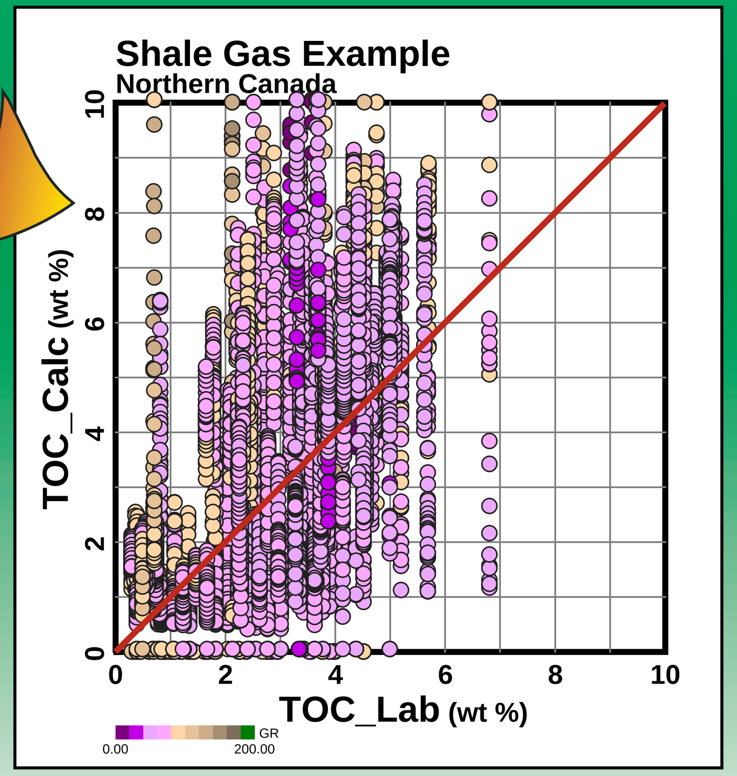
Additional Examples

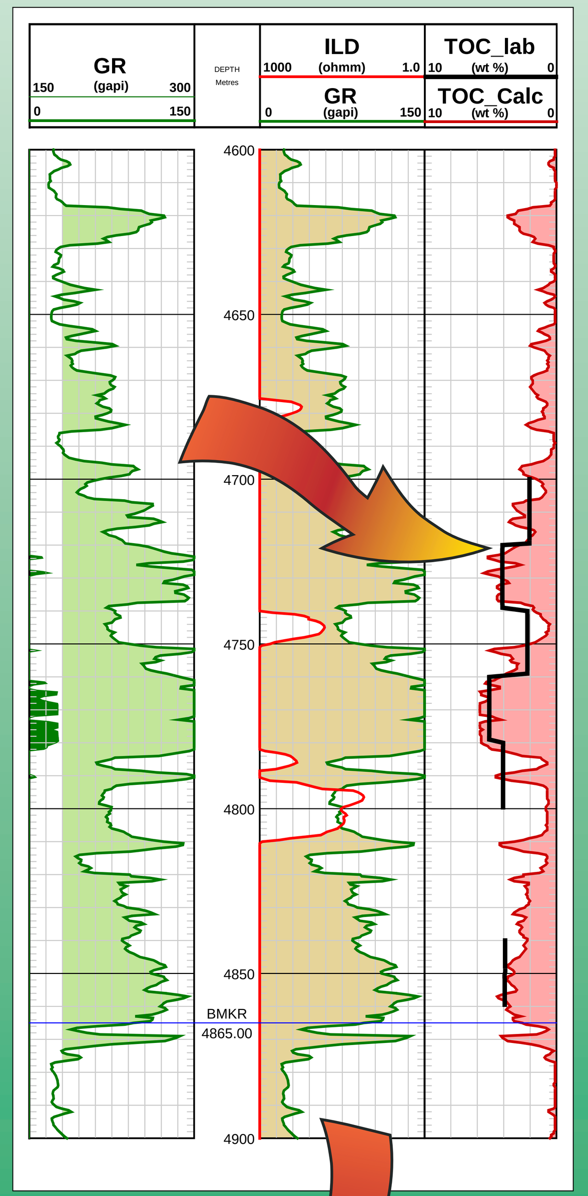


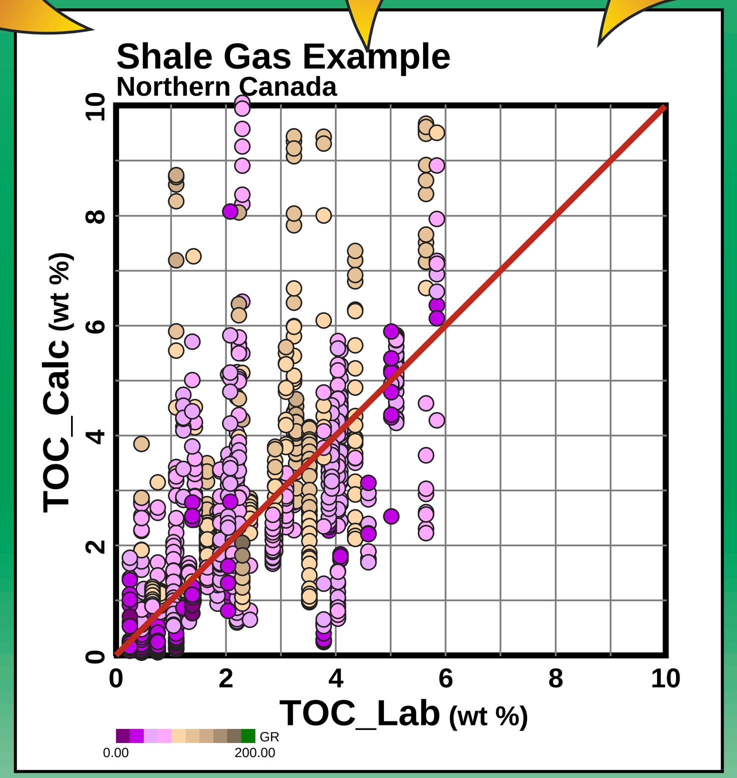
TOC Lab results thought to be "conservative" due to age & condition of samples

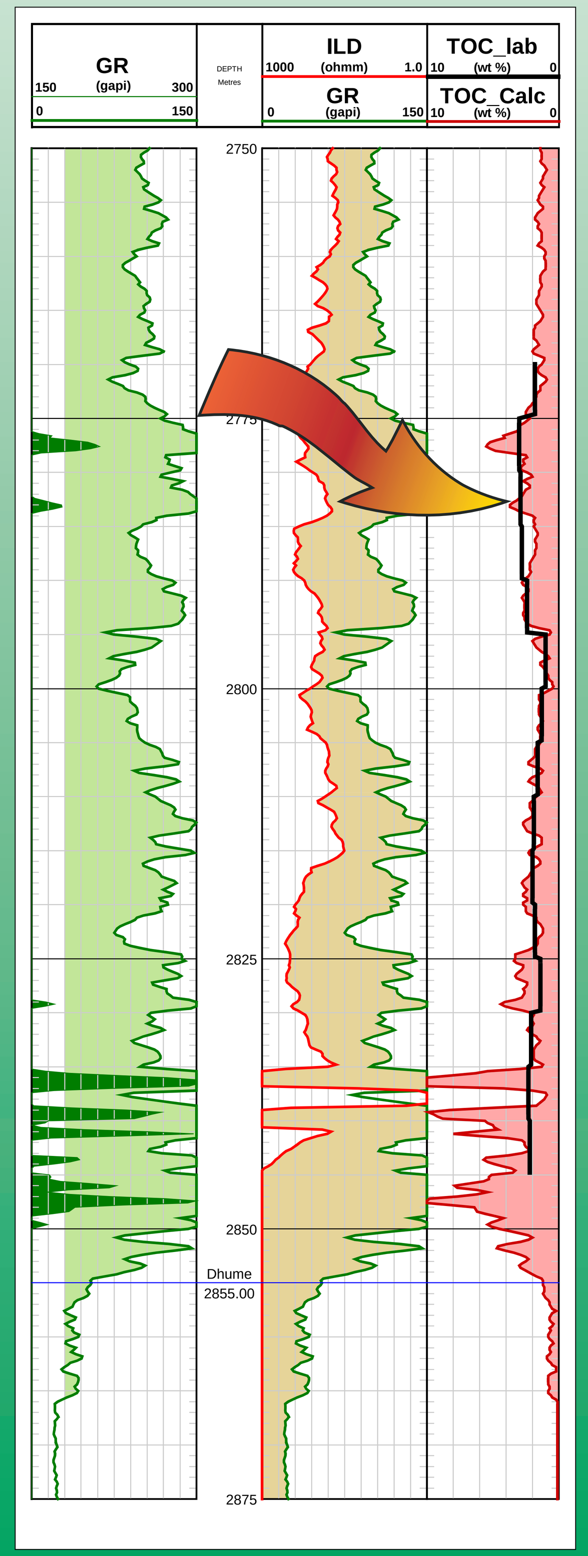












CONCLUSIONS

- It is possible to accurately predict TOC by using Wireline Logs while avoiding borehole effects & parameter selection errors.
- GR vs Rt method presented here builds upon ΔlogR method, but uses GR in place of a porosity log. The Δlog gap between GR and Rt in a "Source" Shale is defined as the units of separation between the curves using the standardized scales.
- Common TOC from RHOB methods are highly susceptible to borehole effects (ie. washouts,) and tend to ignore lithology changes, and appear to require calibration for each case.
- ΔlogR method reduces these errors by using Rt plus one porosity log (DT, NPHI, or RHOB.) This improvement is offset by:
  - the porosity log component of ΔlogR (especially RHOB,) is susceptible to borehole effects;
  - ΔlogR results are very sensitive to the log responses selected for "Non-Source" Shales.
    (Several "Non-Source" Shales, with different log responses for each, could be identified near a potential "Source" Shale.)
  - Porosity Log Scales used in this method are inconsistent, therefore the ΔlogR contribution varies for each porosity log.

Looking Forward:

- Extend research of the GR vs Rt Method as additional log and lab data become available. In particular, test method over entire range of shale maturities, including Oil Shales.
- Expand method to include use of porosity logs where borehole effects are not an issue.

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