Overburden Stress Estimation: A New Model for the UK Sector of the Central North Sea*

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Search and Discovery Article #41741 (2015)**
Posted December 14, 2015

*Adapted from oral presentation given at AAPG/SEG International Conference & Exhibition, Melbourne, Australia, September 13-16, 2015

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Abstract

Pore pressure, fracture pressure and geomechanical studies require accurately determined overburden stress magnitudes, which sum up the combined weight of overlying materials to the depth of interest. Ideally, overburden stress is determined from in-situ density data. Such data is not available for pre-drill studies where offset data or an overburden model must be used. Often, a quick-fix approach is to assume a simple constant gradient (usually 0.9 psi/ft or 1.0 psi/ft) for the overburden or any missing sections of the density log. A simple overburden function or trend is not appropriate in the Central North Sea due to the abrupt changes with depth in lithology and sediment compaction state. In order to minimize this limitation, a new overburden stress model has been developed based on the four distinct, geologically driven, density trends that are seen in the Central North Sea. The sub-divisions are: (1) the over-compacted shallow sediments lying above the mid-Miocene Unconformity (MMU); (2) the progressively compacted sediments between the MMU and the Chalk; (3) the Chalk itself and (4) the sub-Chalk sediments. The overburden stress (σv [psi]) due to each sub-division is dependent on its thickness (h [ft]) and is given by $\sigma v = 0.8858 * h$ above the MMU; $\sigma v = 0.9705 * h + 0.00002 * h2$ from MMU to Top Chalk; $\sigma v = 1.1254 * h$ within the Chalk and $\sigma v = 1.1155 * h$ for deeper sediments.

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AAPG ICE Melbourne, Australia. September 2015

Outline

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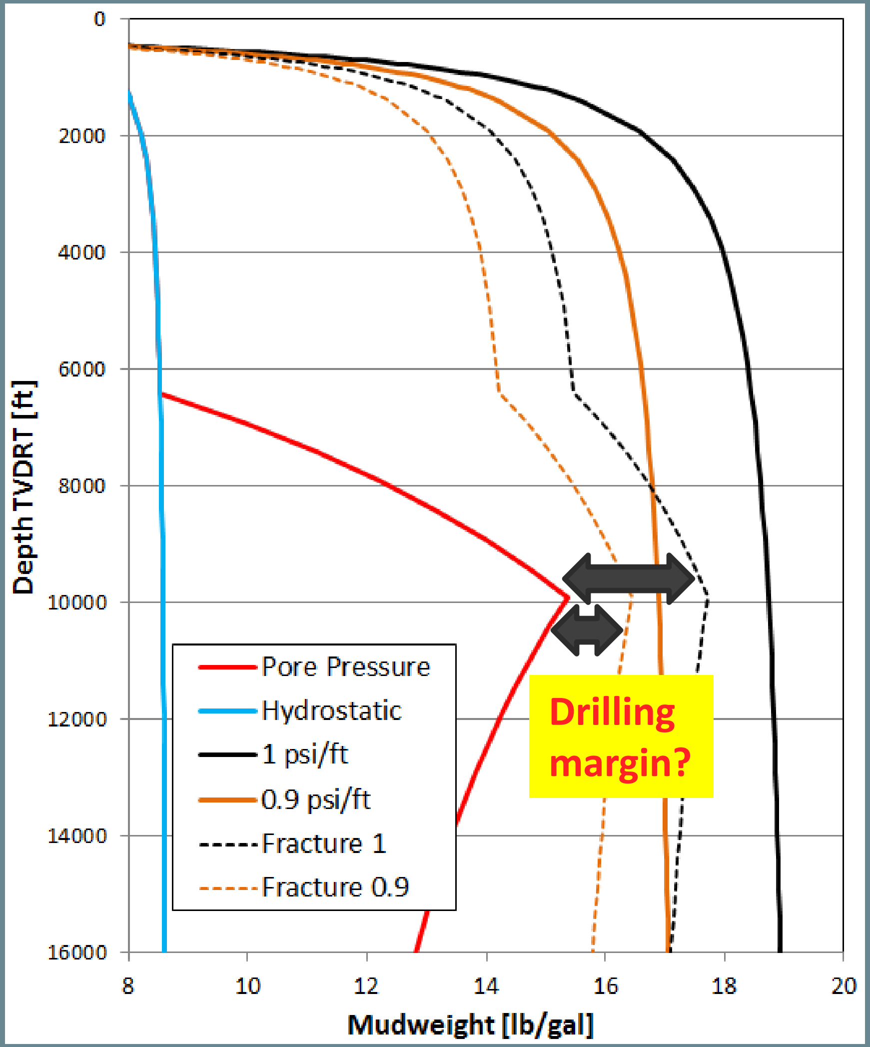
- **Overburden & PPFG**
- **Central North Sea Geology & Density Data**
- **The New Overburden Model**
  - Post-MMU
  - Sub-MMU
  - Chalk Group
  - Sub-Chalk
- **Summary**

Overburden & PPFG

- Overburden is the weight of rocks and fluids above a given point.
- It is a crucial input to pore and fracture pressure calculations:
  - Many PPP methods calculate Vertical Effective Stress and overburden is then needed to find the pore pressure
  - Fracture pressures are often calculated as functions of overburden (OVB) and Pore Pressure (PP), e.g.:

    Fracture Pressure = PP + (OVB – PP) * (v / (1-v))

    [Eaton (1968), v = Poisson's ratio]
- Incorrect definition of overburden leads to errors in:
  - Pore pressure
  - Fracture pressure
  - Drilling window
- Typically, overburden may increase at ~0.9 or 1psi/ft with depth. This is not sufficiently accurate for PPFG work.



CNS Overburden

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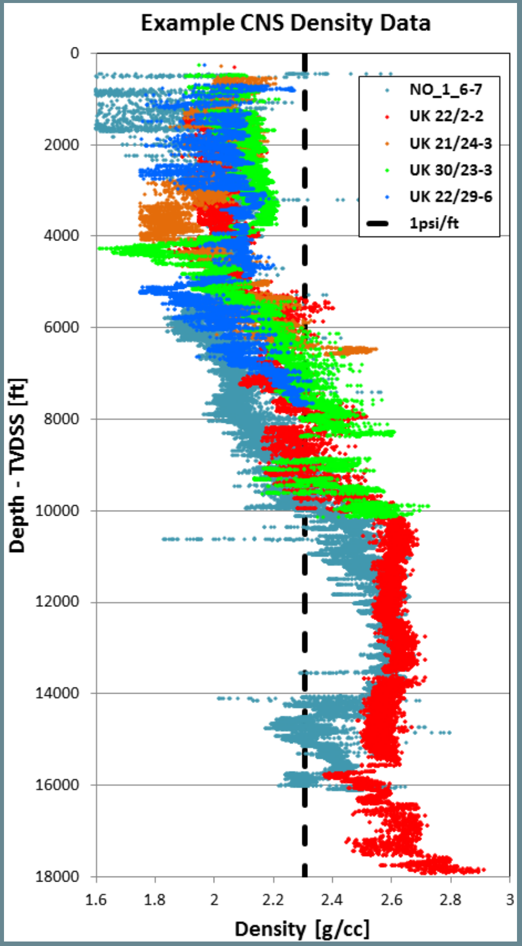
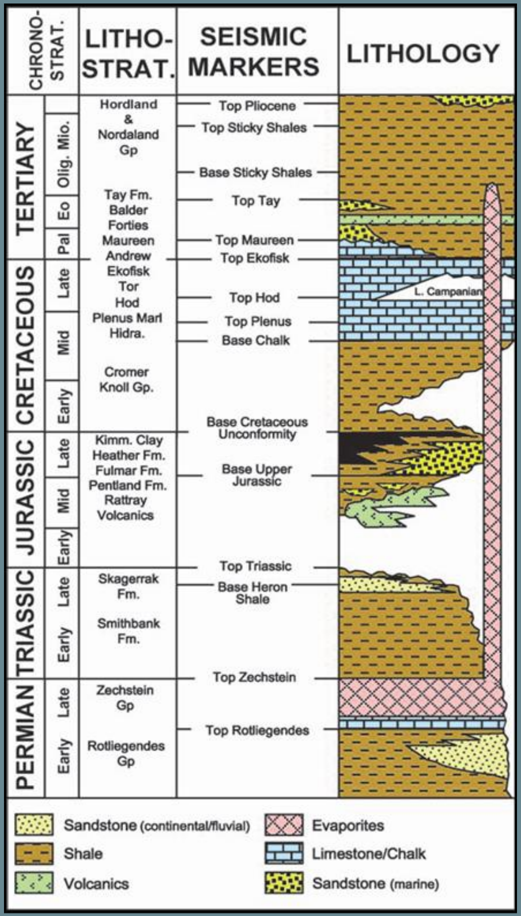
- Simple overburden models do not work in the Central North Sea, due to complex density profiles.
- CNS density profiles due to:
  - Lithology variations
  - Complex burial history (e.g. erosion and glaciation)
- An overburden model related to local geology is required





Millennium Atlas

Central North Sea Overpressures

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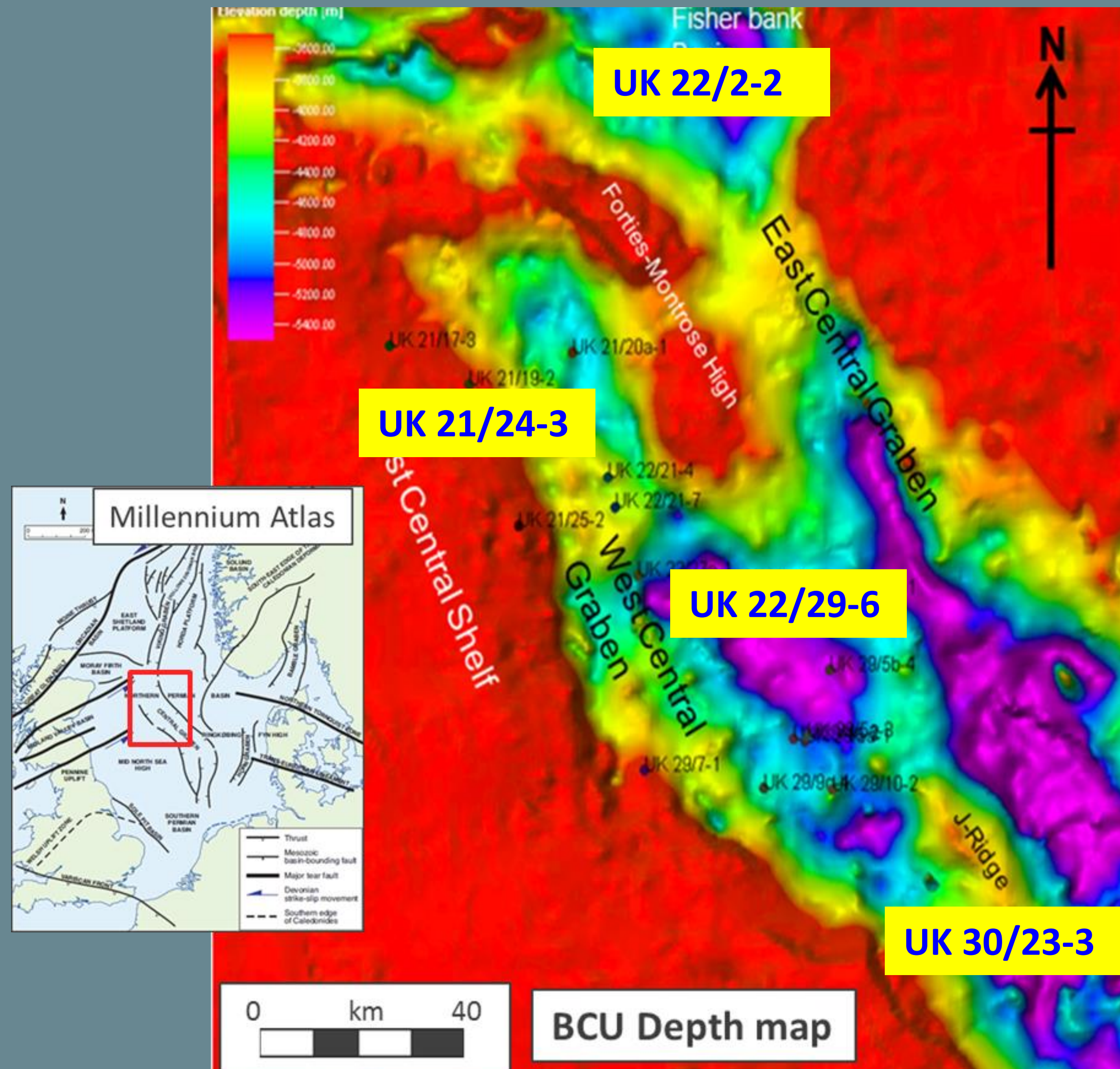
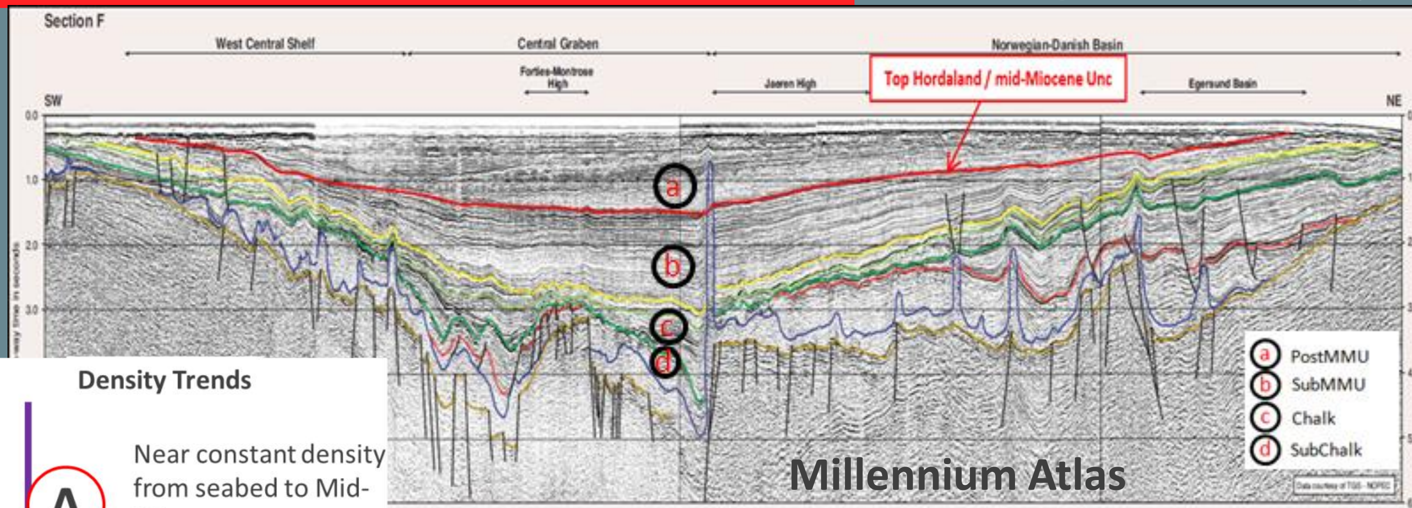
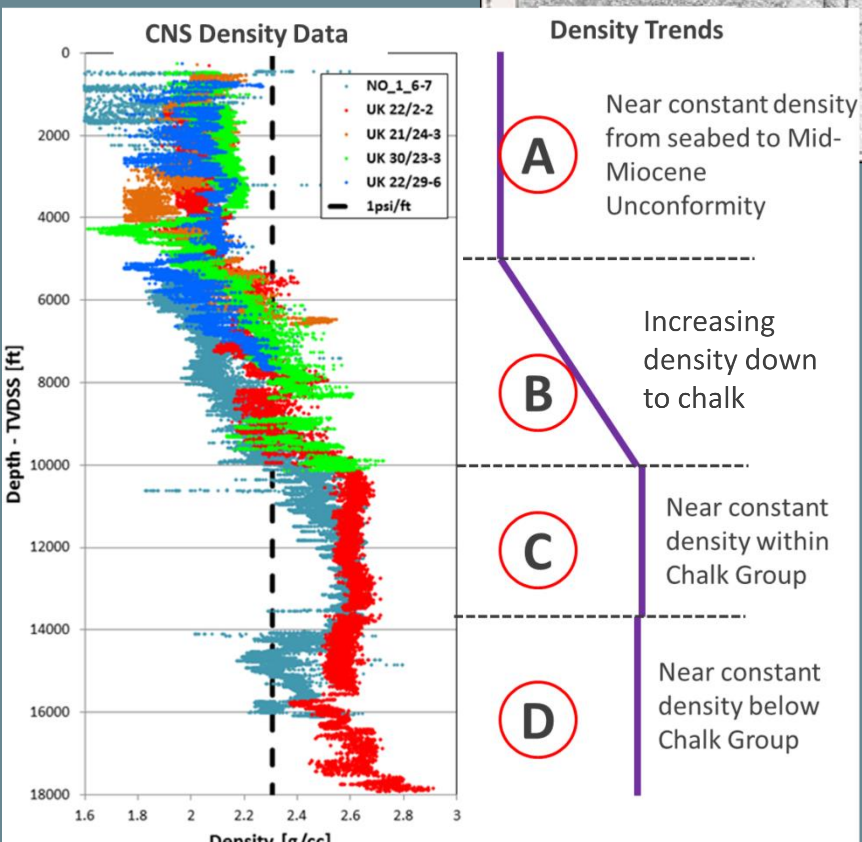
The new overburden model resulted from a study of overpressure generation mechanisms across the Central North Sea.

Wells, for overburden model, chosen with extended extensive density logs from near surface and from across the CNS study area



CNS Densities



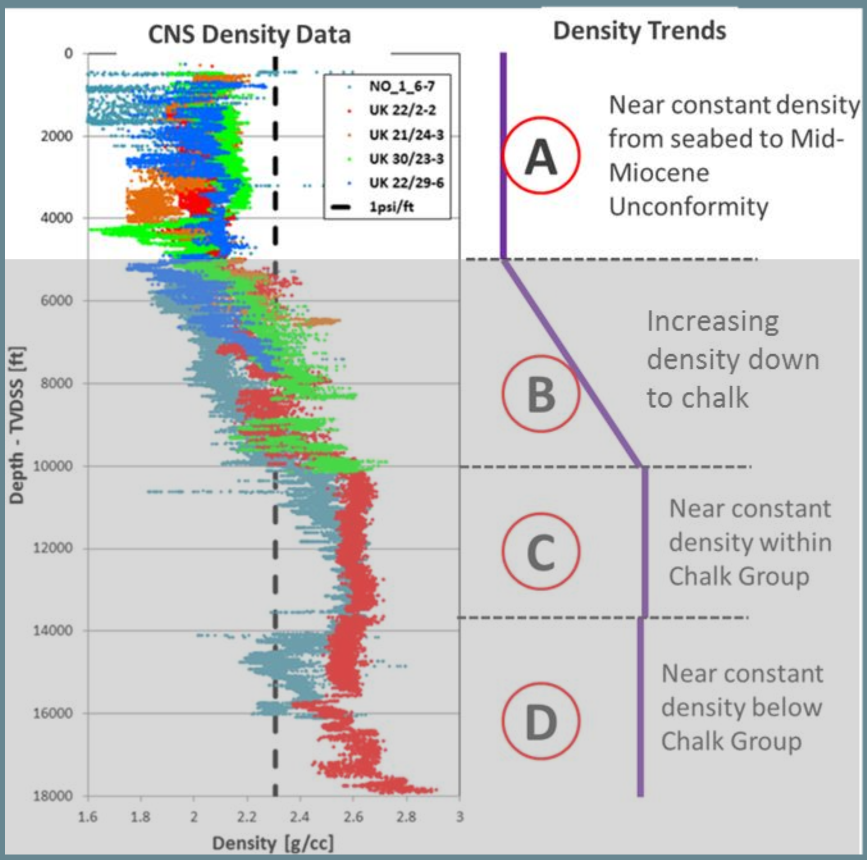


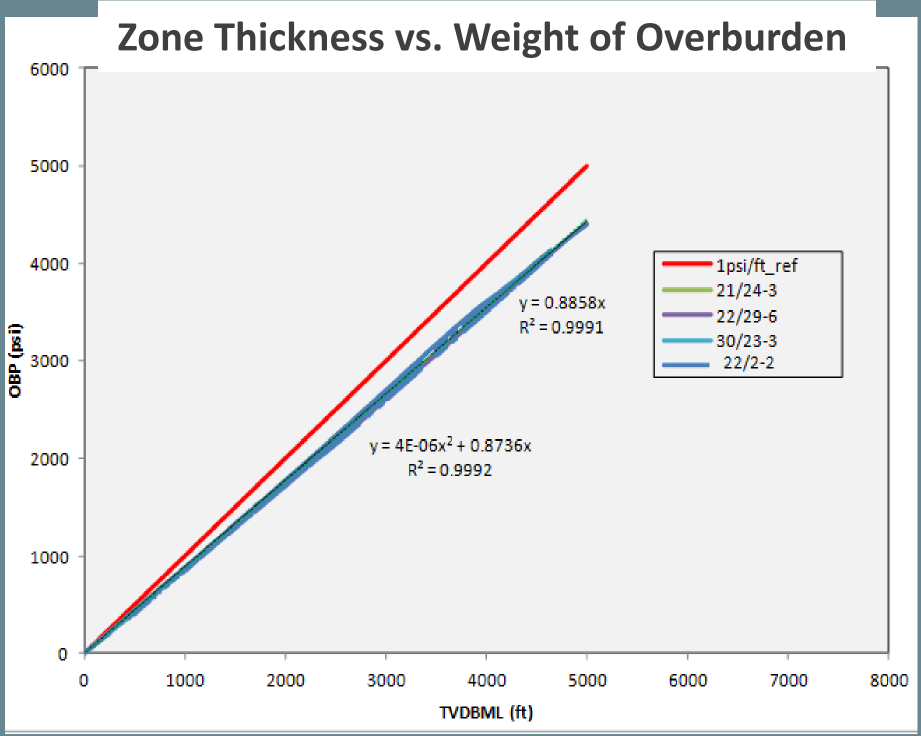
Density profiles are regionally consistent:

- **Constant density above the mid-Miocene Unconformity (MMU),**
- **Increasing density between MMU and Chalk,**
- **A relatively constant density within the Chalk itself**
- **A trend of increasing density beneath the Chalk.**

Assuming 1psi/ft over-predicts shallow densities and under-predicts deep densities

Zone A – Above MMU





Method:

- **Integrate density data in Zone of interest to give local overburden profile**
- **Fit trend through calculated profile**
- $\boldsymbol{\sigma_{v1} = 0.8858 * h}$
  (*h* = thickness of zone in ft)
  Equivalent to average density of 2.043 g/cc. i.e. significantly below 1psi/ft

Zone B – Below MMU

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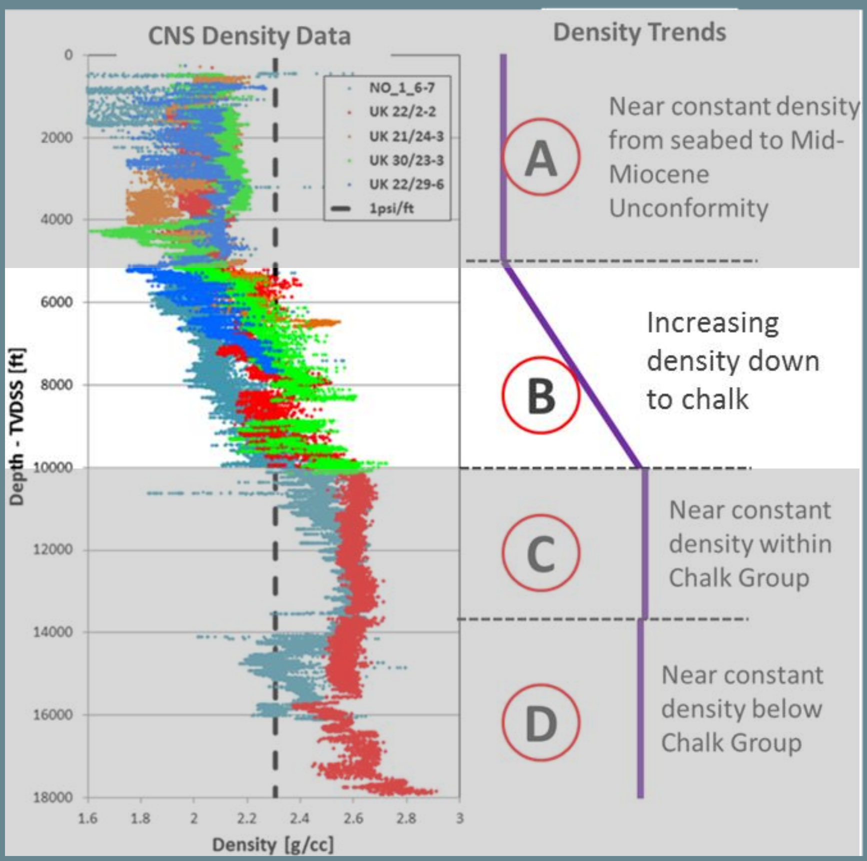
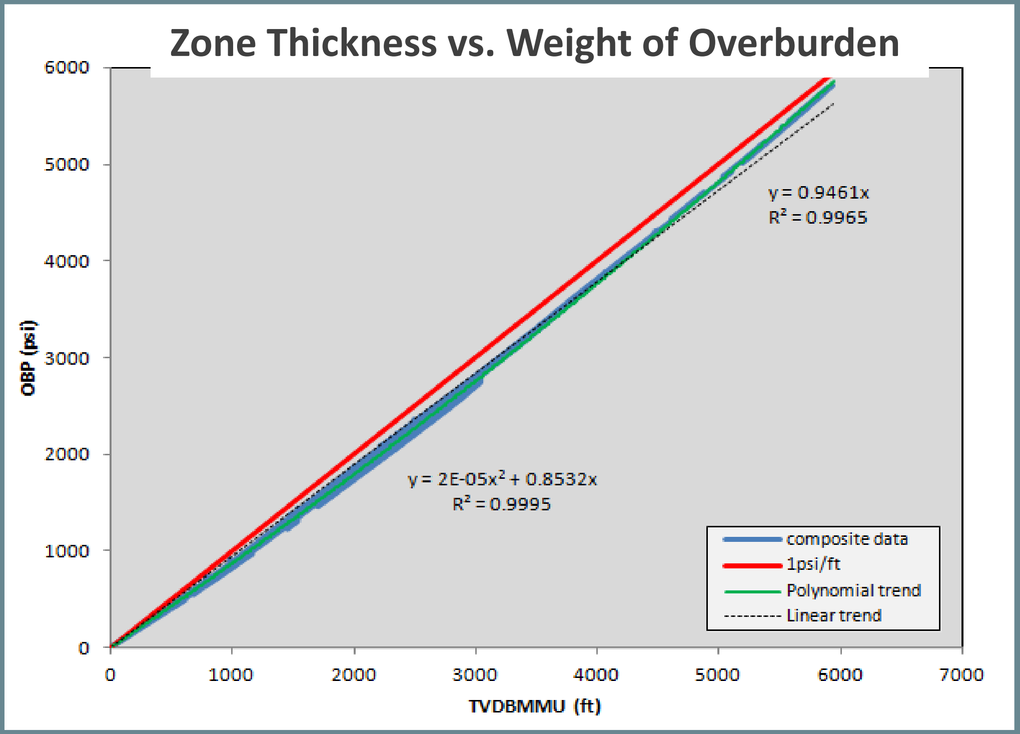
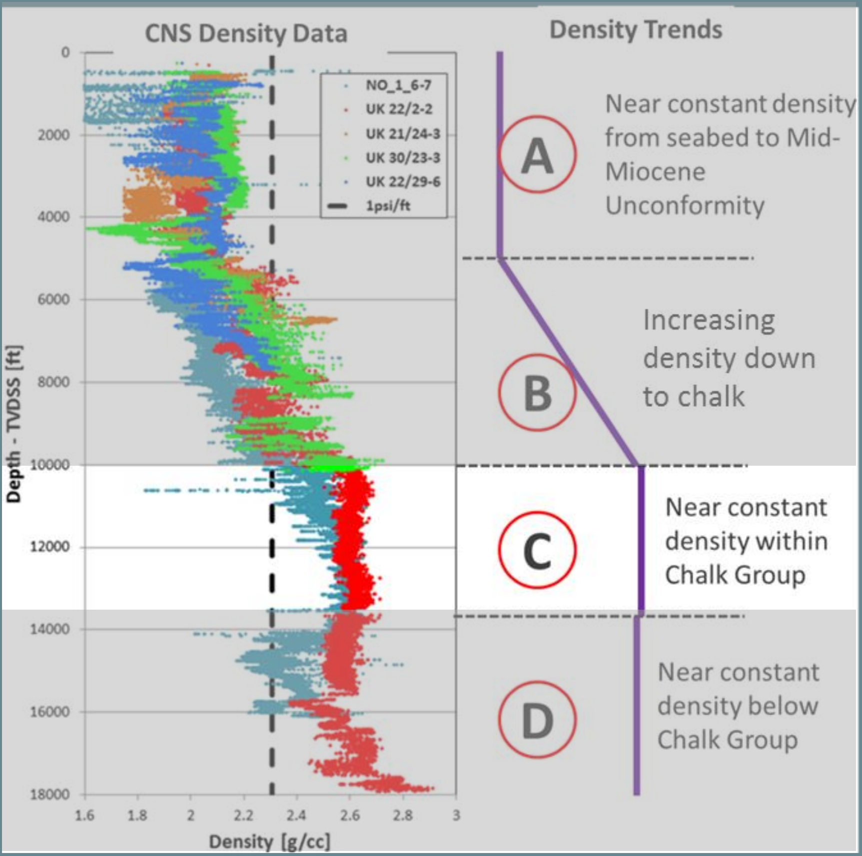


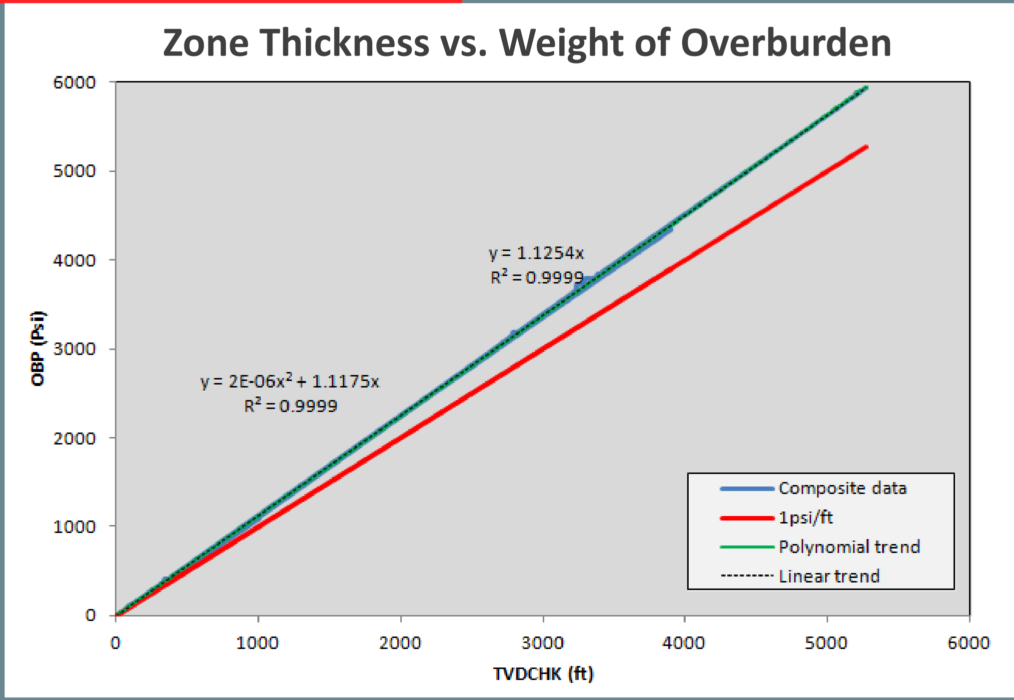


Increasing density with depth below the MMU

- σ_{v2} ***= 0.8532 * h +0.00002 * h²)***
  (*h* = thickness of zone in ft)
  Equivalent to a density at MMU of 1.968 g/cc which then increases steadily

Zone C – Within Chalk





Relatively constant density in the Chalk

Preferred overburden stress relationship:

- $\sigma_{v3} = 1.1254 * h$
  (*h* = thickness of zone in ft)
  Equivalent to a constant Chalk density of 2.5959 g/cc

Zone D – Beneath Chalk

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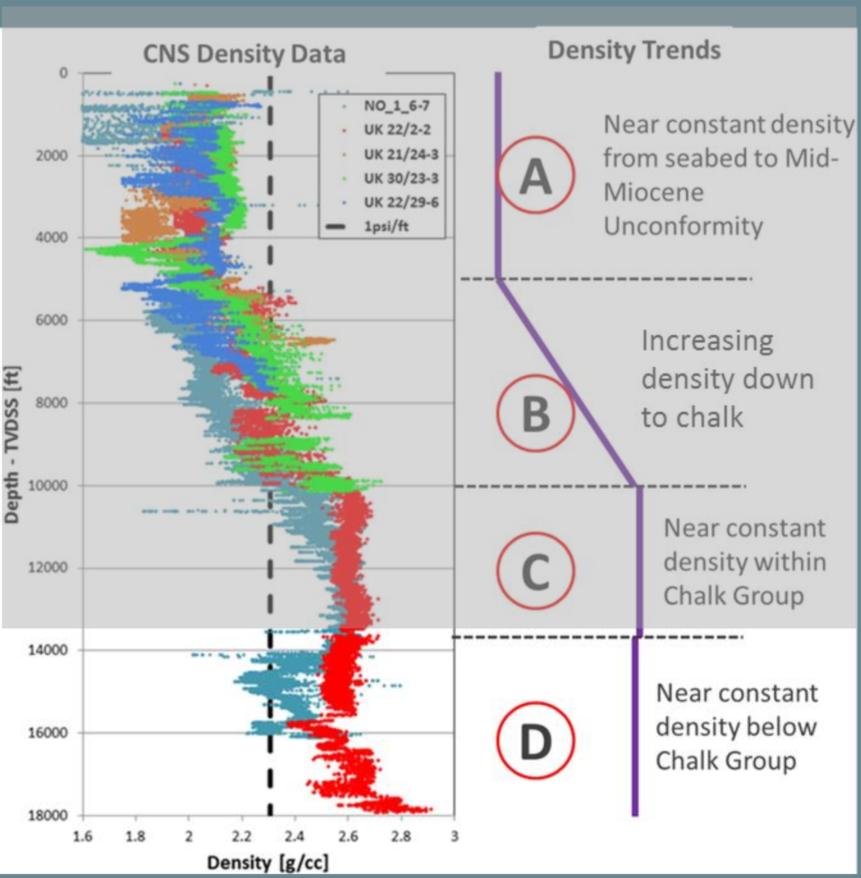

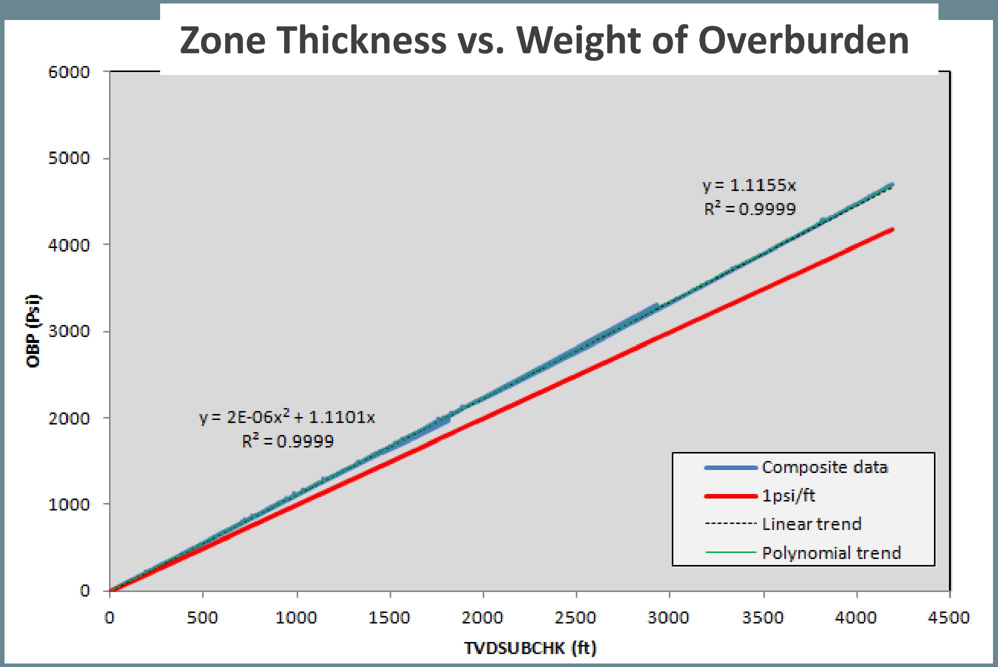

Increasing density beneath the Chalk

Preferred overburden stress relationship:

- ***σ_{v4} = 1.1155 * h***
  (*h* = thickness of zone in ft)
  Equivalent to a constant sub-chalk density of 2.5731 g/cc

Final Overburden Model

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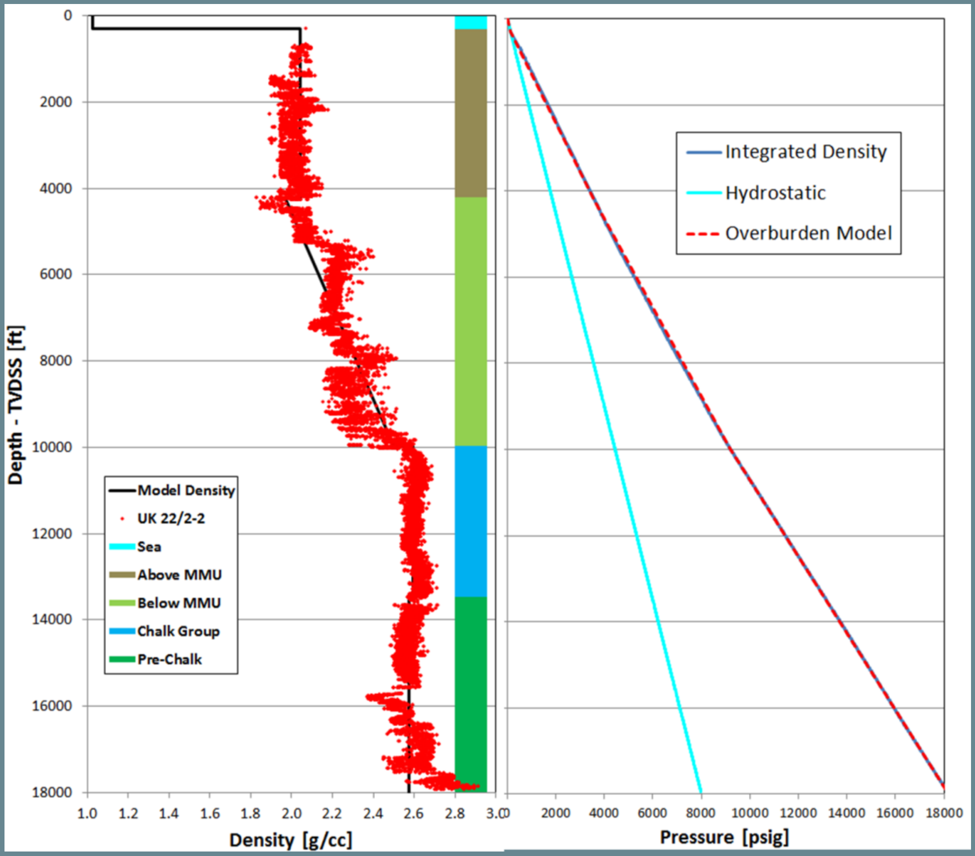
Zone	Formations		Total Overburden
Seawater	Seawater	$\sigma_w = 0.445 * h$	$\sigma_v = \sigma_w$
Zone 1	Seabed to MMU	$\sigma_{v1} = 0.8858 * h$	$\sigma_v = \sigma_w + \sigma_{v1}$
Zone 2	MMU to Top Chalk	$\sigma_{v2} = 0.8532 * h + 0.00002 * h^2$	$\sigma_v = \sigma_w + \sigma_{v1} + \sigma_{v2}$
Zone 3	Chalk Group	$\sigma_{v3} = 1.1254 * h$	$\sigma_v = \sigma_w + \sigma_{v1} + \sigma_{v2} + \sigma_{v3}$
Zone 4	Sub-Chalk	$\sigma_{v4} = 1.1155 * h$	$\sigma_v = \sigma_w + \sigma_{v1} + \sigma_{v2} + \sigma_{v3} + \sigma_{v4}$

Notes:

h = ***thickness*** of zone in ft

Stresses in psig

Overburden Model Example



- Test example on UK 22/2-2
- Overburden from integrated density log compared with overburden using new model
- Curves overlie each other

Summary

- Central North Sea geology does not lend itself to a simple overburden model
- A four zone overburden model has been developed that is consistent with the local geology
- The new overburden model can be applied in pre-drill settings based on key geological interfaces
- The model can also be applied to fill in sections of missing density when analysing existing wells