Tutorial

Given Data - ChalkData_ClassTutorial.xlsx

Problem Statements:

1. Calculate porosity using bulk density, grain density, and fluid density. (Use mineral fraction information for calculating exact grain density) otherwise use the grain density of the dominant mineral.

2. Calculate Bulk modulus: dry and saturated, Shear Modulus: dry and saturated, Poisson's Ratio: Dry and Saturated

3. Calculate Biot's coefficient using a critical porosity (PHIc) of 50%

4. Calculate Vertical Overburden Stress, Terzagh's Stress (Differential), and Biot's Stress (Effective).

5. Calculate the upper and lower bound for the given system using both Voigt-Reuss and Hashin-Shtrikman Method. Use hint from point no. 1.

6. Calculate Gassmann's response for each of the samples using the given information about dry state of the samples, and the mineral fractions. Use the same fluid as in point no.1.

7. Recalculate the compressive- and shear- wave velocity of the samples using Gassmann's output

8. Plot the porosity trend with depth

9. Plot the Stress trend with depth

10. Plot the Modulus trend with depth

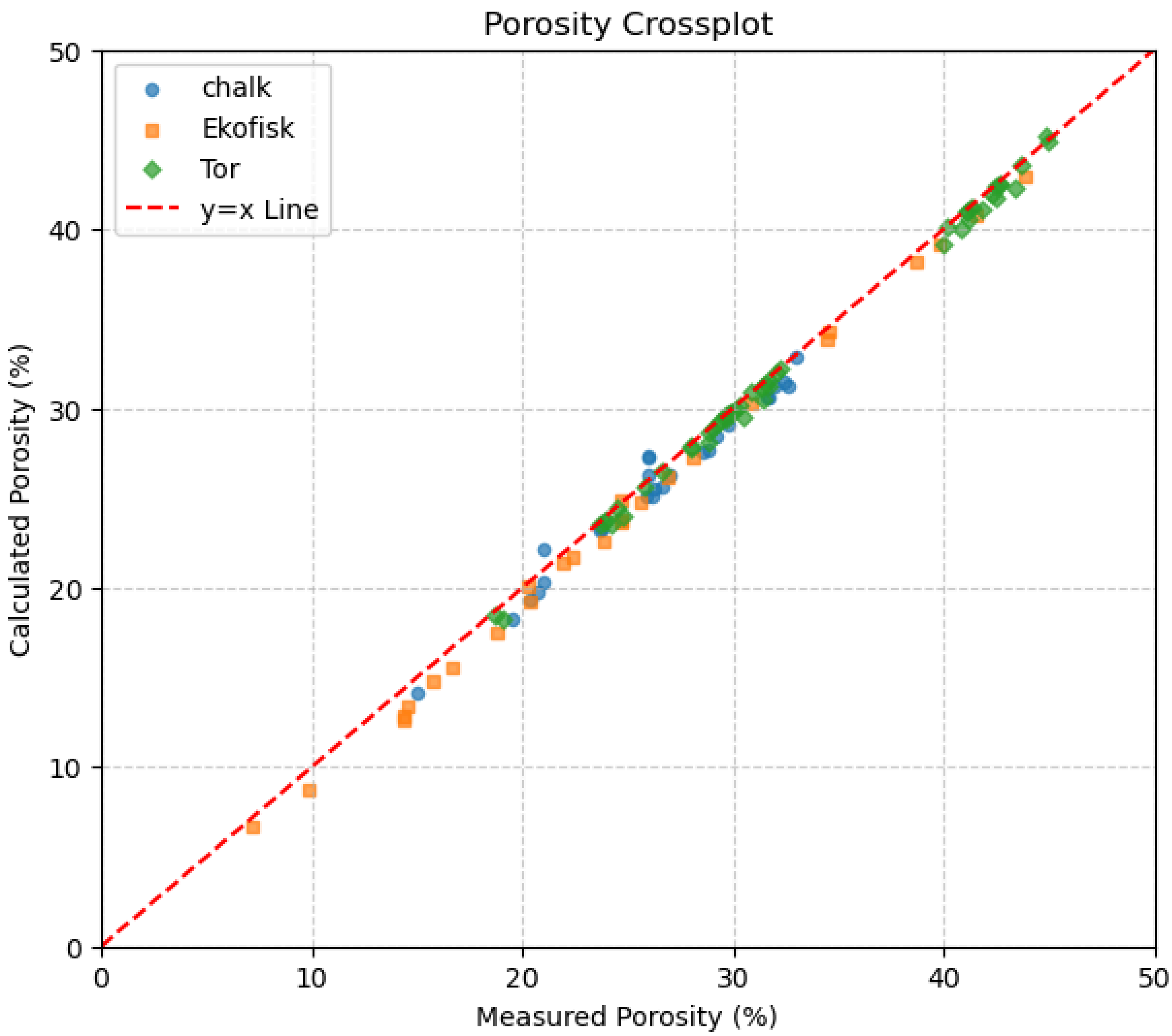
11. Plot the normal V-R and the normal Ha-Sh bounds on the same template

12. Plot the normal Ha-Sh bounds with its modified bounds.

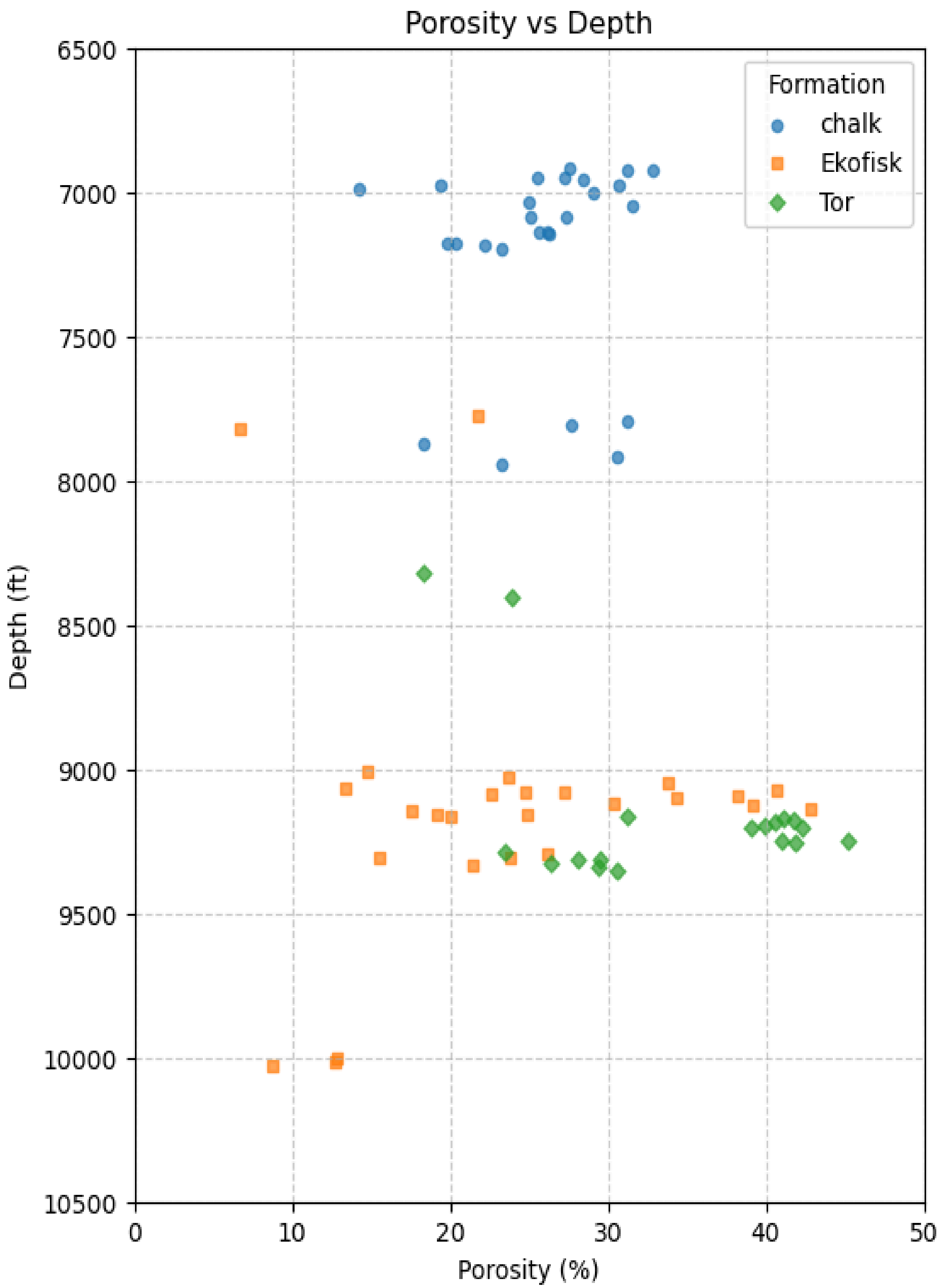
13. Make a cross plot between measured saturated and Gassmann saturated values of compressive- and shear-wave velocities

14. Plot the given core data on the bounds template for bulk and shear moduli and comment on the condition of the reservoir formations/samples

Plots and Interpretation



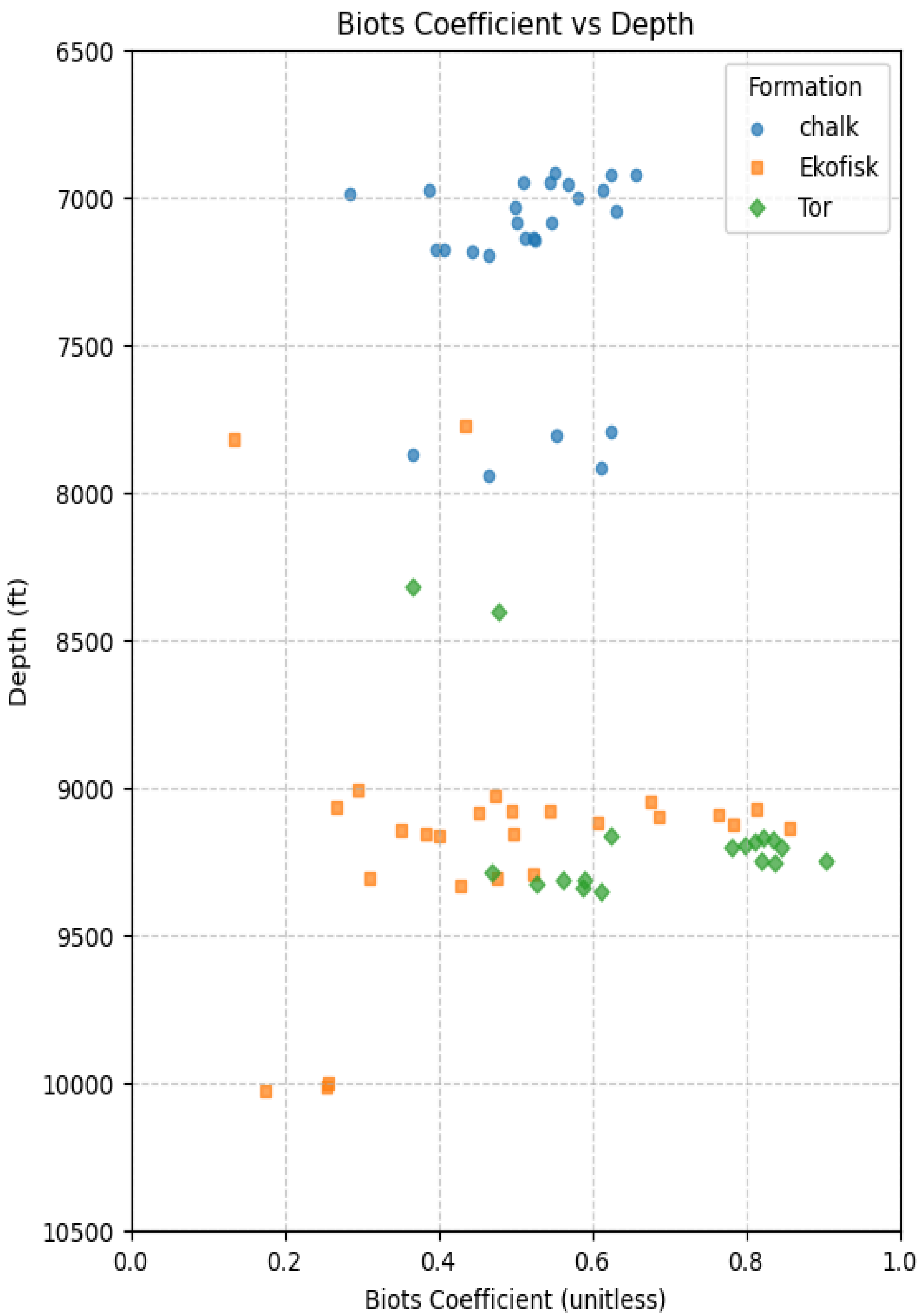
- The data points closely follow the **red dashed line (y = x)**, indicating a **strong agreement** between calculated and measured porosity values.
- The calculated porosity method is reliable and consistent with measured porosity across all samples.



Porosity vs Depth
Formation
chalk
Ekofisk
Tor
Depth (ft)
6500
7000
7500
8000
8500
9000
9500
10000
10500
0
10
20
30
40
50
Porosity (%)

- **Chalk formation** (blue circles) occurs at shallower depths (~7000–8000 ft) and generally shows **higher porosity** (~25–40%).
- **Ekofisk formation** (orange squares) spans a wider depth range (~7700–10100 ft) and exhibits a **larger porosity variation**, including some **very low porosity values** (<10%), especially at greater depths.
- **Tor formation** (green diamonds) lies at greater depths (~8300–9700 ft) and maintains **consistently high porosity** (mostly 30–45%), which is unusual for deeper formations.

- A **general trend of decreasing porosity with depth** is visible in Ekofisk, which aligns with expected compaction effects.
- **Tor defies this trend**, suggesting possible **diagenetic preservation** or **fracturing** that maintains porosity at depth.
- **Chalk** is more porous and shallower, likely representing a younger or less compacted section.


Biots Coefficient vs Depth
Formation
chalk
Ekofisk
Tor
Depth (ft)
6500
7000
7500
8000
8500
9000
9500
10000
10500
0.0
0.2
0.4
0.6
0.8
1.0
Biots Coefficient (unitless)

- **Chalk formation** (blue):
  - Shallower depths (~6900–8000 ft)
  - Biot's coefficient mostly ranges from **~0.6 to 0.9**, indicating **high pore compliance** and lower rock stiffness.

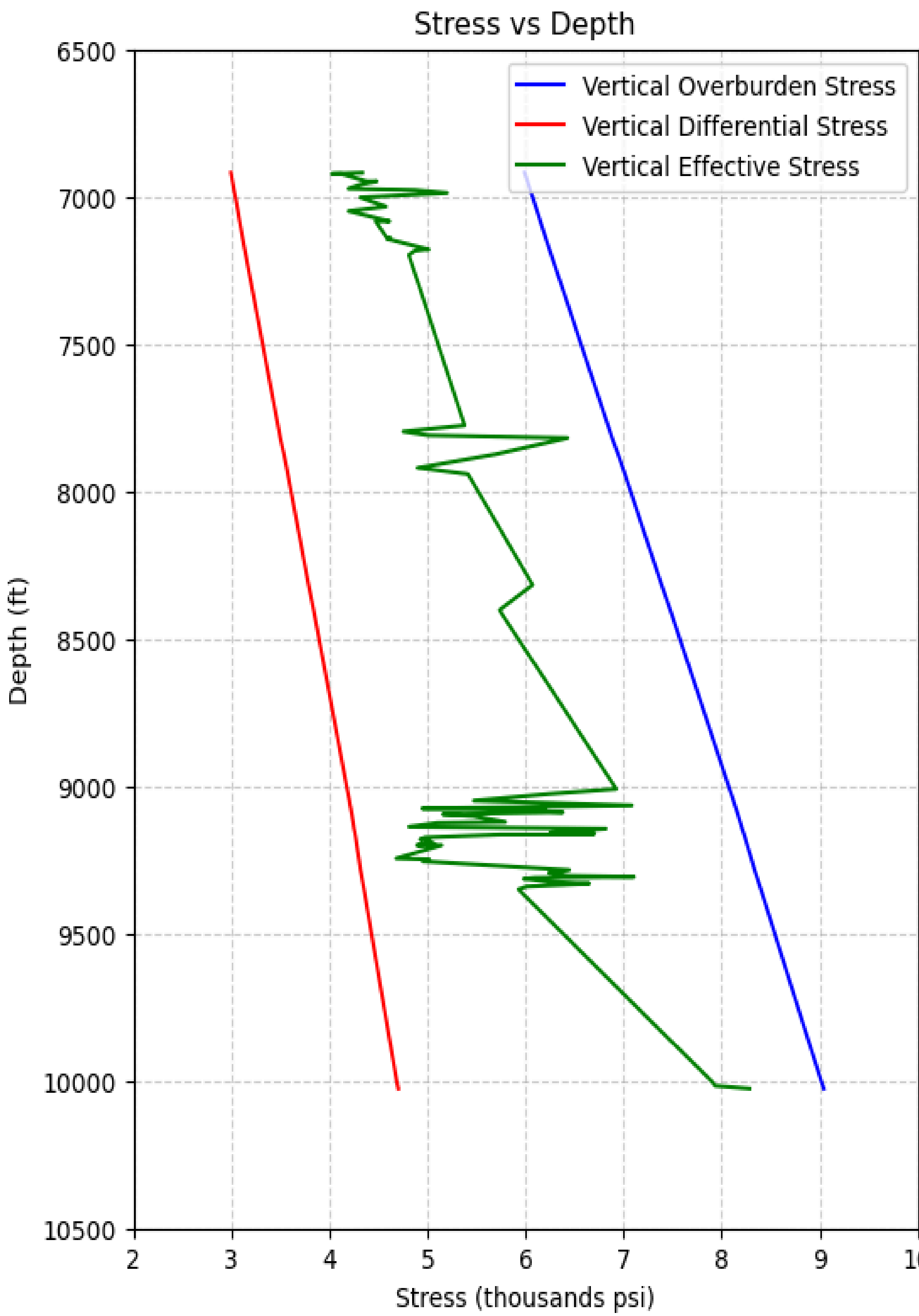
- **Ekofisk formation** (orange):
  - Depths from ~7700 to over 10000 ft
  - **Wider spread** in Biot's values, from **~0.1 to 0.9**.
  - Suggests a **heterogeneous rock frame** — some zones are stiff and compacted (low α), others remain compliant (high α).

- **Tor formation** (green):
  - Found deeper (~8300–9700 ft)
  - Most values between **0.6 and 0.9**, indicating **high porosity and weak frame stiffness**, even at depth.

- There is **no clear decreasing trend** of Biot's coefficient with depth — especially for Tor, which remains highly compliant at great depths.

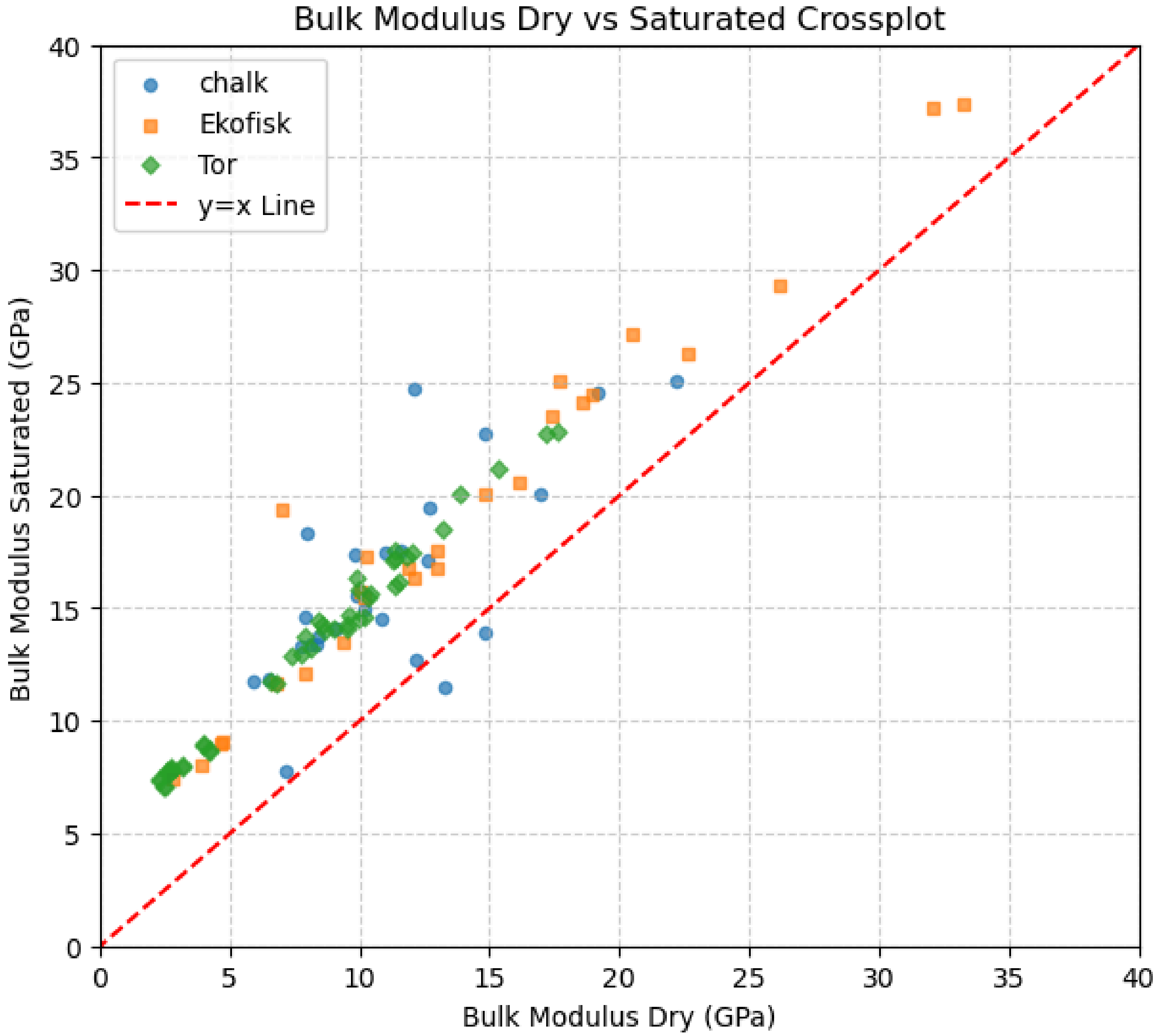
- **Ekofisk's variability** could reflect diagenetic effects or variable cementation.

- **High α values** in Tor and Chalk suggest these rocks are **more sensitive to pore pressure**.


Stress vs Depth
Vertical Overburden Stress
Vertical Differential Stress
Vertical Effective Stress
Depth (ft)
6500
7000
7500
8000
8500
9000
9500
10000
10500
2
3
4
5
6
7
8
9
10
Stress (thousands psi)

- **Vertical Overburden Stress** increases linearly with depth, as expected, due to increasing rock weight.
- **Vertical Effective Stress** (green line) fluctuates more than the overburden, indicating variations in pore pressure and Biot's coefficient along depth.
- **Differential Stress** (red line) increases with depth, showing a steady trend, but it's consistently **lower than overburden stress**, highlighting the role of pore pressure in stress reduction.

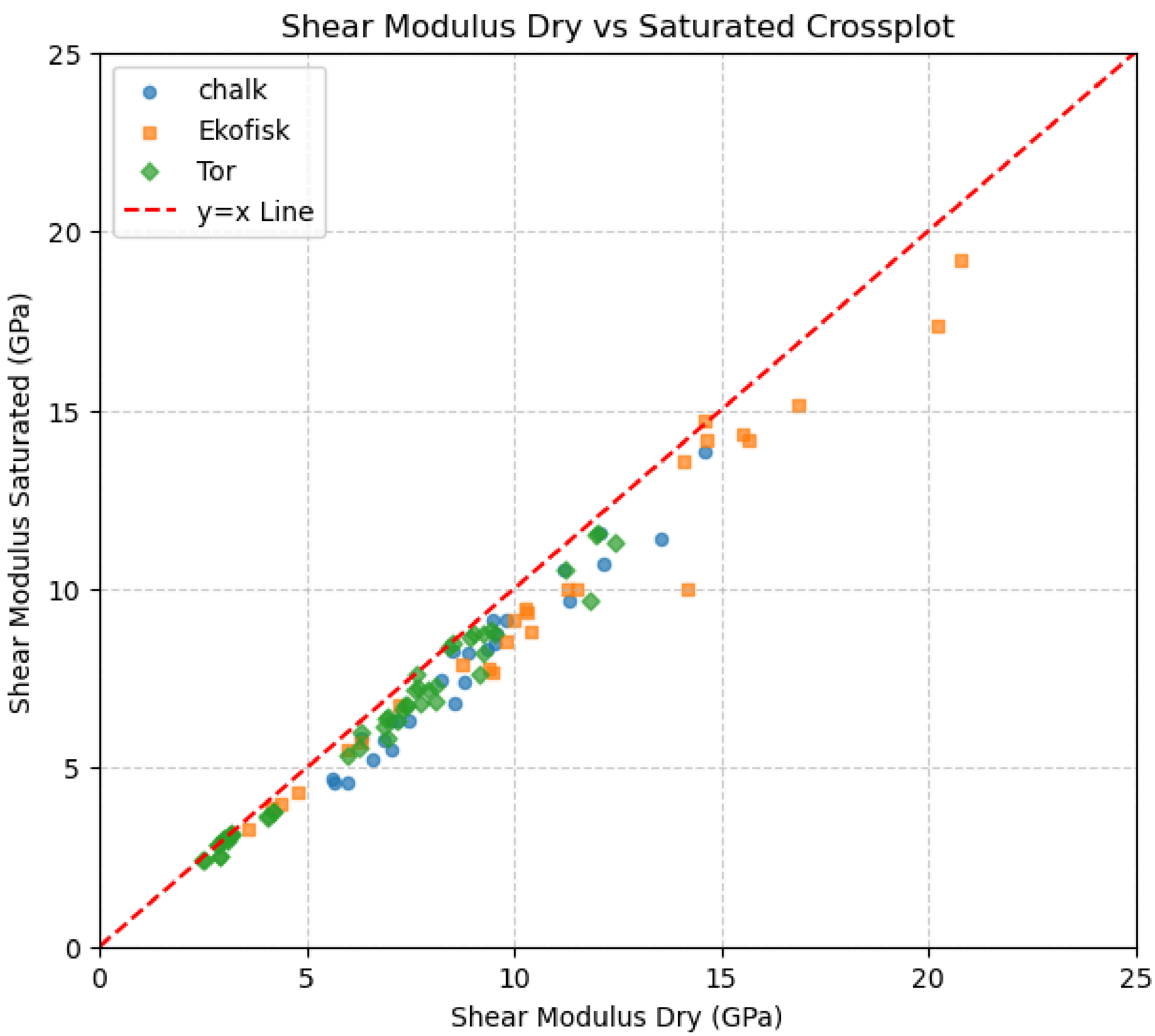
- **Stress regime appears normal**, with effective stress always below total stress.
- The **variation in effective stress** reflects heterogeneous lithology or fluid distribution.
- Zones where **effective stress flattens or drops** might correspond to **overpressured intervals** — crucial for geomechanical modeling and wellbore stability.
- **Differential stress trend** can indicate **compaction trends** or **tectonic influence**, especially if any deviation from linearity is observed.



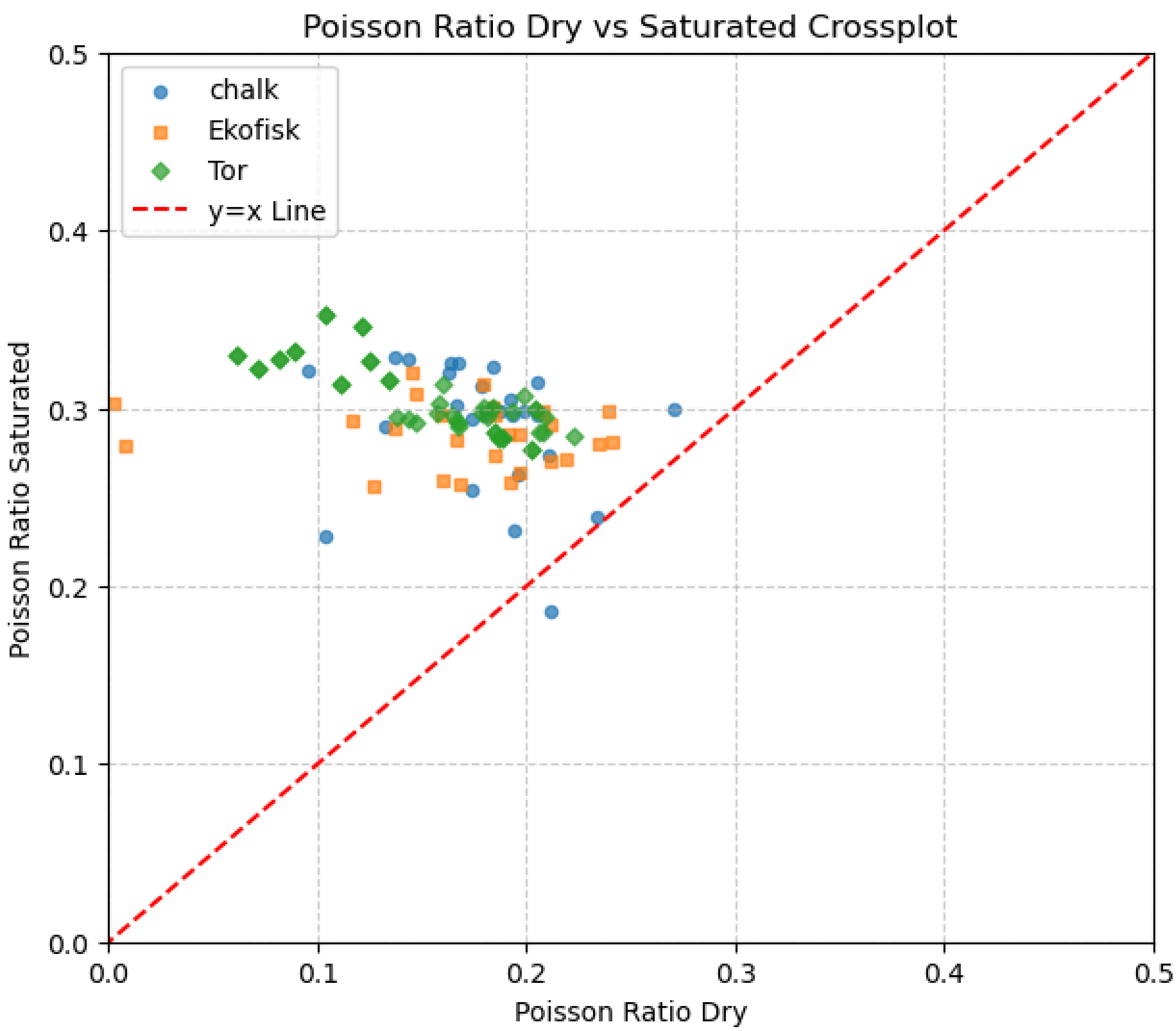
Bulk Modulus Dry vs Saturated Crossplot
chalk
Ekofisk
Tor
y=x Line
Bulk Modulus Saturated (GPa)
Bulk Modulus Dry (GPa)
0
5
10
15
20
25
30
35
40

- **Most points lie above the red dashed line (y = x)**, indicating:
    - **Saturation increases the bulk modulus** — as expected due to the fluid stiffening effect.
- **Ekofisk samples (orange squares)** tend to show:
    - **Higher bulk moduli** overall compared to chalk and Tor, possibly due to **lower porosity or more cementation**.
- **Tor (green diamonds)** and **chalk (blue circles)** are more tightly clustered, with lower modulus values, reflecting their **softer lithology**.
- A few chalk and Tor points lie **close to the y = x line**, suggesting **minimal fluid influence** — possibly due to high porosity or low fluid bulk modulus.

- The plot confirms **Gassmann's fluid substitution effect**: saturation generally increases stiffness.
- Ekofisk is likely more **compacted or cemented** than chalk and Tor.
- The trend provides **insight into rock type and pore structure**: formations with **larger fluid effect** tend to have more compliant frames.

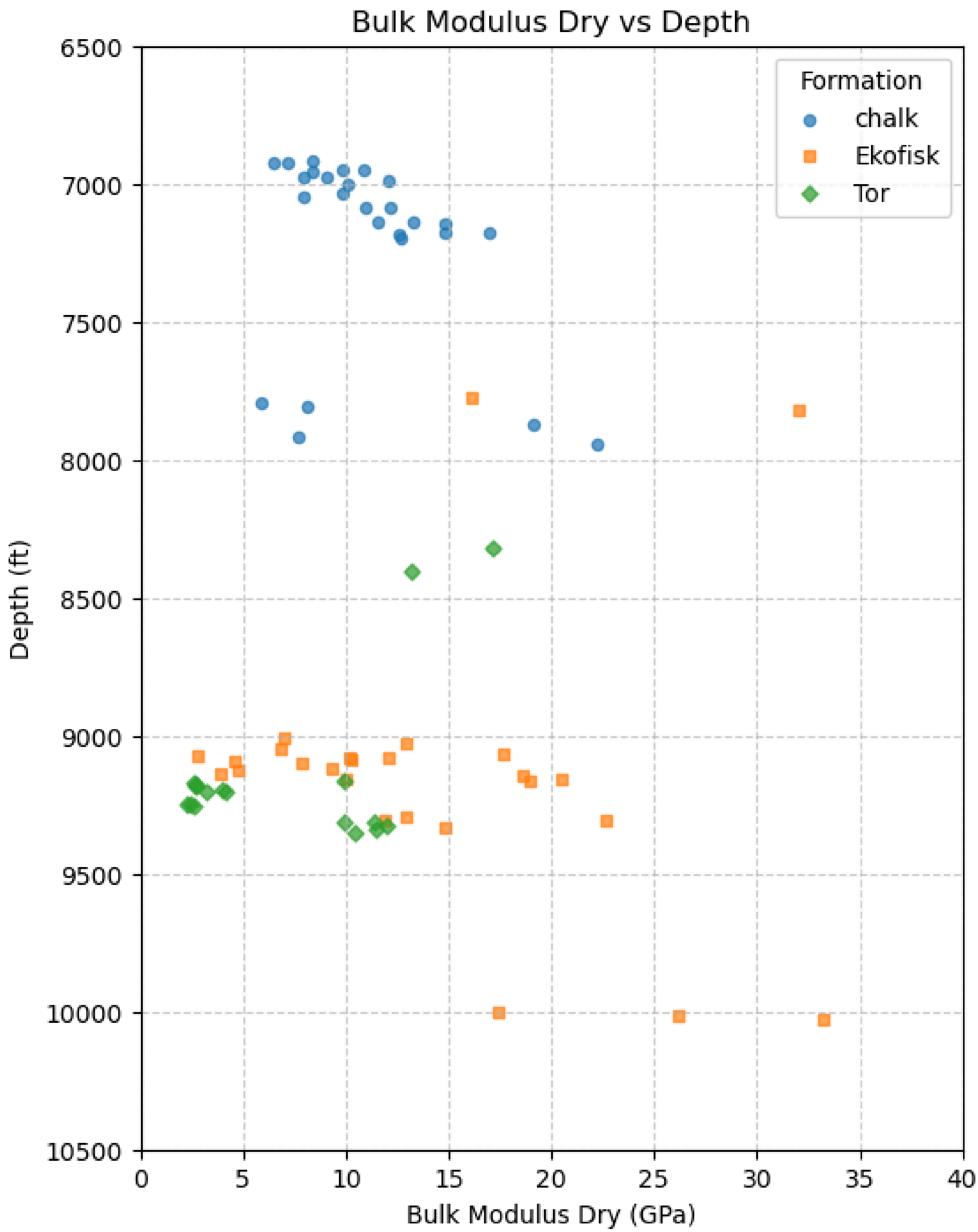


- Most points lie very close to the red dashed line y = x, indicating that the **shear modulus remains nearly unchanged** after fluid saturation.
- This aligns with **Gassmann's theory**, which states that **shear modulus is not affected by fluid substitution** in the rock's pore space. Fluids primarily affect the **bulk modulus**, not shear modulus.
- No significant scatter is observed, suggesting **consistent rock frame properties** across samples.



- **Above the y = x Line:**
  Nearly **all points lie above** the red y = x line, indicating that **Poisson's ratio increases upon saturation**.

- **Why This Happens:**
  When rocks are saturated with fluids:
  - The **bulk modulus increases** (fluids resist compression).
  - The **shear modulus stays nearly constant** (as we saw before).
  - This leads to **increased Poisson's ratio**


Bulk Modulus Dry vs Depth
Depth (ft)
Bulk Modulus Dry (GPa)
Formation
chalk
Ekofisk
Tor
6500
7000
7500
8000
8500
9000
9500
10000
10500
0
5
10
15
20
25
30
35
40

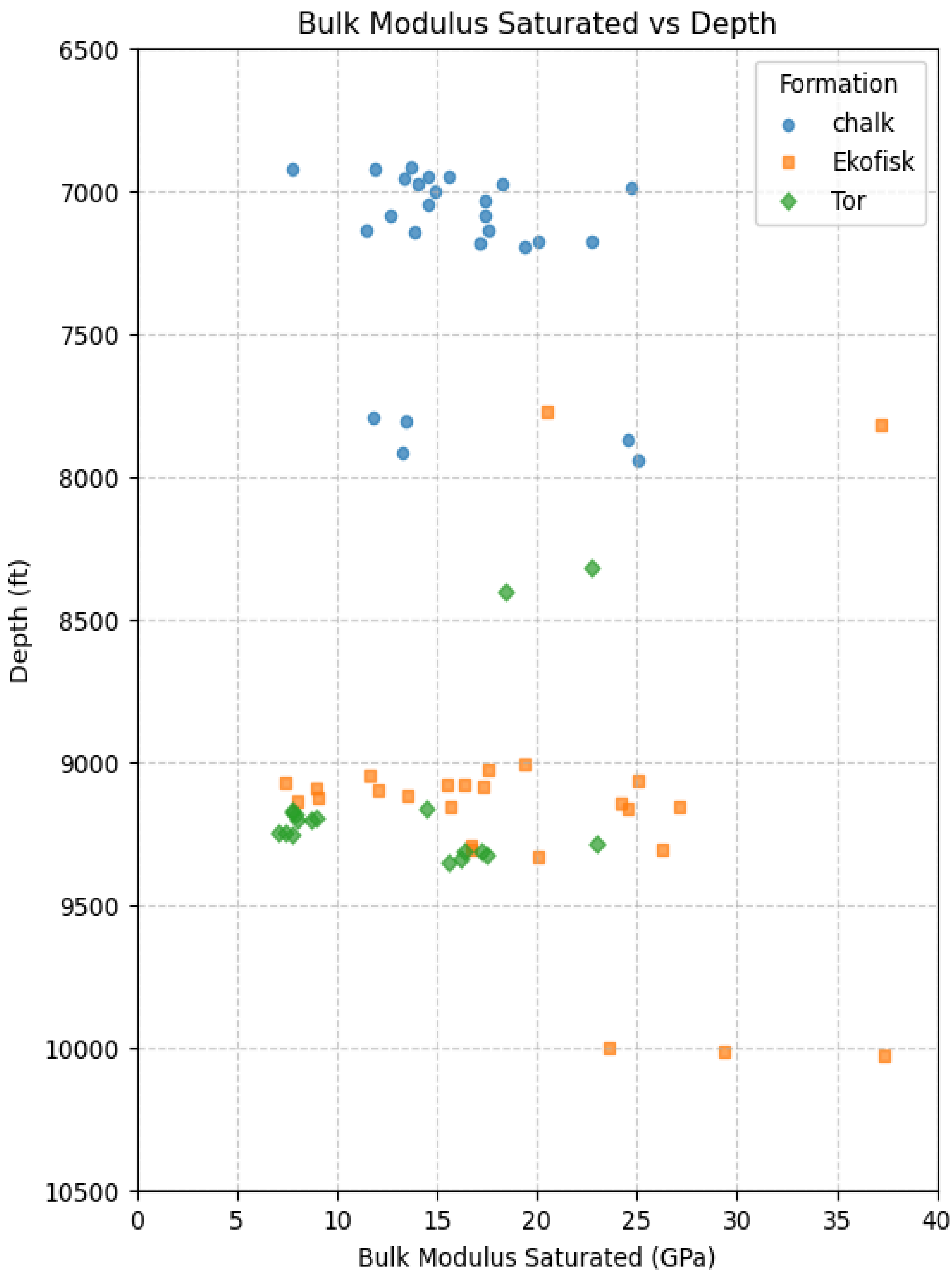
- **Chalk (blue):**
  - Found at **shallower depths** (~7000–8000 ft).
  - Bulk modulus values mostly range between **5–20 GPa**.
  - The values are relatively lower, which aligns with its soft, porous nature.

- **Ekofisk (orange):**
  - At **deeper depths** (~8800–10000+ ft).
  - Shows a wide spread in dry bulk modulus: **5–35 GPa**, with some samples being **very stiff**.
  - Depth likely contributes to **compaction and cementation**, increasing stiffness.

- **Tor (green):**
  - Depth around **8900–9400 ft**, intermediate between chalk and Ekofisk.
  - Bulk modulus mainly in the **7–18 GPa** range.
  - Likely more cemented than chalk, but not as stiff as some deeper Ekofisk units.

- There's a **positive correlation** between depth and dry bulk modulus.
  - Likely due to **increased effective stress**, **cementation**, and **reduced porosity** at greater depths.

- However, it's not linear — lithological variation (formation type) plays a significant role.
  - E.g., some shallow chalk points have a higher modulus than deeper Tor ones — suggesting **lithology and diagenesis** matter too.



Bulk Modulus Saturated vs Depth
Formation
chalk
Ekofisk
Tor
Depth (ft)
6500
7000
7500
8000
8500
9000
9500
10000
10500
0
5
10
15
20
25
30
35
40
Bulk Modulus Saturated (GPa)

1. Chalk (blue)

- Still located around **7000–8000 ft**.
- Saturated bulk modulus values are higher than dry (makes sense due to fluid presence).
- The saturation seems to **boost stiffness**, but the trend with depth is still subtle.

2. Ekofisk (orange)

- Found **below 8800 ft**, extending past **10000 ft**.
- Wide range: **5–38 GPa**.
- Saturation impact is quite visible here; a few points reach **~35–38 GPa**.
- Shows **clear depth dependence**, but again, also reflects lithology & cementation.

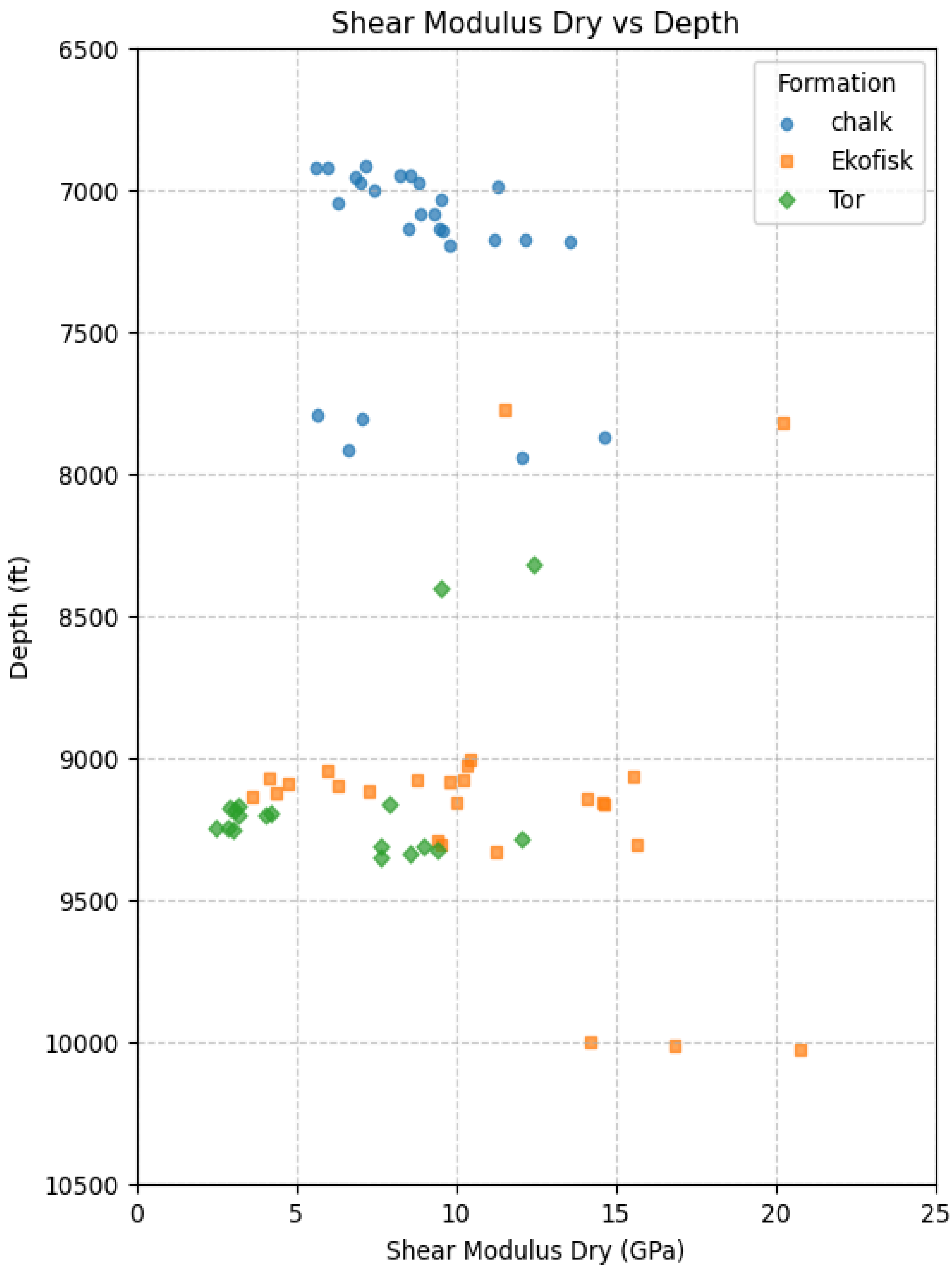
3. Tor (green)

- Located at **~8900–9500 ft**.
- Saturated moduli range: **~7–25 GPa**.
- Overall trend mirrors Ekofisk but with **slightly lower bulk moduli**—consistent with its lithology.

Saturation increases bulk modulus — visible shift compared to dry case.

Depth trends hold, but the gap between formations persists:
Chalk remains less stiff than Tor and Ekofisk.

The increase is not uniform — **pore structure, fluid type, and connectivity** play roles.



Shear Modulus Dry vs Depth
Formation
chalk
Ekofisk
Tor
Depth (ft)
6500
7000
7500
8000
8500
9000
9500
10000
10500
0
5
10
15
20
25
Shear Modulus Dry (GPa)

Chalk (blue)

- Appears in the **7000–8000 ft** depth range.
- Shear moduli range from **~4 to 12 GPa**, with most clustering around **6–10 GPa**.
- Fairly tight spread, consistent with a relatively **uniform lithology and porosity**.

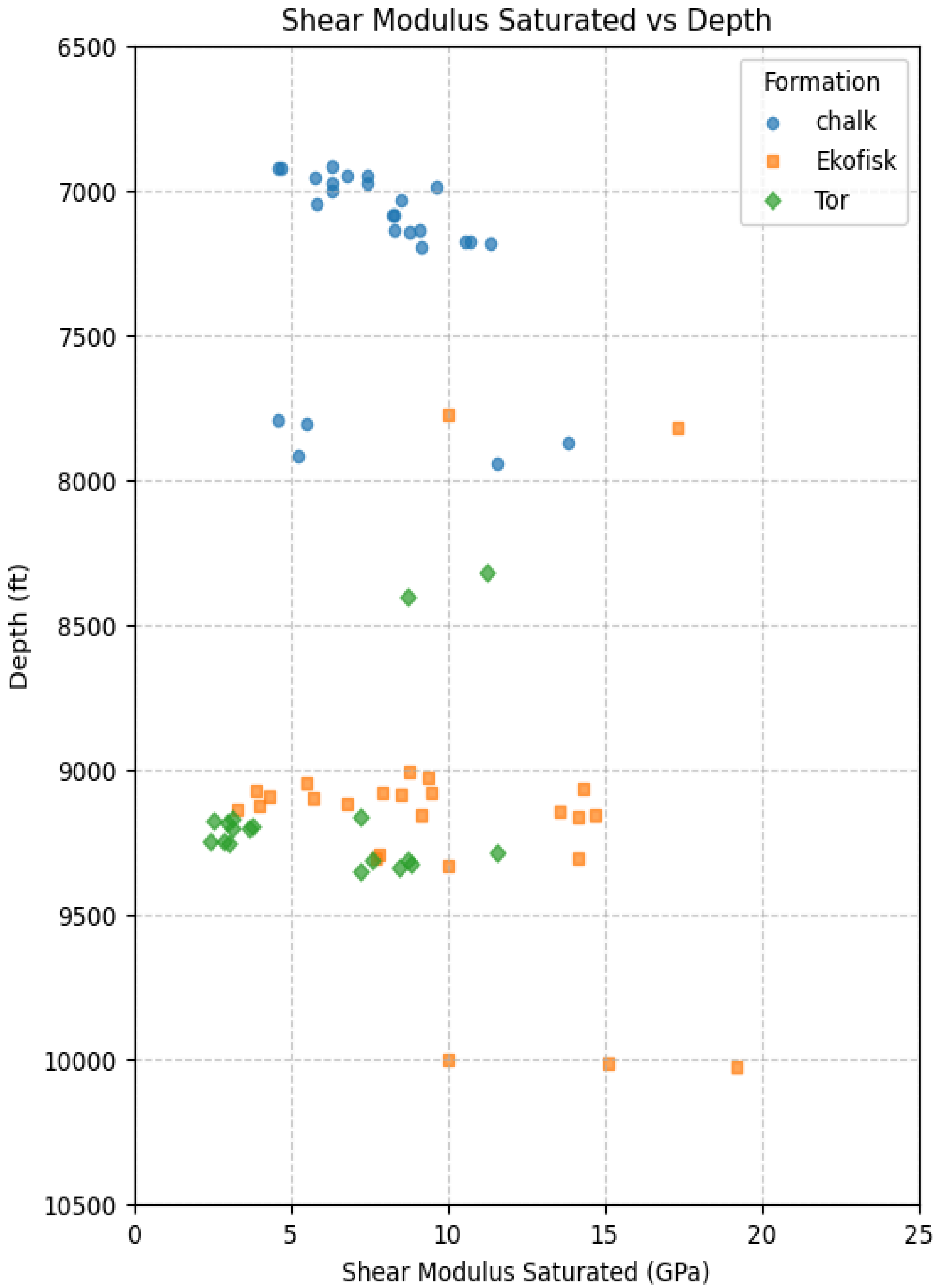
Ekofisk (orange)

- Found **~8800 to >10000 ft**.
- Dry shear modulus ranges **~5 to 22 GPa**.
- Stronger depth dependence — deeper samples generally show **higher shear modulus**, likely due to **compaction and cementation**.

Tor (green)

- Depth range **~8800–9500 ft**.
- Shear moduli mostly fall between **~3 to 12 GPa**.
- On average, a bit softer than Ekofisk — possibly due to slightly **higher porosity or different microstructure**.

- **Ekofisk shows the highest stiffness with depth** — possibly due to greater burial and diagenesis.
- **Tor and Chalk are softer**, and chalk especially shows a narrow range, indicating more uniformity.
- **Fluid doesn't directly influence shear modulus**, so this dry case gives a clear picture of **frame stiffness.**



Shear Modulus Saturated vs Depth
Formation
chalk
Ekofisk
Tor
Depth (ft)
Shear Modulus Saturated (GPa)
6500
7000
7500
8000
8500
9000
9500
10000
10500
0
5
10
15
20
25

Chalk (Blue)

- Appears at **~7000–8000 ft**, shear modulus ~5–11 GPa.
- Similar to dry case — confirming **fluid has minimal impact**.

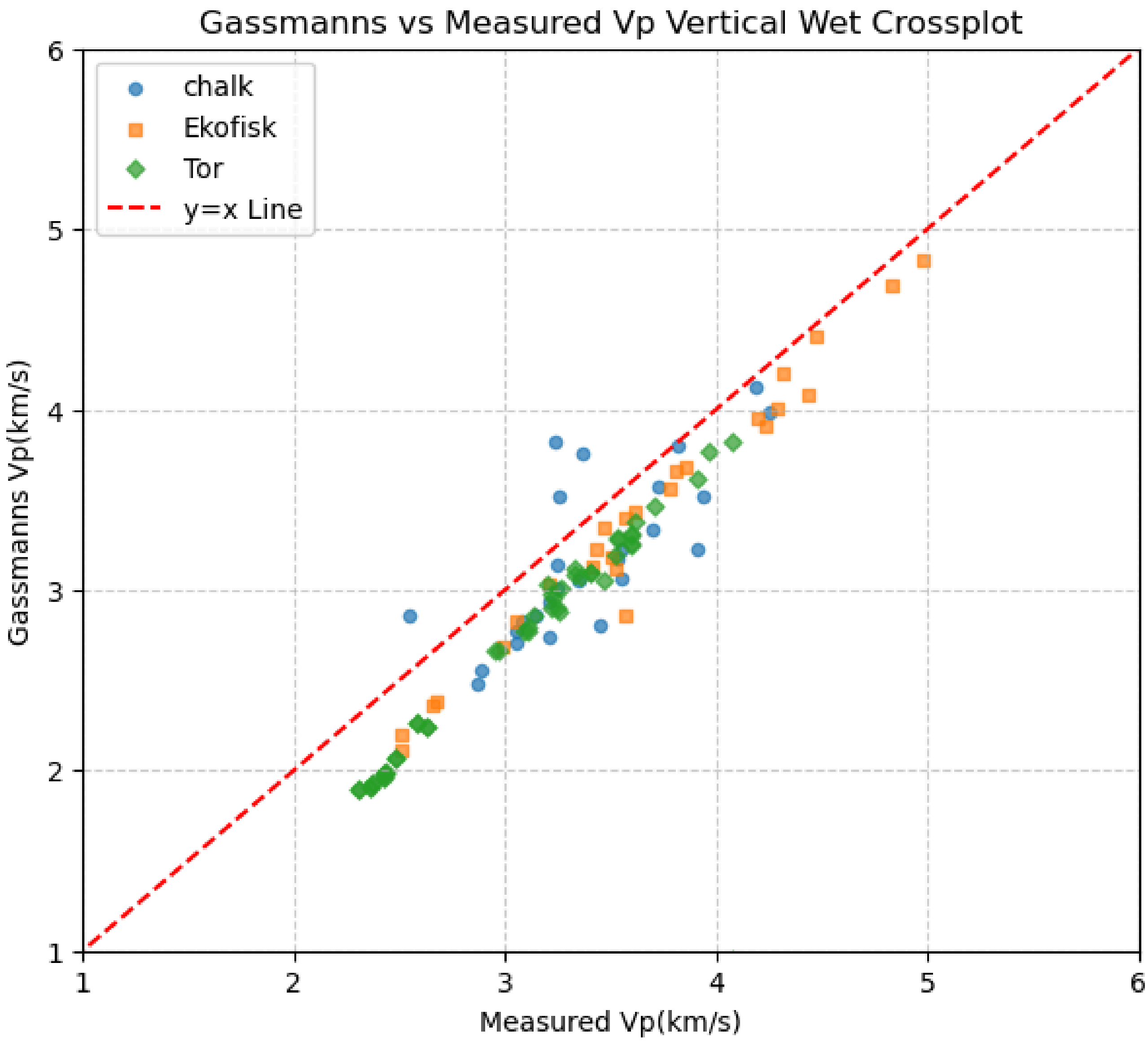
Ekofisk (Orange)

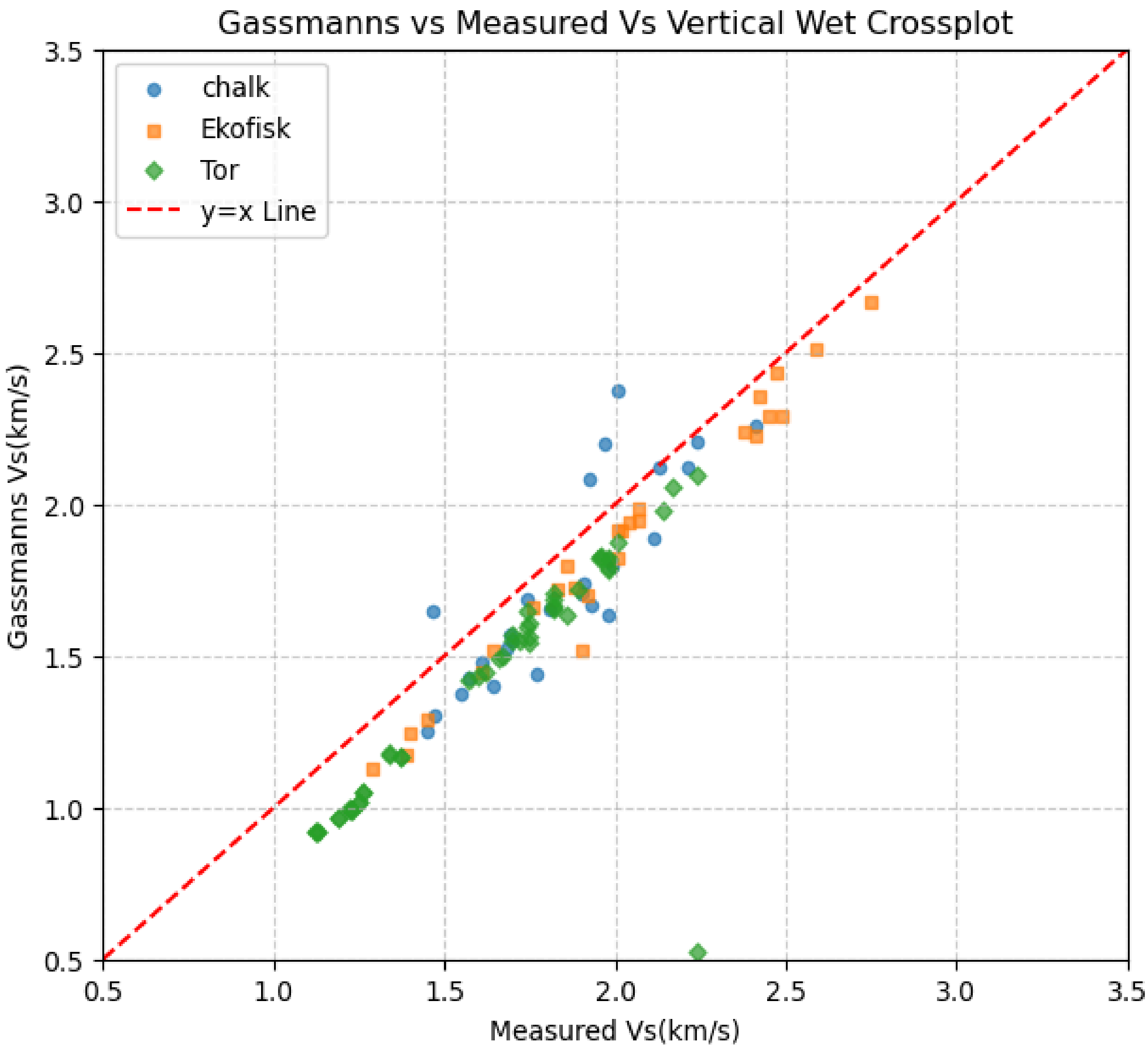
- Found **~8800–>10000 ft**.
- Wider spread of modulus (~5–20 GPa), increasing with depth.
- Fluid saturation doesn't affect this behavior.

Tor (Green)

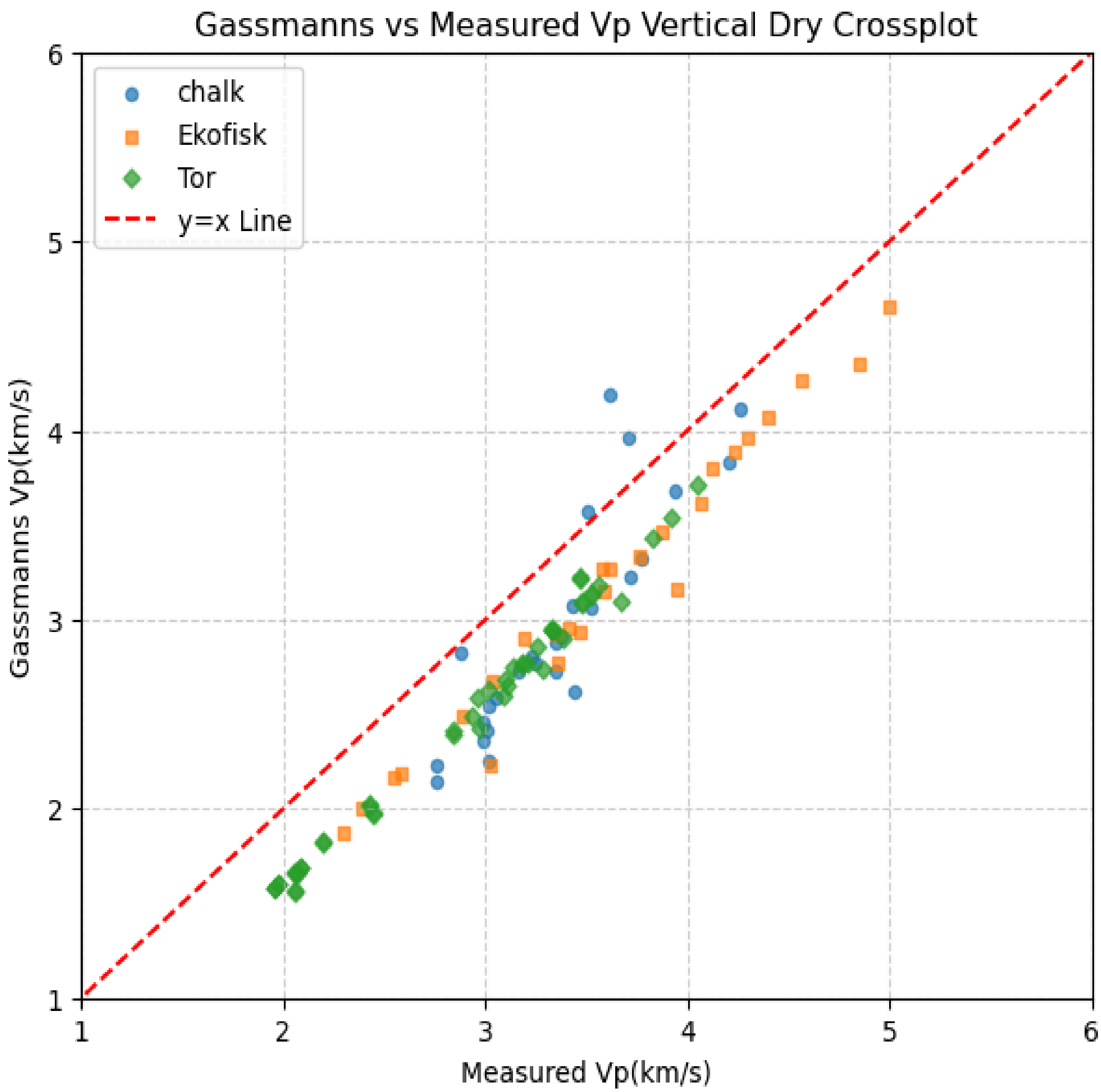
- Depth range **~8800–9500 ft**.
- Modulus values: **~3–12 GPa**, nearly identical to the dry case.

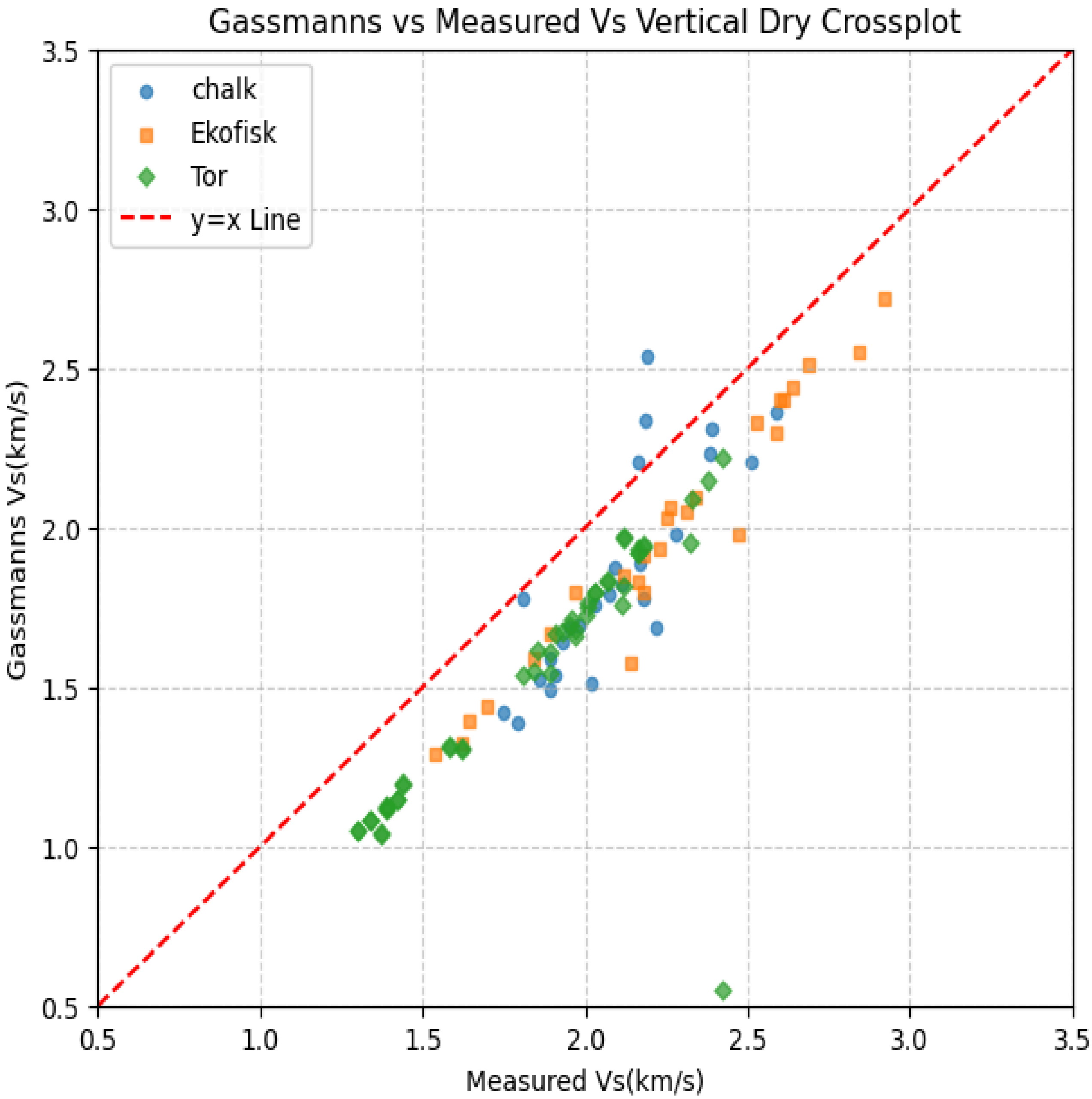
This validates our **Gassmann fluid substitution** results — shear modulus remains constant (doesn't change much) with saturation.


Gassmanns vs Measured Vp Vertical Wet Crossplot
Gassmanns Vp(km/s)
Measured Vp(km/s)
chalk
Ekofisk
Tor
y=x Line
1
2
3
4
5
6



Gassmanns vs Measured Vs Vertical Wet Crossplot
chalk
Ekofisk
Tor
y=x Line
Gassmanns Vs(km/s)
Measured Vs(km/s)
0.5
1.0
1.5
2.0
2.5
3.0
3.5


Gassmanns vs Measured Vp Vertical Dry Crossplot
chalk
Ekofisk
Tor
y=x Line
Gassmanns Vp(km/s)
Measured Vp(km/s)
1
2
3
4
5
6



Gassmanns vs Measured Vs Vertical Dry Crossplot
chalk
Ekofisk
Tor
y=x Line
Gassmanns Vs(km/s)
Measured Vs(km/s)
0.5
1.0
1.5
2.0
2.5
3.0
3.5

In all the above 4 plots, we can see that-

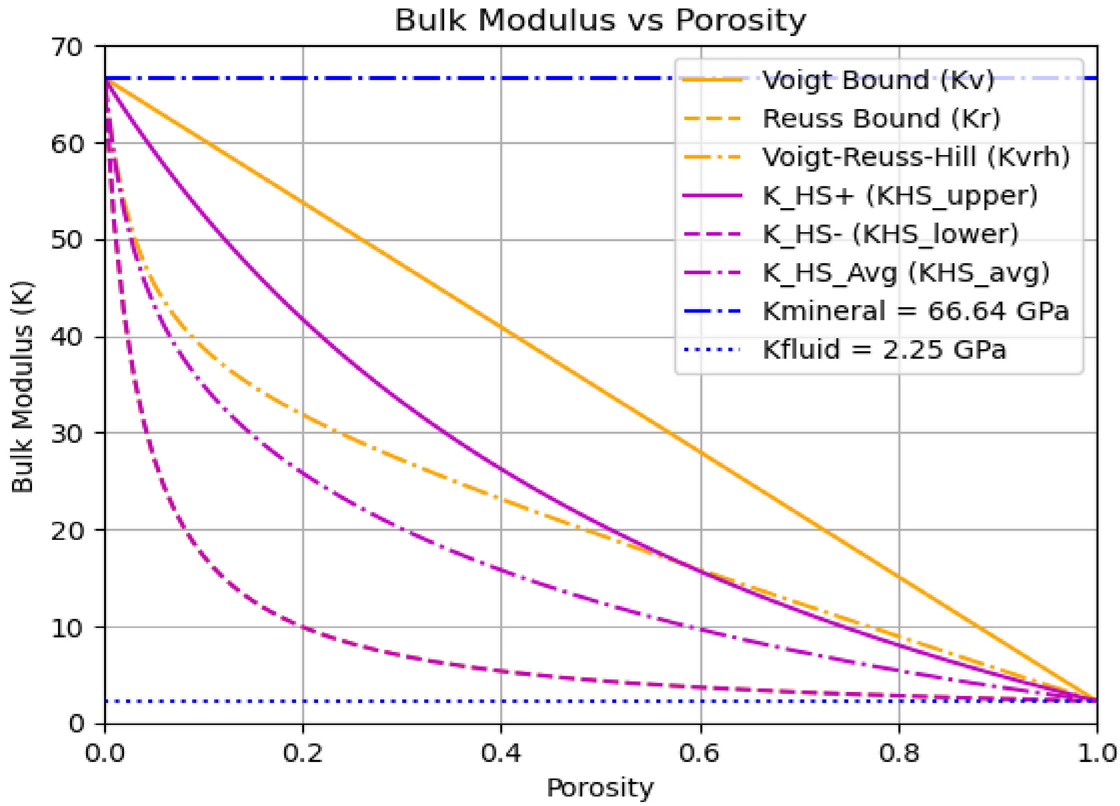
- For most of the data samples, Gassman's Value for (Vp and Vs) is less than the measured values.

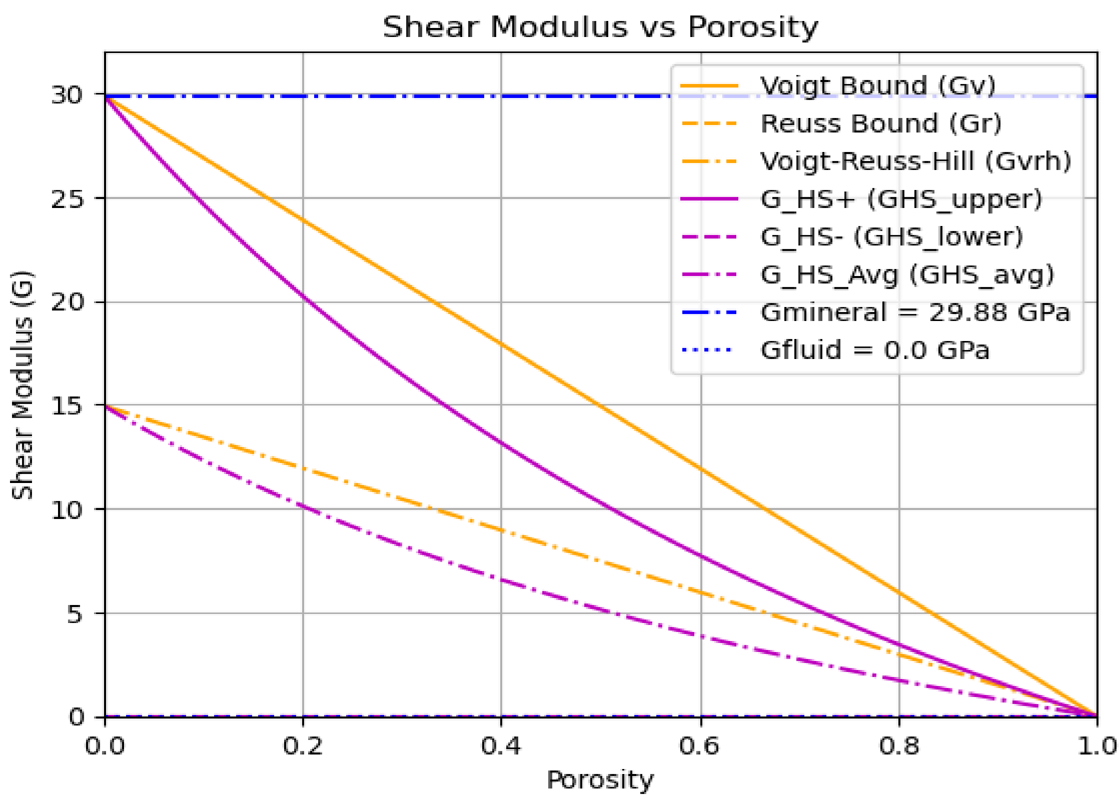
- Means Gassman is underpredicting the property values consistently (especially for the formations - Ekofish and Tor).

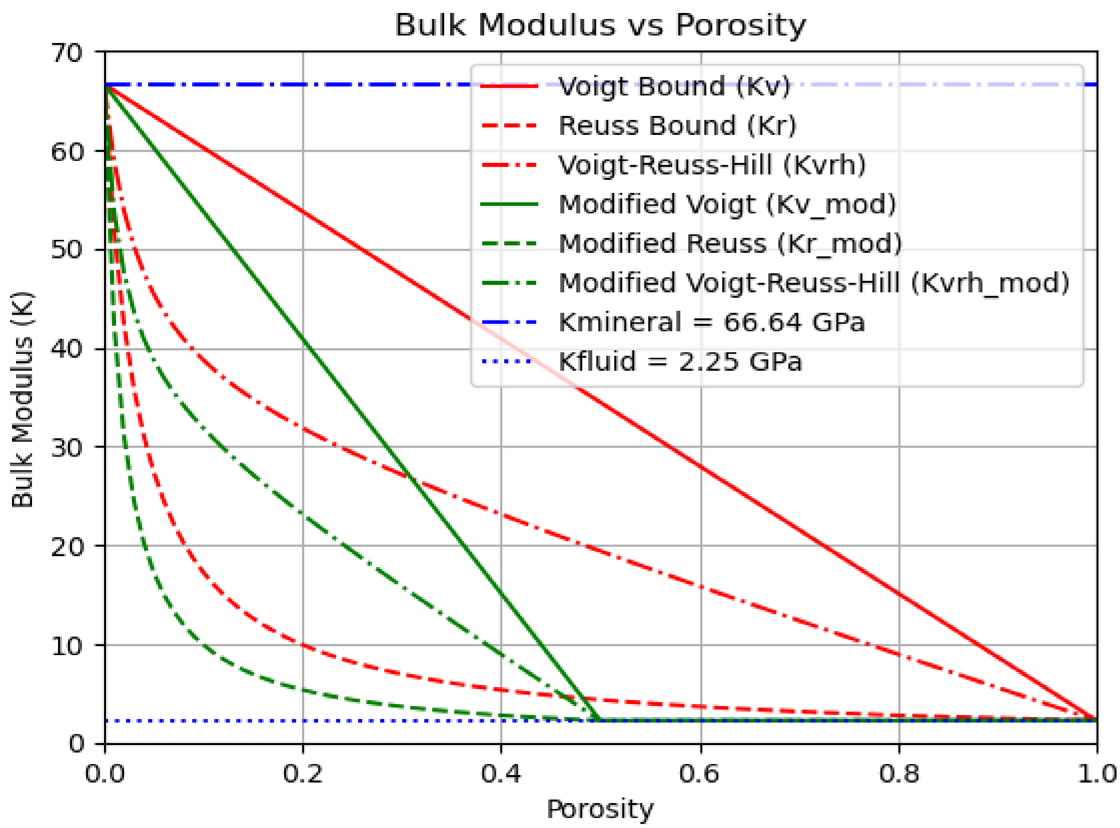
- This tells us that there is systematic error (some bias) for Ekofish and Tor, but not for the Chalk formation.

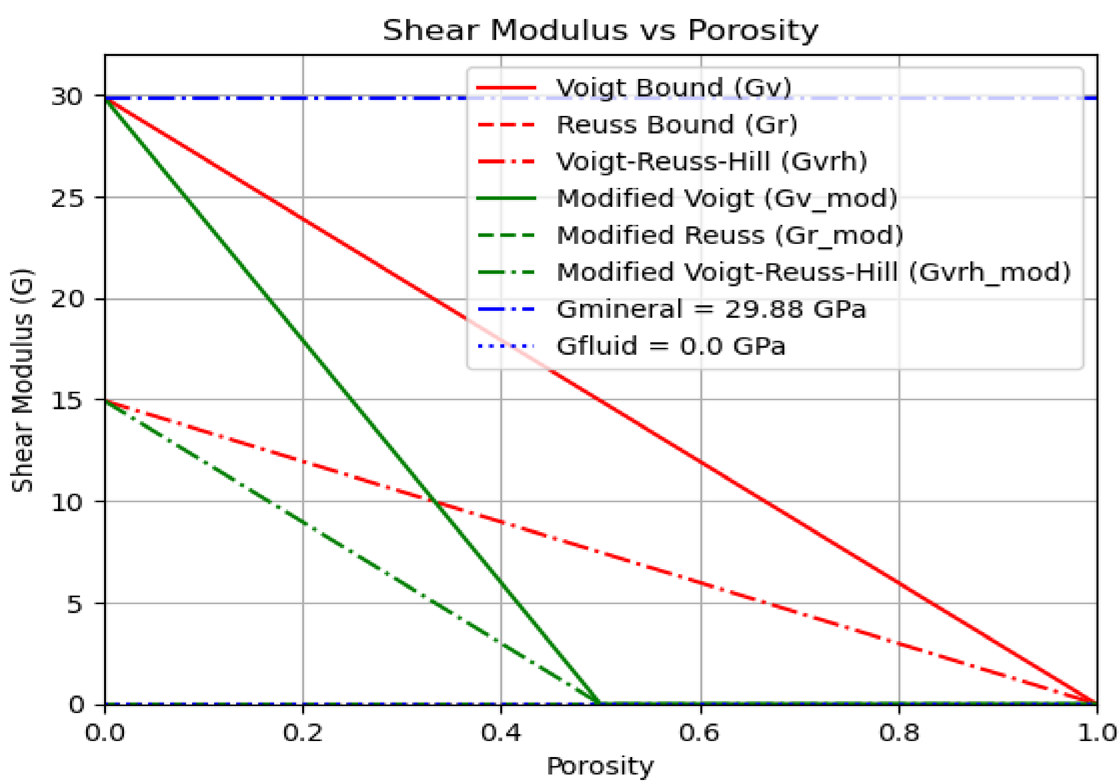
- So we may go with Gassman’s eq. for chalk formation because for large numbers of samples it can generalize better.

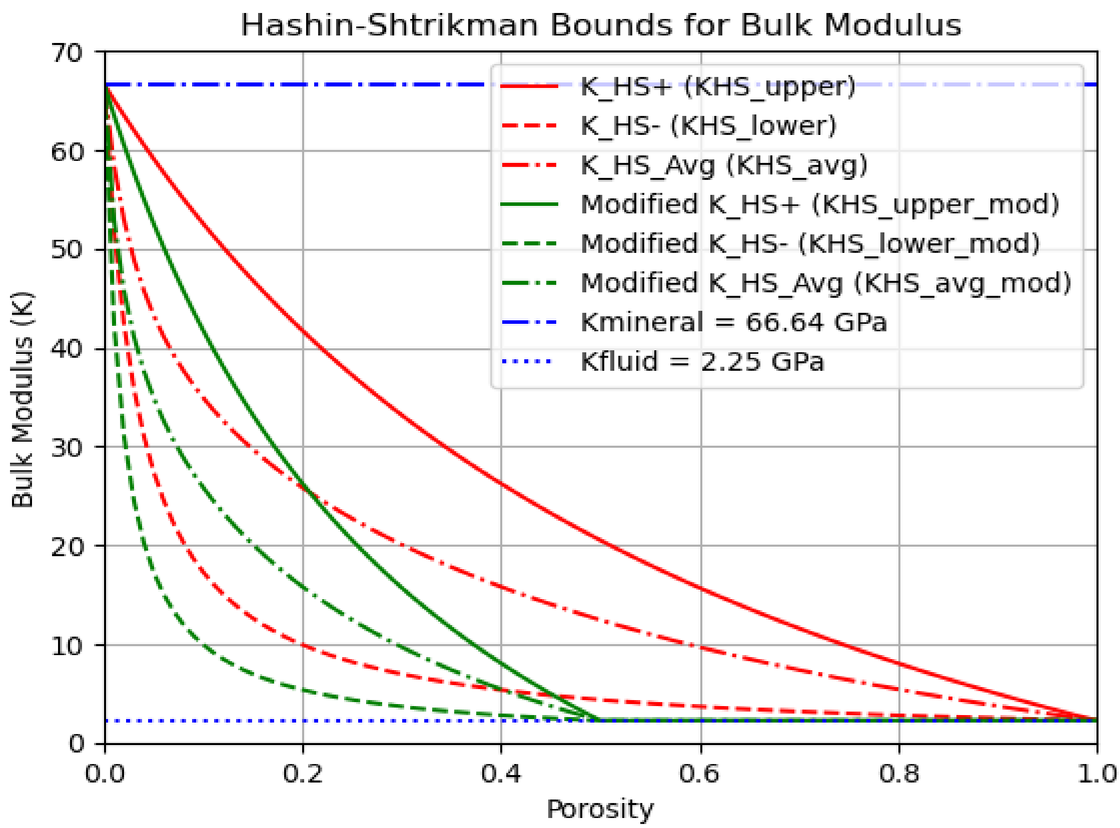
- But we should not use Gassman directly for Ekofish and Tor formations, if we can solve the error of the bias then only we can consider using it.

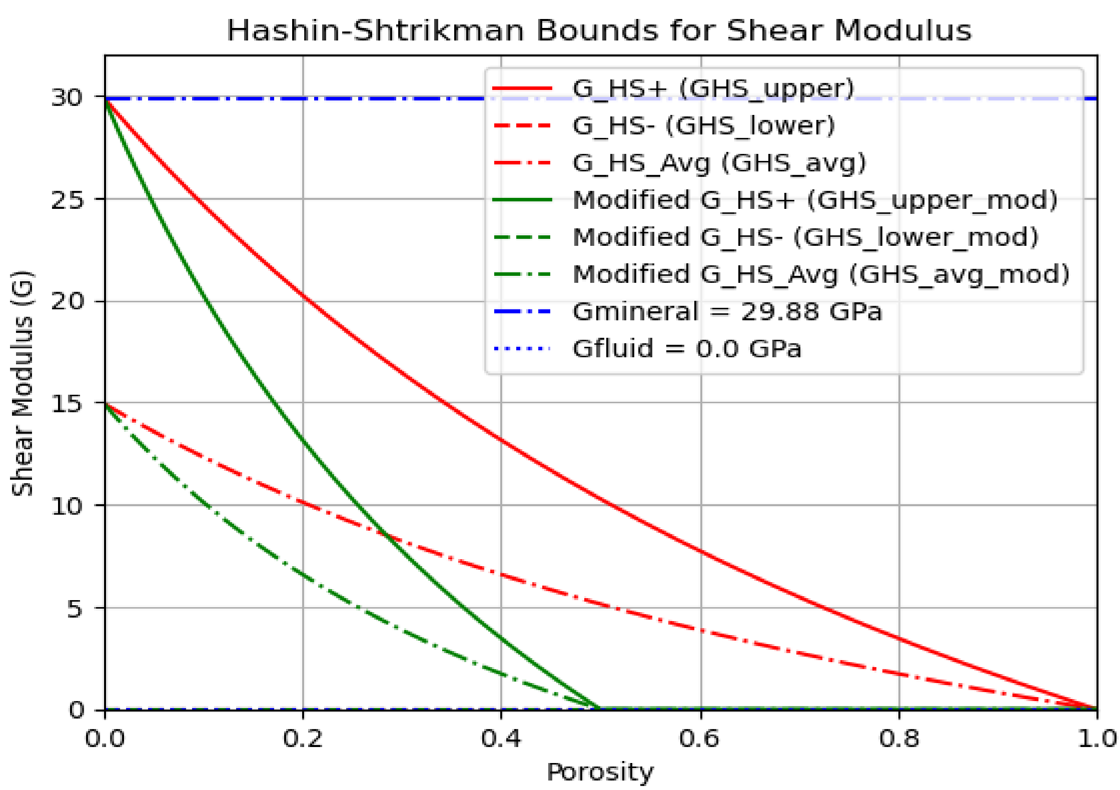

Bulk Modulus vs Porosity
Voigt Bound (Kv)
Reuss Bound (Kr)
Voigt-Reuss-Hill (Kvrh)
K_HS+ (KHS_upper)
K_HS- (KHS_lower)
K_HS_Avg (KHS_avg)
Kmineral = 66.64 GPa
Kfluid = 2.25 GPa
Bulk Modulus (K)
Porosity
0
10
20
30
40
50
60
70
0.0
0.2
0.4
0.6
0.8
1.0

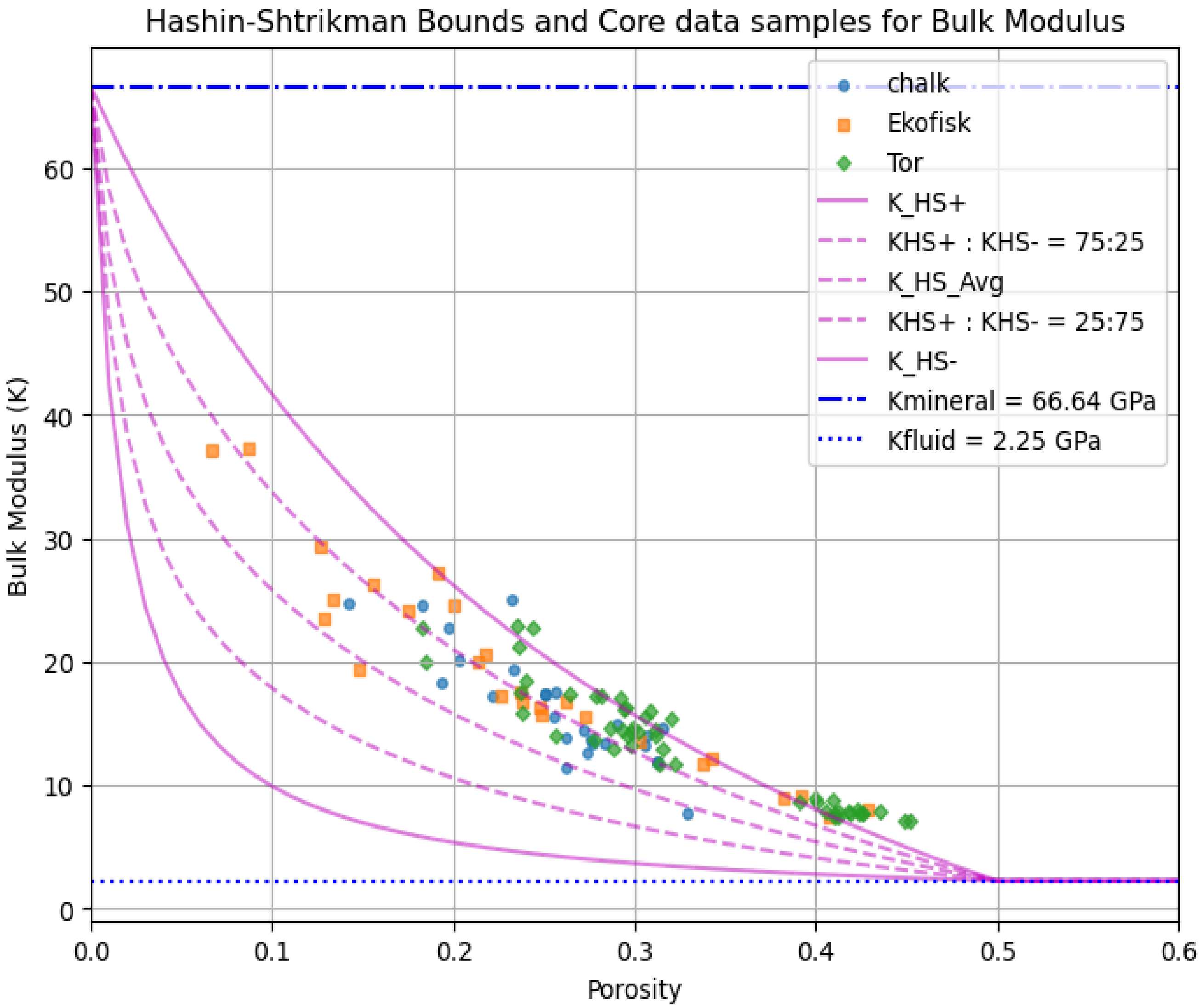

Shear Modulus vs Porosity
Voigt Bound (Gv)
Reuss Bound (Gr)
Voigt-Reuss-Hill (Gvrh)
G_HS+ (GHS_upper)
G_HS- (GHS_lower)
G_HS_Avg (GHS_avg)
Gmineral = 29.88 GPa
Gfluid = 0.0 GPa
Shear Modulus (G)
Porosity
0
5
10
15
20
25
30
0.0
0.2
0.4
0.6
0.8
1.0


Bulk Modulus vs Porosity
Voigt Bound (Kv)
Reuss Bound (Kr)
Voigt-Reuss-Hill (Kvrh)
Modified Voigt (Kv_mod)
Modified Reuss (Kr_mod)
Modified Voigt-Reuss-Hill (Kvrh_mod)
Kmineral = 66.64 GPa
Kfluid = 2.25 GPa
Bulk Modulus (K)
Porosity
0
10
20
30
40
50
60
70
0.0
0.2
0.4
0.6
0.8
1.0

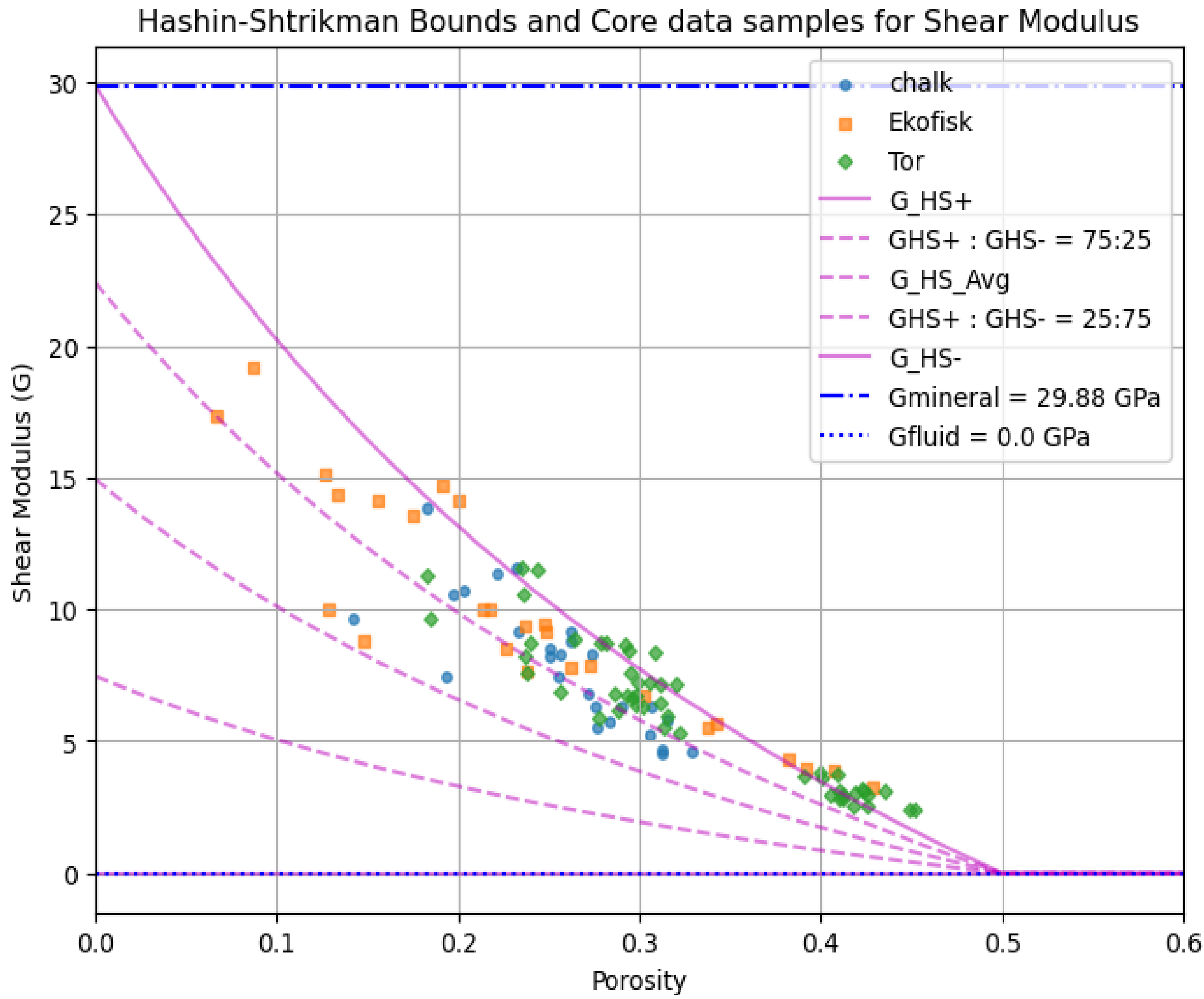

Shear Modulus vs Porosity
Voigt Bound (Gv)
Reuss Bound (Gr)
Voigt-Reuss-Hill (Gvrh)
Modified Voigt (Gv_mod)
Modified Reuss (Gr_mod)
Modified Voigt-Reuss-Hill (Gvrh_mod)
Gmineral = 29.88 GPa
Gfluid = 0.0 GPa
Shear Modulus (G)
Porosity
0
5
10
15
20
25
30
0.0
0.2
0.4
0.6
0.8
1.0


Hashin-Shtrikman Bounds for Bulk Modulus
K_HS+ (KHS_upper)
K_HS- (KHS_lower)
K_HS_Avg (KHS_avg)
Modified K_HS+ (KHS_upper_mod)
Modified K_HS- (KHS_lower_mod)
Modified K_HS_Avg (KHS_avg_mod)
Kmineral = 66.64 GPa
Kfluid = 2.25 GPa
Bulk Modulus (K)
Porosity
0
10
20
30
40
50
60
70
0.0
0.2
0.4
0.6
0.8
1.0


Hashin-Shtrikman Bounds for Shear Modulus
G_HS+ (GHS_upper)
G_HS- (GHS_lower)
G_HS_Avg (GHS_avg)
Modified G_HS+ (GHS_upper_mod)
Modified G_HS- (GHS_lower_mod)
Modified G_HS_Avg (GHS_avg_mod)
Gmineral = 29.88 GPa
Gfluid = 0.0 GPa
Shear Modulus (G)
Porosity
0
5
10
15
20
25
30
0.0
0.2
0.4
0.6
0.8
1.0



Hashin-Shtrikman Bounds and Core data samples for Bulk Modulus
chalk
Ekofisk
Tor
K_HS+
KHS+ : KHS- = 75:25
K_HS_Avg
KHS+ : KHS- = 25:75
K_HS-
Kmineral = 66.64 GPa
Kfluid = 2.25 GPa
Bulk Modulus (K)
Porosity
0
10
20
30
40
50
60
0.0
0.1
0.2
0.3
0.4
0.5
0.6



Hashin-Shtrikman Bounds and Core data samples for Shear Modulus
Shear Modulus (G)
Porosity
chalk
Ekofisk
Tor
G_HS+
GHS+ : GHS- = 75:25
G_HS_Avg
GHS+ : GHS- = 25:75
G_HS-
Gmineral = 29.88 GPa
Gfluid = 0.0 GPa
0
5
10
15
20
25
30
0.0
0.1
0.2
0.3
0.4
0.5
0.6

By looking on both Bulk and Shear Modulus with HS bounds we can say that-

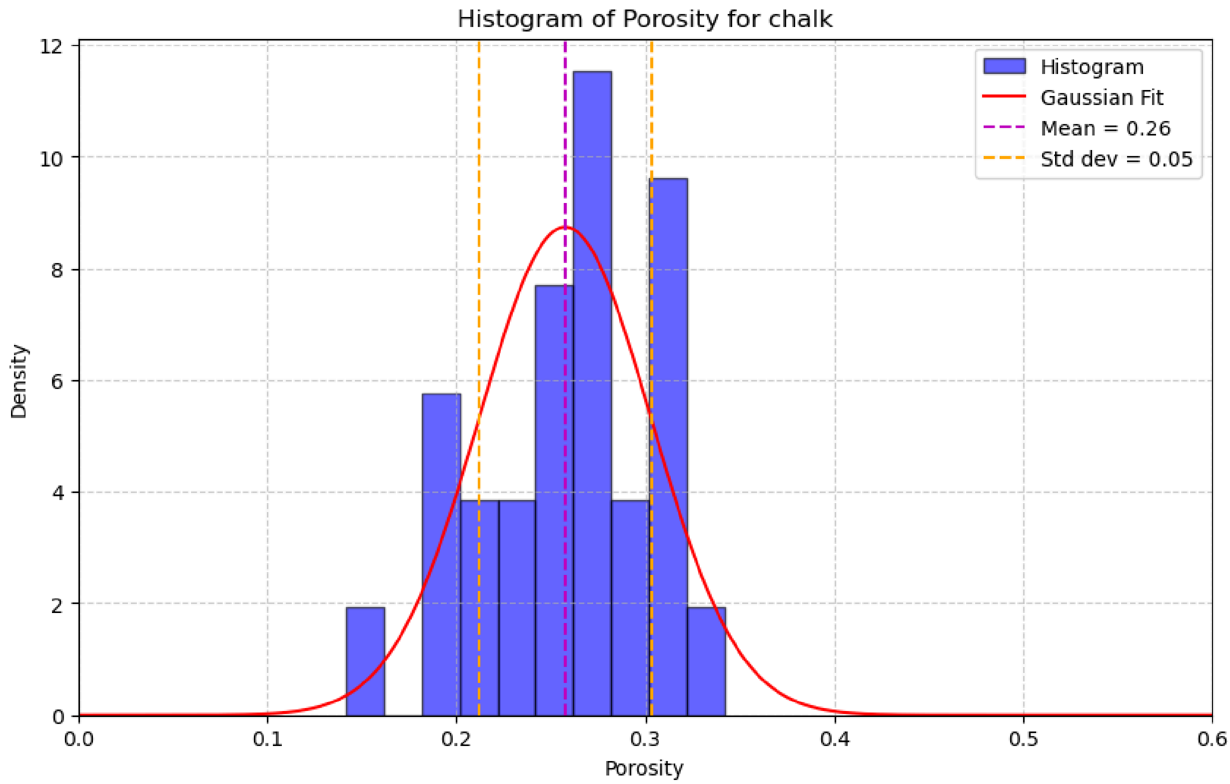
Almost all the data points lie within the HS bounds, confirming the **physical validity** of the samples.

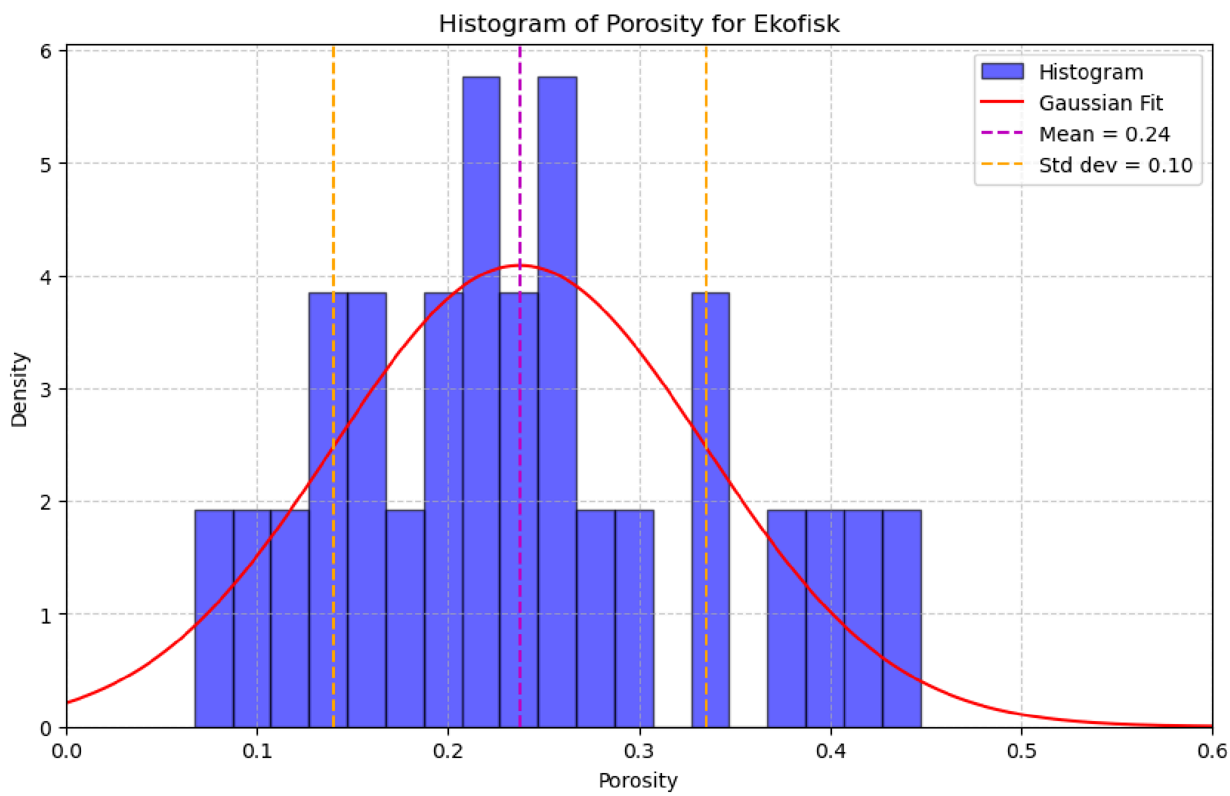
- The formations seem to fall within the bounds - the **K_HS_Avg** and the **Upper bound**, suggesting that the overall rock is behaving as stiffer.

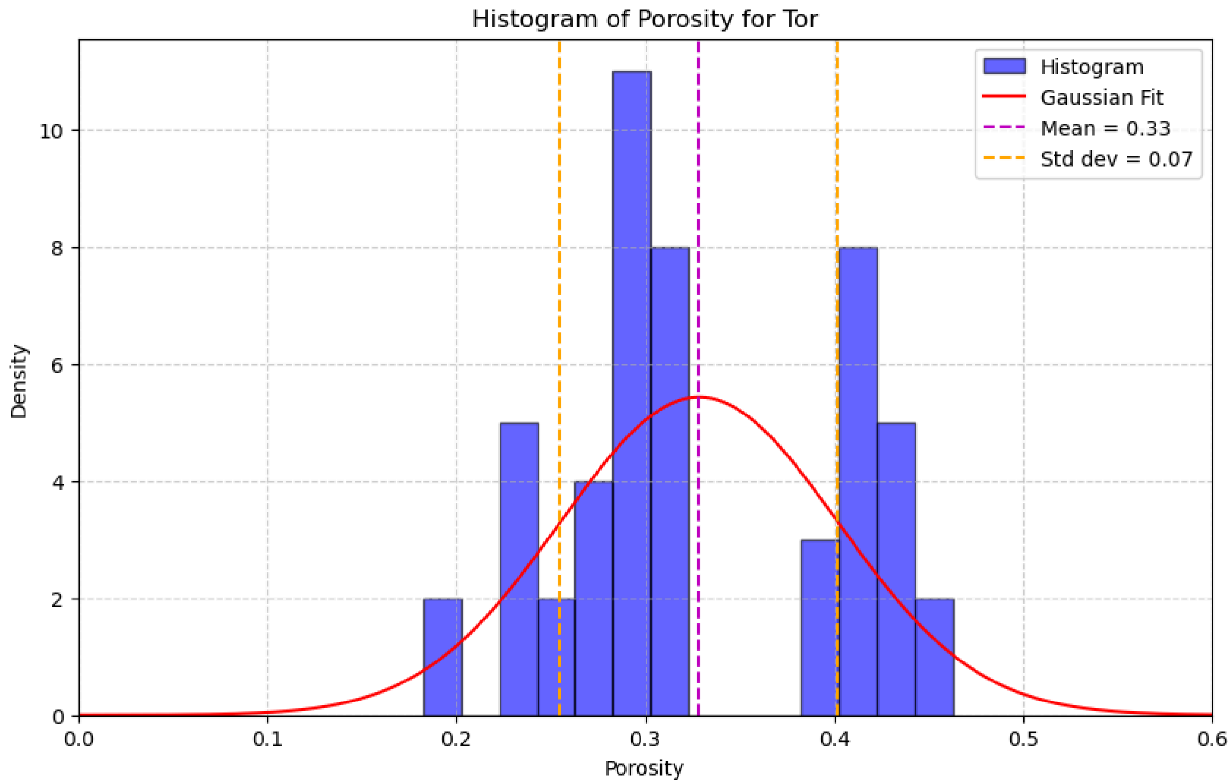
- Tor formation seems to be most stiffer as most of the samples stick near the **Upper bound**.

- Chalk formation seems to be softer than Tor and it looks that it follows a **75:25 weighted bound.**

- Ekofisk has wide range of porosities and Bulk Modulus, suggesting the Diagenetic formation.


Histogram of Porosity for chalk
Histogram
Gaussian Fit
Mean = 0.26
Std dev = 0.05
Density
Porosity
0
2
4
6
8
10
12
0.0
0.1
0.2
0.3
0.4
0.5
0.6


Histogram of Porosity for Ekofisk
Histogram
Gaussian Fit
Mean = 0.24
Std dev = 0.10
Density
Porosity
0
1
2
3
4
5
6
0.0
0.1
0.2
0.3
0.4
0.5
0.6



By looking on Histograms of porosities, we can say that-

- Chalk formation aligns well with Guassian, suggests to have a Unimodal distribution
- Ekofisk is also following Guassian to some extent (less than Chalk) as its deviation from mean is larger than Chalk. Like Chalk, it may also have Unimodal distribution
- Tor is not following Guassian well, rather it looks like it has Bimodal distribution.

Thank You