Estimation of stresses and petrophysical modeling of a paleocene sandstone unit of the well 35/18-1

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Content

1. Motivation and objectives

This report builds a part of an integrated project (*"Integrated Geopressure solutions, P0017 Overpressure study"*)performed by SCOTT PICKFORD for the PORCUPINE STUDIES GROUP (AGIP, CHEVRON, ENTERPRISE OIL, MARATHON, PHILLIPS, PETROLEUM AFFAIRS DIVISION, STATOIL and TOTALFINAEFL).

The overall objective of the integrated Overpressure study is to predict the occurrence of possible overpressured formations away from well control.

Within this overall objective the integrated project this report concentrated on the following tasks:

- Estimate DTS logs for the 35/18-1 well, where dipole sonic data are missing
- Estimate the stress regime for the paleocene sand section in the 35/18-1 well, which shall be investigated.
- Find and modify an empirical rock model in order to match the measured sonic data and model the pressure effect on both, P and S velocities for some key pressure values.

2. Executive summary

- Due to the lack of measured shear sonic logs, a DTS log was estimated from calculated porosity, shale fraction and lithology based on Masons relationship.
- Eberhardt-Phillips relationship (Vp, Vs as function of porosity, shale volume and effective pressure) was modified in order to fit the measured data. A very good fit was achieved between modelled and measured DT.
- Relevant key pressure values were estimated from STATOIL stress compilation, raw data (RFT) and own calculations (vertical stress):

Lithostatic pressure:	12135 psi
Fracture pressure:	8870 psi
Pore pressure:	6448 psi
Hydrostatic pressure	5170 psi

  (Pressure values at 3570 m ≅ 11712 ft)

- Modified Eberhardt-Phillips relationship was used to model the pressure effect on rock framework in paleocene sandstone.

- Average velocity calculated over paleocene sand section. Average velocity over paleocene sand interval fits measured data with an error of only 0.5%. Modelling indicates that, due to a combination of rock parameters and in situ stress state, variations of velocity caused by the reaction of rock matrix on overpressure in this case is likely to be too low to be recognisable seismically.

- Although the applied model was developed based on measurements on shaly sandstone, so that it can strictly speaking not be applied to shales, it is at least interesting to notice that a shale section between the lowermost paleocene sand and the uppermost carbonate, has to be modelled with a very low effective stress (100 bar) in order to fit the measured velocities, and that this shale section is indeed detectable as low velocity anomaly from a seismic velocity analysis.

3. Data utilised

Data used, provided by the Porcupine Studies Group were:

- Porcupine Basin EFT, DST & LOT Pressure data. Compilation of data from different wells, provided by STATOIL
- Petrophysical evaluation report for well 35/18-1 by AMOCO, provided by ENTERPRISE OIL.
- Final Geological Well Report, Amoco Ireland Exploration Company.
- Wire line logs: CALI, GR, DT, ILD LLD, NPHI, RHOB, SP.

4. Determination of stresses at depth of interest

The relevant key pressures for the depth interval of interest, the paleocene sands at MD of 3545 m – 3600 m, were taken on from a compilation of pressure data for the porcupine basin by STATOIL (hydrostatic pressure and fracture pressure, see Figure 3), from raw RFT measurements as documented in the final geological well report (pore pressure), or calculated using the wire line data (lithostatic pressure).

PSG project Well 35-18-1

Depth: 3570 m; 11712 ft conversion factor psi to bar: 0.069

Well	Pressure	Value	Source
35-18-1	Hydrostatic pressure	5170 psi	Statoil plot
35-18-1	Formation pressure	6448 psi	from RFT 3557 m - 3591 m
35-18-1	Fracture pressure	8870 psi	Statoil plot
35-18-1	Vertical stress	12135 psi	SPG, Velocity model & integrated density

Well	Pressure	Value [psi]	Value [kbar]
35-18-1	Effective pressure, FRAC	3265 psi	0.225 kbar
35-18-1	Effective pressure, RFT	5687 psi	0.392 kbar
35-18-1	Effective pressure, MAX	6965 psi	0.480 kbar

Table 1: compilation of relevant stresses for well 35-18-1 at depth interval of interest.

Effective pressures were calculated as differences between the vertical stress and the relevant pressure (fracture, formation, hydrostatic)

5. Lithology dependent Vp/Vs relationship

In order to provide a background model for a seismic inversion, to provide a petrophysical framework for a seismic lithology classification, in the form of crossplots of elastic parameters, and in order to facilitate an estimation of the pressure effect on seismic velocities, the shear slowness DTS was estimated based on Mason's formulation (Mason 1987).

$$DTS = DTC \cdot ((Vsh + Vmatrix) \cdot Rsh + (Vmatrix / (Vsh + Vmatrix)) \cdot Rmatrix$$

with:

DTS:	shear slowness
DTC:	compressional slowness
Vsh:	Volume of shale
Vmatrix:	Volume of matrix (Vmatrix = 1-Vsh)
Rsh:	Vp/Vs ratio of shale; 2.1
Rmatrix:	Vp/Vs ratio of matrix; 1.655 for sand matrix and 1.915 for limestone matrix

6. Petrophysical modelling

Modelling of the pressure effect on seismic velocities was performed based on the formulations of Eberhardt-Phillips et.al. [1]. The Authors developed a relationship base on measurements on 64 water saturated sandstone core samples of different origin:

$$Vp = Ap - Bp\phi - Cp\sqrt{Vsh} + Dp(Pe - e^{-16.7 \cdot Pe})$$

$$Vs = As - Bs\phi - Cs\sqrt{Vsh} + Ds(Pe - e^{-16.7 \cdot Pe})$$

with:

Vp:	p velocity
Vs:	s velocity
Φ:	porosity
Vsh:	Volume of shale
Pe:	effective pressure (defined here as difference between vertical stress and pore pressure)

The coefficient Ap, As, Bp, Bs, Cp, Cs, Dp and Ds were initially determined by the authors in their general formulation to be:

Ap:	5.77
As:	3.70
Bp:	6.94
Bs:	4.94
Cp:	1.73
Cs:	1.57
Dp:	0.446
Ds:	0.361

In an iterative process the parameters in the shale term, Cp and Cs were modified in order to give the best fit for the particular data of well 35-18-1. The values that gave the best fit were: Cp: 2.30; Cs: 2.09.

This modified Eberhardt-Phillips model was used for a systematic modelling of the pressure effect on compressional and shear velocities for the key stress values as given in chapter 4. For results see Fig. 4.

7. Literature

[1] Eberhart-Phillips D., Han D-H., Zoback M.D. Empirical relationships among seismic velocity, effective pressure, porosity, and clay content in sandstones. Geophysics, Vol. 54 No. 1, 1989, p.82-89

[2] Gassmann F., 1951, Ueber die elastizitaet poroeser medien. Vierteljahresschrift der Naturforschenden Gesellschaft Zuerich, 96, 1-23

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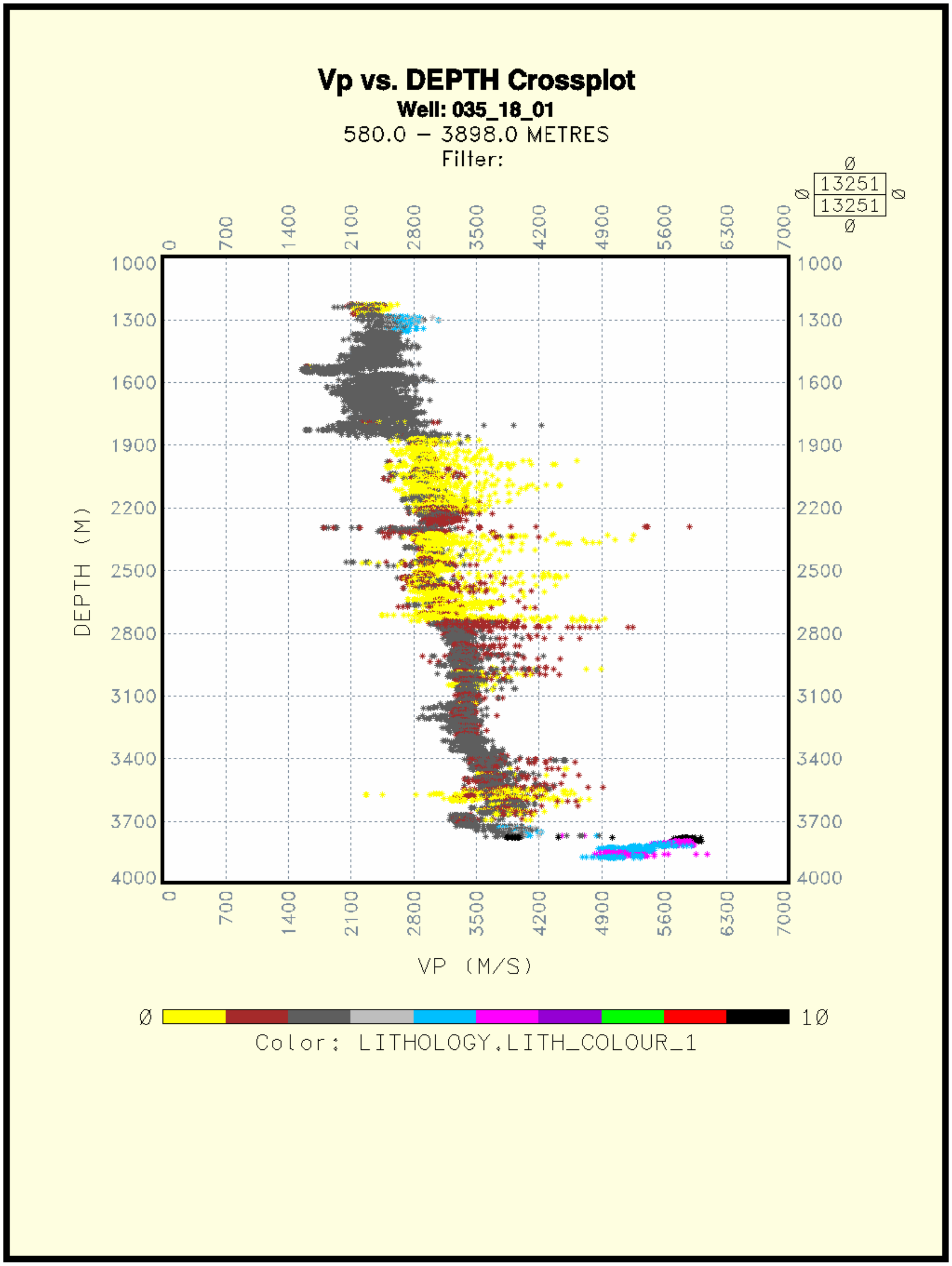

Fig. 1: Compressional Velocity as function of depth

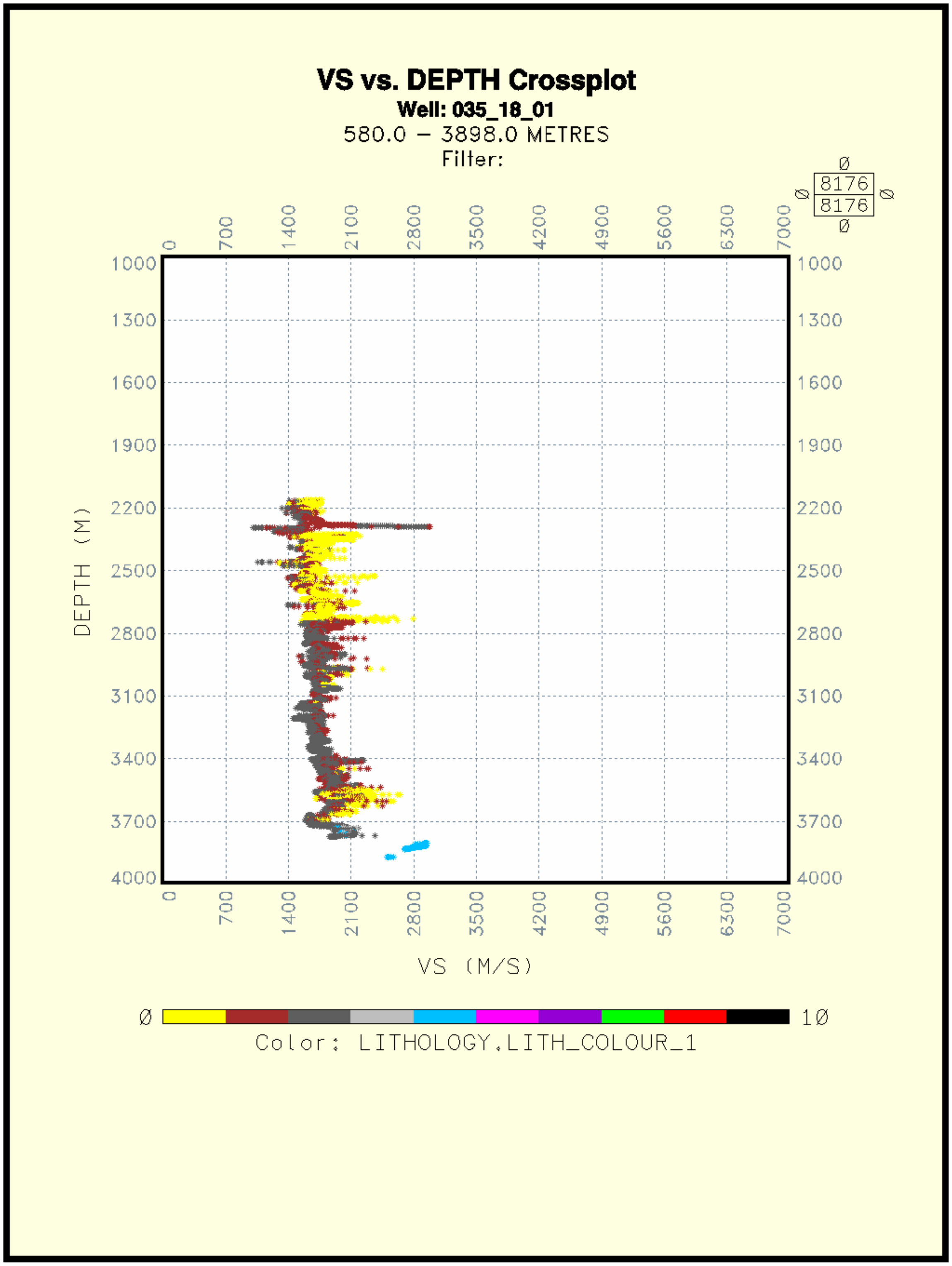

Fig. 2: Shear velocity – calculated using Masons formulation - as function of depth.

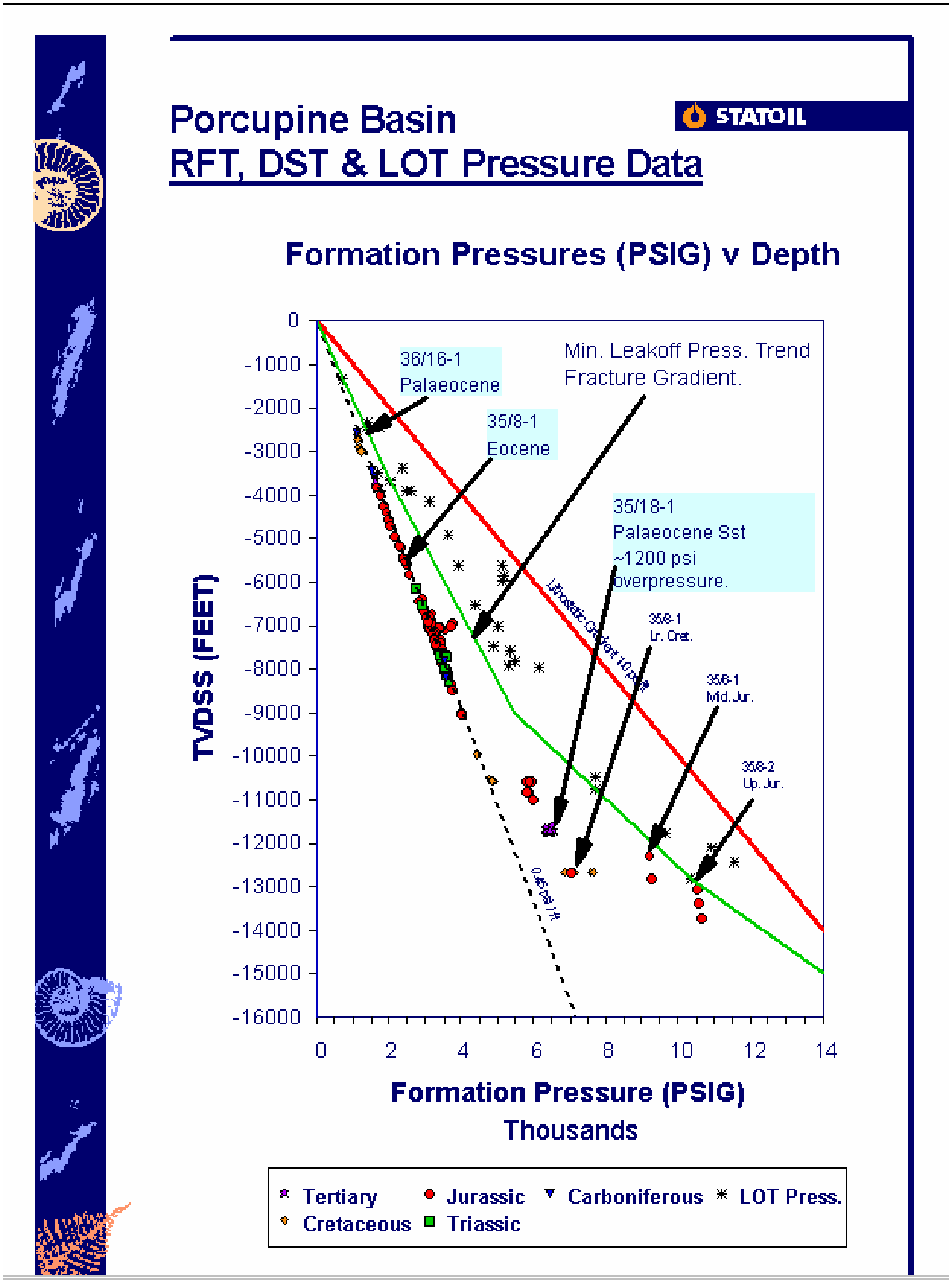

Fig. 3: Compilation of pressure data for the Porcupine basin by STATOIL.

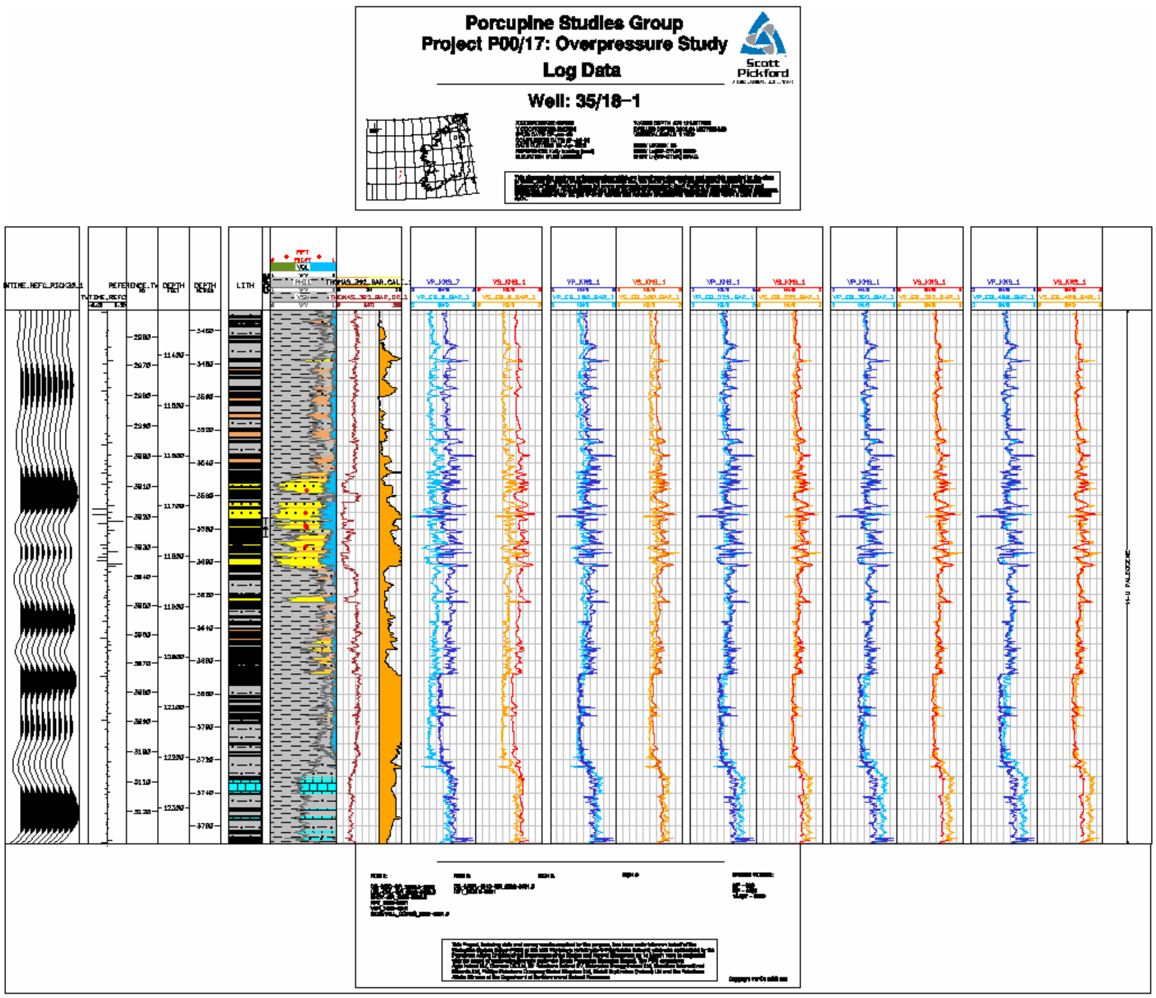

Fig. 4: Modelled P and S velocities for several key pressure values. Note that the Eberhadt-Phillips relationship which the modelling is based on, is strictly speaking only valid for sands or shaly sands, not for pure shales. (The cgm file for this figure 35-18-1-pressure-modeling.cgm is part of this report.)

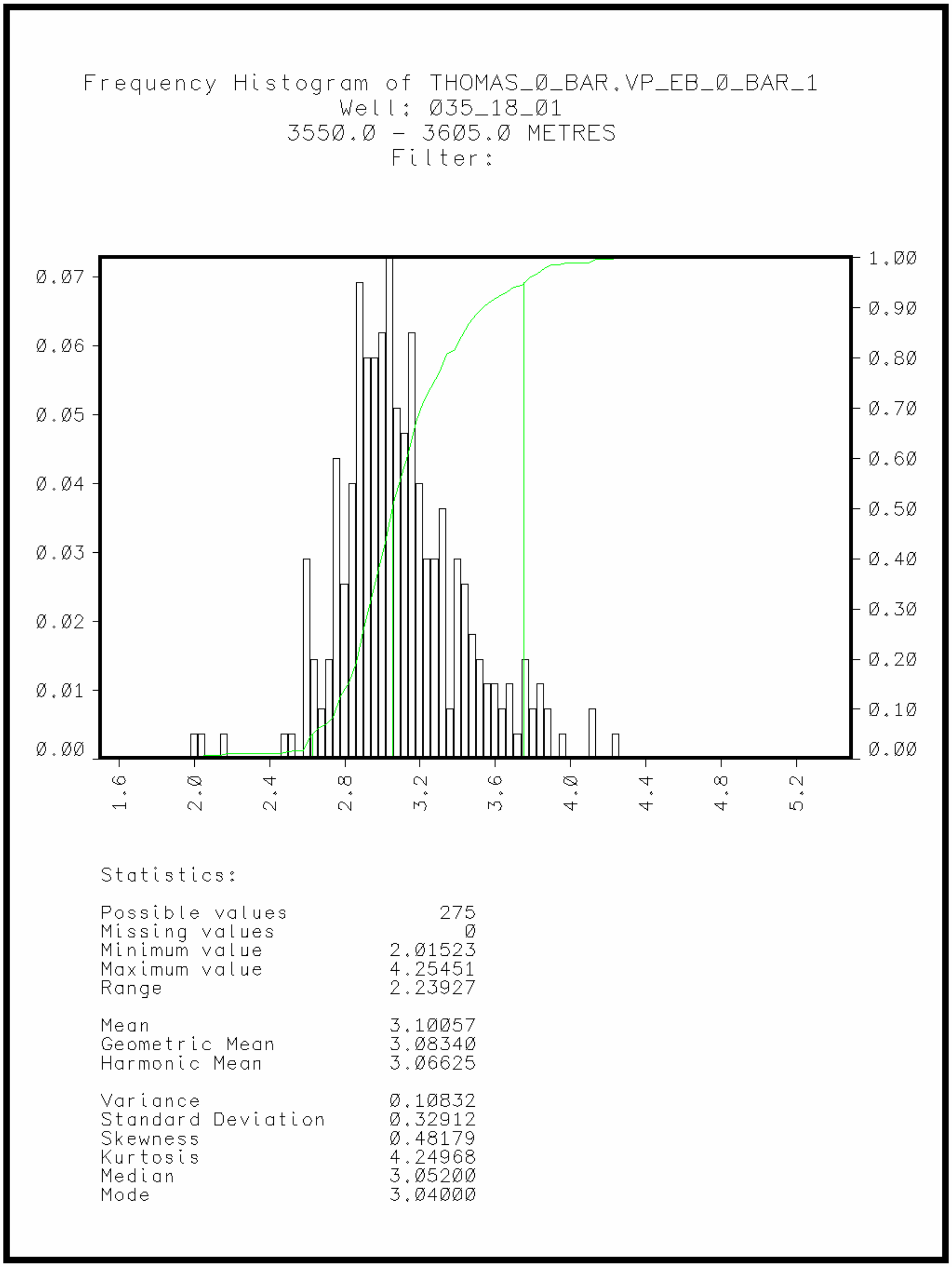

Fig. 5: Histogram of modelled velocity for paleocene sand at effective stress σ_{eff} of 0 bar.

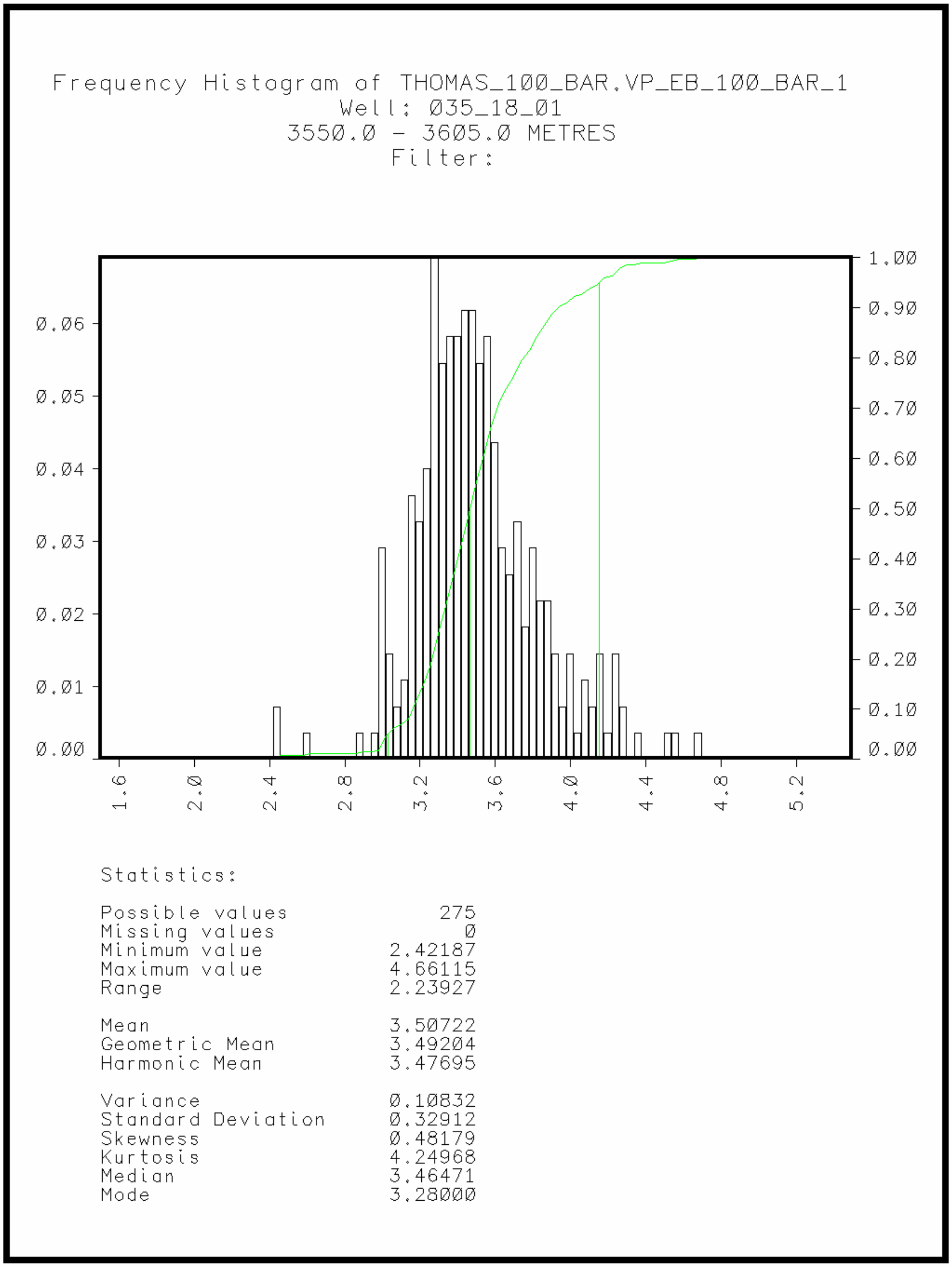

Fig. 6: Histogram of modelled velocity for paleocene sand at effective stress σ_{eff} of 100 bar.

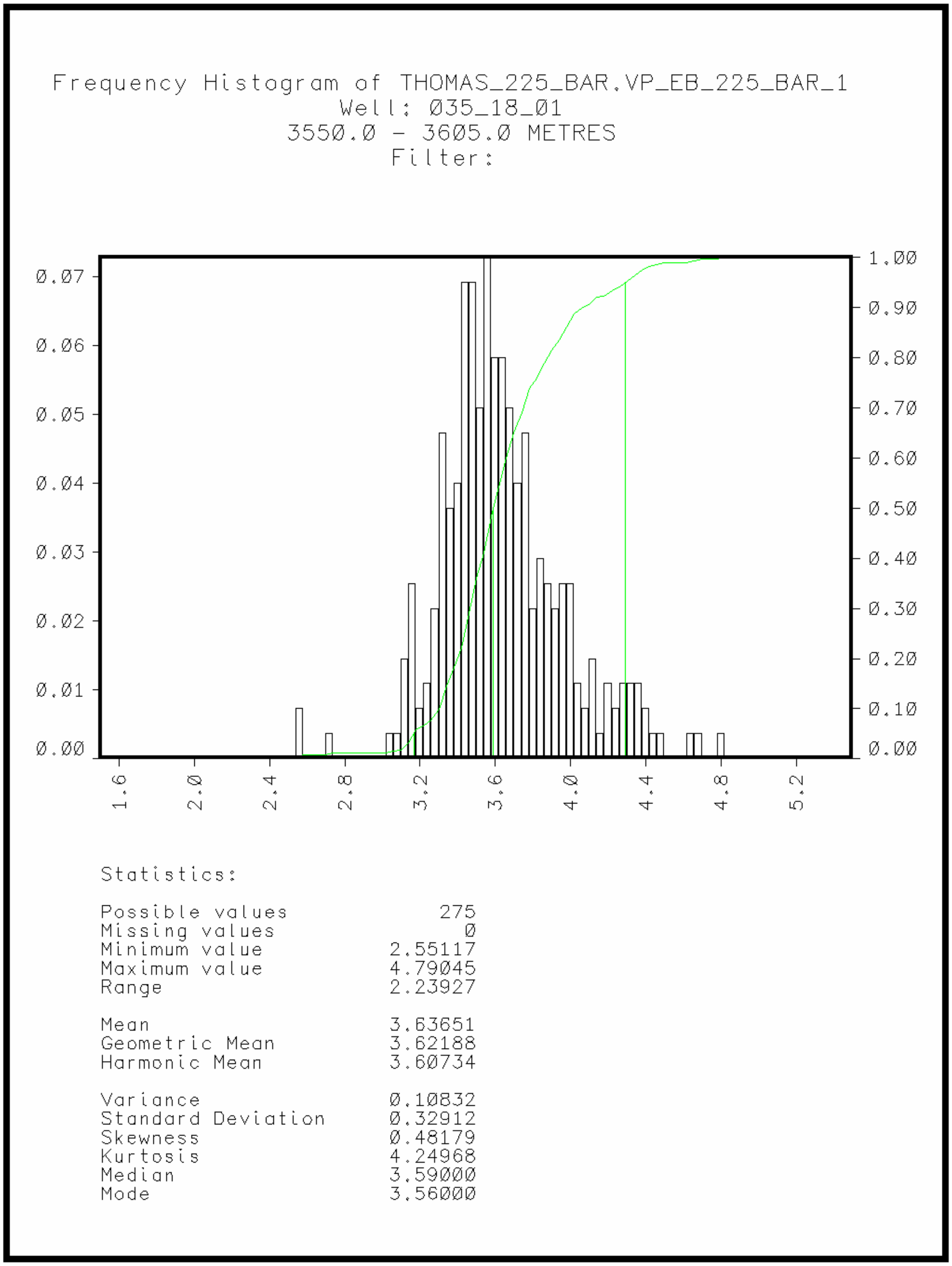

Fig. 7: Histogram of modelled velocity for paleocene sand at effective stress σ_{eff} of 225 bar.

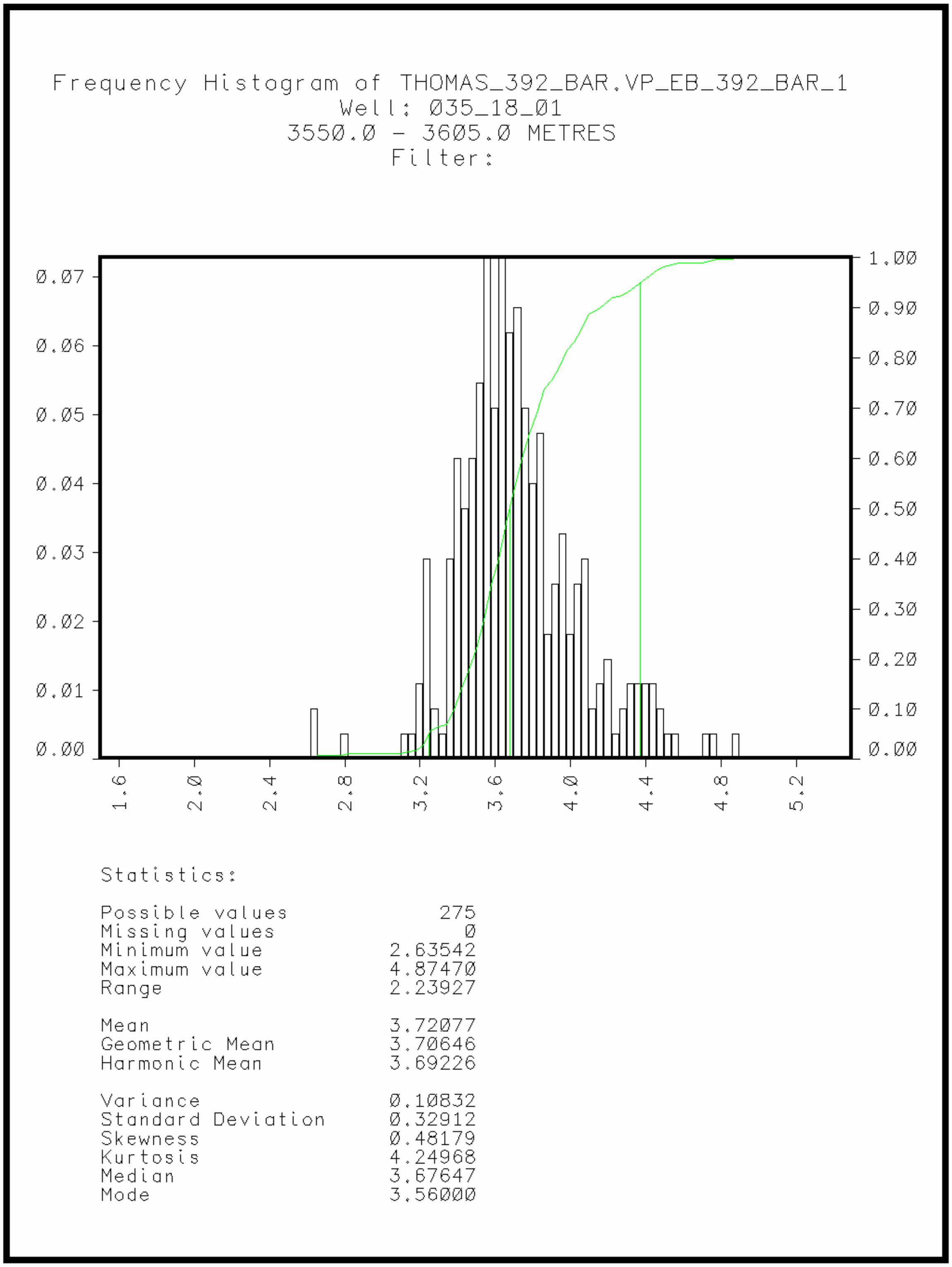

Fig. 8: Histogram of modelled velocity for paleocene sand at effective stress σ_{eff} of 392 bar.

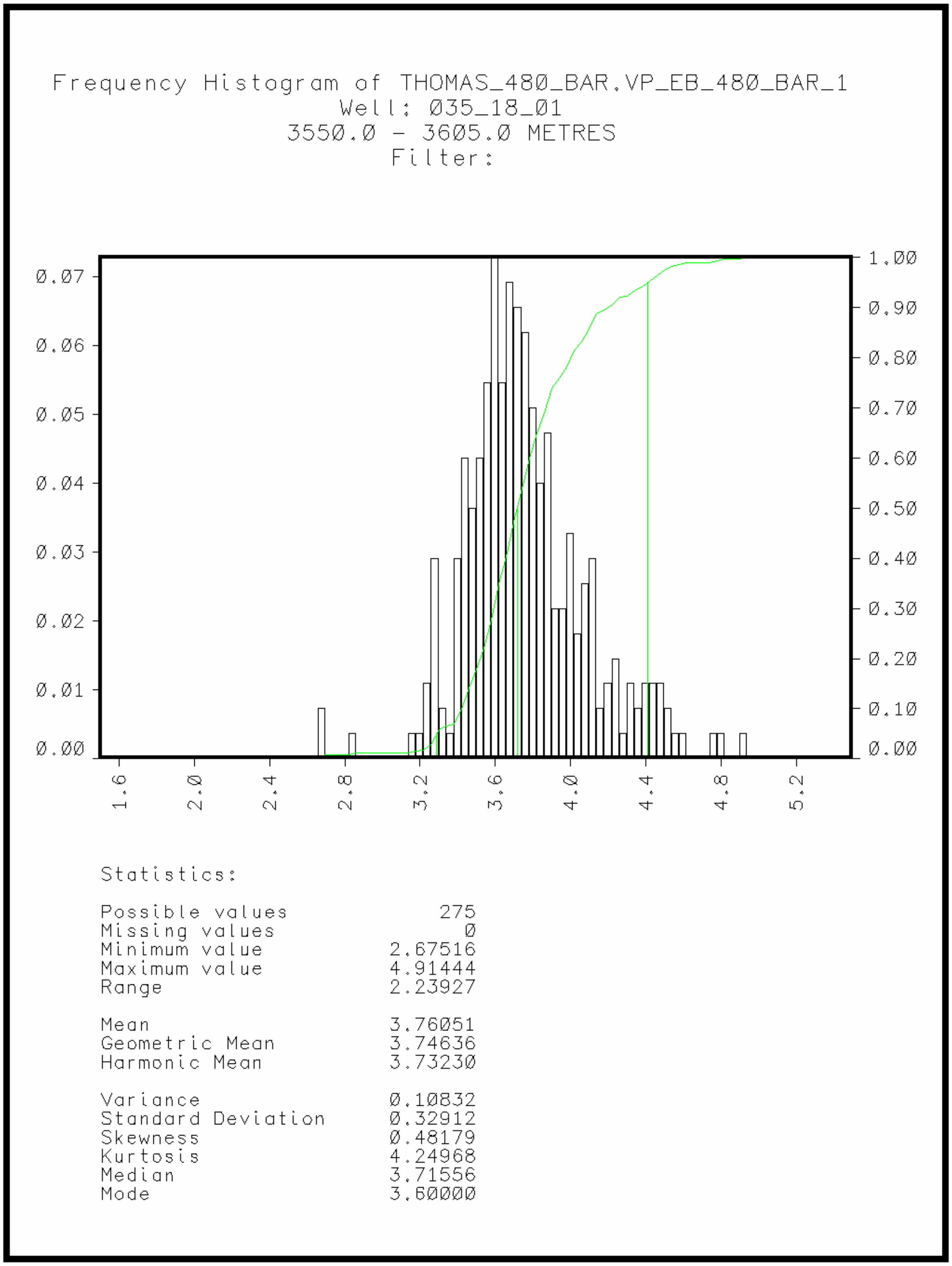

Fig. 9: Histogram of modelled velocity for paleocene sand at effective stress σ_{eff} of 480 bar.

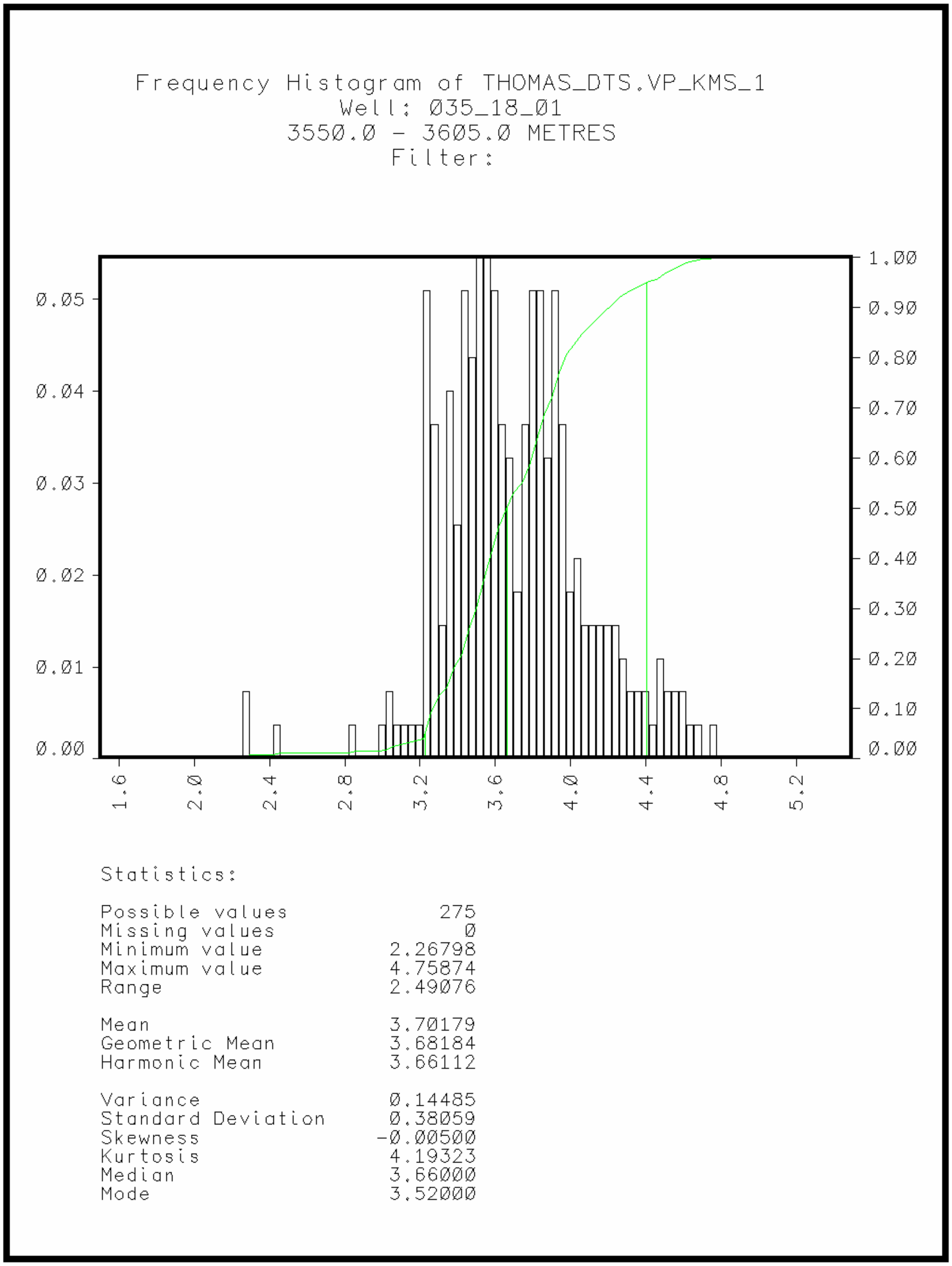

Fig. 10: Measured velocity of paleocene sand.