

OVERPRESSURE, THERMAL MATURITY, TEMPERATURE AND LOG RESPONSE IN **BASINS OF THE GRAND BANKS OF NEWFOUNDLAND**

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HIGHLIGHTS

Overpressures:

· appear transient

INTRODUCTION

Overpressures are present on the Grand Banks in some wells and not in others. The regional distribution is unknown. This Grand Banks Atlas sheet shows where they are present, the magnitude, top overpressure, relation to burial depth, maturity major faults and formations. It investigates the relationship between these factors. Tmax and Vitrinite versus depth profiles rarely show a clear linear, increasing trend on the Grand Banks. This problem

instigated the investigation of a

possible connection with

Overpressures have been described in several publications

generally as part of a study of a local area. McAlpine (1990)

briefly mentioned overpressure in the Jeanne d'Arc Basin

and stated that the Fortune Bay is always undercompacted

according to a sonic-depth plot, although not always

overpressured. Hydrocarbons are found in the overlying

hydrostatically pressured regime. Rodgers and Yassir (1993)

used RFT data only and derived a hydrological flow regime

that sparked some discussion (Issler, 1994). They did use

some questionable or less than ideal data points to make

their point (e.g. hydrostatic pressure (HP) or mud weight

values to prove 20 kPa/m, and low-permeability intervals in

Trave E-87 in the Rankin Formation). They also stated the

overpressure is present "virtually throughout the basin, and is

concentrated mainly in Jurassic sediments". Williamson et al.

(1993) used DST and mud weight data in the same basin and

modelled ages for formation of overpressures and

hydrocarbon migration. All authors suggested several

mechanisms that may cause the overpressure, but none

stated that it is undercompaction alone. Only the sonic logs

were used, and to a small extent; density and resistivity log

were neglected. Wade (1991) described the overpressure

system on the Scotian Shelf. He concluded that overpressu

is present in every well deep enough southeast of th

basement hinge line and a faulting system parallel to the

Abenaki Bank edge. This hinge line is a structural feature

parallel to the Nova Scotia coast line about 50 km northwest

of Sable Island, across which basement depth increases

rapidly. The Abenaki Bank is a Jurassic carbonate bank

under which there are no known overpressures, but they are

present southeast of its edge. The position of the Bank i

likely related to the hinge line location. The overpressure i

its only cause. Overpressures are found in several

formations, from Logan Canyon to Mic Mac, and from depths

of 2700 to almost 5200 m, whereby the bottom seal has never

been reached. The pressures increase generally in steps

through a transition zone until the pressure is hard. Individual

fault slices appear to be sealed compartments. Although

Wade (1991) stated that the shales are normally compacted.

he showed a decrease in shale velocities somewhere below

the top overpressure. The temperature isotherm of 130 C

appears to be a better correlation to top overpressure than the

onset of velocity decrease. Wade (1991) expected the

overpressure regime to continue to the northeast into the

Previous Work

overpressure.

The data are presented in six figures on the sheet and a depth plot for each well in the Appendix. The two first figures are maps, the others are the pressure and other well data plots. The two maps are self-explanatory.

computer program running in Matlab. They consist of six components. Part one is formation temperatures are indicated. Their scantiness does not allow many conclusions. The formation tops are shown, but absence of good samples does not allow an exact placement of the Banquereau.

column, and the Gamma ray has been bulk-shifted as required. The gamma shale range was chosen with the help of the rock-shale% column. The resulting sonic and resistivity curves of part 2 were plotted semi-logarithmically, after filtering out high-frequency spikes from the sonic curve. Similarly, in part 3, the sonic was only plotted where the shale percentage is above 75 (part 4).

Parts 2 and 3 show the log curves. The casing points are in the Gamma ray

different authors as indicated. For Tmax this is not practical, and all data were plotted after filtering out poor data as outlined under methods. The zig-zag pattern on the trend lines in both maturity curves started the investigation in the verpressures. In some wells they correspond to the deviations on the sonic curve, in others not. This gives the strong impression of overpressures being transient, with longer lag times in the maturity and log curves than for the actual

including those wells that do not appear to have overpressure. The Appendix also contains a table to show which pressure type the wells do have.

the depth-pressure plot. It shows the trend lines for fresh and salt water, and the lithostatic pressure. Seldom are pressures encountered above 85% of lithostatic, the rock appears to fracture before the lithostatic pressure is reached. Hence this trend-line is also shown, in orange. In addition to the pressure data, the corrected

Appendix I contains the plots for all the wells that have data in BASIN database

are not present in all wells, even in adjacent wells in the same field

are not related to formation temperature, are not in the same

have different character from those on Scotian Shelf

formation in adjacent wells (Figures 5 and 6)

• may be hard in and north of the Jeanne d'Arc Basin

may be soft, or barely medium, in the Whale Basin

may suppress vitrinite maturity (Figures 3 and 4)

· have not always corresponding indications on sonic logs

• may suppress Rock Eval Tmax maturity (Figures 3 and 4)

• are present outside Jeanne d'Arc Basin

are not related to certain formations

are not related to burial depth

top is soft or medium, not hard

likely leaked away along some faults

do not leak along every fault

• The map is based on DST/RFT or mud data

NEWFOUNDLAND

Overpressures are present outside the Jeanne d'Arc Basin Whale Basin has at most soft overpressures

• Hard overpressures are present in the north, soft ones mainly in the south. Overburden thickness is highly variable: from 1200 to 5100 m.

· Maximum overpressures are mainly in the Oil Window, but some are immature, and others overmature

Hard and no overpressures may be found in adjacent wells

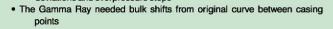
Laurentian Channel area. (Continue: go to "Methods", top right of panel)

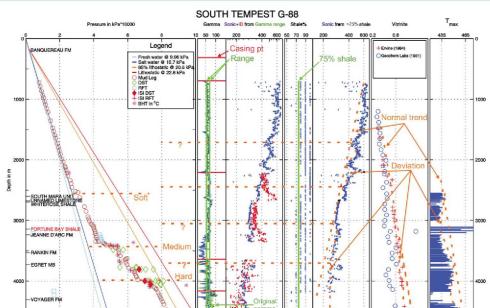
 Overpressure increases in steps from soft to hard • The steps in the pressure profile are not particular to specific formations Formation temperatures not too high or low for the overburden in the overpressure zone, i.e. the temperatures do not appear to be

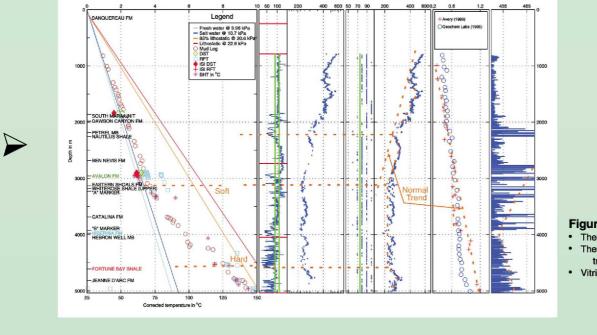
related to the pressures. The resistivity (ID) curve mimics the sonic curve to some extent The normal compaction trend of the sonic curve shows many deviations, not all corresponding to steps in the pressure profile

• The sonic deviations are not a good indicator for overpressure: a tentative match is with the soft overpressure level • The vitrinite trend line shows deviations, or "suppression",

corresponding to sonic deviations and overpressure steps • The Rock Eval trend shows Tmax suppression corresponding to sonic deviations and overpressure steps







SOUTH MARA C-13

Gamma Scrilc from Gamma range Shale% Sonic from >75% shale Vitrinite

OVERPRESSURES & MATURITY

There is a gradual increase in pressure profile There is some correspondence with sonic trend deviation levels soft and hard /itrinite and Tmax suppression are apparent

* Too shallow for overpressure

from DST/RFT data

No overpressure

Soft overpressure

Medium overpressu

Hard overpressure

No overpressure

Soft overpressure

Medium overpressure

Hard overpressure

900 Sediment thickness above overpressure class

1000 No maturity data for top max overpressure

1000 Oil window at top max overpressure > Maturity

Faults Diapirs

900 Immature at top overpressure

4000 Gas window at top max overpressure

SOUTH MARA UNIT E PAYSON CANYON NAUTILUS SHALE 3000 BEN NEVIS FM ... "B" MARKER: = WHITEROSE SHALE (I - WHITEROSE SHALE Corrected temperature in °C

. The top of the overpressure may be found in any formation

free fluid, so any "pores" (i.e. fluid inclusions) should

Overpressures are not confined to a few formations

Many overpressures are in the salt. The salt has no.

be at virtually lithostatic pressure.

 There is no overpressure • The temperatures are similar to ones in overpressured wells in Figs 3,4,6

There appears to be no Tmax suppression

. The top of overpressure is soft or medium, and

•The overburden thickness to top overpressure is

again highly variable: 1200 to 4100 m

The top of the overpressure is mainly in the Oil

while one (Bittern M-62) is in the Gas window

with an anomalously thin overburden value.

Gamma Sonic+ID from Gamma range Shale% Sonic from >75% shale Vitrinite ma

Window, but locally is immature.

hard in Nautilus C-92 only.

WHITEROSE J-49

2 4 6 8 10 50 100 200 400 600 50 70 80 200 400 600 2 0.8 12 455 465

NEWFOUNDLAND

Figures 5 and 6 form a "cross-section" that shows overpressure in Whiterose E-09 and none in J-49 in the same formations.

2 4 6

Figure 6: Overpressure increases in steps to hard There is some correspondence with sonic deviation

WHITEROSE E-09

10 50 100 200 400 600 50 70 90 200 400 600

OVERPRESSURES,

Scale 1:1 000 000

Kilometres 25 0 25 50 75 100 Kilometres

FORMATION, & MATURITY 2827 Rank

Too shallow for overpressure

No overpressure

Soft overpressure

Medium overpressure

Soft overpressure

Medium overpressure

Banq Banquereau BenN Ben Nevis

QUESTIONS AND FUTURE WORK

This Atlas sheet presents the data available and some conclusions

Remaining questions:

1. What caused the overpressure's

the same time?

Future work:

2. When did the overpressure start?

4. Do faults leak periodically and if so, how often?

added, a fairly complete history of the fluids will result.

5. When was the hydrocarbon generation?

e.g. the more normally compacted shale.

No overpressure

900 Immature at top overpressure

4000 Gas window at top overpressure

Faults

3. Is hydrocarbon generation partly or completely responsible for the overpressure?

How compartmentalised are the reservoirs, i.e. does the overpressure charge them all at

7. Can the overpressure be predicted from 3D seismic by studying the velocity anomalies?

Most of the first six questions can be answered by a fluid inclusions and fission-track study.

Measuring the pressures and relative time of formation of fluid inclusions will provide the

answers. If the ages and temperatures resulting from apatite and zircon fission tacks are

The overpressures in the Grand Banks cannot be predicted from the sonic response,

formation name, depth or temperature. Careful analysis of seismic stacking velocities in

Gulf Coast settings has allowed a prediction of start overpressures. This technique will

have to be tested in the Grand Banks, because the geological system is quite different with

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Teige, G.M.O., Hermannud, C., Wenssen, L., Nordgård Bolås, H.M. 1992: The lack of relationship between overpressure and porceity in North Sea and Haltenbenken shales. Marine and Petro-sum Google (6, pp261-36).

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Lithostratigraphy 11: Overpressure 1; Overpressure 2. N: East Coast Basin Atlas Series, Scotian Shelf.

Allaria: Geoodenoo Centre, Geological Survey of Canada, p.71-73

1000 No maturity data for top overpressure

900 Sediment thickness above top overpressure

1000 Oil window at top overpressure > maturity

FORMATIONS:

Jd'A Jeanne o Arc
Miss Mississauga
Naut Nautilus
Rank Rankin
Smar S Mara
VerC Verill Canyor
volc volcanics
Voya Voyager
Whal Whale
WhRs Whiterose
Wind Windsor

Pressure data were collected from DST/RFT and mud weights derived be (a subjective) 0.2 MPA over the hydrostatic salt water trend. A specific from daily drilling reports. Well kicks and Formation Leak Off tests were mud weight cannot be used for this, because with increasing depth the not used; the latter only shows formation strength over a short interval. difference with the salt-water trend will become larger. Mud weights. I (in the appendix). Interesting to note is that Springdale M-29, without becoming increasingly overbalanced. the Banquereau. Neither depth nor formation name provides clues to Plot.

presence of overpressure in this small sample set. To avoid crowding in the pressure plots (see also Appendix A), the Log data are digital from BASIN database. Bulk shift was applied to the hydrostatic measurements were omitted, because they contribute little Gamma ray curve if the interval between casing points appeared wrong

beyond a tool-quality check. permeable were discarded.

The mud data were calculated from depth and mud weights as indicated shows a linear trend. in the daily drilling reports. Because the mud weights are prepared using Overpressured sections supposedly show a deviation from the trend (or overbalanced. This presents a problem when picking the top of filtered for low TOC and S2 and anomalous Tmax data.

Lithostatic pressures are represented by a straight trend, corrected extensive system of faulting is responsible. We suspect that faults in the

The best pore pressure data are from DST/RFTs, More prevalent are deep enough to reach it have overpressure. This is a major difference

that the system measured by the sonic and resistivity logs has not yet Mexico. shows that the overpressure, although requiring a minimum depth of show retardation in their maturation. Carr explains it plausibly by the 1200 m. is not related to specific depths. It may also, in the shallower retention of volatiles in the vitrinite so that aromatics are prevented from cases, reflect a bleeding off of pressure from greater depths into forming. This was backed up by experimental work showing vitrinite shallower compartments. There are several examples where, below a under vacuum matures much easier than under normal conditions, and soft-overpressure interval, the pressure returns to hydrostatic (i.e. much later under overpressure. Methane and other volatiles can Kittiwake P-11, North Dana I-43, Phalarope P-62, Terra Nova K-08, dissolve in water, in substantial quantities. Under higher pressures, more Whiterose E-09, J-49 and N-22; see Appendix I; in Bittern M-62, Hebron volatiles can be dissolved, but they are released again under normal I-13 and Spoonbill C-30 the return to lower pressure is related to a casing pressure. We propose that under an overpressured regime the volatiles point). None of these "compartments" has been confirmed or refuted by cannot escape from the formation, and dissolve in the water. The sonic RFT or DST. The probable bottom of the hard overpressure and resistivity logs react specifically to water in the formations. Water

Hibernia C-96, Hebron I-13 in App. I). Nevertheless, a few observations released, hence the effect of the overpressure remains visible on the can be made. First, the geothermal gradient is quite variable, probably logs and in maturity profiles. even within fields. Terra Nova has a much lower gradient of about 25 The maps (Figures 1 and 2) show that overpressure has been C/km than for example Hibernia with about 30 C/km. This latter value encountered outside the Jeanne d'Arc basin. Especially to the north and appears more common in the general area, but there appear to be also east of that basin, hard overpressures are present, although not in every higher values. Wade (1991) compared temperatures with onset of well. To the south, in Horshoe, Carson and Whale sub-basins, no hard overpressure and saw a very tentative relationship. This relationship with overpressures have been found, they appear to be soft with a few barely onset is not evident in Grand Banks. At first glance there may seem to be medium. The Laurentian Channel may well be the boundary between 115-120 C. But certainly not all temperatures of 120 or above and the Grand Banks-south regime with soft and localised overpressure. correspond with hard overpressure (e.g. Puffin B-90). This apparent Another boundary lies immediately south of the Jeanne d'Arc basin, in relationship has more to do with the hard pressures being below about which hard overpressures are present. 4000 m. It really falls apart in North Ben Nevis P-93 where the Although the faults clearly do have an effect on the presence of temperature reaches 115-120° C at 4000 m while the hard overpressure overpressure, the fault pattern shown on the maps does not show any

field (Hibernia, Whiterose) that reach sufficient depths, do have overpressure. Figures 5 and 6 show that Whiterose J-49, reaching a deeper total depth than E-09, does not have any overpressure, while both wells penetrate the same formations. The log curves, however, do have a similar response with dog legs. The likely explanation is that the

about one width of a mudweight circle away from the salt water line on the plots.

 Hard overpressure: 65-100% between hydro- and 85% lithostatic Good pressure data: ISI and FSI from DST/RFT Reasonable pressure data: Mud weights from daily reports • TOC: 0.4%; S2: 0.2 mg hydrocarbon/g rock; Tmax: 410 C Sonic curve based on rock-shale: 75%

while the former indicates mud underbalance. The well kicks are in Table however, tend to be kept constant over substantial intervals, thus any overpressure indication in mud weight or DST/RFT, suffered a kick in The temperatures are from logging runs and corrected with a Horne The pressure trends on the plots have been corrected for water depth

The best pressure data are Initial-Shut-In (ISI) and Final-Shut-In (FSI) log interval is indicated in green. Due to radioactive silts/sands, a shale DST/RFT (Drill stem test/Repeat Formation Tester) measurements: they range was selected. Only for the gamma data within this shale range represent pure pore pressure. Both ISI and FSI data were plotted, were sonic and resistivity (ID) data plotted. Similarly, only where rock because the ISI can be too low from formation damage and the FSI may shale is > 75%, i.e. above the cut-off line, is the second sonic curve have suffered pressure draw-down. The RFT intervals indicated as non-plotted. Ideally both sonic curves should be equal. The sonic and resistivity curves have a logarithmic scale. A normally compacted profil

expected pressures and drilling exponents, they are in general Figs 3-6). Maturity data are from BASIN database. Rock Eval data were

and if rock shale % was similar across these points. The original Gamma

for water depth. This is not correct, because the shallowest formations currently compressional state cannot leak, but the tangential set are not compacted, but no actual densities are available. The (Figures 1 and 2) in the extensional regime may well leak. Probably, this pressure plots show the hydrostatic trends for fresh water and salt leakage is episodic, where the pressure builds up to near 85% lithostatic. water. The latter is based on the maximum salinities found in the area the fault then starts leaking off the pressure, and seals again, similar to (Hibernia), RFT data plot in the normal pressure zone between both the primary migration of hydrocarbons from a source rock, On the trends, but the wells clearly do not all have the same salinity. Scotian Shelf, all wells southeast of the Abenaki Bank Edge that are

mudweight data, but they suffer the draw-back that they are artificial and between both areas, and the faulting system and possibly its timing is the based on expected pore pressures. Thus, a soft overpressure based on underlying cause. mud data is somewhat suspect. This discrepancy is obvious from the The doglegs in the log curves do not always correspond with the plots for Terra Nova H-99 and Hebron I-13, where the mud indicates soft pressure-increase steps. Usually there is one dogled starting already overpressure, and the DST/RFT indicate no overpressure. In many wells, slightly above 1000 m, and there is no corresponding overpressure cell. however, the soft overpressure is confirmed by DST/RFT data. Possibly this dogleg is caused by undercompaction without Most wells with hard overpressure have a substantial transition interval, corresponding overpressure, or the overpressure was not noticed in this shaly section because the interval was drilled as fast as possible. To establish the cause of overpressure, the actual pressure data were Occasionally there are severe hole problems. The suppression of

compared with the well log traces of the shales: gamma ray, porosity, maturity (vitrinite reflectance and Tmax) also creates doglegs on depth density, sonic and resistivity. Overpressure due to undercompaction profiles that should be linear, Many of these doglegs are at similar levels causes shifts in all but the gamma ray log (Fertl, 1976). This is as those observed in the well logs. supposedly due to the proportionally greater amount of water in the On the Canadian Eastcoast, overpressure effects are not the same as formation. Hence in a similar lithology, the porosity, density and in the Gulf of Mexico, where overpressure is due to undercompaction. resistivity should be lower and the sonic log should show higher delta-t On the Scotian Shelf, the overpressure does not have the same values. In the normally compacted shales, the logs show a profile trend signature as in the Gulf: only the resistivity and sonic logs show doglegs. with depth. Into the overpressure zone, this general trend may remain, The excess porosity appears absent, causing authors to suggest models but shows a shift to the right on the plots at the top of the overpressured where the sediments compacted normally, and then later hydrocarbon zone, below the transition interval that appears as a dogleg (Figure 3). generation created the overpressure. This is similar to what Teige et al On careful inspection, the new trend generally becomes slightly less (1999) describe for their North Sea and Haltenbanken data. On the steep. On the Grand Banks, most of the wells show this shift in trend, in Grand Banks, this absence of excess porosity also appears and is similar fact, each well may show several doglegs. But many of the doglegs do to that on the Scotian shelf, although a slightly more pronounced log not correspond to the onset of overpressure or a step in the pressure response is visible, hinting at a small undercompaction component. B profile. This gives the impression that the overpressure is transient, and comparison, the log response is not nearly as strong as in the Gulf of returned to equilibrium. An explanation for this behaviour is discussed In all these areas, retardation in vitrinite maturity has been observed. below. Also, the density log does not correspond with the zones of Two publications may explain this phenomenon. Teige et al. (1999) show overpressure. It is in many wells similar to the sonic, but not in all of them. that in the North Sea and Haltenbanken only the sonic and resistivity Undercompaction overpressure usually starts at a specific formation, logs show effects of overpressure, while the other porosity logs do not generally a shale or evaporitic sequence. On the Grand Banks, this does similar to Grand Banks. They conclude that overpressure is not related to not happen. If a small area such as Hibernia is studied, it may appear increased porosity, but possibly to fractures in the rocks created by the that a formation like the Fortune Bay Shale is the start of the overpressure. Hydraulic fracturing due to hard overpressure is quite overpressure. Over the general area, however, overpressure starts in likely. Our study shows, however, that soft overpressure also appear formations from Banquereau to Fortune Bay shale. This is similar to the visible on those logs (e.g. Figure 4). Fracturing of the rocks by soft (smaller) range of formations (Wade, 1991) on the Scotian Shelf. Hence, overpressure does not seem plausible at those lower, almost hydrostatic the overpressure is not related to specific formations. Depth variation in pressures at the start of the transition interval, that never has suffered the onset of overpressure is substantial. It varies from about 1200 to 4700 hard overpressure. Another paper, by Carr (1999), may shed light on the m. On the Scotian Shelf it ranges from 2700 to 5200 m. This large range actual mechanism. Vitrinite samples from overpressured zones may

overpressure, even if it is soft. When the pressure is released, the The temperatures from logging runs are a scant and poor data set (e.g. process of release and healing of seal is too fast for the volatiles to be nd a temperature of about the Scotian Shelf regime where all deeper wells show hard overpressure

obvious relationship. This is in part because the faults are mapped in Comparing between wells, not all wells, not even all wells in the same one plane, and the tops of overpressures are in different planes.

The following (generally subjective) boundaries have been used: Soft overpressure: 10-35% between hydro- and 85% lithostatic For "soft" designation, the data point has to be at least 0.2 MPa (or of fluids prevents pore pressure measurements.

Medium overpressure: 35-65% between hydro- and 85% lithostatic

Mud data are man-made, may reflect grossly overbalanced mud. Overpressures in shales may not be noticed. In salt sections the absence



compartments has nowhere been penetrated on Grand Banks, neither with dissolved volatiles would explain the behaviour observed under

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