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FRANCISCA-1

Francisca-1, Core sedimentology Report to DANOP

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Core Sedimentology Francisca-1

Report to DANOP

Jan Andsbjerg

Confidential report

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11

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
MINISTRY OF ENVIRONMENT AND ENERGY

GEUS

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1. Summary

The present report has been prepared for Dansk Operatørselskab I – S (danop). The cores were logged 19th to 25th of October 1998.

The cored intervals of Francisca-1 consist of mainly sandy turbidite deposits and muddy open slope sediments. Three major successions, each representing a transition from sand dominated turbidites to overlying open slope deposits are recognised in the cores.

The lowermost succession in core-5 from the top of Fan A shows a rather abrupt transition from thick-bedded turbidites with the fine-grained top-intervals missing, deposited in submarine channels, to open slope mudstones.

The thickest succession cored as cores-2, -3 and -4 in the middle to upper part of Fan 3/2 (1618 - 1579 mRT) consists of thick- and thin-bedded turbidite sands, rarely with preserved fine-grained top intervals, deposited in submarine channels and in proximal levee environments. Higher in the succession are normally graded turbidites with more or less complete Bouma T_a - T_e sequences. These turbidite sands were probably deposited in a slightly more distal environment, probably less confined by channel margins than in the lower part of the succession. The transition from the turbidite sands to the open slope deposits consists of normally graded, fine-grained turbidites of mainly heterolithic siltstone representing a distal levee or fan fringe environment.

The uppermost succession (above 1579 mRT) uppermost in Fan 3/2 consists of relatively thick-bedded, normally graded turbidite sands, commonly with the fine-grained top interval intact, deposited in both channel and non-channel environments. The transition to the open slope deposits above is dominated by silty, heterolithic, fine-grained turbidites. Uppermost in core-1 is a two metres thick massive sandstone, that probably was deposited in a channel that cuts into the open slope mudstones.

A high mud content in the matrix of many turbidite sands and the presence of abundant mud laminae in most turbidite sands is probably due to the textural composition of source material possibly in combination with fluctuating energy levels in turbidite flows and poor sorting due to short travel distance.

The gradual or abrupt abandonment of turbidite deposition and transition to open slope deposition may have been caused either by a regional decrease in the sediment supply due to sea level changes or climate variations, or autocyclic shifts in the position of feeder channels or fan lobes.

2. Core-1: 1561.0 – 1580.7 mRT

2.1 Description

In core-1 core depths equals well log depths (Schlumberger AIT- GR-DT Run#1, Suite#2) minus 1.3 m. Core 1 comprises an upper part (to 1563.5 mRT) dominated by massive sand, a middle part (1563.5 – 1572 mRT) dominated by siltstone, and a lower part (1572 – 1579 mRT) characterised by heterolithic sand.

The upper sandstone unit consists of a two metres thick well sorted, slightly consolidated, massive bed of very fine sand. The sand bed has an erosive base and a sharp upper boundary. Two systems of fractures or micro faults cut each other at an angle of approximately 70°. One system of fractures is seen to be offset 0.5 – 1 cm, where it is cut by the other system. Besides a weakly developed upward increase in grain-size the sand bed is ungraded.

The siltstone dominated middle part of core-1 consists of brown and olive black to brownish grey siltstone. The lower part of the siltstone which shows a general upward fining trend to 1569 mRT is dominated by 40 to 70 cm thick normally graded, heterolithic siltstone units with abundant sand laminae and with thin sand beds at the sharp lower boundaries. The sand laminae may show ripple or climbing ripple cross lamination. Lenticular bedding occur commonly in the heterolithic siltstone intervals. Bioturbation is weak to abundant and the trace fossil assemblage includes Chondrites, Helminthopsis and horizontal traces of back-fill meniscs (echinoid trace?). The upper part of the siltstone (1568.5 – 1563.5 mRT) shows a weak coarsening upward trend. Approximately two metres (1565.2 – 1567.4 mRT) of the upper siltstone interval is heterolithic with abundant thin sand laminae. The heterolithic interval is bioturbated with Chondrites and Planolites burrows.

The heterolithic sand dominated lower part of core – 1 is characterised by 10 to 40 cm thick heterolithic sand beds with sharp or erosive bases, and a normally graded upper part that shows a gradual transition to a thin mudstone. The sand commonly is well sorted and semi- to poorly consolidated, finely laminated or showing ripple or climbing ripple cross lamination. Occasionally massive or faint parallel bedding occur above the base of sand beds. These characteristics are typical for Bouma-type turbidites. Bouma T_{bcde} units (plane laminated sand overlain by ripple cross-laminated sand and heterolithic silt and mud drape) are common and occasionally also T_{abde} units (massive sand, plane laminated sand, heterolithic silt and mud drape) is present. Slump structures, sand injections and water escape structures are common. Burrows, mainly horizontal back-fill meniscs, Chondrites, Planolites and possibly Thalassinoides, are common in the more fine- grained laminae.

2.2 Interpretation

The normally graded heterolithic sand beds in the lower part of core-1 represent deposition from waning turbidity currents. During deposition the turbidites were probably unconfined by channel walls possibly on a proximal levee. Rare sandy debris flows are represented by massive, non-graded sand beds (e.g. 1572.5 mRT).

The transition from the lower turbidite sand interval to the upward fining lowermost part of the siltstone interval represents cessation of turbidity currents and a dominance of open slope deposition. The normally graded siltstone units in the transition interval were deposited as fine-grained turbidites in a distal levee environment. The weak upward coarsening pattern in the upper part of the siltstone interval may suggest a position on the distal fringe of a prograding submarine fan.

The erosively based, massive sand uppermost in core-1 may represent deposition in a submarine channel.

3. Core-2: 1579 – 1580.65 mRT & Core-3: 1581.5 – 1599.5 mRT

3.1 Description

In core-2 core depth equals well log depth depths (Schlumberger AIT- GR-DT Run#1, Suite#2) minus 1.3 m. Core/log shift in core-3 is 0.3 m. Cores-2 and -3 consist of an upper part comprising all of core-2 and core-3 to 1584 mRT dominated by silt- and claystone, a middle part from 1584 to 1588.25 mRT of mainly normally graded sand beds separated by mudstones, and a lower part from 1588.25 mRT characterised by more amalgamated sand beds with thin mudstone laminae.

The 5 metres thick upper mudstone interval consists of an upward fining and an upward coarsening brown and olive black siltstone separated by a one metre thick claystone. The siltstone intervals are heterolithic with thin sand laminae causing a faint lamination. The siltstone is bioturbated with Chondrites, Helminthopsis, Terebellina and possibly Scalarituba. A 0.5 cm thick hollow, cylindrical bone fragment is found in the claystone at 1581.8 mRT.

The succession 1588.25 - 1584 mRT is characterised by up to 80 cm thick normally graded, heterolithic sand beds separated by mudstone interbeds up to 30 cm thick. There is typically a gradual transition between the upward fining sand beds and the superimposed mudstones. Most sand beds show sharp or erosive bases. The sand beds exhibit planar lamination sometimes with shallow scours, climbing ripple lamination, current ripple lamination and particularly in the more fine-grained sediments a variety of deformation structures such as sand injection and slumps. Sand beds can be described as Bouma units T_{cde} and T_{bde}. Chondrites and Planolites have been recognised in the bioturbated fine-grained parts of the deposits.

Below 1588.25 mRT the lowermost succession in core-3 is dominated by 20 to 50 cm thick beds of mainly non-graded very fine sand. A few beds are normally graded. Sands are poorly to well sorted, poorly consolidated and frequently with a muddy matrix. Sand beds have sharp or erosive bases that frequently cut into underlying sand beds. The sand is interbedded by 0.5 – 2 cm thick mud laminae, that create a heterolithic appearance. Gradual transitions between sand beds and the mudstone laminae do not occur; the sand beds commonly have sharp upper boundaries which are overlain by the thickest mud laminae. Sand beds are dominated by climbing ripple cross-lamination; but also plane lamination and current ripple cross-lamination is common. Small erosive scours occur in a few beds. In a weakly inversely graded sand at 1598.8 mRT are bi-directional current ripples. A few beds show evidence of sand injection and slumping.

3.2 Interpretation

The lower part of core-3 was deposited by turbidity currents. In the mainly non-graded sand beds the presence of erosive scours and of bi-directional current ripples may indicate influence of bottom currents. The sharp upper boundaries and the missing normally graded

(T_{de}) upper heterolithic interval in most sand beds may suggest deposition in submarine channels, where the finer grained sediments were carried over the channel margins and swept further down slope. The shift between intervals dominated by thick-bedded turbidite sands (thicker than 30 cm) and thin-bedded, mainly non-graded turbidite sands probably reflects proximality – distality changes, or shifts between in-channel deposition (thick-bedded turbidites) and overbank/levee deposition (thin-bedded turbidites).

The normally graded turbidites in the upper part of the sandy succession were probably deposited in an environment unconfined by channel walls, possibly on a proximal levee. The normally graded siltstone units above the sandy succession represent fine-grained turbidites on the distal levee.

The gradual transition to mudstones in the upper part of core-3 suggests a gradual abandonment of a submarine fan or lobe followed by dominantly open slope deposition. The upward coarsening pattern in the upper part of the mudstone interval may suggest the approach of an active fan or channel.

4. Core-4: 1599.5 – 1618.2 mRT

4.1 Description

In core-4 core depth equals well log depth (Schlumberger AIT-GR-DT Run#1, Suite 42) minus 0.3 m. The deposits of core-4 are dominated by very fine and rarely fine sand with a heterolithic appearance caused by abundant mud laminae. Sand is generally well sorted. The sand occur as 10 to 120 cm thick beds separated by 1 to 5 cm thick mud laminae. Sand occur both as normally graded and non-graded beds with non-graded beds the more common. The mud laminae lie directly on the sharp upper boundaries of the sand beds; a gradual change from sand to overlying heterolithic silt and mudstone has not been observed in this succession. The sand beds are organised in one to three metres thick units that are dominated by either normally graded or non-graded beds. Siderite? nodules occur within some intervals.

The uppermost 5.6 metres of core-4 consist of 30 to 80 cm thick normally graded sand beds, with an interval of non-graded sand at the top continuing into the basal part of core-3. The sand beds have erosive or sharp lower boundaries, in one case overlain by intraformational mud-clasts. Upper boundaries are sharp or cut by the erosive lower boundary of the overlying sand bed. Some sand intervals have a massive appearance, but otherwise the sand is dominated by plane slightly undulating, lamination and climbing ripple crosslamination with subordinate current ripple lamination. Ripples may exhibit offshoots that drape neighbouring ripples. The sand beds can be described as Bouma T_{ab}, T_{ac} and T_{bc} units.

The interval between 1605.1 and 1607.8 mRT is dominated by non-graded, heterolithic sand beds. The sand is characterised by plane lamination or, sometimes faint, current ripples and climbing ripple cross-lamination. Most sand beds are less than 15 cm thick. The mud laminae are dominantly clay.

From 1607.8 to 1610.55 mRT most sand beds show a more or less well developed normal grading. All sand beds have sharp upper boundaries and the thicker normally graded sand beds have erosive lower boundaries. Many sand beds show plane lamination overlain by a climbing ripple cross-laminated upper part. Also current ripples may occur in the upper part of sand beds. Throughout most of this succession there seems to be an overall upward fining grain-size trend.

The lowermost part of core-4 between 1610.55 and 1618 mRT is dominated by non-graded sand beds, but also a few less than one metre thick intervals of normally graded sand beds and two inversely graded beds occur. The non-graded sand beds typically vary between 5 and 20 cm in thickness. A single bed attain 70 cm in thickness. The sand is characterised by climbing ripple cross-lamination, which occur in all the normally graded intervals and in some non-graded beds, and by an often faint slightly irregular or undulating plane lamination. Also current ripple cross-lamination occur. An inversely graded sand bed show slump structures.

4.2 Interpretation

The sands of core-4 were deposited by turbidity currents in submarine channels (thick-bedded sands with sharp upper boundaries) and on submarine levees (thin-bedded sands mainly). A few sand beds may represent debris flow deposits.

5. Core-5: 1707 – 1724.4 mRT

5.1 Description

In core-5 core depth equals well log depth depths (Schlumberger AIT- GR-DT Run#1, Suite#2) minus 2.3 m. Core-5 consists of an upper mud-dominated part (1707 – 1717.5 mRT) and a lower sand-dominated part (1717.5 – 1724.4 mRT).

The 10.5 metres thick upper part of core-5 is dominated by a brownish black to greyish black claystone. The lowermost one to two metres above the uppermost sandstone bed in the lower part of the core shows an upward fining pattern from siltstone to claystone. In the uppermost part of the mudstone succession is a 35 cm thick, thoroughly bioturbated siltstone with Terebellina, Planolites and Chondrites. A 25 cm thick, irregular sandstone bed at 1711.8 mRT is probably caused by sand injection.

The lower part of core-5 consists of fine to mainly very fine, poorly consolidated sand with thin beds and laminae of claystone and siltstone. Sand beds vary in thickness from one metre to 30 cm, and most have erosive lower boundaries and show a more or less well developed normal grading. Above 1720.5 mRT the sand beds are dominantly plane laminated with current ripples and water escape structures. However, the uppermost sand bed (1717.5 – 1717.8 mRT) shows slump structures, some current ripples and has intraformational mudstone clasts above the basal boundary. Two approximately one metre thick sand beds between 1720.5 and 1722.8 mRT show faint lamination with some current ripples in the lower part overlain by plane lamination. The lowermost one metre thick bed of core-5 consists of massive sand showing a poorly developed normal grading, with a normally graded, 20 cm thick heterolithic siltstone at the top. The mudstone laminae between the sand beds are thoroughly bioturbated and may show Planolites and Thalassinoides burrows.

5.2 Interpretation

The normally graded sand beds of the sandy lower part of core-5 were deposited by waning turbidity currents and possibly partly reworked by bottom currents. Whereas the bedding types such as plane lamination and cross-lamination that typically occur in turbidite sands are present in most of the sand beds, normal grading is only weakly developed and the transition to the upper mud-drape is replaced by a sharp boundary in most beds. The sharp upper boundary and lack of a gradational sand/mud transition at the top of these beds may be indicative of deposition in submarine channels, where the finest sediment was carried over the channel margins and deposited on the levees. The bioturbated mudstone laminae between the sand beds are the result of open slope deposition, that took place in a well oxygenated environment between density flow events.

Above the uppermost sand bed a thin upward fining siltstone/claystone interval suggests a rapid abandonment of the submarine sand lobe. The mudstone succession in the upper part of core-5 represents open slope deposition, that took place in a well oxygenated environment.

6. Sedimentary environments and facies

6.1 Facies

- Massive, non-graded, well-sorted sand, two metres thick bed, erosive base and sharp upper boundary, fractures and microfaults. Possible channel fill deposit.
- Normally graded, thick- and thin-bedded (30 – 80 and 5 –30 cm) turbidite units of very fine sand with heterolithic siltstone at top and sometimes fine sand at base. Turbidites may have heterolithic appearance due to abundant mud laminae in sandy part. Turbidites include common plane lamination (Bouma T_b), climbing and current ripple cross-lamination and wavy bedding (T_c), plane laminated heterolithic siltstone (T_d) as transition to overlying mudstone and occasionally structureless sand (T_a) above basal erosive boundary. Bioturbation occur commonly in upper fine-grained part showing Planolites, Chondrites and Thalassinoides. Occasional horizontal back-fill meniscs in sandy part.
- Thick-bedded turbidite sand of very fine and occasionally fine sand showing indistinct normal grading. Some intervals have heterolithic appearance due to mud laminae. Beds are up to one metre thick with faint bedding or structureless and rare current ripple cross-laminated intervals. There is an erosive lower boundary and sharp upper boundary without a gradational transition to overlying mudstone.
- Thin-bedded (5-10 cm), normally-graded and non-graded turbidites of very fine sand separated by 1 – 5 cm mud laminae. Upper boundary is sharp and lower boundary is sharp or occasionally erosive. Common sedimentary structures are climbing- and current ripple cross-lamination and plane lamination and less commonly faint lamination or structureless.
- Non-, normally- or inversely graded beds of very fine and rarely fine sand. Sand beds may show current ripples, sometimes bi-directional, small erosive scours, plane lamination and occasionally deformation structures. Facies is interpreted as bottom current reworked sand.
- Non- or inversely graded, very fine sand with irregular bedding or deformation structures. Upper boundary is sharp and lower boundary sharp or erosive. Interpreted as sandy debris flows.
- Normally graded, 50 – 80 cm thick, heterolithic siltstone units. Sharp or erosive based, 1 – 5 cm thick sandstone laminae are normally- or non-graded. Siltstone shows lenticular and faint planar bedding and current ripples in sand laminae. Thorough bioturbation may exhibit Helminthopsis, and Chondrites. Facies is interpreted as fine-grained turbidites deposited on distal fan or levee.
- Siltstone and claystone successions that are non-graded or show indistinct fining up or coarsening up trends. Bioturbated with Terebellina, Chondrites, Planolites and Thalassinoides and faint parallel bedding. Interpreted with open slope deposits.

6.2 Depositional model

In core-5, which is situated approximately 100 m below core-4, the thick-bedded turbidite sands of the lower part were deposited in submarine channels, where the finer material was carried beyond the channel margins. In this succession there is a rather abrupt transition from turbidite sands to overlying open slope deposits.

The main part of the deposits in cores 1 – 4 were deposited as turbidites in a submarine fan or lobe environment. The lower part of this succession is dominated by thick- or thin-bedded turbidite sands that commonly lack the fine-grained top intervals. The main part of these turbidites was deposited in submarine channels, where a large part of the fine-grained sediment was carried over channel margins and swept on to more distal parts of the fan. Some sand beds show evidence for interaction of turbidity currents and bottom currents, causing reworking of turbidity deposits and possibly deposition from traction currents. However, there is no decisive evidence for the nature of the bottom currents. A gradual change to turbidites with intact fine-grained tops and with thicker mudstone drapes occur in core-3. This may indicate deposition in slightly more distal settings, probably less constrained by channel banks. The normally graded siltstone turbidites that occur as transition to the mudstone successions uppermost in core-3 and in core-1 were deposited on distal levees or on the channel fringe. The upward fining silt to claystone intervals above the fine-grained turbidites represent gradual abandonment of fan or lobe and a transition to open slope deposition. Repeated reactivation of fan system occur with the appearance of fan- and channel sands at the base of core-1 (1579 mRT) and uppermost in core-1 at 1563.5 mRT before final abandonment of the fan system.

Many sand beds in this succession has a distinct heterolithic appearance caused by a more pronounced presence of mud laminae than normally seen in turbidite sands. This may reflect both the textural composition of the source material and possibly a fluctuating energy level during turbidite events.

Enclosure 1

Legend

Lithology

- Sandstone
- Siltstone
- Clay/claystone
- S Siderite
- Claystone/shale clasts
- Macrofossils

Sedimentary structures

- Cross bedding
- Cross lamination
- Horizontal lamination
- Faint lamination
- Water escape
- Deformed/Slumped bedding
- Sand injection
- Fault

Bioturbation

- *Chondrites*
- *Helminthopsis*
- *Planolites*
- *Thalassinoides*
- *Zoophycos*
- *Horizontal backfill meniscs*
- 1.5"plugs

Enclosure 2

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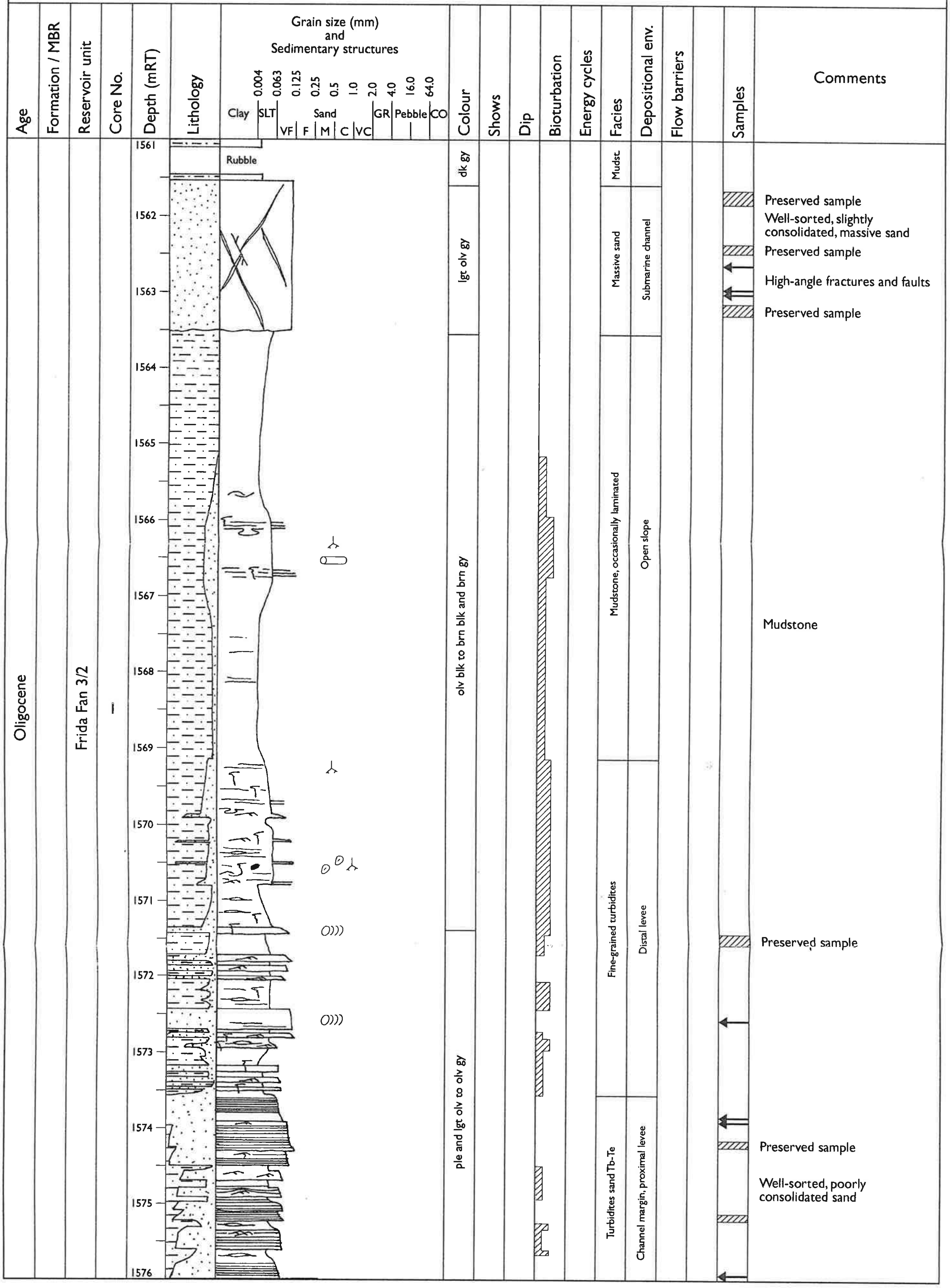
CORE SEDIMENTOLOGICAL LOG

Well: Francisca-1 (5604/24-1)
Country: Offshore Denmark
Field / Area: Norwegian-Danish Basin
Core No(s).: 1
Formation(s):

Interval(s) cored: 1561-1576m
Scale: 1:50
Date: 19-8-98

Log shifted interval(s): 1562.3-1577.3m
Geologist(s): Jan Andsbjerg (GEUS)



Enclosure 3
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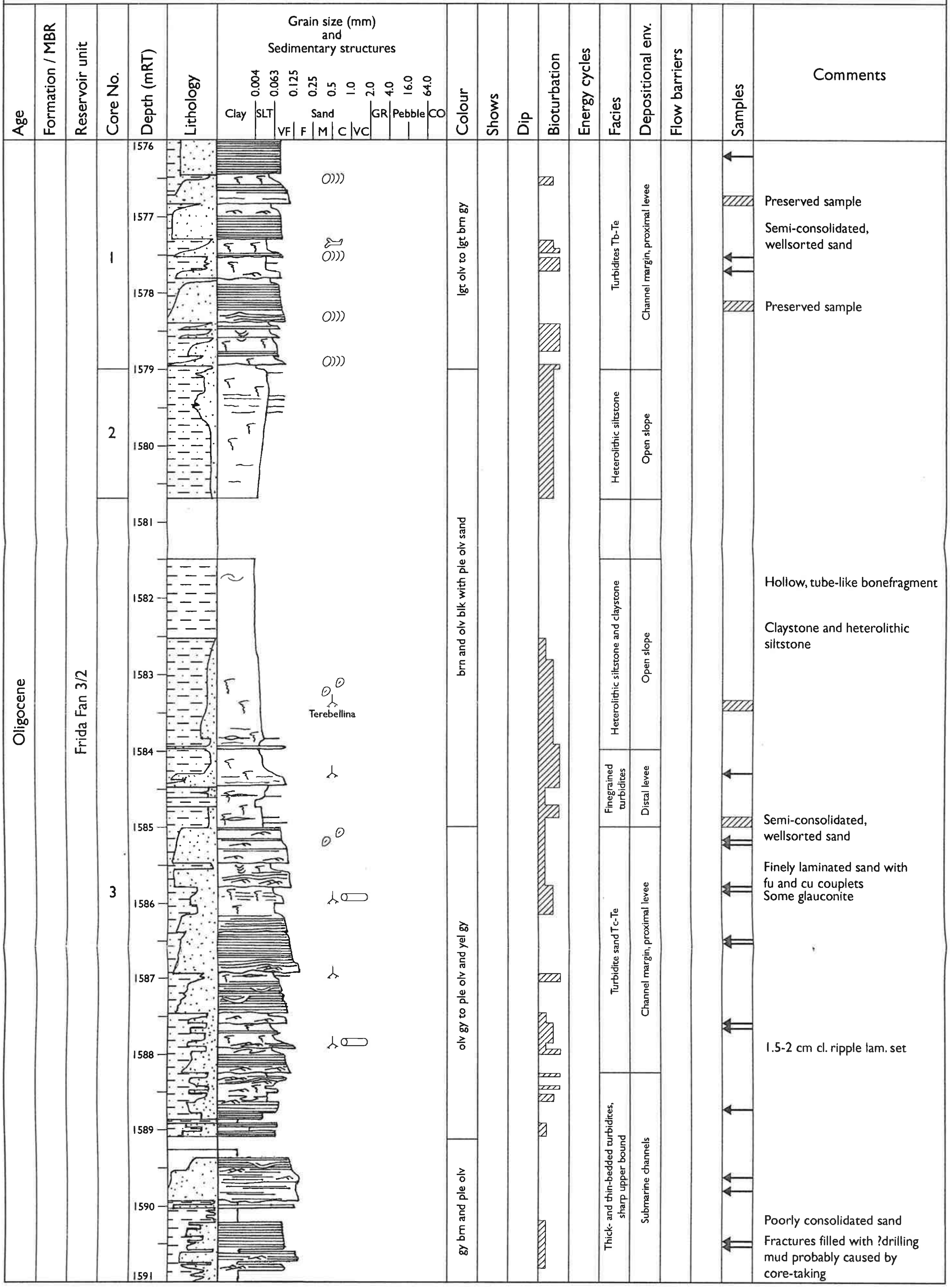
CORE SEDIMENTOLOGICAL LOG

Well: Francisca-1 (5604/24-1)
Country: Offshore Denmark
Field / Area: Norwegian-Danish Basin
Core No(s).: 1-2-3
Formation(s):

Interval(s) cored: 1576-1580.7m
1581.5-1591m
Scale: 1:50
Date: 19-8-98

Log shifted interval(s): 1577.3-1582m
1581.8-1591.3m
Geologist(s): Jan Andsbjerg (GEUS)



Enclosure 4
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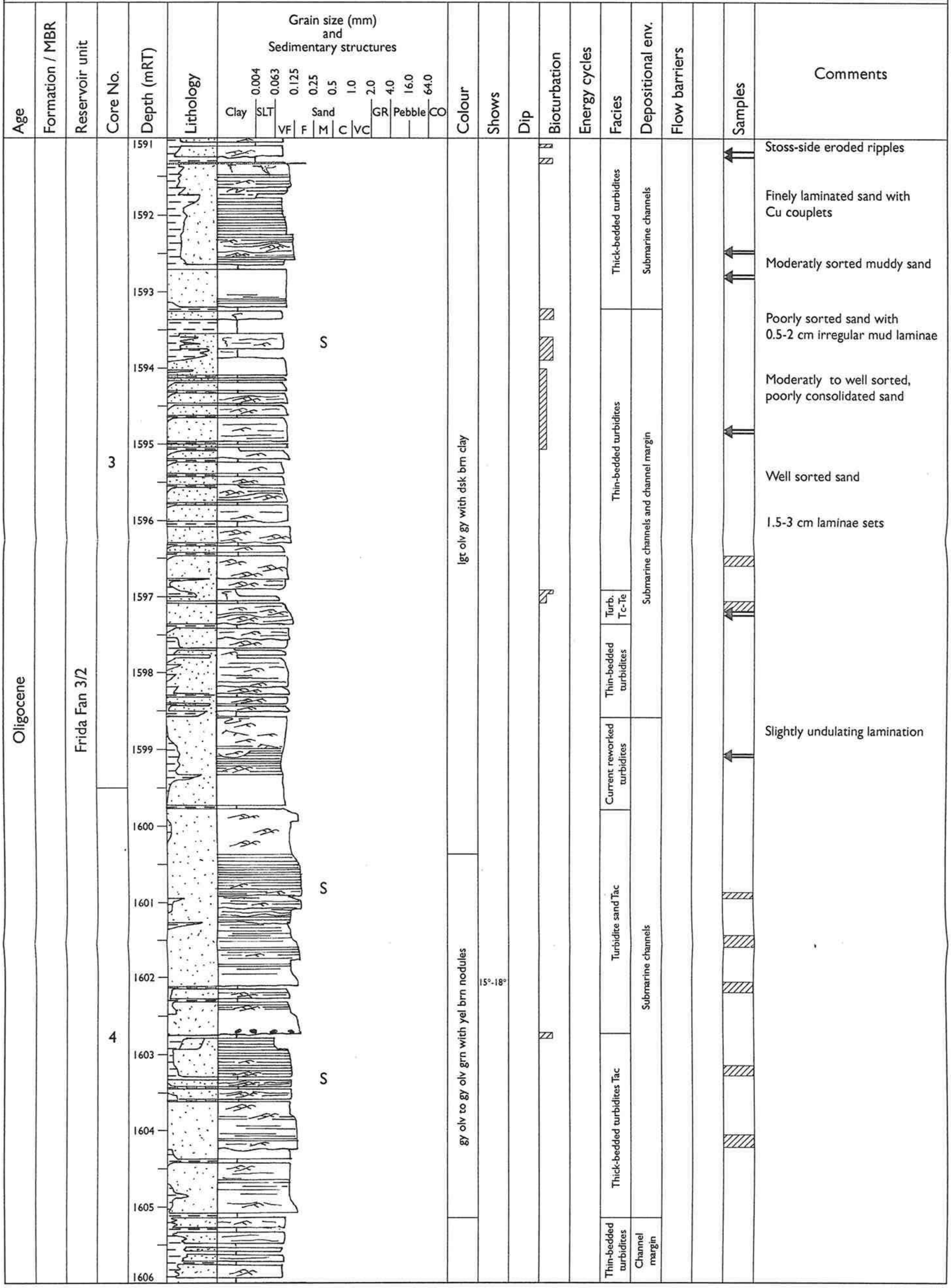
CORE SEDIMENTOLOGICAL LOG

Well: Francisca-1 (5604/24-1) Interval(s) cored: 1591-1606m Log shifted interval(s): 1591.3-1606.3m
Country: Offshore Denmark
Field / Area: Norwegian-Danish Basin
Core No(s).: 3-4 Scale: 1:50 Geologist(s): Jan Andsbjerg (GEUS)
Formation(s): Date: 20-8-98



Enclosure 5
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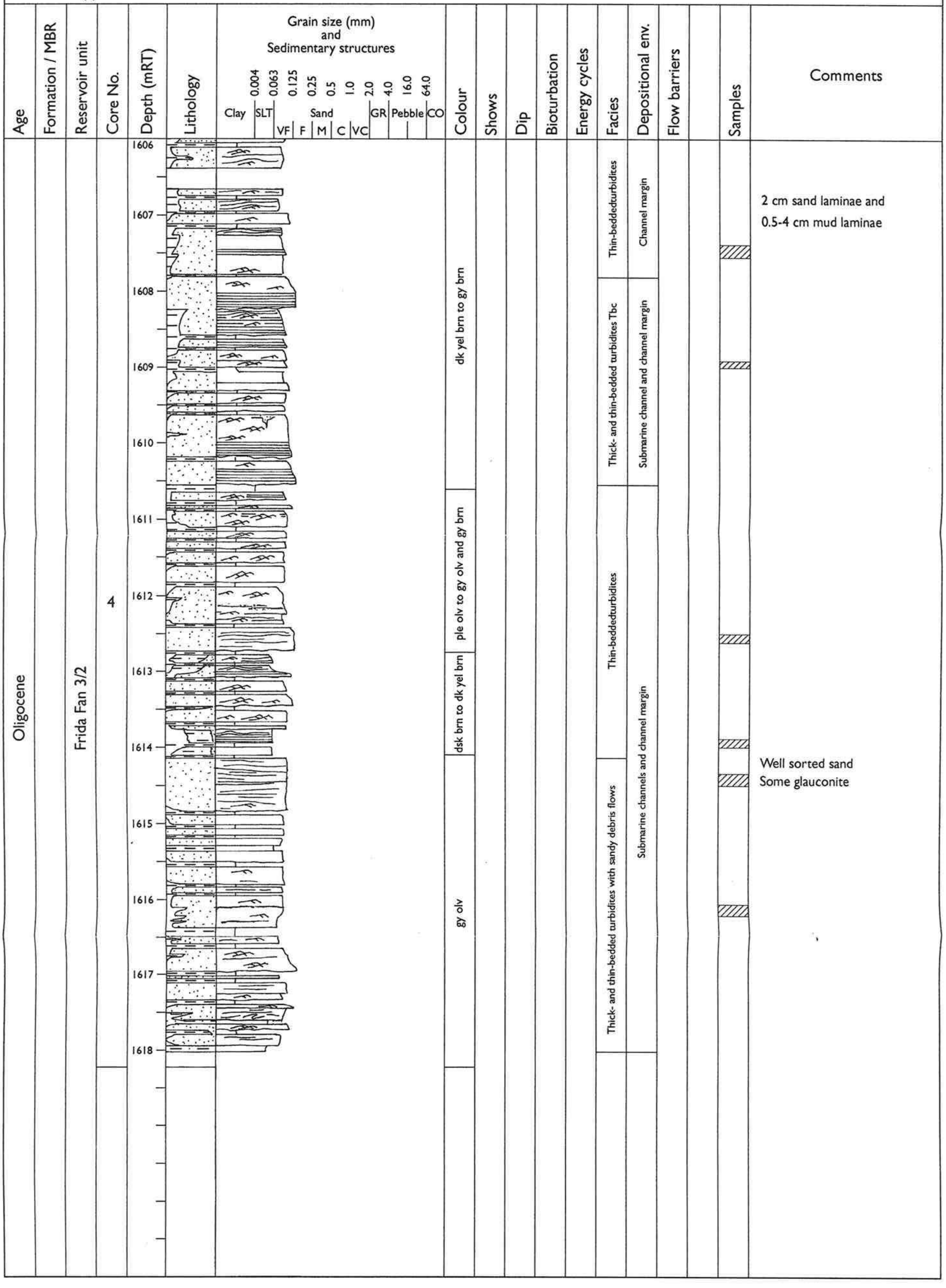
CORE SEDIMENTOLOGICAL LOG

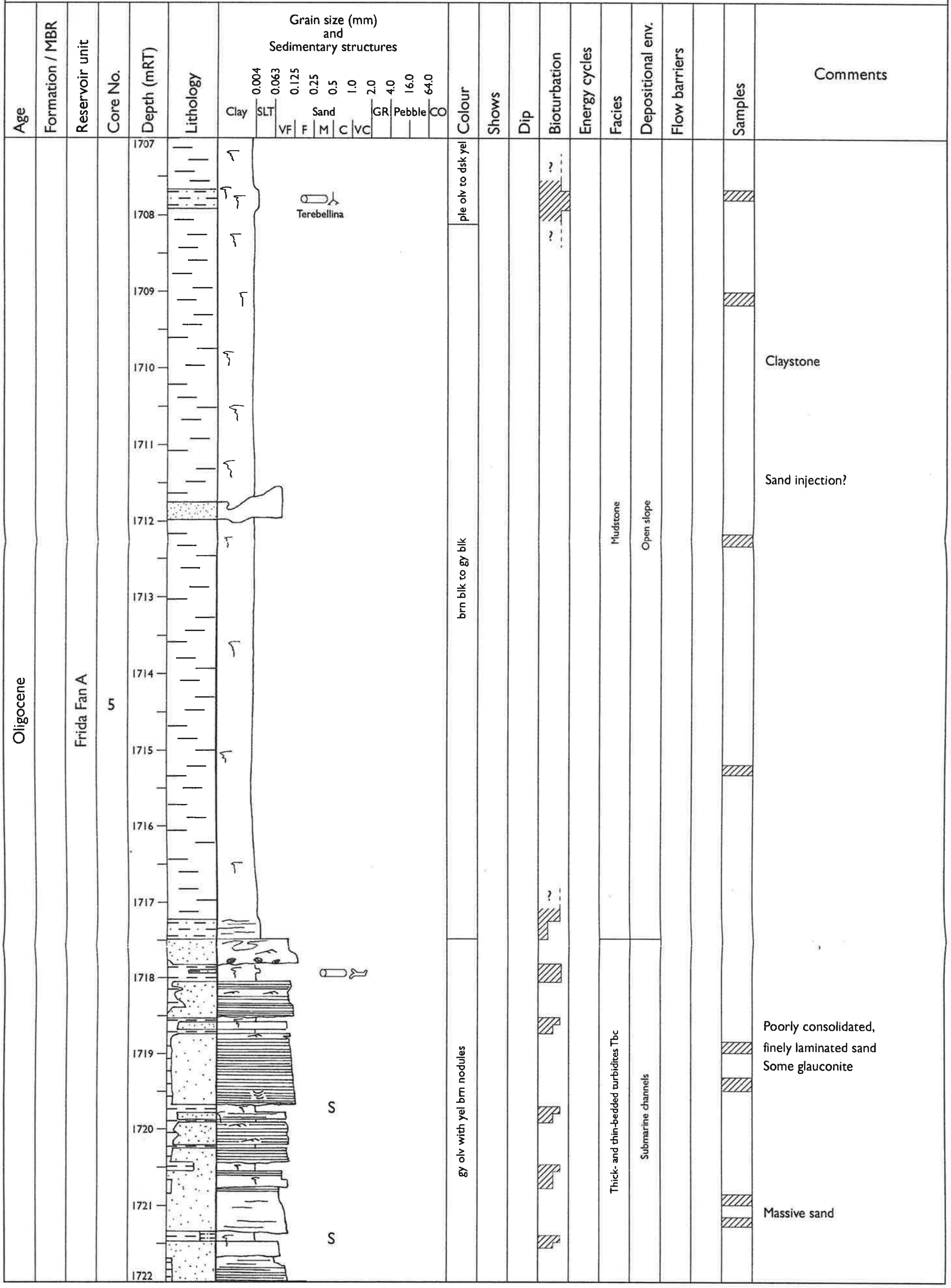
Well: Francisca-1 (5604/24-1) Interval(s) cored: 1606 -1618 m Log shifted interval(s): 1606.3-1618.3m
Country: Offshore Denmark
Field / Area: Norwegian-Danish Basin
Core No(s).: 4 Scale: 1:50 Geologist(s): Jan Andsbjerg (GEUS)
Formation(s): Date: 21-8-98



Enclosure 6

CORE SEDIMENTOLOGICAL LOG

Well: Francisca-1 (5604/24-1)
Interval(s) cored: 1707-1722m
Log shifted interval(s): 1709.3-1724.3m
Country: Offshore Denmark
Field / Area: Norwegian-Danish Basin
Core No(s).: 5
Scale: 1:50
Geologist(s): Jan Andsbjerg (GEUS)
Formation(s):
Date: 25-8-98



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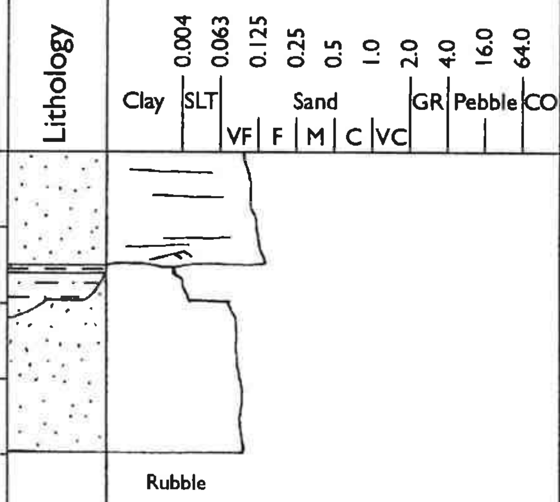
CORE SEDIMENTOLOGICAL LOG

Well: Francisca-1 (5604/24-1)
Country: Offshore Denmark
Field / Area: Norwegian-Danish Basin
Core No(s).: 5
Formation(s):

Interval(s) cored: 1722-1724.4m
Log shifted interval(s): 1724.3-1726.7m
Scale: 1:50
Date: 25-8-98
Geologist(s): Jan Andsbjerg (GEUS)

Age	Formation / MBR	Reservoir unit	Core No.	Depth (mRT)	Lithology	Grain size (mm) and Sedimentary structures	Colour	Shows	Dip	Bioturbation	Energy cycles	Facies	Depositional env.	Flow barriers		Samples	Comments
Oligocene		Frida Fan A	5	1722 1723 1724			gy olv					Thick-bedded turbidites	Submarine channels				Massive sand Massive sand



Enclosure 8
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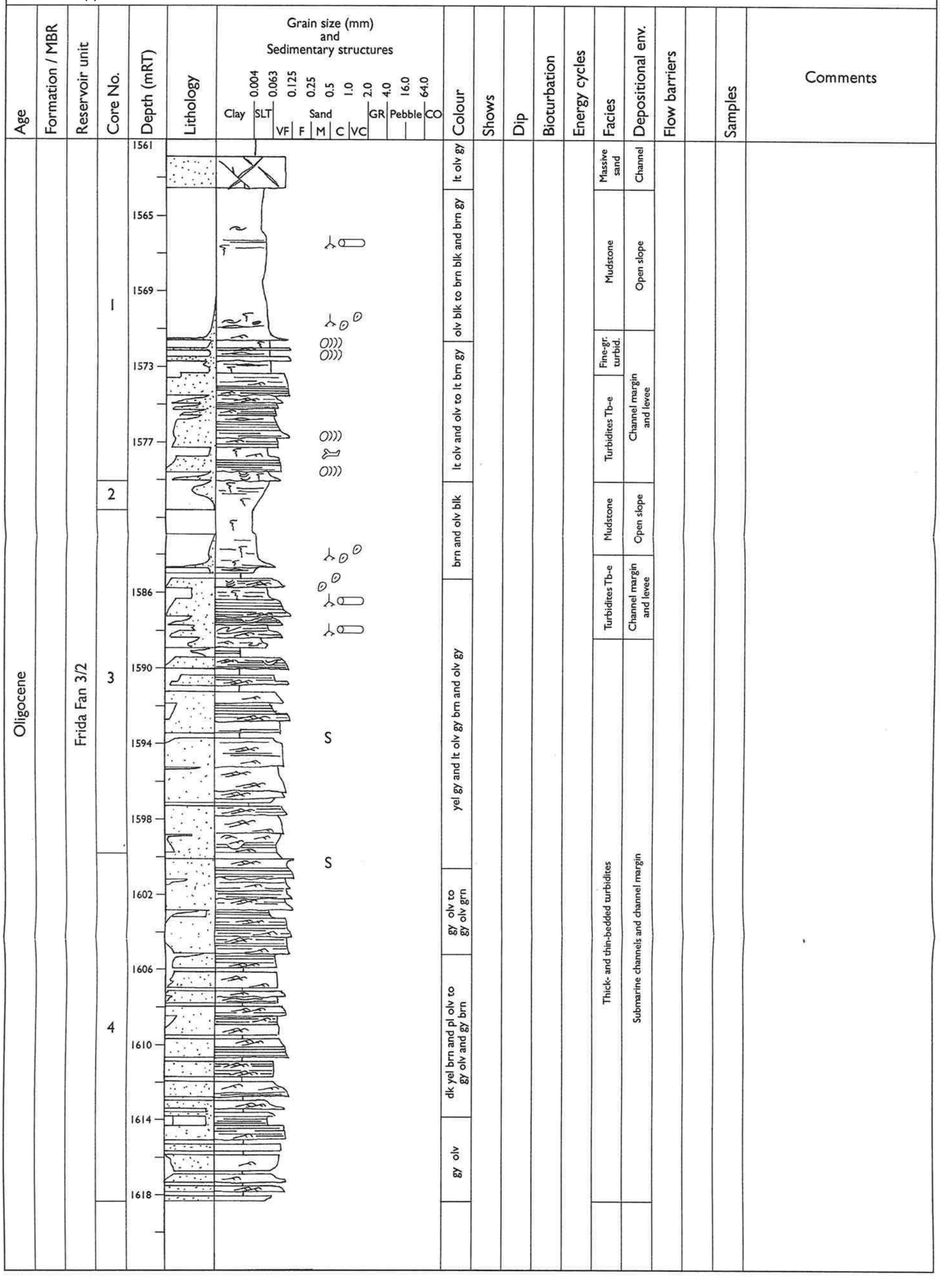
CORE SEDIMENTOLOGICAL LOG

Well: Francisca-1 (5604/24-1) Interval(s) cored: 1561-1618m Log shifted interval(s):
Country: Offshore Denmark
Field / Area: Norwegian-Danish Basin
Core No(s).: 1-2-3-4 Scale: 1:200 Geologist(s): Jan Andsbjerg (GEUS)
Formation(s): Date: 21-8-98



Enclosure 9
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CORE SEDIMENTOLOGICAL LOG

Well: Francisca-1 (5604/24-1)
Interval(s) cored: 1707-1724.4m
Log shifted interval(s): 1709.3-1726.3m
Country: Offshore Denmark
Field / Area: Norwegian-Danish Basin
Core No(s).: 5
Scale: 1:200
Geologist(s): Jan Andsbjerg (GEUS)
Formation(s):
Date: 25-8-98