Overview Zechstein Lithology Bergermeer Field

1. Introduction

A brief study of the lithostratigraphy of the Zechstein of the Bergermeer Field has been carried out. For this study composite and mud logs of all existing Bergermeer wells have been used. Apart from the Z3 Carbonate ("Platten Dolomite") no core data is available for the Zechstein.
The main objectives were:

- Detailed description of the lithology of the basal part of the Zechstein;
- Identify markers / features in the basal part of the Zechstein to enhance the prediction of the distance to top reservoir while drilling the future wells;
- Subdivide prognosed lithostratigraphy (full column).

For correlation purposes a TVDSS correlation panel for the Zechstein has been made at 1:500 and 1:1000 vertical scale.

The Bergermeer Rotliegend gas field consists of 2 blocks separated at reservoir level by a NW-SE striking normal fault.

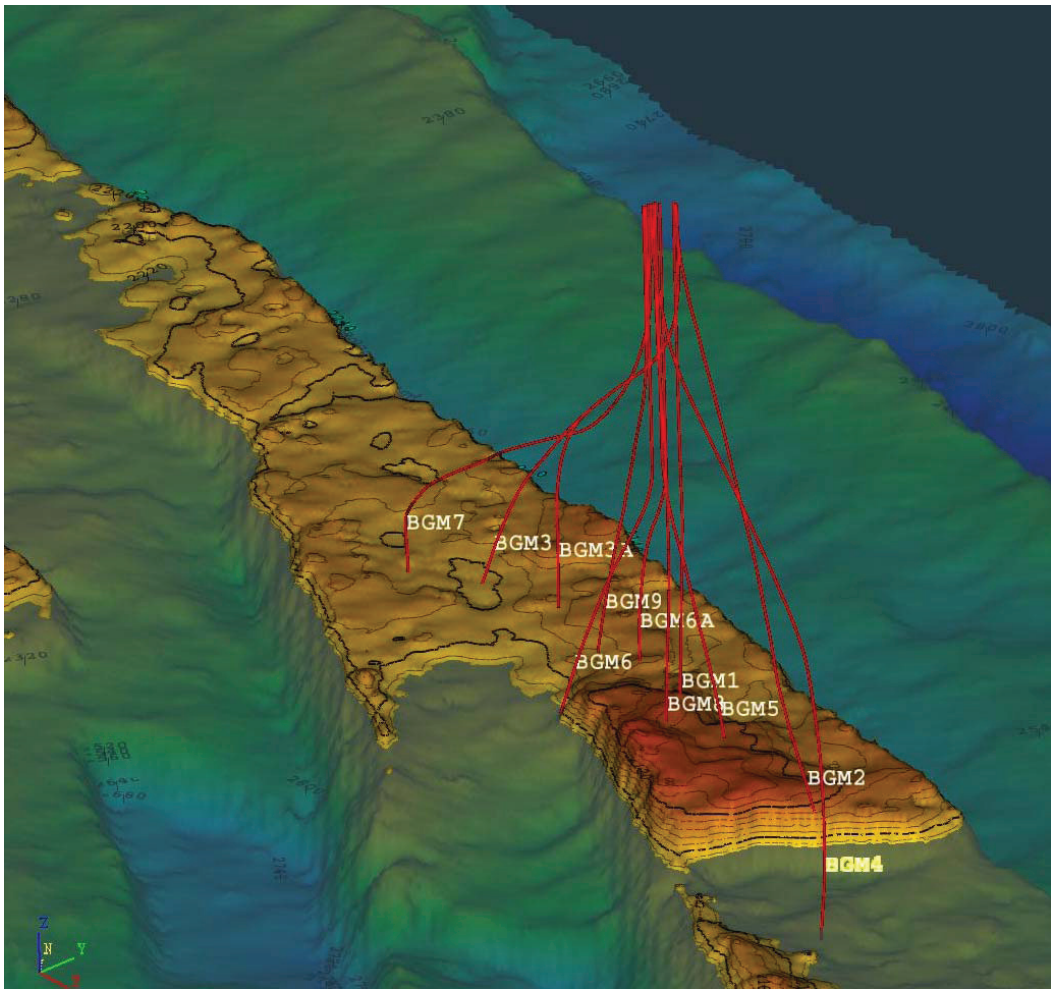

Fig.1 - Trajectories existing wells.

2. Detailed Lithostratigraphy Zechstein

- The upper part of the Zechstein has a variable thickness ranging from 10-65m TV and consists of anhydritic Claystone and Salt with Anhydrite and Claystone intercalations. This interval is contributed to the Zechstein Upper Claystone (ZEUC). In some Bergermeer wells the Z3 Salt Member is present with a vertical thickness up to 60m (e.g. BGM-6). Thin layers, up to a few meters, of K-Salts can be inferred from GR-logs.
  Gas readings are low in this section.

- The sequence Z3 Anhydrite Member, Z3 Carbonate Member ("Platten Dolomite") and Grey Salt Clay is present throughout the entire Bergermeer Field, clearly recognizable on wireline logs (sonic and density) and rather constant in thickness. The vertical thickness varies from 44 – 52m, with the highest thickness recorded in the SE part of the field.
  The top of the Z3 Anhydrite could be obscure when just looking at the GR, but the top is usually marked by a negative drilling break. The thickness of the Anhydrite is only 3-4m TV. The Platten Dolomite is evident from drill cuttings as it is the first occurrence in the Zechstein of light brown and grey anhydritic Dolomite. This interval shows usually an increase in gas levels compared with the above- and underlying units. The porosity in the Platten Dolomite in the Bergermeer Field is poor in general, although locally vuggy porosity is recorded in some Bergermeer wells. Core data from BGM-1 show total porosities of 17-19% in the upper part. The Dolomite can be (micro)fractured and mud losses could occur.
  The GR is low at the top of the interval, but increases slowly with depth, indicating a gradual increase in clay content in the basal part and ends with a sharp peak corresponding to the Grey Salt Clay (ZEZ3G). The Grey Salt Clay is a few meter in thickness and is a good regional marker. *The vertical distance to top Rotliegend is at least 180m* (apart from the BGM-2 well where the Zechstein is partly faulted out).

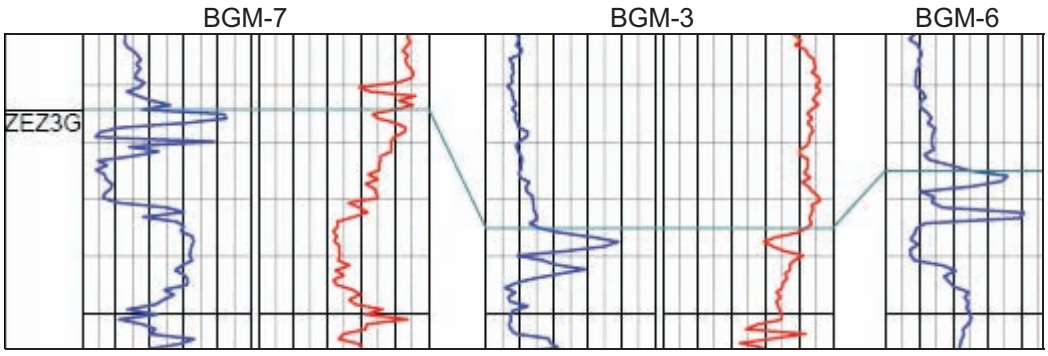

Fig. 2 - GR (blue) showing "double peak" of Grey Salt Clay and K-Salt.

- The top of the Zechstein 2 Formation is taken at the base of the Grey Salt Clay. At the top is a thin Anhydrite bed present, followed by 10-15m TV interval of Salt (locally some K-Salt) and some Polyhalite. In the NW part of the field a high peak is visible on the GR just below the Anhydrite, resulting in a typical "double peak" pattern. This second peak is absent in the SE part of the field. The background gas levels drop from the top of the Zechstein 2 Formation and remain low until the top Rotliegend.

The underlying unit of alternating Anhydrite, Claystone and thin Salt beds has in the NE block a rather constant vertical thickness of +/- 50m. In the SW block the thickness varies from 50-120m.
This unit is followed by 25-100m of Salt (ZEZ2H; no K-salts) with maximum thickness developed in the SW block. The Salt contains Anhydrite streaks and thin Claystone beds. *The vertical distance from the base of the ZEZ2H to top Rotliegend is 80-120m.*
The basal 20-35m of the Zechstein 2 Formation consists of pure Anhydrite followed by anhydritic and calcareous Claystone (ZEZ2A) and locally minor argillaceous Limestone. This Claystone is best developed in the central part of the field and thins towards the edges. The base of the Zechstein 2 Formation can be obscure due to the absence of a distinct Zechstein 2 Carbonate ("Haupt Dolomite") in the area and in places where no anhydritic Claystone is encountered (e.g. BGM-3/5).

- The top of the Zechstein 1 Formation is taken at the base of an anhydritic Claystone, but could be difficult to identify. The upper part consists of a massive slightly argillaceous and dolomitic Anhydrite (ZEZ1W or Werra Anhydrite). Thin red brown and grey Claystone beds are intercalated which can be up to 5m in thickness (e.g. BGM-3). Locally in the SW block is a minor amount of fine to coarse Sandstone recorded. The total thickness of the Anhydrite varies from 40-70m, but could be up to 90m in case of an obscure boundary with the Zechstein 2 Basal Anhydrite (ZEZ2A).

- The basal 18-33m of the Zechstein sequence (Z1 Carbonate and Coppershale Members) on top of the Rotliegend reservoir is very constant throughout the Bergermeer field. See correlation graph (fig. 3) below for a typical GR-character. For detail see Zechstein correlation panels.

  From top to bottom this interval consists of:

  - 6 - 10m TV calcareous and anhydritic grey Claystone with high GR readings. Just above the middle of the interval is a thin layer with lower GR-readings, indicating Limestone or Anhydrite. *Top is 18-33m vertical above Rotliegend;*

  - 4 - 6m TV brown grey, argillaceous Limestone with low GR readings. *Top is 12-23m vertical above Rotliegend;*

  - 7 - 15m TV brown grey and dark grey argillaceous Limestone alternating with an increasing amount towards the bottom of thin grey, calcareous and anhydritic Claystone; irregular increasing in GR readings. *Top is 8-17m vertical above Rotliegend;*

  - 1-2m TV dark grey Claystone ("Coppershale") with the highest GR spike. *Top is 1-2m vertical above Rotliegend.*

  Locally in the SW block is a minor amount of fine to medium grained Sandstone intercalated. The gas readings in this interval are low in general and only start to rise significantly when the Rotliegend gas leg has been penetrated. Only in BGM-2 and BGM-8 background gas levels are slightly higher than in the Z1 Anhydrite, with a maximum of 0.4% and 0.1% respectively.

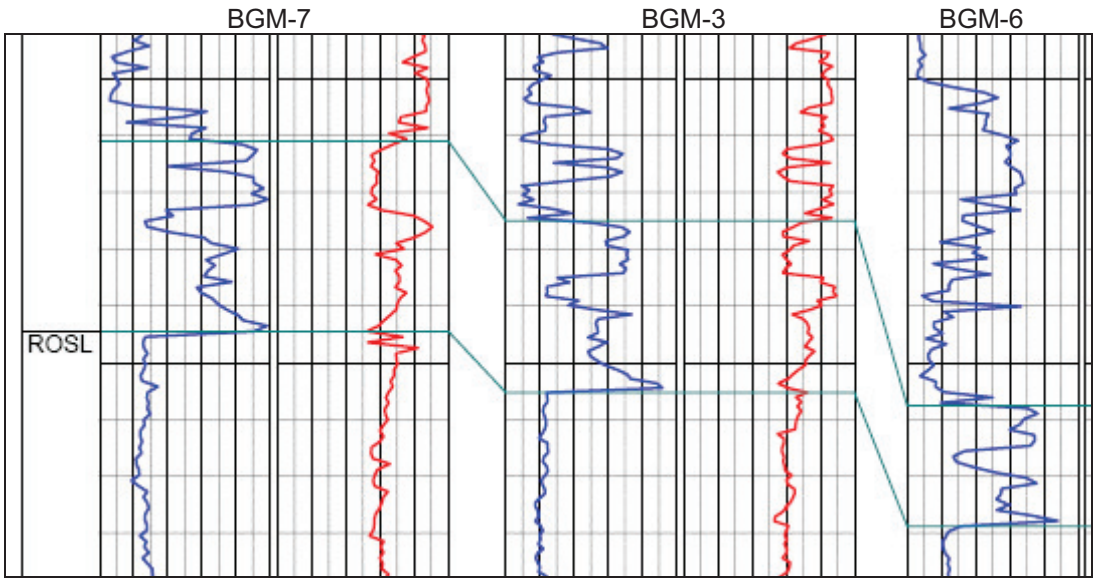

Fig. 3 - GR (blue) and Sonic (red) character of basal Zechstein.

	BGM-7 mTV	BGM-3 mTV	BGM-6 mTV	BGM-1 mTV	BGM-8 mTV	BGM-5 mTV	BGM-2 mTV
ZEUC/3H	40	9	65	23	25	32.35	16
ZEZ3A	2	4	3	3	4	3	3
ZEZ3C	39	42	46	40	44	46	49
ZEZ3G	3	4	3	3	3	2	3
ZEZ2	64	103	124	61	61	67	24
ZEZ2H	95	41	95	23	60	43	
ZEZ2A	24	24	24	35	24	20	
ZEZ1W	61	68	37	41	54	61	28
ZEZ1C	32	29	19	21	16	17	27
ZEZ1K	1	1	1	1	2	1	2
ZEZ2 - ZEZ1K	277	266	300	181	217	209	81
ZEZ2A - ZEZ1W	85	92	61	76	78	81	28
ZEZ2A - ZEZ1K	118	122	81	98	96	99	57
Zechstein	362	325	417	250	293	292	152

Table 1 – True vertical thickness of Zechstein member and intervals (not corrected for formation dip angle).

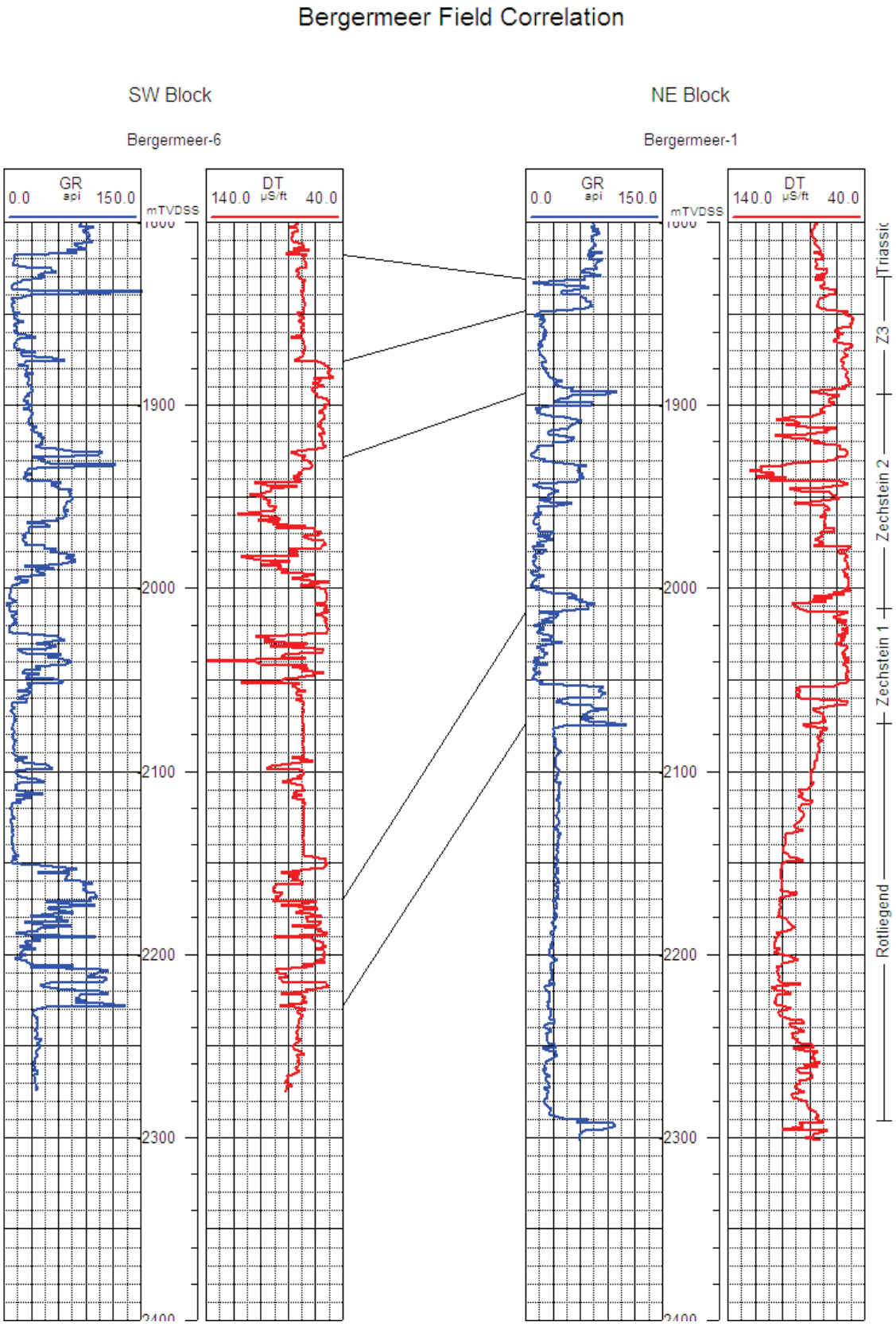

Fig. 4 – Correlation diagram showing variation across field in the Zechstein.

3. Actual Lithostratigraphy for some Bergermeer Wells

			BGM-7		BGM-1		
Group	Formation	Member	Top mMD	Top mTVDSS	Top mMD	Top mTVDSS	Lihology
NS	Undifferentiated		9	0.0	4.5	0.0	Sand and Clay(stone)
KN	Holland (KNGL)	Lower Holland Marl (KNGLL)	883	833.7	835	830.4	Marl, Claystone
	Vlieland (KNNC)		1027	943.6	957	952.4	Claystone
AT	Aalburg (ATAL)		-	-	1310	1305.5	Claystone
	Sleen (ATRT)		1845	1335.1	-	-	Claystone
RN	Keuper (RNKP)		1857	1341.4	1317	1312.6	Anhydritic Claystone
	Muschelkalk (RNMU)	Upper Muschelkalk (RNMUU)	2052	1441.3	1363	1358.5	Dolomitic Claystone
		Muschelkalk Evaporite (RNMUE)	2107	1468.1	1404	1399.5	Dolomite, Marl
	Röt (RNRO)	Upper Röt Claystone (RNROU)	2199	1512.5	1470	1465.4	Claystone, Siltstone
		Main Röt Evaporite (RNRO1)	2435	1630.0	1478	1473.4	Anhydrite, Salt, Claystone
	Solling (RNSO)	Solling Claystone (RNSOC)	2448	1636.7	1483	1478.3	Claystone
		Basal Solling Sandstone (RNSOB)	2493	1660.9	1518	1513.3	Sandstone
RB	Volpriehausen (RBMV)	Volpriehausen Sandstone (RBMVL)	2501	1665.5	1520	1515.3	Sandstone
	Lower Buntsandstein (RBSH)	Rogenstein (RBSHR)	2556	1697.6	1546	1541.3	Claystone, Oolitic Limestone beds
		Main Claystone (RBSHM)	2694	1790.3	1683	1678.2	Claystone
ZE	Z. Upper Claystone (ZEUC)		2754	1832.3	1830	1824.8	Anhydrite, Salt, Claystone
	Zechstein 3 (ZEZ3)	Z3 Salt (ZEZ3H)	2782	1852.5	-	-	Salt
		Z3 Anhydrite (Z3Z3A)	2810	1872.8	1852	1846.7	Anhydrite
		Z3 Carbonate (ZEZ3C) "Platten Dolomite"	2813	1874.9	1855	1849.7	Dolomite/Limestone
		Grey Salt Clay (ZEZ3G)	2866	1914.2	1896	1890.8	Claystone, Salt
	Zechstein2 (ZEZ2)		2868	1915.8	1900	1894.8	Anhydrite, Salt, Claystone

		Z2 Halite (ZEZ2H)	2943	1980.0	1959	1953.6	Salt, Claystone beds
		Z2 Basal Anhydrite (ZEZ2A)	3047	2075.5	1982	1976.5	Anhydrite, Claystone
	Zechstein1 (ZEZ1)	Z1 Anhydrite (ZEZ1W)	3072	2099.2	2017	2011.3	Anhydrite, Claystone beds
		Z1 Carbonate (ZEZ1C)	3137	2161.6	2058	2052.3	Limestone, Claystone
		Coppershale (ZEZ1K)	3170	2193.5	2079	2073.3	Claystone
RO	Slochteren Sandstone (ROSL)	Upper Slochteren (ROSLU)	3171	2194.5	2080	2074.3	Sandstone

N.B. BGM-7 encountered a fault at 2428m, resulting in a partly repeated Upper and Lower Germanic Trias (RN/RB).

Please note that not all formations are present in the existing Bergermeer wells due to unconformities or faulting. Especially the Aalburg Formation, Basal Solling Sandstone and Z3 Salt Members can be absent.

Prognosed depths for future wells can be taken from Deviator (W. van Soest) when well trajectories have been finalized.

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4a. General lithology summary of the SW (downthrown) block

Offset wells BGM-3/6/7/9.

Zechstein 3 / 4 to top Z3 Anhydrite:

- Thin Anhydrite/Salt bed at the top;
- Red – orange brown ("Red Salt Clay") and dark grey Claystone, and /or Salt with minor Anhydrite (+/- 10-60m TV). Locally thin K-salt layers.

Zechstein 3 Anhydrite to Grey Salt Clay:

- Thin Anhydrite layer (ZEZ3A);
- Light brown Dolomite with intercrystalline and locally vuggy porosity, interbedded with light to dark grey, argillaceous and slightly carbonaceous, dense Dolomite, total thickness 40-50m TV (ZEZ3C "Platten Dolomite");
- Thin dark grey, swelling Claystone at the base (ZEZ3G).

Zechstein 2

- Thin Anhydrite layer at the top;
- +/- 10-15m TV Salt and pink Polyhalite / K-Salt;
- +/- 50-120m TV grey and red brown Claystone alternating with Anhydrite and thin Salt and Dolomite beds;
- 40–100m TV Salt with thin beds of Anhydrite and grey Claystone (ZEZ2H);
- Anhydrite locally followed by grey, anhydritic and calcareous Claystone (total ca 25-35m TV, ZEZ2A). N.B. there is no distinct development of the Zechstein 2 Carbonate ("Haupt Dolomite").

Zechstein 1

- 40 – 70m TV predominantly Anhydrite with grey Claystone and Dolomite streaks, locally minor amount of fine to coarse Sandstone. BGM-3 encountered a ca 90m TV Anhydrite sequence (ZEZ2A+ZEZ1W) with alternations of distinct red brown and grey, silty Claystone beds in the lower half of the interval;
- 20-33m TV sequence of grey anhydritic Claystone, followed by Limestone and Dolomite interbedded with an increasing amount of grey Claystone towards the base. Locally minor amount of fine to medium grained Sandstone. No losses recorded;
- 1-2m TV dark grey Claystone ("Coppershale") at the base.

4b. General lithology summary of the NE block

Offset wells BGM-1/2//3A/4/5/6A/8.

Zechstein 3 / 4 to top Z3 Anhydrite:

- Thin anhydritic Salt bed at the top;
- Red – orange brown ("Red Salt Clay") and dark grey Claystone, alternating with thin Anhydrite beds (+/- 10-35m TV).

Zechstein 3 Anhydrite to Grey Salt Clay:

- Thin Anhydrite layer (ZEZ3A);
- Light brown, anhydritic Dolomite with intercrystalline and locally vuggy porosity, interbedded with light to dark grey, argillaceous and carbonaceous, dense Dolomite, total thickness 40-48m TV (ZEZ3C "Platten Dolomite");
- Thin dark grey Claystone at the base (ZEZ3G).

Zechstein 2

- Thin Anhydrite layer at the top;
- Up to 10m TV Salt and pink Polyhalite;
- +/- 40-60m TV grey and red brown, occasionally sandy Claystone, alternating with Anhydrite and in the basal part light brown dolomitic Limestone;
- +/- 25-50m TV Salt with thin streaks of Anhydrite and grey Claystone (ZEZ2H);
- Anhydrite followed by grey, calcareous Claystone with minor argillaceous Limestone. Interval 20-35m TV (ZEZ2A);
- N.B. there is no distinct development of the Zechstein 2 Carbonate ("Haupt Dolomite").

Zechstein 1

- Ca 40-90m TV predominantly Anhydrite with minor grey Claystone and Limestone streaks;
- 18-30 TV sequence of grey, anhydritic and calcareous Claystone, interbedded with grey, dolomitic and argillaceous Limestone. No losses recorded;
- 1m TV dark grey Claystone ("Coppershale") at the base.

5. Conclusions

Only the Z3 Carbonate ("Platten Dolomite") and the basal 18-33m (TV) of the Zechstein on top of the Rotliegend are rather constant in lithology and thickness throughout the Bergermeer Field. The Grey Salt Clay (ZEZ3G) is a good marker across the field.
The Zechstein 2 Formation and Z1 Anhydrite Member (ZEZ1W or Werra Anhydrite) show more variation in lithology and thickness. In the SW block the total thickness varies between 270m and 300m TV and in the NE block between 175 and 210m TV. Below the Grey Salt Clay is in the NW part of the field a few meter thick Potassium Salt and/or Polyhalite layer present, resulting in a "double peak" on the GR-trace. This layer seems to be absent in the SE part, or at least less distinct. The thickness of the Z2 Salt (ZEZ2H) varies considerably, but in case of a thin Salt layer, a thick Anhydrite is present and vice versa, resulting in a relative uniform thickness (Z2+ZEZ1W) within the blocks. The vertical distance from the base of the Z2 Salt to the top of the Rotliegend varies from 80-120m in the SW block and is +/- 95-100m in the NE block.
The boundary between the Zechstein 1 and Zechstein 2 Formations could be difficult to identify due to the absence of the Z2 Carbonate ("Haupt Dolomite") and can not act as a reliable marker. In such cases prediction for the distance to top Rotliegend should be based on the vertical thickness of the various members as seen across the field (see table 1, page 4).
The Zechstein 1 Formation consists of a massive argillaceous and dolomitic Anhydrite (ZEZ1A or Werra Anhydrite) in the upper part and calcareous/anhydritic Claystone and argillaceous/anhydritic Limestone (ZEZ1C) in the basal part. In the SW block thin Sandstone streaks can occur in the Zechstein 1 Formation. The individual Claystone beds in the Werra Anhydrite are not correlatable, but the Z1 Carbonate/Coppershale sequence is good correlatable throughout the field. The top of this basal member is 18-33m above the Rotliegend. No fractures and resulting losses are known from this basal part. The Werra Anhydrite, as well as the basal part will provide a good casing seat under normal overbalanced drilling conditions.
It is recommended to have at least a GR-sensor in the drill string at all times while drilling the Zechstein, since drill cuttings are often ambiguous due to hole cleaning issues in high angle wells and due to the mud type (e.g. solvable salts in water based mud systems). It is advised to make a trip in case of GR-tool failure. GR only is not conclusive in evaporites, but GR-correlation combined with cuttings descriptions will give enough reliability for the estimated distance to the top of the Rotliegend while drilling a complete Zechstein sequence.

6. Digital Attachments

BGM_Panel_ZE_1000.pdf Zechstein Correlation Panel vertical scale 1:1000
BGM_Panel_ZE_500.pdf Zechstein Correlation Panel vertical scale 1:500
BGM_Strat_Prognosis.xls Prognosis Lithostratigraphy

Henk van Gastel (DTN)
17-09-2008

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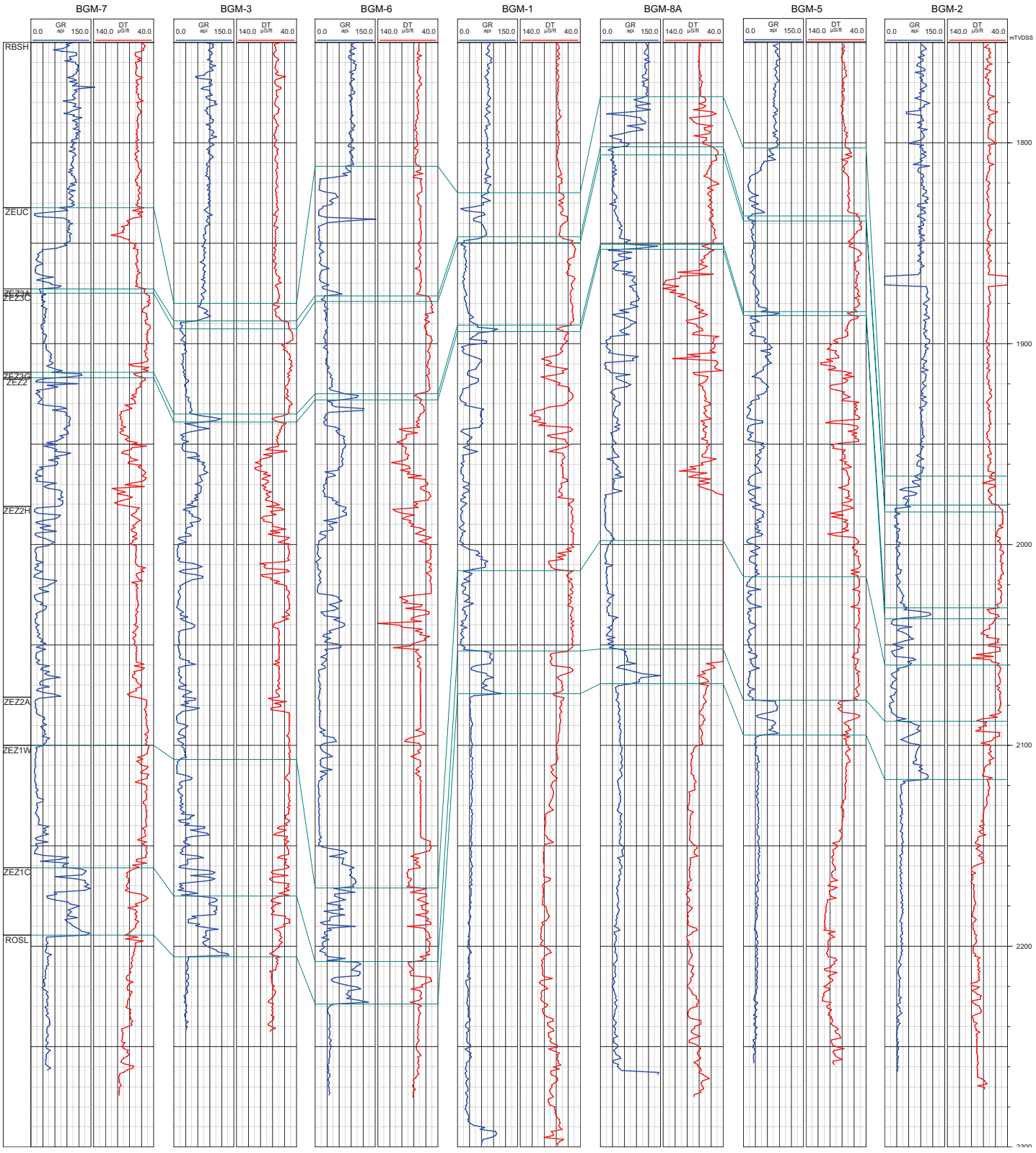
Bergermeer Field Zechstein Correlation Panel

TVDSS Display NW-SE



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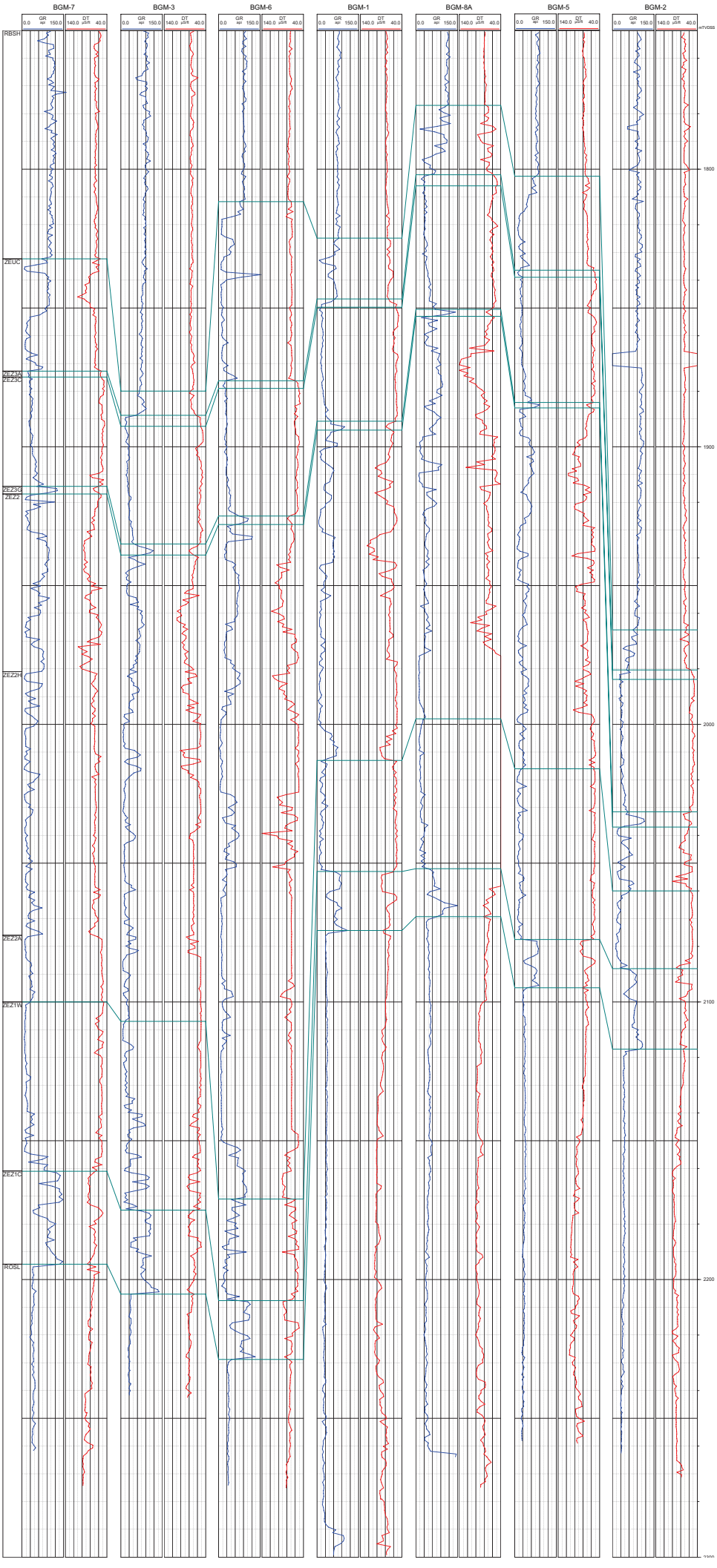
Bergermeer Field Zechstein Correlation Panel

TVDSS Display NW-SE



Prognosed Lithology Bergermeer Field

Group	Formation	Member	Top mMD	Top mTVDSS	Lihology
NS	Undifferentiated				Sand and Clay(stone)
KN	Holland (KNGL)	Lower Holland Marl (KNGLL)			Marl, Claystone
	Vlieland (KNNC)				Claystone
AT	Aalburg (ATAL)				Claystone
RN	Keuper (RNKP)				Anhydritic Claystone
	Muschelkalk (RNMU)	Upper Muschelkalk (RNMUU)			Dolomitic Claystone
		Muschelkalk Evaporite (RNMUE)			Dolomite, Marl
	Röt (RNRO)	Upper Röt Claystone (RNROU)			Claystone, Siltstone
		Main Röt Evaporite (RNRO1)			Anhydrite, Salt, Claystone
	Solling (RNSO)	Solling Claystone (RNSOC)			Claystone
		Basal Solling Sandstone (RNSOB)			Sandstone
RB	Volpriehausen (RBMV)	Volpriehausen Sandstone (RBMVL)			Sandstone
	Lower Buntsandstein (RBSH)	Rogenstein (RBSHR)			Claystone, Oolitic Limestone beds
		Main Claystone (RBSHM)			Claystone
ZE	Z. Upper Claystone (ZEUC)				Anhydrite, Salt, Claystone
	Zechstein 3 (ZEZ3)	Z3 Salt (ZEZ3H)			Salt
		Z3 Anhydrite (Z3Z3A)			Anhydrite
		Z3 Carbonate (ZEZ3C) "Platten Dolomite"			Dolomite/Limestone
		Grey Salt Clay (ZEZ3G)			Claystone, Salt
	Zechstein2 (ZEZ2)				Anhydrite, Salt, Claystone
	Zechstein1 (ZEZ1)	Z1 Anhydrite (ZEZ1W)			Anhydrite, Claystone beds
		Z1 Carbonate (ZEZ1C)			Limestone, Claystone
		Coppershale (ZEZ1K)			Claystone

RO	Slochteren Sandstone (ROSL)	Upper Slochteren (ROSLU)			Sandstone