Anticipating Geo-Drilling Hazards by Sharing Geo-Drilling Events Information Nationwide

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contribution to SPE Annual Technical Conference and Exhibition 2019

Abstract

Drilling hazards can lead to significant cost overruns during the drilling phase and might cause unsafe situations or potentially harm the environment. Often the local geology, when poorly understood, is the trigger of a drilling incident. By sharing past drilling experience and in particular observations on Geo-Drilling Hazards, via a suitable platform, well planning and risk assessment can be carried out more effectively. After analysing historic drilling reports, observations on drilling incidents have been compiled using a structured approach. Classification schemes allow systematic capture of key information in a format suitable for a database. In this process the observations (*facts*) during the drilling operation are analysed and classified into a limited number of *event types*. By interpreting the data in the geological context, the underlying geohazard type has been determined by selecting from a defined (and limited) number of *geological causes.* The resulting information can be accessed via an online user interface with GIS functionality and advanced analysis options.

The Geo-Drilling Events (GDE) database currently covers some 1000 boreholes from the Netherlands. Around 1400 geo-drilling events have been analysed systematically allowing to identify drilling hazard hotspots in a statistically meaningful sense. Examples of geo-drilling events include *stuck tool, gains, losses, H2S.* The underlying geological phenomena i.e. the “geo-drilling hazards” include geological conditions such as: *fault, swelling clay,* or *anomalous pressures*. By correlating these with other information, in particular seismic data, the risk of geo-drilling hazards in a planned well can be assessed. For example; it appears that 65% of the (strong) overpressures observed in de Zechstein formation are linked to the Platten dolomite member. This unit can often be identified on seismic and this hazard is therefore, to some degree, predictable.

Planned well trajectories can now be screened efficiently for geo-drilling hazards. The GDE Tool based on advanced classification criteria allows to share relevant well information across all operators active in the Netherlands. This includes newcomers, like geothermal operators who carry out a lot of drilling nowadays. The GDE Tool allows everyone to learn from the experience on drilling hazards gathered over the years by oil companies.

Background

More than 6000 wells have been drilled in the Dutch subsurface for varying purposes and by multiple operators. Petroleum wells covering both on- and offshore Dutch territory often had target depths typically between 2 and 4 km TVD. Given the fact that the Netherlands is densely populated and closely packed with infrastructure, onshore wells are often drilled with deviated trajectories to reach out for subsurface targets from well pads. This implies long trajectories and a lot of overburden rocks to be drilled that can host geo-drilling hazards. Obviously, here in particular, careful planning is required to drill wells without incidents.

New operators are entering the country regularly to explore for oil and gas or for geothermal targets. In all cases they aim to drill wells cost-effectively and safely. To do so they need access to the drilling experience that was gathered by the wells drilled previously. Given that a lot of the drilling incidents that have been encountered are related to complex geology, it is paramount that well planners make use of offset well reviews where experience with the geo-drilling hazards is well documented. EBN, the Dutch state company participating in most oil and gas exploration and production in the Netherlands and soon also involved in geothermal ventures, saw the need to share information regarding geo-drilling hazards amongst the drilling operators. In this way uncertainties regarding the subsurface hazard profile can be reduced and drilling can become safer. For this goal a tool was created that allows access to relevant subsurface information without compromising on data confidentiality issues and with full support of the entire Dutch operator community.

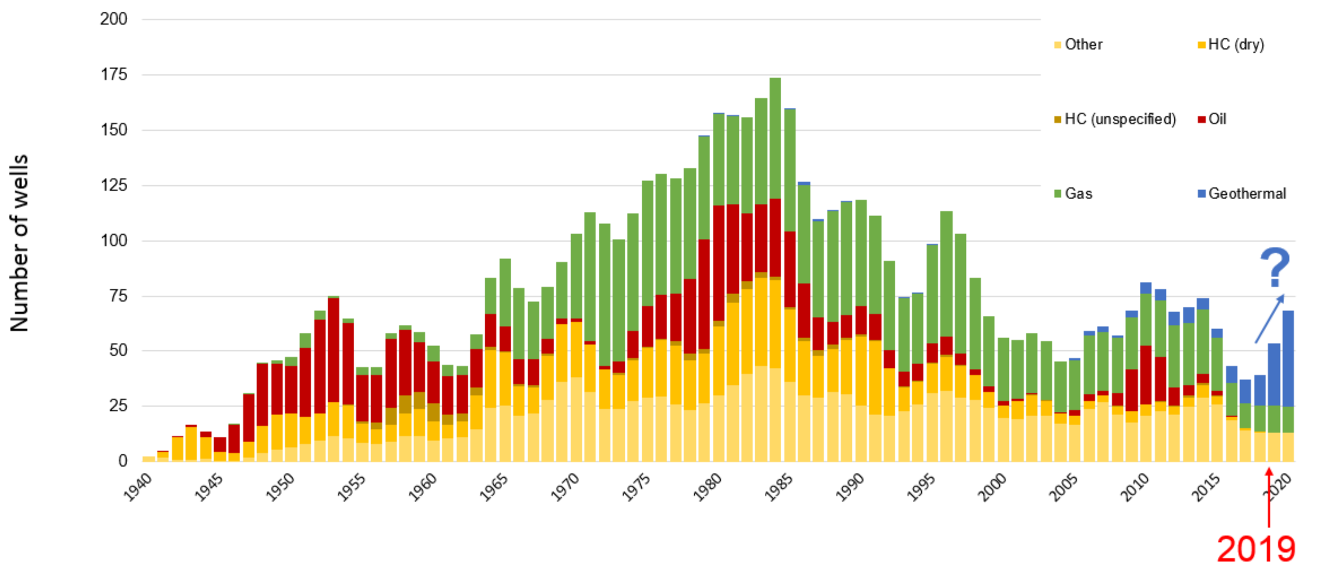

Fig. 1 *Illustrates which wells have been drilled over the years in the Netherlands, on- and offshore. Color-coding based on well outcome. In recent years geothermal wells are on the rise, emphasizing how the operator landscape is changing. Typically, geothermal wells are being drilled by different (and small) operators with limited access to drilling experience from the past.*

Method

Numerous events do occur while drilling a well. The objective here is to capture and share information from drilling records that is relevant to predict geo-hazards and that related to geo-drilling incidents. To help define which information is to be recorded, the concept of the Drilling Incident Triangle is introduced

The root cause of drilling incidents (*events*) can be found in a wide range of processes, which can be classified, at a higher level, according to three contributing factors: *organizational*, *engineering* and *geology*. Organizational causes can be linked to human errors, such as operational judgement mistakes or logistical mishaps. Engineering issues can be caused by mechanical equipment failure. Often drilling incidents do result from a combination of these factors. Depending on the “weight” of the contributing factors, each drilling incident can, in principle, be plotted in this ternary diagram (**Fig. 2**). Here we focus on geo-drilling hazards and hence record only drilling incidents that have a significant geological component in the cause: the so-called ‘Geo-Drilling Events’ (GDEs). Geoscientists, collaborating with well engineers are required to analyze well reports to identify GDEs and to understand the underlying geological hazard.

By meticulously analyzing historic drilling reports, relevant observations on drilling incidents and the related underlying geological mechanisms (geohazards) have been compiled using a structured approach. The information is subsequently fed into a database and made available via an online user interface. The latter is all that the user sees, but the interface plus the underlying database in combination with the procedures and rules used in the analyses are referred to as the ‘GDE Tool’.

Important elements of the GDE Tool are:

a) Multi-disciplinary thinking is essential. Geo-Drilling Events can only be understood properly by combining knowledge from well engineering and geology. Also, information from petrophysics (e.g. log measurements), geomechanics (e.g. break-outs), reservoir engineering (e.g. pressures), and geochemistry (e.g. H2S) are often parts of the puzzle to explain a certain incident.
b) Making a clear distinction between the observations while drilling and the interpretation in terms of the geology. First: what are the facts? Which key drilling parameters have been recorded? This part is referred to as *Geo-Drilling Event (GDE)*. Only thereafter one can start to estimate what geological condition might have contributed to the incident. This step typically considers further data e.g. cuttings, wireline logs, seismic, experience gathered from other wells. This part is referred to as *Geo-Drilling Hazard (GDH)*.
c) Classification schemes: both the observations (GDEs) as well as the interpretations (GDHs) are categorized to help in the analysis. The classification schemes are designed to honor the MECE principal (mutually exclusive, complementary exhaustive). In this way the information is grouped and can effectively be entered into a database for further analysis. In figure 5, a full overview is given of the GDEs, GDHs and the Severity of the incident. The latter is a semi-quantitative assessment of the event in terms of incident severity and can be used for example to filter on *high impact* events.
d) A user-friendly interface allowing to check for correlations and to investigate geospatial relationships. Details are provided where required by zooming in an area or GDE-type
e) Audit trail available: links to the underlying documents that were used in the analysis are recorded in the database and allow for more in-depth investigations.
f) Support from the user community. EBN asked the operators in the Netherlands for input how to organize the sharing of this information. They agreed that it was in everybody’s interest that drilling takes place as safe as possible. Drilling incidents can harm the reputation of the entire industry and hence are to be avoided. The plan to give newcomers access to information regarding drilling hazards was unanimously supported. Very helpful is that data from Dutch wells, including

well reports, do become public after 5 years (specified by law) and hence confidentiality for those wells is no issue.

The core of the GDE Tool is the GDE database that contains the relevant information. One basic record of the database describes one event in one well and consists, amongst others, of the following parameters:

1. Well name
2. Depth: where incident occurred
3. Type of drilling incident (e.g.; *stuck pipe*; coded according classification)
4. Stratigraphy (e.g. *Zechstein*; coded according agreed stratigraphic classification)
5. Underlying geological cause (geohazard, e.g. *squeezing salt*; coded according classification)
6. Explanation of incident and recovery (narrative, free format)
7. Audit trail and pointers to underlying reports.

This GDE database is connected to other EBN databases allowing to tap into other information that is helpful in the analysis. For example, as events are typically reported in depth along hole, true vertical depth can be calculated automatically by bringing in the deviation data from the corporate well database, defining an XYZ subsurface position for each GDE. Also, the relevant stratigraphy, the name of the operator, year of drilling etc. is available.

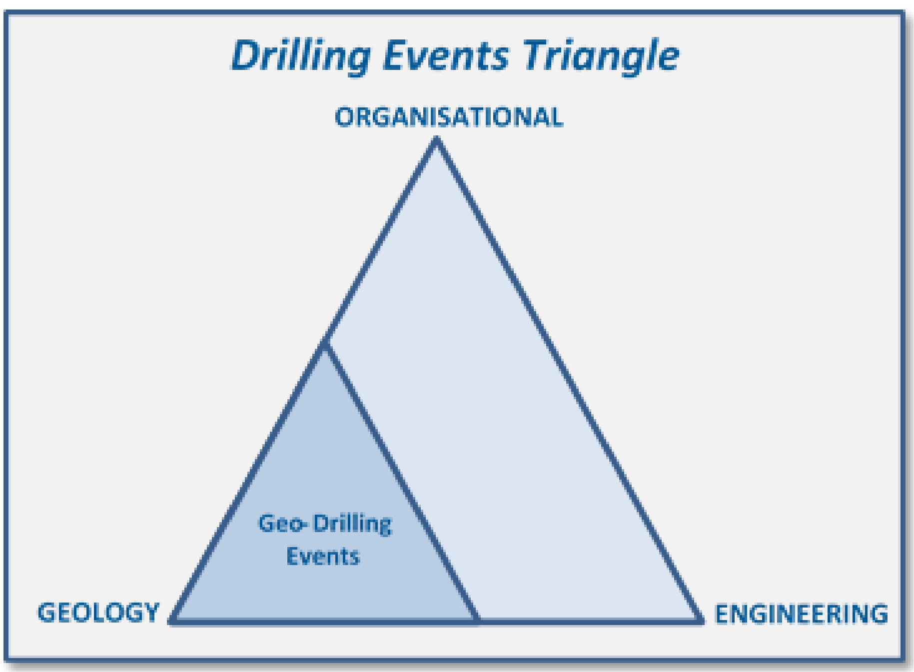

Fig. 2 *Ternary diagram showing the three factors that can lead to drilling events and which can be plotted anywhere in this triangle based on their nature. Geo-Drilling Events have a significant geological component in their cause (after Hoetz et al. 2013).*

Geo-Drilling Event Classification			Severity Guidelines		
GDE_CODE	GDE_Type	GDE Description	High examples	Medium examples	Low examples
Hole Geometry					
1	Stuck Tubular/Tool	Stuck pipe and/or excessive overpull and/or torque of the drill string or casing. Incidents may include: - Stuck pipe occurance during the drilling phase - Casing stuck and/or prematurely set due to no further progress while running in - Hole pack-off - Excessive reaming and/or hole cleaning required in combination with excessive overpull/torque - Differential sticking - Obstruction running liner or casing in the hole - Stuck logging tool (with the exception of a washout)	Lost drilling assembly in hole Prematurely set casing string in different than planned formation with effect on shoe strength Prematurely set casing string	Excessive jarring, reaming and/or circulation required Differential sticking requiring to spot a light fluid (e.g. base oil) pill to reduce overbalance Hole obstruction during casing running requiring an additional BHA check trip or opening up the hole	Excessive torque and/or overpull, but manageable
2	Clay Balling	Swelling and sticking clay causing - a packed off drilling assembly - blocked flowline/flowriser - inability to continue drilling (no ROP)	Lost tophole and/or sidetracked due to pack-off and subsequent stuck pipe	Significant time delay due to clay balling. Multiple trips required. High-volumes swabbing occurrence due to clay balling	Clay balling occurrence but manageable
3	ROP	Excessive wear of the drill bit resulting in reduced rate of penetration and/or excessive number of bit trips Unexpected reduction in ROP resulting in significant delay	Excessive number of bit trips required due to extreme bit wear	Multiple bit trips required due to excessive bit wear	Reduced ROP and significant bit wear observed
11	Steering	Difficulties while steering the drilling assembly during drilling, either in rotary or sliding mode. For example due to formation change or formation dip angle.	Failed to reach objective	Steering difficulties, multiple BHA's required. Trajectory outside targetbox (at objective)	Steering difficulties, more time required to steer BHA
10	Washout	Unconsolidated formation, collapsing into the hole. Washed out formations as a result of mud type or excessive local circulation, possibly in combination with (anomalous) geology.	Washout resulting in accidential sidetrack Washouts resulting in insufficient cement around casing or liner	Washout resulting in significant quality loss of logging results	Washout requiring additional reaming or working of pipe/tools
9	Deformed Tubular	Deformed or collapsed casing/liner/tubing during well contruction or re-entry of an existing well, possibly in combination with (anomalous) geology.	Deformed casing/liner/tubing resulting in - significant operational delay (> 5 days NPT) - Complete loss of functionality of well	Deformed casing/liner/tubing resulting in - moderate operational delay (1-5 days NPT) - partial loss of functionality of well	Deformed casing/liner/tubing resulting in - minimum operational delay (< 1 day NPT) - no loss of functionality of well
Pressures					
4	Gain	Flow of formation fluid into the borehole during well construction.	Influx exceeding kick tolerance Kick-loss situation Well Control situation resulting in >5 days regaining well control Kick resulting in prematurely setting casing	Well control situation requiring well to be circulated to heavier fluid in controlled manner (over the choke) High pressures requiring a contingency liner to be set to allow drilling ahead	Able to control influx whilst drilling ahead Increased mud weight to overbalance formation pressure
5	Losses	Lost drilling fluids and/or cement into the formation during well construction	Total losses, unable to keep the hole full. Total losses leading to a kick/loss situation. Losses during cement job resulting in lower TOC than planned Losses compromising section target Losses resulting in prematurely setting casing	Numerous LCM pills required to cure losses Gunk and/or cement pills required to cure losses	Losses curable whilst drilling (eg. By adding LCM material)
Geology and Fluids					
7	HC	The unpredicted occurance of hydrocarbons while drilling	Mitigating the unpredicted occurance of HCs giving rise to - significant operational delay (> 5 days NPT) - Complete loss of functionality of well - Prematurely setting casing	Mitigating the unpredicted occurance of HCs giving rise to moderate operational delay (1-5 days NPT)	Mitigating the unpredicted occurance of HCs giving rise to minimum operational delay (< 1 day NPT)
8	H2S	The unpredicted occurance of H2S while drilling	Mitigating the unpredicted occurance of H2S giving rise to - significant operational delay (> 5 days NPT) - Complete loss of functionality of well - Prematurely setting casing	Mitigating the unpredicted occurance of H2S giving rise to moderate operational delay (1-5 days NPT)	Mitigating the unpredicted occurance of H2S giving rise to minimum operational delay (< 1 day NPT)
6	Lithology	Unexpected and/or unpredicted formation encountered while drilling. Actual formation depth significantly different than prognosed.	Missed final drilling target Failed to find objective	Found objective but after significant delay e.g. after sidetrack.	E.g. Formation coming in significantly deeper or shallower than prognosed (>100m) but no compromises on well design and/or target missed
12	Other	Other geological-related incidents that cannot be caterogized by any other code in this table. **Note: Non-geological drilling incidents are not recorded in this database**			

Geo-Drilling Hazard Classification		
HAZ CODE	HAZ Type	Description
Rocks		
F	**Fault** (Faults/fractures in the borehole)	Destabilised rocks due to (natural) faulting/ fracturing. Resulting in anomalously high permeability (losses) and/or excessive cuttings/ cavings. Note that karstification might show up similarly as faults but is strictly spoken a different geological phenomena (see R)
C	**Swelling Clay** (Chemically unstable sediments)	Reactive formations (eg. swelling clays)
S	**Squeezing Salt** (Unstable evaporites)	Borehole formation deforming caused by high (litho) pressures mobilising evaporites
W	**Unstable Sediment** (Mechanically unstable sediments)	Unconsolidated formation (eg. washouts) Cavings due to high pressure Weak zones in formation
B	**Boulders**	Large detached rocks in borehole, typically originating from conglomerate
R	**Rock Properties** (Unexpected hard/soft or unexpected permeable)	Unexpected hard or soft formations Abrasive formation causing excessive bit wear Steering difficulties due to soft/hard alternation Dip angle
Fluids		
D	**Depleted Reservoir**	Low reservoir pressure (e.g. due to nearby production)
E	**Shallow Gas**	Unexpected gas shows at shallow depths
G	**Anomalous Pressures**	Unexpected or unpredicted high or low geopressures: High pressures exceeding expected formation pressures (e.g. unexpected brine flows, brine pockets) Formation fluid pressures lower than expected (e.g. unexpected depletion due to nearby production)
H	**H2S**	Unexpected occurrence of hydrogensulfide gas in borehole
Other		
M	**Mapping Uncertainty**	Unexpected formations Subsurface mapping is generally based on well and/or seismic data. Results are based on interpretation and can contain errors or has large uncertainty. Structural complexity, T2D conversion, flanks, unexpected fault/offset
Z	**Other / Unknown** (Other/Unknown Geo Hazard)	Other geological hazard (e.g. unconformities) or unknown geological hazard.

***Fig. 3** Table with classification guidelines for Geo-Drilling Events, Severity and Geo-Drilling Hazards.*

Typical drilling events in the Southern North Sea

Geo drilling events are classified into 12 categories, (**Fig. 3**). Main categories are *stuck pipe*, *kicks* and *losses*, covering about 75% of the identified drilling events.

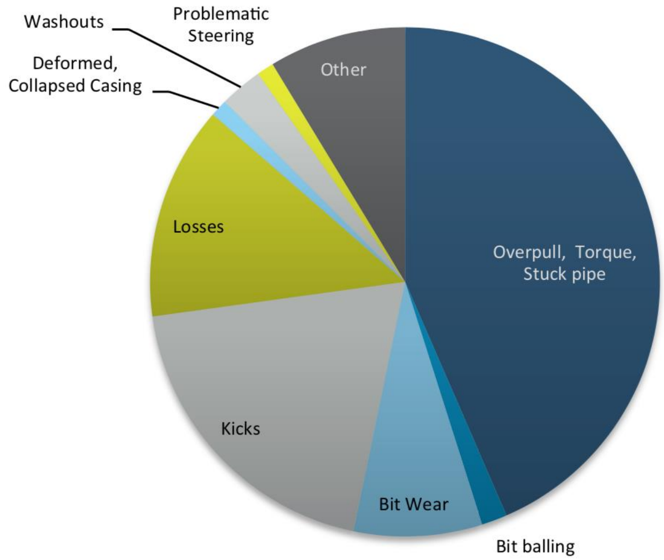

Fig. 4 Some 1400 Geo-drilling events identified in ~ 1000 boreholes

The stuck pipe category includes excessive resistance (overpull, torque) of the drill string and bottom hole assembly (BHA) during the drilling phase, resistance during casing or liner installation, and resistance of any (logging) tools in open hole. This category captures most drilling events (43% of total) and occurs in all stratigraphic members and include shales, evaporites and fault zones. The inclination (hole angle) at the GDE subsurface location is also captured, which adds value to the quick analysis that can be done using the GDE Tool. Typically, hole inclination is a relevant factor in analysing hole pack-off events and/or reported unstable shale intervals. The narrative section in the database contains, for each GDE, a condensed sequence of events, capturing relevant information, as available from drilling reports, such as mud types and weights, drilling parameters and recovery methods.

Drilling fluid losses (21%) and gains (or *kicks*, 12%), are also common GDE's and lead to substantial NPT. In some cases, gains can induce loss circulation scenarios and vice versa. In such cases the events have been attributed arbitrarily to the initial or dominant event in the GDE database. The majority of the high severity kicks occur in the Zechstein formations. Losses occur predominantly in the shallow formations.

Note that drilling events for this database have been identified from drilling reports and logs. The resulting GDE records and corresponding geo drilling hazards are therefor biased towards recorded events during the drilling phase. For instance, collapsed casing typically occurs post-drilling, possible much later in the well life and therefore this geo-hazard may not be picked up from reports and data available.

The GDE Tool allows for directly generating a Well Offset Review of a chosen subset of wells. The offset wells can be selected from a map or from a list. The offset review table is then displayed in a typical offset format presenting the stratigraphic groups as rows and the offset wells in columns. The intersected cells display the short GDE narrative, providing an offset well snapshot that can also be exported to XLS format for further use. See illustration in figure 5.

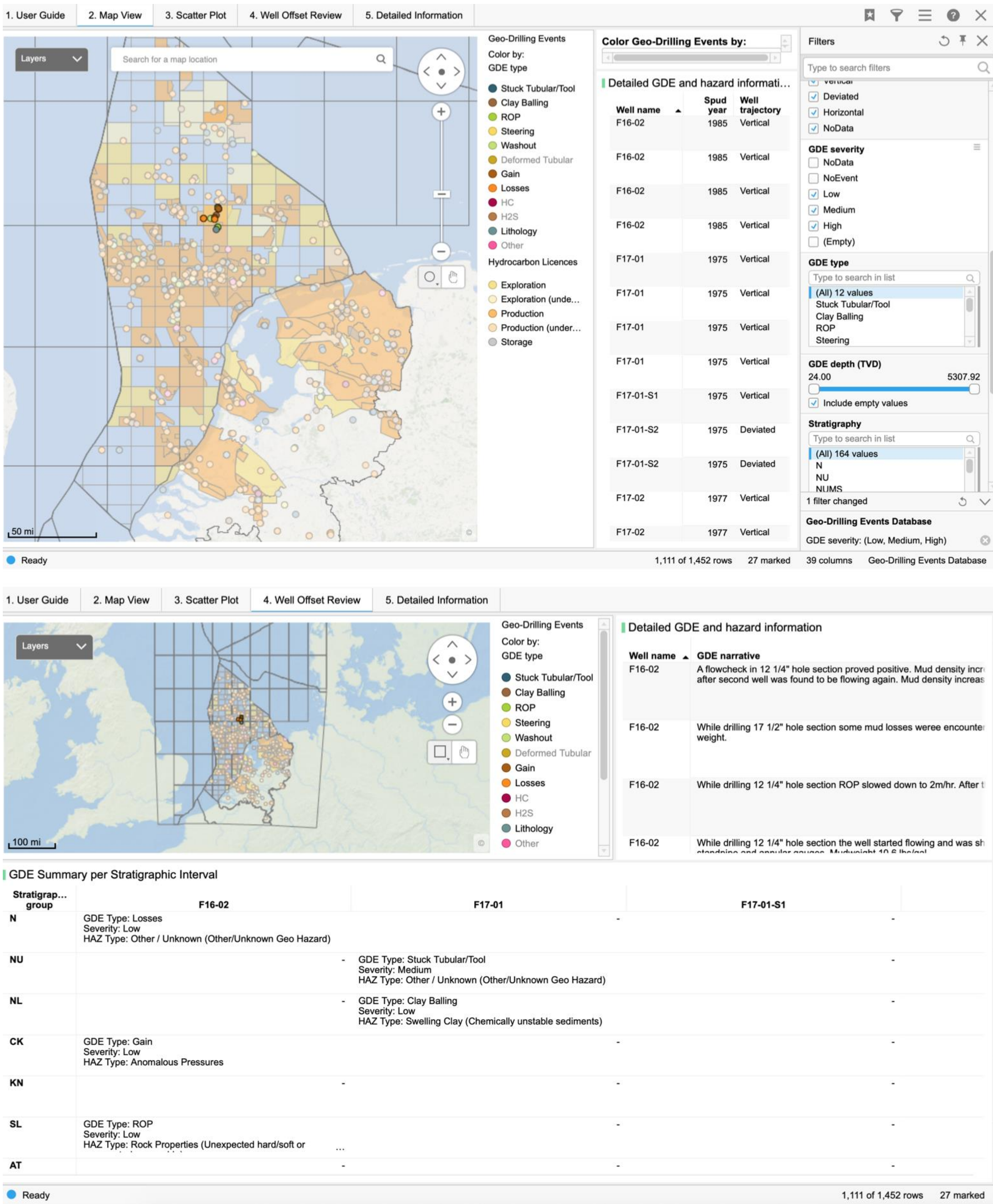

Fig. 5 Selecting wells and well offset functionality in the GDE Tool

Results: statistics

The Geo-Drilling Events (GDE) database currently covers some 1000 boreholes from the Netherlands. Around 1500 Geo-Drilling Events have been analysed systematically allowing to identify drilling hazard hotspots in a statistically meaningful sense (***Fig. 6)***. Examples of geo-drilling events include *stuck tool, gains, losses, H2S.* The underlying geological phenomena i.e. the "geo-drilling hazards" include geological conditions such as: *fault, swelling clay*, or *anomalous pressures*. By correlating and extrapolating this information using seismic data, the risk of geo-drilling hazards in a planned well can be assessed. For example; it appears that 65% of the (strong) overpressures observed in de Zechstein formation are linked to the Platten dolomite member. This unit can often be identified on seismic and the hazard is therefore, to some degree, predictable.

From the GDE statistics it became clear that the evaporitic Zechstein sequence is responsible for most of the GDEs in the category high/medium severity. In many cases the impact is such that sidetracking was required to recover from the incident. The underlying geohazards do vary e.g. high overpressure, unexpected hydrocarbons, H2S and squeezing salt that blocks the drill string or even leads to casing collapse.

Obviously, it pays to know where these hazards are particularly present. Anticipating these hazards is very helpful in the well design and in the drilling phase. Fig 7 shows, as an example, where Zechstein drilling events have been recorded. The symbols are color-coded by the type of geohazard. Anomalously high overpressures are a regular occurrence and often results in costly Non-Productive Time (NPT) and hole abandonment. Regularly sidetracking is required to avoid the geobody that contains these high pore pressures.

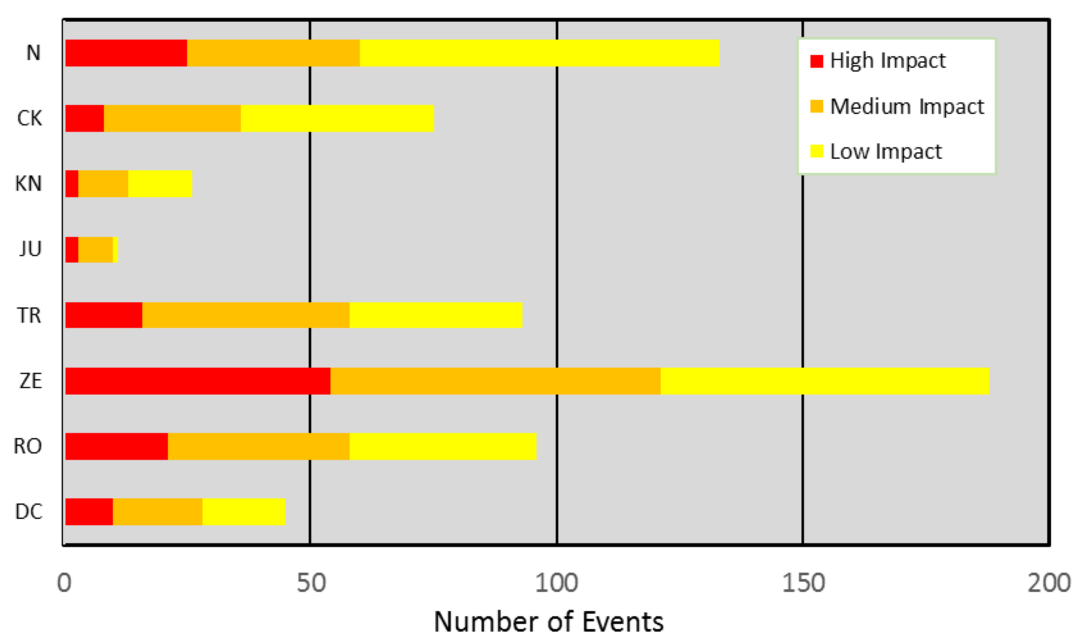

Fig. 6 *Reported Geo-drilling Events per stratigraphic periods from shallow (N) to deep (DC). For this bar chart only deep wells have been selected to avoid bias towards shallow strata.*
Color-coding according to incident severity of the GDE.

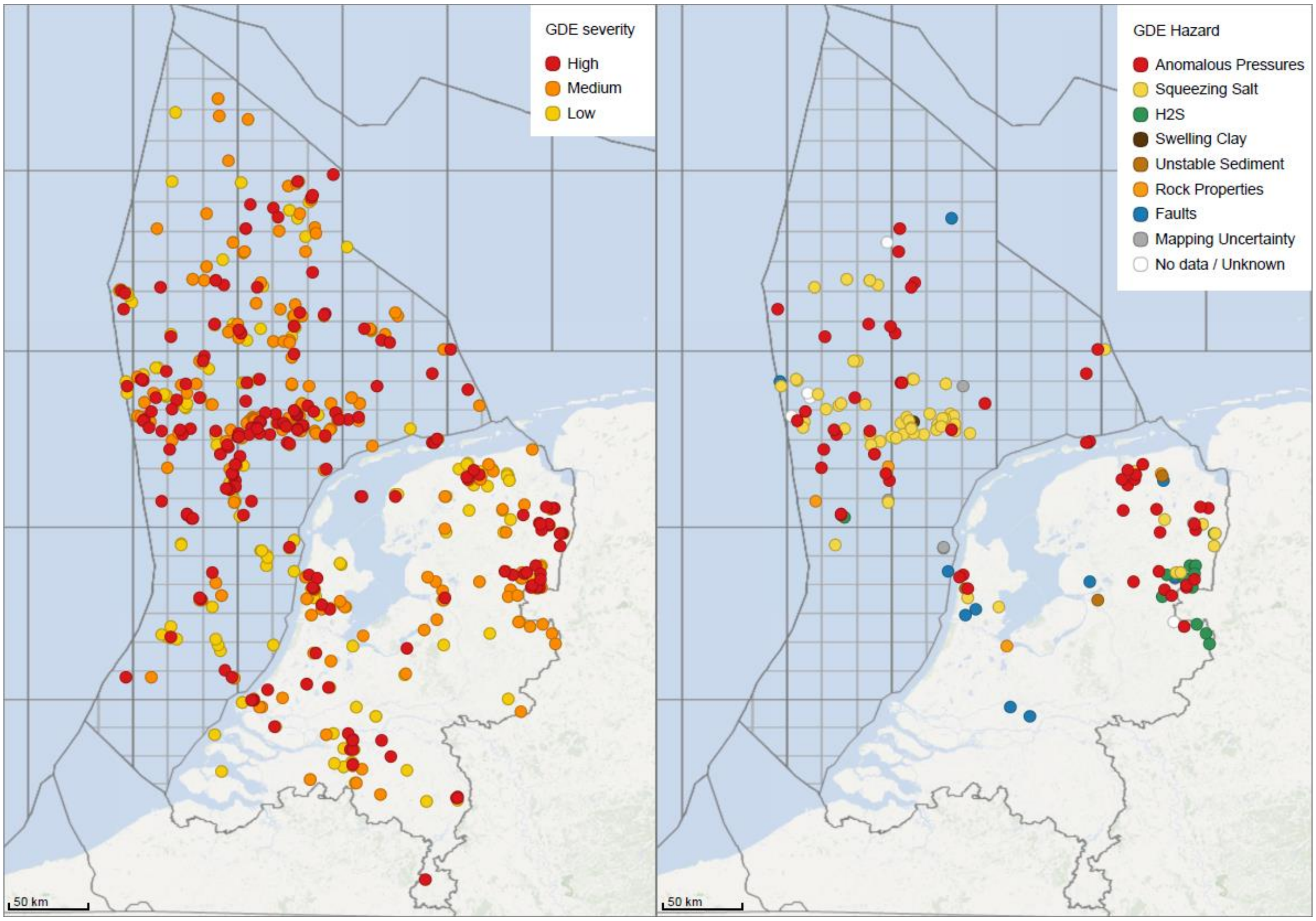

Fig. 7 *Left: map of the Netherlands with all GDEs plotted from the database. Color-coded by severity. Right: GDEs from Zechstein only. Color-coded by geo-drilling hazards. Overpressures (kicks) are indicated in red.*

Results: Zechstein examples

The so-called ZeZ3 A/C stringers (rifted blocks of Zechstein 3 Anhydrite/ Carbonate or "Platten Dolomite") are isolated blocks fully embedded by halite. With no connective path available to dewater the carbonates, the compaction process can result in increased pore pressures which can rise up to lithostatic pressure. Figure 8 illustrates the rifting process of the break-up of the competent slab of Anhydrite/ carbonate rock sandwiched between ductile halite: Strassfurt below and Leine halite above. Wells targeting hydrocarbons at the Rotliegend reservoir level do cross the Zechstein which is a high--quality regional seal. Sometimes these wells do intersect the isolated stringer blocks. The GDE database currently contains 68 records of overpressures from intra Zechstein strata. The cross plot (fig. 9) shows the pore pressures from these wells that have been derived from the mud weight needed to stabilize the well after having observed a kick. Some wells encountered overpressures in excess of 300 bar.

In many cases (67%) these kicks from the Zechstein do coincide with the ZeZ3 stringer based on depth criteria. From this population of the overpressured stringers as observed in a well (40 cases), this stringer is also clearly visible on seismic data in 78% of the cases (10% is inconclusive e.g. due to poor -or lacking- seismic). Only one case was observed in a high continuity stringer (i.e. not broken up according to seismic data). All other cases of stringer kicks were associated with discontinuities (faults) near the wellbore (9 cases were inconclusive due to poor -or lacking- seismic (Schilder, 2019).

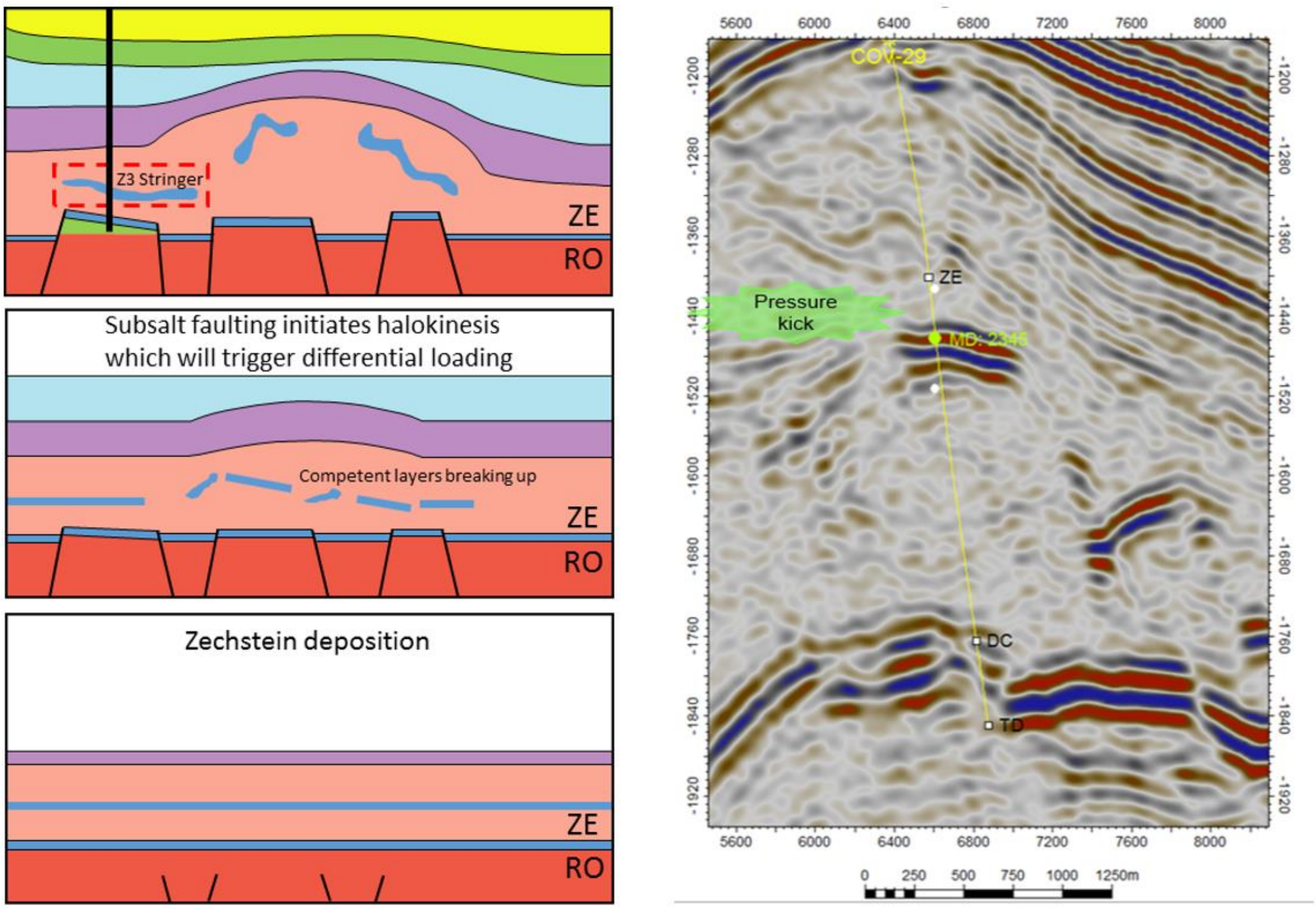

Fig. 8 *Left: Diagram showing 3 stages of the development of stringers from bottom (initial situation after deposition of the full Zechstein sequence). Middle: Competent layers (ZEZ3A/C) broken up due to tectonic extension and salt flow. Top: ZeZ3 stringer intersected by well targeting Rotliegend prospect. Right: Seismic section showing well which took a pressure kick exactly at the depth where a ZEZ3 stringer can be identified.*

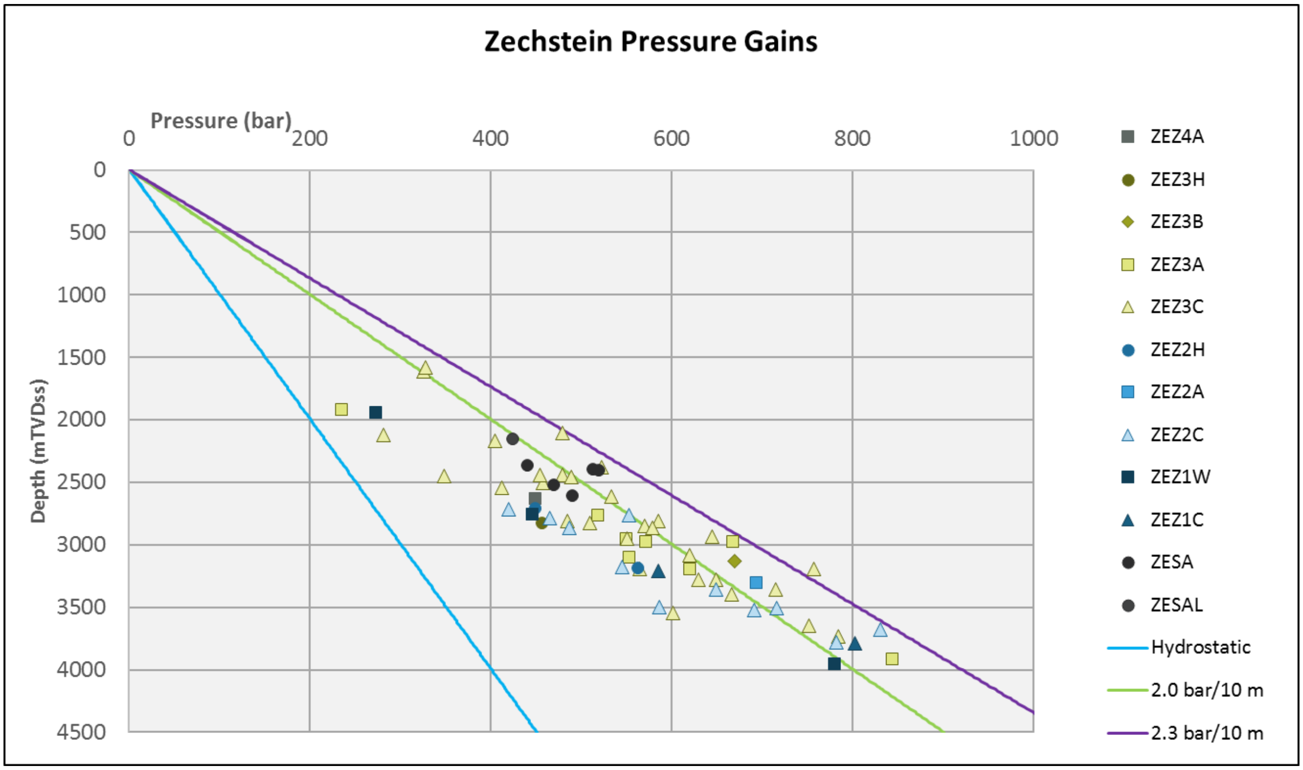

Fig. 9 *Pressure-depth plot for Zechstein pressure kicks. Symbols are coded by stratigraphic (sub)member. The green symbols refer to ZeZ3 stringers. Lines illustrate hydrostatic gradient (1.0 bar/10 m), theoretical lithostatic gradients of 2.0 bar/10 m and 2.3 bar/10 m of which the latter approximates the fracture gradient. Many kicks show pressures around the lithostatic pressures (~2.0 bar/10 m).*

Conclusions

In the Netherlands detailed data on geo drilling hazards is readily available for all drilling operators as a result of a Joint Industry Project. The need for save drilling is considered a common responsibility and collaboration in this area is widely accepted. The Geo-Drilling Events (GDE) database currently covers some 1000 boreholes from on and offshore. Around 1400 Geo drilling Events have been analysed systematically allowing the identification of drilling hazard hotspots in a statistically meaningful sense. An important element of the database is the classification schemes that have been developed to characterize observations (events) and interpretations (geo-hazards). Examples of geo-drilling events include: Stuck Tool, Gains, Losses, H_2S. The underlying geological cause i.e. the “geo-drilling hazards” include geological conditions such as: fault, swelling clay, or anomalous pressures. By correlating these data with other information, in particular seismic data, the risk of geo drilling hazards in a planned well can be assessed. For example; it appears that 65% of the (strong) overpressures observed in de Zechstein formation are linked to the Platten Dolomite member. This unit can often be identified on seismic and the hazard is therefore, to some degree, predictable. Planned well trajectories can be screened efficiently for geo drilling hazards. The user friendly GDE DB Tool allows everyone to learn from the experience on drilling hazards gathered over the years by oil companies. This includes new, small parties, like geothermal operators who carry out a lot of the drilling nowadays.

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WWW.NLOG.NL. Government furnished portal providing information about oil, gas and geothermal energy exploration and production in the Netherlands.